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Innovations in Indian, Chinese and Israeli Agriculture

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Foreword

India, China and Israel are fast-growing economies in the world today. From 1991 onwards, their gross domestic products (GDP) grew at an average annual rate of 6.4%, 9.6% and 3.4%, respectively (The World Bank, 2019). Although all three countries embody economic success, their historical as well as current experiences in the field of agriculture remain unique. All three nations experienced significant food deficits as they embarked in parallel on their journeys as independent nations in the late 1940s. Today, each is producing enough to feed their respective populations. While much progress has been seen in these countries, many challenges remain to achieve the Global Goals across the developing world by 2030. Growing populations are increasing pressure on natural resources (soils, water, air, forests), inequality is rising with large numbers of smallholders increasingly left behind, gender disparities remain critical, climate change increases weather volatility, malnutrition and micro-nutrient deficiencies are progressing slowly at best, rural youth from low productivity, low-income communities leave farming, and increasing urbanisation requires ever more food to be transported from hinterlands to urban centres in a safe and seamless manner.

The power of human creativity to develop innovative products and services is immense. How India, China and Israel transformed from food scarcity to food surplus is a story of innovation not just in production technologies, but also in devising incentives and creating institutions that enabled local farmers to be successful. This comparative study of innovations is important in at least three respects. First, it is important to understand the specifics of how innovations achieved transformative impact in each country's unique complex context. Second, each country has lessons for the other. Third, when considered together, their experiences can be very useful for other developing countries that are formulating economic strategies and agricultural reforms, to feed their large and burgeoning populations.

I appreciate the work done in this book which takes a long view on the economic, agricultural and technology developments in each of the three countries. In particular, I am happy to learn how innovations unfolded from one product segment to another, including crops and livestock, in each country. The authors have studied and presented clearly the role of science and technology and the contribution made by evolving incentives and institutions. This reinforcing triangle of technology, incentives and institutions, created an innovation system that drove fundamental progress in the agricultural sector to the benefit of vast numbers of farmers in each country. I am sure that this book will be a useful resource for researchers, planners, policy makers, funders, investors and other stakeholders not only in these three countries, but also in other developing countries, who are looking to bring about transformation in their own agriculture sectors.

Basel, Switzerland

Simon Winter
Executive Director
Syngenta Foundation

Preface

Over the years, India, China and Israel have all risen successfully to a formidable task: feeding their populations despite very difficult growing conditions. This challenge has often been compounded by natural calamities and other factors. Indian per capita GDP nonetheless more than tripled between 1990 and 2019, rising from $1809 to $6754 at constant 2010 PPP rates (The World Bank, 2020). The Chinese increase in the same period has been even more spectacular, from $1423 to $16,116. At 8.5%, China's average annual GDP per capita growth has been more than double that of India (4.6 %) over the last three decades (The World Bank, 2020). Israel has witnessed a modest 1.8% per annum rise since the 1990s.

Statistics on farming and poverty offer further interesting insights. China's agricultural GDP has risen by an annual average of 4.5% over the last 40 years, well ahead of the 1% average annual growth in population (NSBC, 2017). In India, over the same period, the agricultural sector has grown at an average of 3.5% per annum while the population has increased at an average annual rate of 1.7% (The World Bank, 2020). In both countries, the increases in GDP gradually reduced poverty. In India, the head count ratio of people with a daily income of $1.90 or less (at 2011-12 prices) declined from 50.6% in 1990 to 13.4% in 2015 (The World Bank, 2020). The decline in poverty was even more dramatic in China from 66.3% in 1990 to 0.5% in 2016. In Israel, it hovered steadily around 0.2%.

These three very different countries' successes merit close study. Besides mapping their own possible future strategies, such study also offers lessons for countries still struggling to produce enough food, feed and fibre for their populations.

This book discusses and dissects the factors behind the successes, especially in agriculture. It talks about the many challenges and long turmoil and strife along the road to food security. Technological innovations and agricultural reforms transformed three food-deficient nations into major exporters of staples (India), processed food (China) and agricultural technology (Israel). What policies made this possible? What was the role of institutions governing access to critical inputs such as land, water, mechanisation, extension and infrastructure? What role did incentive structures play, especially through markets, price support and subsidies, trade and tariffs? What can developing and transition countries learn from the Indian, Chinese and Israeli experiences? What might the three countries learn from each other? What challenges will confront them by 2030 and beyond? Which further innovations can help meet these challenges?

The book also evaluates which aspects of the agricultural innovation system (AIS) have been particularly effective across the three countries, and which were notably weak. For this, we have adopted the conceptual framework of AIS, the agricultural innovation system. This framework advocates moving from single elements of innovation towards a system approach. Such an approach enables institutions and stakeholders' networks to respond better to farmers' needs (Pound and Conroy, 2017; FAO, 2018). The World Bank describes an "innovation system" as a network of organisations, enterprises and individuals focused on bringing new products, processes and forms of organisation into economic use, together with the institutions and policies that affect their behaviour and performance (World Bank, 2006).

Three critical lessons stand out. The first is that strong political will and commitment are crucial for a country to move from food deficit to surplus. The three countries studied have all faced immense food shortages; their governments' role in increasing agricultural production has been critical. Each nation took a different route to develop technological innovations, design incentive policies and set up institutional structures to support agricultural growth and ensure food security. Taken together, their experiences show that if a country has its own capacity to develop technologies, such as improved varieties, government should continue to support the national R&D and innovation system. If a country is not well positioned to do so, it should be open to acquiring technology from outside, either through the public or private sector. An enabling policy environment must be in place, including an appropriate system of intellectual property rights.

The second lesson is that technology is a necessary but alone not a sufficient condition for success. The right incentives for farmers are critical for its large-scale adoption. For new technology to induce higher production, farmers must achieve remunerative prices. Our three studied countries all implemented a range of incentive policies to help farmers grow better harvests.

Thirdly, we note the importance of the right institutional framework governing access to critical agricultural inputs such as land, water, mechanisation and extension. In China and Israel, government owns the major part of arable land, while India has much greater private ownership. After the commune system failed, China moved to household responsibility system with secured land contract rights. This change unleashed farmers' productivity. However, communes still dominate Israeli agriculture. Our lesson here is that each country must identify the most suitable system of land administration and rights, depending on its political configuration and social capital.

There is, in short, a need for a balanced mix of forward-looking innovations, policies and institutions. The right combination enables a country to deal with the complex and dynamic challenge of population growth, rising income, food and nutrition security, urbanisation, shifting demand patterns and climate change, while also ensuring sustainable agriculture. Along with strong R&D capabilities, the ability to innovate is often related to collective action, co-ordination and knowledge exchange amongst multiple stakeholders. This process involves not only researchers, extension workers and farmers, but also many other food chain contributors such as processors, distributors and consumers. Their interactions and collaborations are critical for continuing innovation. This in turn stimulates growth and moves the agricultural sector towards greater efficiency, social inclusivity and environmental sustainability.

We hope that our historical evaluation of growth in the three selected countries will generate interest and discussion amongst researchers, policy makers, value chain participants, start-up entrepreneurs and all other parties fascinated by the complex challenges of feeding tomorrow's world.

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Abbreviations

ADRTC	Agricultural Development and Rural Transformation Centre
AI	Artificial Intelligence
AICRIP	All India Coordinated Rice Improvement Project
AIDIS	All India Debt and Investment Survey
AIS	Agricultural Innovation Systems
AKOL	Agriculture Knowledge On-line
AMUL	Anand Milk Union Limited
AP	Andhra Pradesh
APC	Agricultural Prices Commission
BAHS	Basic Animal Husbandry Statistics
BFDA	Brackish Water Fish Farmers' Development agency
BFT	Bio-flocs Technology
CACP	Commission for Agricultural Costs and Prices
CBS	Central Bureau of Statistics
CCAP	China Centre for Agricultural Policy
CGIAR	Consultative Group on International Agricultural Research
CGWB	Central Ground Water Board
CHCs	Custom Hiring Centres
CIF	Cost, Insurance and Freight
CIFT	Central Institute of Fisheries Technology
CIMMYT	International Maize and Wheat Improvement Center
CIP	Central Issue Price
CNCIC	China National Chemical Information Center
CoE	Centres of Excellence
CPI	Consumer Price Index
CRRI	Central Rice Research Institute
CSEs	Consumer Support Estimates
CWC	Central Water Commission
DAP	Di-ammonium phosphate
DBT	Direct Benefit Transfers

DCS	Dairy Cooperative Societies
DES	Directorate of Economics and Statistics
DFI	Doubling Farmers' Income
DNA	Deoxyribonucleic Acid
DoAHDF	Department of Animal Husbandry, Dairying and Fisheries
DWR	Directorate of Wheat Research
ECA	Essential Commodities Act
F&V	Fruits and Vegetables
FCI	Food Corporation of India
FFDA	Freshwater Fish Farmers' Development Agency
FSSAI	Food Safety and Standards Authority of India
GCF	Gross Capital Formation
GDP	Gross Domestic Product
GDPA	Gross Domestic Product of Agriculture
GEAC	Genetic Engineering Approval Committee
GHG	Greenhouse Gas
GIS	Geographic Information System
GM	Genetically Modified
GMSP	National GM Variety Development Special Programme
GoI	Government of India
GPS	Global Positioning System
GSS	General Support Services
Ha	Hectare
HF	Holstein Friesian
HP	Horse Power
HRS	Household Responsibility System
HT	Herbicide Tolerant
HYV	High Yielding Varieties
ICAR	Indian Council of Agricultural Research
ICRIER	Indian Council for Research on International Economic Relations
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
ICT	Information and Communication Technology
ID	Irrigation District
IIHR	Indian Institute of Horticultural Research
INR	Indian Rupees
IoT	Internet of Things
IPA	Intensive Pond Aquaculture
IPI	Institutional Changes, Policy Support and Investment in Agricultural Infrastructure
IPM	Integrated Pest Management
IPR	Intellectual Property Rights
IRRI	International Rice Research Institute
ISAAA	International Service for the Acquisition of Agri-biotech Applications
IWGSC	International Wheat Genome Sequencing Consortium

KLDB	Kerala Livestock Development Board
LEC	Loan Eligibility Cards
LTSCs	Land Transfer Service Centres
MCS	Mechanisation Custom Services
Mg	Milligram
Mha	Million Hectare
MI	Micro Irrigation
MIDH	Mission for Integrated Development of Horticulture
MMPO	Milk and Milk Products Order
MMT	Million Metric Tonnes
MOA	Ministry of Agriculture
MOP	Muriate of Potash
MP	Madhya Pradesh
MSPs	Minimum Support Prices
MV	Modern Varieties
MW	Megawatts
MWR	Ministry of Water Resources
NABARD	National Bank For Agriculture And Rural Development
NAFIS	Financial Inclusion Survey
NCU	Neem Coated Urea
NDDB	National Dairy Development Board
NECC	National Egg Co-ordination Committee
NFDB	National Fisheries Development Board
NGOs	Non-Governmental Organizations
NHB	National Horticulture Board
NICRA	National Innovations on Climate Resilient Agriculture
NITI Aayog	National Institution for Transforming India
NPK	Nitrogen, Phosphorus and Potassium
NPRs	Nominal Protection Rates
NSA	Net Sown Area
NRA	Nominal Rate of Assistance
NWRS	Negotiable Warehouse Receipt System
OECD	Organisation for Economic Co-operation and Development
OF	Operation Flood
PBGSBS	Paschim Banga Go-Sampad Bikash Sanstha
PDS	Public Distribution System
PGMSR	Photoperiod-sensitive Genic Male Sterile Rice
Ppm	Parts per million
PPP	Purchasing Power Parity
PRC	People's Republic of China
PSEs	Producer Support Estimates
R&D	Research and Development
R&E	Research and Education
RFID	Radio Frequency Identification Devices
RKVY	Rashtriya Krishi Vikas Yojana

RMB	Renminbi
RSS	Remote Sensing System
SHCs	Soil Health Cards
SPF	Specific Pathogen-Free
SRI	System of Rice Intensification
STFFP	Soil Testing for Formulated Fertilisation Programme
T/ha	Tonnes per Hectare
TAMP	Total Agricultural Machinery Power
TE	Triennium Ending
TFP	Total Factor Productivity
TGMS	Thermosensitive Genic Male Sterile
TRQs	Tariff Rate Quotas
TSP	Temporary Storage Programme
UAV	Unmanned Aerial Vehicles
UP	Uttar Pradesh
USD	United States Dollars
VAD	Vitamin A Deficiency
VAT	Value Added Tax
VC	Venture Capital
WA	Wild Abortive
WDCL	Women Dairy Co-operative Leadership
WHO	World Heath Organisation
WTO	World Trade Organization
WUAs	Water User Associations
XT	Extension Training

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Chapter 1
Introduction

By any yardstick, India, China and Israel have been striking economic success stories in recent years, more so in their agricultural fields. They all have also experienced a lot of turmoil and strife for decades and centuries in their respective histories. China and India, the two most populous countries today, are ancient civilisations and have rich economic histories. They have also faced a number of famines resulting in a large number of starvation deaths, and yet they have emerged out of all this with hard policy and technological choices, accelerating their growth to unprecedented levels and today, exemplify hope and promise for a brighter future. Their experience in recent decades, with a peep into their situation prevailing over centuries, present several important lessons for developing countries that are still struggling to achieve food security and a better future for their people.

According to Angus Maddison's estimates, India and China were the two largest economies by gross domestic product (GDP) in purchasing power parity (PPP) terms for a long period of time since the beginning of the Common Era.[1] In year 1 of the Common Era, for example, India's contribution to the world's GDP was almost as high as 40% followed by China at 30% (Fig. 1.1). Both countries dominated global GDP almost until 1820. While India's share in global GDP started gradually declining as Britain's East India company spread its wings in India during the seventeenth century, its decline accelerated further as the East India company handed over rule to the British Crown (the Queen) in 1858, after the first war of independence broke out in 1857 in India (the British called it a rebellion). The British Raj used India as its richest colony and as a source of raw material supply as well as a market for feeding Britain's industrial revolution. China too lost its dominance quickly between 1820 and 1900, partly due to inner strife, but also due to the spreading of the industrial revolution in the USA and Europe.

This chapter has been authored by Ashok Gulati and Ritika Juneja, both affiliated to the Indian Council for Research on International Economic Relations, New Delhi, India.

[1] It is another term for Christian era or AD 1 and dates from at least the early 1700s.

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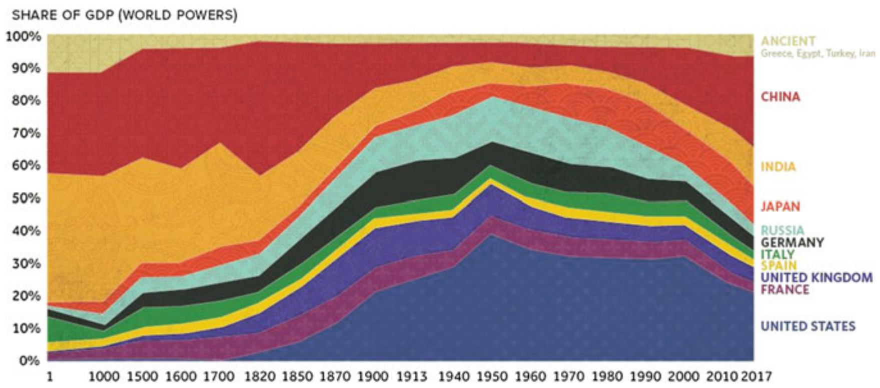

Fig. 1.1 Percentage share in World GDP. *Source* "Statistics on World Population, GDP, Per Capita GDP, 1-2008 AD", Angus Maddison; IMF (visualcapitalist.com)

India struggled for a long time to get its independence from the British, which it finally got on 15 August 1947; and China's leadership declared the founding of the People's Republic of China on 1 October 1949, after a civil strife with the Nationalist Party (Kuomintang). The State of Israel was established on 14 May 1948, after it freed itself from the British Empire. Although much smaller in size and population than China or India, the predominant community of Israel (Jews) has a long history of trauma and persecution. Almost 6 million Jews were killed in Europe between 1939 and 1945 by the Nazis with the help of local forces. The Holocaust remains the major tragedy of the twentieth century, which continues to inform the thinking of Israel and its leaders. This tragedy was soon followed by a litany of violent and non-violent conflicts with its Arab neighbours.

In a way, therefore, all three countries had a sort of fresh start in late 1940s, after much strife and conflict. How did they stabilise their "newly born" nations, and how did they progress over the decades under varying economic models? And in particular, how did they feed their people? The policy innovations, technological choices and institutional changes they made in this regard may provide some valuable lessons to several other developing countries.

Going a little farther into ancient times with respect to agriculture, it is interesting to note that Indian agriculture began with early cultivation of plants and domestication of crops and animals (Gupta 2004). The Indus Valley Civilisation, that goes as far back as 5000 years from today, marked a breakthrough when irrigation and water storage systems were developed, which eventually led to more planned settlements (Rodda and Ubertini 2004). In China, analysis of stone tools by Professor Liu Li and others showed that the origins of Chinese agriculture were rooted in the pre-agricultural Palaeolithic age, when hunter–gatherers harvested wild plants. The Neolithic sites in eastern China also document rice cultivation some 7700 years ago (Zong et al. 2007). In Israel, according to some archaeologists, people began to practice agriculture during the Mesolithic Period as some artefacts indicated soil cultivation and cattle raising (The Gale Group 2008). Subsequently, in the Neolithic

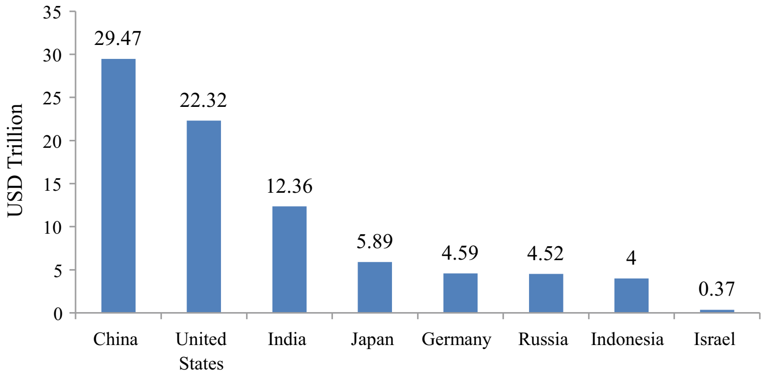

Fig. 1.2 GDP of selected countries in current PPP terms (trillions of international dollars). *Source* International Monetary Fund Data Mapper tool (2019)

Period up to roughly 8500–4300 BCE, artefacts corresponding to the production of crops and use of agricultural implements increased. However, it was only in the nineteenth century, with the Zionist movement and Jewish immigration to Palestine, that modern farming in the country began (Tal 2007).

Thus, China, India and Israel were predominantly agricultural countries over the centuries. In the late seventeenth century, India and China experienced structural transformation with the development of industries. From Britain to America to the rest of Europe, the Industrial Revolution spread across the world and played an integral role in laying down the foundations of modern society. The Industrial Revolution, however, helped the West pull ahead, and the USA emerged as the largest economy during late eighteenth century (Fig. 1.1). However, things are changing fast. According to IMF's estimates for 2019, in terms of PPP in current US dollars, China's GDP has already out-stripped the GDP of USA, followed by India with a GDP in PPP terms (current dollars) at USD12.36 trillion (Fig. 1.2). Israel too has shown modest growth with GDP at USD375 billion in 2019.

On the food and agriculture front, it is worth noting that India had been hit several times by severe famines, most notoriously during British rule. In total, cumulatively, over 60 million lives were lost during famines in eighteenth, nineteenth and the first half of the twentieth century (British rule), the latest being the Bengal Famine of 1943, which is said to have claimed 1.5–3.0 million lives due to starvation (Sen 1981). During mid-1960s, consecutive droughts plunged the country into an unprecedented "ship to mouth" crisis such that it leaned heavily on food aid under PL 480 from the USA for survival (Chopra 1981).

China too had a history of famines. During 1876–79, the Great North China famine is said to have claimed 9–13 million lives, the Great Qing famine of 1907–11 in East and Central China claimed 25 million lives, the famine of 1942–43 (mainly in Henan) also claimed about 2–3 million lives and the Great Chinese Famine of 1959–61 claimed about 30 million lives and coincided with the period of Great Leap Forward (Ashton et al. 1984).

Israel, too, in its early years, faced chronic food shortages. During the 1950s, the government imposed rationing on the population, limiting citizens to half a loaf of bread per person per day, 60 g of corn, rice and flour—with only 75 g of meat allocated per month (Seidman 2008).

This backdrop of history in terms of the challenges to feed the growing populations of China, India and Israel is important for moulding their policies, institutions and technological choices in the area of food and agriculture in the years to unfold. This could be a key pointer to other developing countries that are experiencing rapid population growth and that have limited water and good quality soils, and which find it a challenge to produce enough food, feed and fibre for their populations.

India is still predominantly an agrarian country in terms of workforce engaged in agriculture (around 43% in 2019), although the share of agriculture in overall GDP has consistently declined from about 54% in 1951 to about 16.5% in 2019. In terms of irrigation, India's irrigation cover is 48% of the country's cultivated area. India's gross cropped area, as a result of such irrigation is 198 million hectares, and its agriculture output is valued at USD407 billion (Gulati and Gupta 2019).

China largely meets its growing demand for food from domestic production (about 95% self-sufficiency) despite limited natural resources (5% of world fresh water and less than 8% of global arable land). Agricultural production and productivity improved significantly after the agricultural reforms introduced in 1978. The agricultural sector registered an impressive growth of about 7% per annum during 1978–84, and it helped in faster poverty reduction and diversification of the food basket. China's average annual growth rate of agricultural GDP has been 4.5% during the past 40 years, which is much higher than the 1% average annual growth in population over the same period (National Bureau of Statistics of China 2018).

Israel, despite being largely arid or semi-arid (about two-thirds of its land), with relatively poor soil quality and modest precipitation became a world technology leader through its innovative approach to agricultural development. In order to address the water shortage problem, the Israeli Government invested heavily in developing alternative hydrological sources, such as purification and recycling of sewage water (such that 86% of this recycled wastewater is used for irrigating agriculture fields) and desalination of seawater (Tal 2016). Recent statistics indicate that of the 1.15 billion cubic metres of water utilised by Israel's farming sector, 60% comes from recycled wastewater or marginal brackish sources. Only 40% of irrigated water comes from freshwater sources (Tal 2016). Its ability to overcome the water challenge resulted in an increase in the cultivated area from 165 thousand hectares in 1948 to some 620 thousand hectares as of 2018, and the number of farming communities has more than doubled (Israel Central Bureau of Statistics 2020).

Looking at the economic as well as agricultural performance of the three countries, some key questions arise. What innovations in production technologies made these outcomes possible? What sorts of incentives were provided to farmers, and how did they affect farmer's choices? What role did institutions play in the management and utilisation of land, water, farm machinery and agricultural extension? What are the challenges likely to be faced by these three countries, say in 2030 and beyond?

Can they meet these challenges and how? What lessons could the story and their experiences of agricultural growth provide for the rest of the developing world?

This book attempts to respond to these very questions. The book is organised as follows. Following this brief introductory chapter, the next chapter presents an overview of the economies of the three countries with a focus on agriculture. Chapters 3 and 4 discuss innovations in production technologies in India and China, respectively. These chapters examine in detail technological innovations in seeds, farming practices, irrigation technology, fertiliser application, precision and protected farming, artificial intelligence, etc., that set the growth trajectory in agriculture. They also highlight how some technological innovations resulted in revolutionary changes in production. Chapters 5 and 6 focus on effective incentives provided to farmers in India and China, respectively, and how government pricing and market reforms policies affected incentives for cultivators in these two countries. We also look at innovative policies that improve farmers' incentives without distorting the efficient functioning of markets. Chapters 7 and 8 present innovations in accessing and managing agricultural land, water, farm machinery and extension services in India and China, respectively. Chapter 9 looks at the transformation of Israeli agriculture with focus on various innovations that range from production technologies to incentive structures to management of basic resources for agriculture such as land, irrigation and agricultural extension. Chapter 10 provides a comparative picture of innovations in production technologies, incentives and institutions in the three selected countries and how these innovations contributed to agricultural growth and rural transformation. And finally, Chap. 11 presents the way forward with a futuristic vision towards 2030 and beyond. It lists major challenges that agriculture in these three countries are likely to face by 2030 and beyond, and how current and emerging innovations can provide the basis for a response to these challenges. In particular, this chapter looks at challenges arising out of rising population and incomes that will increase demand pressure for food, feed and fibre in the years to come; changes in demographic profiles; malnutrition, climate change and urbanisation. The chapter gives some concluding observations that may be useful to these three countries in particular and many other developing countries in general.

References

Ashton, B., Hill, K., Piazza, A., & Zeitz, R. (1984). Famine in China, 1958–61. *Populatiom and Devlopment Review, 10*(4), 613–645.

Chopra, R. N. (1981). *Evolution of food policy in India.* Macmillan India Limited.

Gulati, A., & Gupta, S. (2019, October 31). Market incentives, direct income support for farmers are far more effective in increasing agricultural productivity. *The Indian Express.*

Gupta, A. K. (2004). Origin of agriculture and domestication of plants and animals linked to early Holocene climate amelioration. *Current Science, 87*(1), 54–59.

Israel Central Bureau of Statistics. (2020). Population, (site last visited, April 6, 2020). https://www.cbs.gov.il/en/subjects/Pages/Population.aspx.

National Bureau of Statistics of China. (2018). *China statistical year book*. China: National Bureau of Statistics of China.

Rodda, J. C., & Ubertini, L. (2004). *The basis of civilization–Water science?* Wallingford, Oxfordshire, U.K.: International Association of Hydrological Science.

Seidman, G. (2008). Unexceptional for once: Austerity and food rationing in Israel, 1939–59. *Southern California Interdisciplinary Law Journal, 18*(95), 95–130.

Sen, A. (1981). *Poverty and famines: An essay on entitlement and deprivation.* Oxford University Press.

Tal, A. (2007). To make a desert bloom: The Israeli agricultural adventure and the quest for sustainability. *The Agricultural History Society*.

Tal, A. (2016). Rethinking the sustainability of israel's irrigation practices in the Drylands. *Water Research, 90*, 387–394.

The Gale Group. (2008). *Agriculture in Israel: History and overview*. Retrieved April 20, 2020, from Jewish Virtual Library. https://www.jewishvirtuallibrary.org/history-and-overview-of-agriculture-in-israel#3.

Zong, Y., When, Z., Innes, J., Chen, C., Wang, Z., & Wang, H. (2007). Fire and flood management of coastal swamp enabled first rice paddy cultivation in east China. *Nature, 449*(7161), 459–462.

Chapter 2
Overview of India, China and Israel

2.1 India

2.1.1 Backdrop of Indian Agriculture

India is the largest democratic country in the world accounting for 17.8% of global population (United Nations Projections 2019) The scale of democracy can be gauged from the fact that in the 2019 parliamentary elections, roughly 610 million people voted to choose their representatives for Parliament, the highest number so far in world history (Business Standard 2019). The importance of this democratic set-up is reflected in the fact that, after independence in 1947, India never faced the kind of large-scale famine-induced starvation deaths that were quite common during the British Raj. This singular achievement of the democratic set-up, with its checks and balances, becomes even more relevant when it is juxtaposed against the severe shortage of food during the mid-1960s when the country was faced with back-to-back droughts. In fact, this food crisis sowed the seeds of the Green Revolution in the late 1960s and the white revolution in the 1970s and 1980s. These revolutions in agriculture transformed India from a net importer of food to a self-sufficient agricultural economy (Pingali et al. 2019).

However, the economic strategy of heavy industrialisation under state leadership that India adopted since 1956 and later on, the socialist pattern in the early 1970s, failed to deliver high economic growth rates. The country landed in a serious economic crisis in July 1991, when growth plummeted to 1.1% (1991–92), inflation soared to more than 13% in fiscal 1991–92[1] and foreign exchange reserves dropped

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[1]Base: 1982 = 100. The inflation rate for industrial workers was 15.7% in 1991–92 and for agricultural labour (AL), 19.3% (Base 1960-61=100); source: https://dbie.rbi.org.in/DBIE/dbie.rbi?site=statistics.

A. Gulati et al., *From Food Scarcity to Surplus*,
https://doi.org/10.1007/978-981-15-9484-7_2

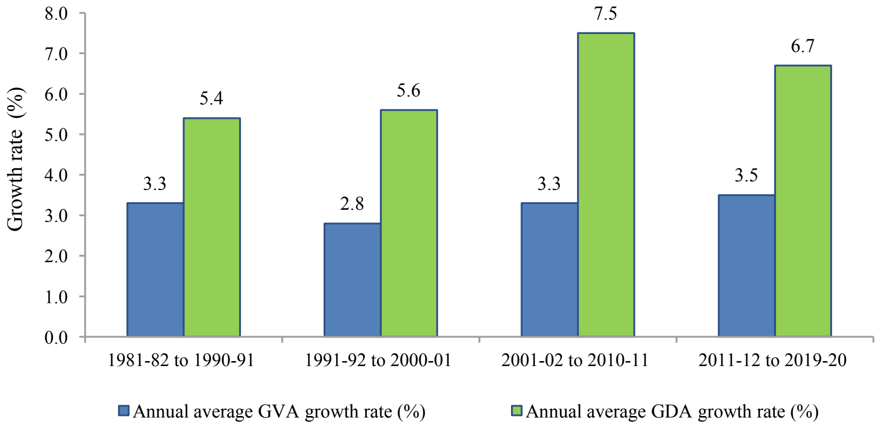

Fig. 2.1 Average annual growth rate in GDP and agricultural gross value added in India (per cent). *Source* National Accounts Statistics (2019)

to USD1.1 billion in June 1991, just enough for 2 weeks of imports (Ahluwalia 2020; Reserve Bank of India 2005).[2] It is at this juncture, in July 1991, that India ushered in economic reforms, steering the country away from a regime of controls and protectionist policies to a somewhat market-oriented system.

It is important to emphasise that the government, at first, introduced a stabilisation programme, using a market-oriented approach with a much larger role for the private sector and moving towards greater integration with the world economy. But besides the broad objective of liberalisation, privatisation and globalisation, the government aimed to achieve the twin goals of a reduction in the fiscal deficit and currency devaluation.

India's economic reforms were by "stealth", implemented slowly and gradually, and consequently, the flow of benefits was delayed (Ahluwalia 2020). It may be noted that making policy changes in a democratic country poses special challenges, unlike in China, where the political system makes it easier to implement several policy changes in one go. India, as they say, is inherently a debating society,[3] while China is a mobilising society.

Nevertheless, these reforms started paying dividends handsomely after a few years of stabilisation, making India the fifth largest economy in the world in 2019, surpassing France and the UK in US current dollar terms[4] and the third largest after China and the US in purchasing power parity (PPP) terms at 2011–12 prices.

What structural transformation was brought about in the economy with these economic reforms can be judged by the following facts: India's integration with the global economy, as measured by the trade to GDP ratio, increased more than three times after the reforms. The trade (of goods and services) to GDP ratio, which was

[2]https://www.rbi.org.in/Scripts/PublicationsView.aspx?id=2686.

[3]Sen (2005) "The Argumentative Indian" (published by Allen Lane).

[4]https://www.imf.org/external/datamapper/NGDPD@WEO/OEMDC/ADVEC/WEOWORLD.

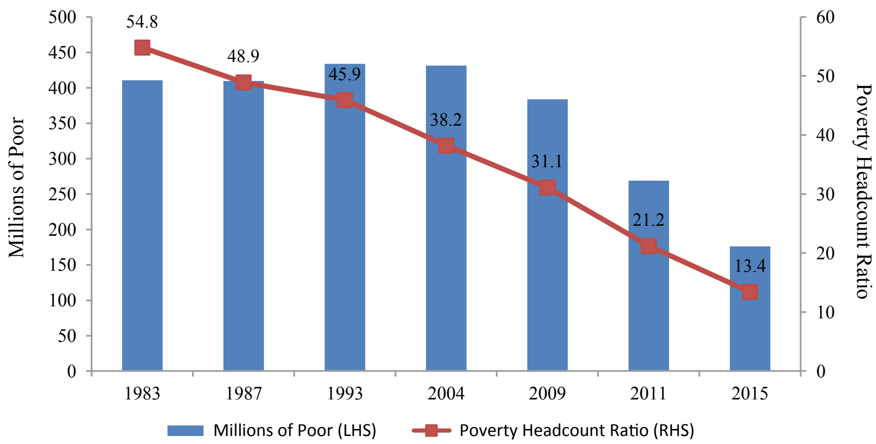

Fig. 2.2 Poverty trends at USD1.90 a day (2011 PPP) in India. *Source* World Development Indicators (2019)

just 15.5% in 1990, peaked to 55.8% by 2012, and after that receded to 43.8% by 2018 (Fig. 2.1). Despite the fall in the ratio since 2012, it was higher at 43.8% in 2018 than China's trade to GDP ratio of 38% (World Development Indicators 2019). This difference between India and China's trade to GDP ratios is because India is a major exporter of services, where it has a comparative advantage, while China is a major exporter of goods (Economic Survey 2019).

Furthermore, as a result of the gradualist process, economic growth, measured in terms of the average annual growth in GDP, accelerated from 5.4% during the 1980s to 5.6% in the 1990s to 7.5% during the decade of the 2000s and remained roughly at 6.7% from 2011–12 to 2019–20 (National Accounts Statistics 2019) (Fig. 2.1).

This increase in overall GDP growth rates also resulted in rising per capita incomes, leading to a gradual decline in extreme poverty in India. Measured by a per day per capita income of USD1.9 (at PPP of 2011–12 prices), the head count ratio gradually declined from 54.8% in 1983 to 45.9% in 1993 to 38.2% in 2004 and to 13.4% in 2015 (World Development Indicators 2019) (Fig. 2.2).

2.1.2 Agricultural Growth and Transformation

According to the Land Use Statistics, 2015–16, India is the seventh largest country in the world covering an area of 3.28 million square kilometres (Government of India 2018), of which 139.5 million hectares (Mha) is the reported net sown area and 198 Mha is the total cropped area with a cropping intensity of 141.3% in 2015–16 (Government of India 2017). The net sown area works out to be 42.5% of the total geographical area. The net irrigated area is 67.3 million hectares (2015–16) (Government of India 2017).

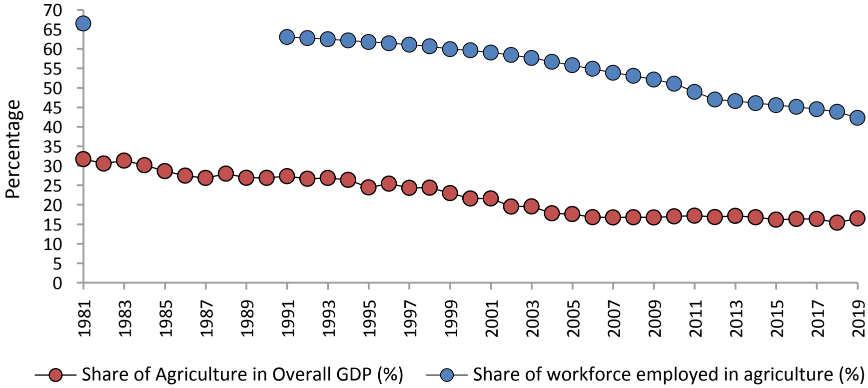

Fig. 2.3 Share of agriculture in overall GDP and share of workforce employed in Indian agriculture (per cent). *Source* World Development Indicators (2019) (https://data.worldbank.org/indicator/NV.AGR.TOTL.ZS?locations=IN, https://data.worldbank.org/indicator/SL.AGR.EMPL.ZS?locations=IN)

Agriculture in India continues to be a key sector, affecting the livelihoods of nearly half of the country's population (Gulati et al. 2019). The sector contributes 16.5% to the country's GDP (World Development Indicators 2019). From 1981 onwards, agricultural GDP increased at an annual average rate of 3.2% per annum (Fig. 2.1), which is lower than China's 4.5%.

Structurally, over the past 40 years, Indian agriculture has experienced slow and gradual transformation from a subsistence-based sector to a modernised agricultural system (Pingali et al. 2019). The development of the Indian economy has been accompanied by a sharp decline (from 30% in 1981 to around 16.5% in 2019) in the contribution of agriculture to GDP (Fig. 2.3). However, the proportion of the workforce engaged in agriculture declined more slowly from 63% in 1981 to 43% in 2019 (Fig. 2.3). This can be attributed to the lack of sufficient non-farm employment opportunities as well as low levels of education and skills of rural workers. They are either incapable of moving out of the agricultural sector (OECD/ICRIER 2018) or labour markets are unable to absorb the surplus underemployed labour from the agricultural sector (Pingali et al. 2019). As a result, labour productivity in agriculture continues to remain low, severely affecting value addition from agriculture. Raising labour productivity will require not only raising land productivity but also "diversification" towards high-value agricultural activities such as dairy farming, poultry rearing, horticulture and fisheries, along with moving large numbers of people to off-farm jobs.

2.1.3 Trends in Agricultural Diversification

While the grain sector has continued to dominate the agricultural sector in India, the share of grains in total cropped area has declined steadily over the last 40 years from 73% in the triennium ending (TE) 1982–83 to 68% in TE 1992–93 and further to 62% in TE 2015–16, whereas the share of non-grain crops in the total cropped area has slowly increased from 27% to 38% between TE 1982–83 and TE 2015–16.

However, the real index of diversification within agriculture requires inclusion of the non-crop sector, especially livestock. An important measure is the changing share of each product category in the overall value of agricultural output. Figure 2.4 presents these changing shares over the period from TE 1982–83 to TE 2016–17. It is clear that the share of food products has become more diverse with a move away from staple crops to cash crops, horticulture and livestock products. In particular, the share of livestock has risen from 20% in TE 1982–83 to 31% in TE 2016–17. During the same period, the contribution of horticulture crops increased from 14 to 21%. According to the experts, this shift is "driven by increased domestic and export demand for non-cereals" (Mullen et al. 2005). Further, changing consumption patterns with rising incomes, urbanisation and changing relative prices of cereals and non-cereal foods also resulted in a diversification of the food basket. It is worth noting that technological innovations such as improved cultivars, high-yielding breeding stock and the establishment of an efficient supply chain together with policy changes such as the delicensing of the dairy sector (2002), and the launch of the National Horticulture Mission (2005) (Ferroni 2012) gradually improved the supply capacity for these high-value products.

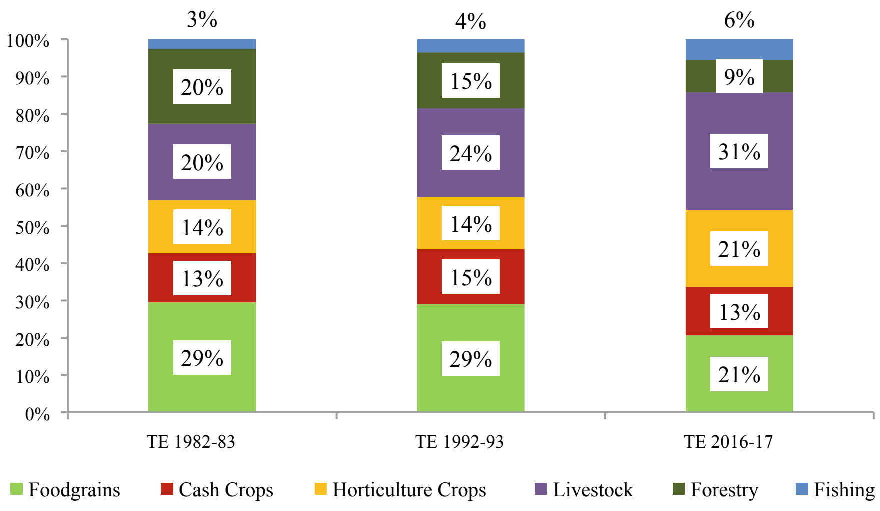

Fig. 2.4 Changes in value shares of different crops in India (per cent). *Source* National Accounts Statistics (2019)

2.1.4 Gradual Globalisation of Indian Agriculture

Despite significant successes in agriculture during the late 1960s and 1970s that gave India its Green Revolution (wheat) and white revolution (milk), the over-arching trade and marketing policies remained restrictive and anti-farmer (during the pre-liberalization years).

a. On the one hand, the country's overvalued exchange rate taxed its otherwise globally competitive agriculture sector.
b. On the other, the exceptionally high-import duties on industrial commodities discriminated against the farm sector.

Until reforms started in 1991, Indian agriculture was hardly integrated with global agriculture. Its trade (exports plus imports)-to-agricultural GDP ratio in 1990–91 was just 4.7%. With economic reforms, this sector was also gradually liberalised. First, quantitative restrictions on exports and imports of most of agricultural commodities were gradually removed. This change in policy also got a fillip with the signing of the WTO agreement on agriculture in 1995. Most importantly, tariffs on the imports of most agricultural crops were significantly reduced and were kept well below the bound rates of duty agreed upon under the WTO agreement.

As a result, agricultural trade as a percentage of the agricultural GDP doubled from 4.7% in 1990–91 to 9.4% in 1999–2000 before peaking at 20.9% in 2012–13. Thereafter, it slipped from this peak, but even in 2018–19, it was still at 15.1%, more than three times the level that existed when reforms started (Fig. 2.5).

In nominal US dollar terms, India's agricultural exports increased 7 times, from USD6.1 billion in 2001–02 to USD43.6 billion in 2013–14 (Fig. 2.5). However, after achieving this peak, exports have fallen a bit in the wake of falling global prices. Agricultural imports also increased sharply, from USD4 billion in 2001–02

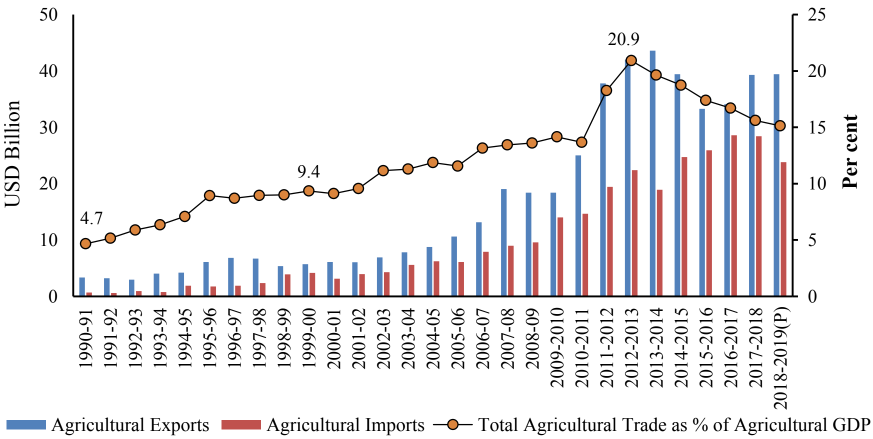

Fig. 2.5 Agricultural exports and imports (in USD billion) and total trade as a percentage of agricultural GDP in India. *Source* World Development Indicators (2019)

to USD18.7 billion in 2016–17, and thereafter, came down a bit. Overall, India has remained a net exporter of agricultural products in the post-reform period.

While these achievements are reasonably impressive, India still faces the challenges of poverty and malnutrition. In 2015, India had 176 million people (accounting for 13.4% of the total population) under extreme poverty (World Development Indicators 2019); about 14% of its population was also malnourished. India's share in global poverty and malnutrition remained high at about 24%. This is expected to remain a challenge for India over the next decade and is likely to get even more severe with climate change and increasing urbanisation. We will take up these issues in detail in the last chapter on the way forward.

2.1.5 Innovations in Indian Agriculture

Technological Innovations

Technological change has been a key driver of agricultural growth in India. Over the past 15 years, India's expenditure on agricultural R&D in real terms (2011 prices) has increased from USD1.90 billion in 2000–01 to USD3.29 billion in 2014–15 (ASTI 2016). According to experts, investment in research and development (R&D) translates into higher productivity, higher rates of return and improved economic performance (Ramasamy 2013). In Chap. 3, we discuss the innovations that made India a net exporter of agricultural products. The chapter also spells out innovations in input usage and other farm management practices that have significantly affected overall production as well as productivity.

Innovations in Incentives

Policies play a crucial role in structuring the incentive framework that govern market operations, output prices, input usage as well as the overall ecosystem in which farmers operate. In addition, innovative incentives strive to deliver, demonstrate and encourage the adoption of new technologies and modern practices in agriculture (Ganguly et al. 2017). Against the backdrop of consecutive famines during the mid-1960s, agricultural policies in India were focused on achieving food security. Since the early 1990s, India underwent substantial economic policy reforms, making the country a net exporter of agricultural produce. It is worth noting that the agricultural sector in India continues to be supported domestically through two major policy instruments: minimum support price (MSP) for basic staples and the provision of input subsidies that in many ways are restrictive, distorting and non-sustainable. Chapter 5 discusses and provides a critical evaluation of these policy interventions in detail. The chapter gives a detailed account of innovations in the incentive structure, introduced by the central and the state governments as well as investment in infrastructure for development. The chapter also captures the impact of such policy measures on farmers by evaluating producer support estimates (PSEs) over time.

Innovations in Institutions

Besides knowledge and technology, inputs such as land, water, mechanisation and the extension system continue to be key growth catalysts in Indian agriculture. Therefore, the quality of institutions that govern access to these inputs is critical to ensure efficient, equitable and sustainable use of resources by farmers. In India, a number of innovations in the institutional arrangements for land, water, farm machinery and agricultural extension have taken place. Chapter 7 gives a detailed account of the innovations in institutions in each of these input systems and the quality of outcomes.

2.2 China

2.2.1 Background

China has nearly 18.4% of the world's population, but a much smaller share of its natural resources for farming. The country has nonetheless largely been able to meet its growing demand for food from domestic production. In 2015, China produced 95% of its own food with respect to staple crops (Huang and Yang 2017). Over the past 40 years, inflation-adjusted agricultural gross domestic product (GDP) increased by an annual average of 4.5%, well ahead of the one per cent average annual population growth (NBSC 2010 and 2019). This is despite having only about 5% of the world's freshwater resources and less than 8% of the world's arable land.

China's agriculture has experienced rapid transformation in the past four decades. Grain production and large-scale on-farm employment dominated the sector before economic reforms started in 1978. Since then, agriculture has significantly diversified, with a much higher share of commercialised and high-value commodities. Off-farm rural employment has also increased markedly.

Growth in agriculture and off-farm employment have raised farmers' income and dramatically reduced poverty. The number of rural Chinese living in extreme poverty fell from 250 million in 1978 to fewer than 15 million in 2007. The extreme rural poverty rate dropped from 32% to less than three per cent in the same period. Even though the poverty threshold rose from RMB 1274/day in 2010 to RMB 2300/day at 2010 prices (slightly more than USD2/day at purchasing power parity) after 2010, the rural population under the poverty line decreased from 165.67 million (or 17.2% of rural population) in 2010 to 5.51 million (0.6% of rural population) in 2019. China was the first developing country to meet the Millennium Development Goals (MDGs) target to reduce the population living in poverty by more than half ahead of the 2015 deadline.

While these achievements are impressive, China's agriculture also faces great challenges. Increased food production has been at the expense of the environment and sustainable development (Zhang et al. 2013; Lu et al. 2015). Rising wages have increased the cost of food production and lowered China's agricultural competitiveness in the global market, which raises concerns about national food security (Huang

2013; Han 2015). Despite considerable growth in farmers' earnings, the rural–urban income gap remains large. The country is also concerned about how to modernise its agriculture with hundreds of millions of small-scale farms.

In early 2018, to foster agricultural and rural development, China initiated a Rural Revitalisation Development Strategy. To implement the strategy, there are lessons that the country can learn from its own past development. Some lessons from China may also be applicable for agricultural development and transformation in other developing countries.

This introductory chapter provides brief information on Chinese agricultural growth and transformation, and on major enabling factors. These include institutional innovation, technological changes, incentive reforms and investment. The three subsequent chapters provide further details of the enabling factors.

2.2.2 Agricultural Growth and Transformation

2.2.2.1 Agricultural Growth and Production Structure Changes

In the past four decades, the value of agricultural output in real terms has grown at an average annual rate of 5.3% (Table 2.1). Within the sector, annual growth rate of grain production was two per cent, about twice the population growth rate. More important than the rise in grain production, there has been a steady shift away from grain to production of higher-value cash and horticultural crops. In addition, average annual growth rates for cotton, sugar, edible oil crops and fruits were 4%, 5.2%, 6.1% and 11.1%, respectively, over the period (1952–2018). Livestock and aquaculture production have been growing even faster than the crop sector. The production of meat rose by an annual average of 5.7%, fish by 7% and dairy by 8.6%.

Large differences in the growth rates among commodities, within the overall rapid agricultural growth, resulted in considerable structural change in China's agricultural economy. Overall economic growth, urbanisation and market development have changed. The level and composition of Chinese food consumption have also driven changes in the agricultural production structure. Within crops, the proportion of area under non-grain cash crops increased from less than 20% in 1978 to nearly 30% in 2018. Over the same period, the share of the non-crop sector (mainly livestock and fishery) in total value of agricultural output increased from 20 to 46% (NBSC 2010 and 2019).

2.2.2.2 Path and Stages of Agricultural Transformation

Agricultural transformation in China took place in several stages (Table 2.2). The two main shifts have been the move away from staple food production to high-value crops and from agricultural to non-farm activities in rural areas. The major characteristics of each stage of agricultural transformation are summarised below.

Table 2.1 Average annual growth (per cent) of agriculture in China (1952–2018)

	Perform	Reform period[a]						
	1952–78	1978–84	1984–00	2000–05	2005–10	2010–15	2016–18	Average
Agri. GDP	2.2	6.9	3.8	3.9	4.5	4.1	3.6	4.5
Agri. gross output value	3.4	5.9	5.9	5.3	4.8	4.3	3.7	5.3
Grain (cereal + tubers + soya beans)	2.5	5.5	0.9	1.0	2.5	2.4	−0.1	2.0
Cotton	4.0	17.9	−0.6	6.4	2.0	−0.1	1.4	4.0
Edible oil crops	1.4	17.6	6.4	0.9	1.5	2.3	0.4	6.1
Sugar crops	7.8	13.6	3.7	4.8	5.3	0.7	2.1	5.2
Fruits	4.0	8.5	12.5	26.2	5.8	5.9	1.6	11.1
Vegetables		4.6	8.3	3.1	1.5	2.7	1.4	5.1
Meat		7.8	9.1	2.9	2.7	1.8	−0.5	5.7
Pork + beef + mutton	4.4	11.4	7.5	2.9	2.4	1.8	−0.9	5.6
Poultry			14.9	2.9	4.2	2.0	0.9	8.3
Dairy			8.2	25.6	5.7	0.6	−1.1	8.6
Fishery	4.7	4.2	12.1	3.6	4.0	4.6	1.3	7.0

Sources Authors' estimates based on data from NBSC, various issues of the National Statistical Yearbook from 2000 to 2019, and China Compendium of Statistics 1949–2008 (NBSC 2010)
Note Except for vegetables, the growth rates of individual and groups of commodities are based on production data; agricultural GDP and agricultural gross value refer to values in real terms. Meat production data are available since 1979; poultry production data are available since 1985

- Stage 1: *Primary focus on staple food production before 1980.* Following the 1949 Communist Revolution, the government focused on meeting increasing food demand for its growing population. China used 89% of land for grain production in 1950; this figure was still high at 80% in 1980 (NBSC 2010).
- Stage 2: *Agricultural diversification beginning in the early 1980s.* After China's rural reform started in 1978, the rapid growth of grain production helped farmers allocate more land, water, labour and capital to labour-intensive, higher-value cash crops and meat products, significantly increasing their income from agriculture.
- Stage 3: *Agricultural specialisation, mechanisation and rising non-farm employment since the early 1990s:* With rising agricultural productivity and national industrialisation, rural labour has increasingly shifted from agriculture to off-farm

Table 2.2 Paths, IPIs, rural transformation and sequence of IPIs in China

Stage	Paths of transformation	Additional IPIs in each stage and sequence
1	Focus on staple food production	Institutions (e.g. land policy), technology, extension and irrigation (to raise cereal productivity)
2	Agri. diversification	Plus market reform and improvements in marketing, irrigation and road infrastructure
3	Agricultural specialisation and mechanisation and rising non-farm employment	
3.1	Farming and part-time non-farm employment	Plus polices to support township and village enterprises (TVEs); labour-intensive industrialisation in urban areas
3.2	Increasing specialisation in farm or non-farm employment	Plus labour and land rental institutions and markets
3.3	Rapid agri. mechanisation and more off-farm employment	Plus accelerating urbanisation; farm mechanisation, land consolidation
4	Integrated urban–rural and sustainable agricultural development	Plus eliminating urban–rural divisions; sustainable agriculture; Rural Revitalisation Development Strategy

employment. In the early years of this stage, the shift mainly occurred through the development of township and village enterprises. Part-time off-farm employment opportunities emerged. After the late 1990s, urbanisation and labour-intensive industrialisation further pulled rural labour to off-farm income-generating activities in both rural and urban areas. Rising off-farm wages, particular after the mid-2000s, led to increasing specialisation in farming and the move to non-farming activities. Some farmers rented out their land; others started to increase farm size and mechanise agricultural production (Huang and Ding 2016; Wang et al. 2016). By 2015, about 60% of rural labour worked off-farm and more than one-third of the total contracted land was transferred among farmers.

- Stage 4: *Integrated urban–rural and sustainable agricultural development since the middle 2000s:* The first three stages focused on increasing production, which led to the excessive use of fertilisers and pesticides and intensive use of land and water. Despite a significant increase in farmers' income during the reform period, urban incomes grew faster. There were also large gaps in public good provision, favouring urban over rural areas. In the light of these challenges, China has pursued a nationwide urban–rural integrating development strategy since the early 2010s and sustainable agriculture development since the mid-2010s. In 2018, China initiated the Rural Revitalisation Strategy, aimed at modernising agriculture and the rural economy significantly by 2035 and fully modernising it by 2050.

2.2.3 Major Factors Driving Agricultural Growth and Transformation

Many factors have contributed to China's agricultural growth and transformation. Those that have played the largest enabling roles are rural institutional changes, policy support and investment in agricultural infrastructure (IPIs). Changes outside agriculture, particularly labour-intensive industrialisation and urbanisation, which provided more employment opportunities for rural labour, were additional contributors to the agricultural and rural transformation in the country.

Technological Changes

China has developed a strong public agricultural research and development (R&D) system. It is the world's largest in terms of staff and covers nearly every discipline in agriculture and related fields (Huang 2013). In 2011, China was estimated to have at least 68,000 research staff working in the public agricultural R&D system (Hu and Huang 2011). China has also developed the largest agricultural extension system in the world with about 700 thousand employees in recent years (Babu et al. 2015). Technological innovation has been one of the major sources of agricultural productivity growth and has facilitated China's agricultural transformation over the past several decades. Chapter 4 presents details of major technological innovations, notably in major crops, livestock and fishery production, in irrigation, chemical fertilisers and farm machinery, and in biotech and digital technologies.

Incentive Reforms and Investment in Agriculture

China adopted a gradual reform approach for its agricultural markets. Market reforms have played important roles in resource allocation and agricultural transformation. Farmers have gained from increased allocative efficiency based on market prices (deBrauw et al. 2004). China's "open door" process also helped integration into international markets. A recent significant incentive policy change has been the shift from taxing to subsidising agriculture. Investment has also created a solid foundation for steady agricultural growth in China and rapid agricultural transformation. China is one of a few large countries that have substantially increased agricultural investment in recent decades. The most significant investments are in irrigation, rural market infrastructure, land improvement and agricultural technology. Chapter 6 presents details of the incentive structure for Chinese farmers. Investment in agriculture will be discussed in various chapters.

Institutional Innovations

China's first rural reform, the household responsibility system (HRS), was implemented during 1978–1984. This dismantled people's communes and contracted cultivated land to individual households in each village, mostly on the basis of the amount of people and/or labour per household. The first term of the land contract was 15 years. After the first term ended in the late 1990s, it was extended to 30 years in the second term and will be further extended for an additional 30 years after the end of the second term in the late 2020s. Institutional reforms have also occurred in many other areas, including innovative institutional arrangements for water, farm machinery and extension services. Chapter 8 presents details of each of the major institutional innovations governing the agricultural sector.

2.3 Israel

2.3.1 Background

The state of Israel is a parliamentary democracy (The Embassy of Israel 2016). It has a single chamber parliament (the Knesset) of 120 members. The seats in the Knesset are allocated under the system of proportional representation, wherein voters cast ballots for an entire party. The leader of the largest party or voting bloc gets the chance to form the government and, if successful, becomes the Prime Minister for a term of four years (OECD 2010). The head of state is the President who is elected by a simple majority of the Knesset, for a term of seven years (The Embassy of Israel 2016).

Administratively, Israel is divided into six districts, namely Northern, Haifa, Central, Tel Aviv, Jerusalem and Southern. Geographically, it is divided into four major regions: the narrow coastal plain, which extends along the Mediterranean Sea and includes much of Israel's agricultural land; the inland, which covers mountain ranges and highlands from the north to the edge of the Negev Desert in the south; the Rift Valley, which lies below the Dead Sea level; and the Negev Desert in the south, which is extremely arid and includes flatlands and mountains (OECD 2010).

Israel's annual GDP growth rate has been 3.3% since the 2000s. In 2018, overall GDP at current prices was USD0.36 trillion.[5] Per capita income in 2018 was high at USD42,987 compared to USD9516.1 in China and USD1990 in India in current US dollar terms. But in PPP terms, at current USD, the gap in per capita GDP is smaller: Israel is at USD39,919.2, China is at USD18,236.6, and India is at USD7762.9.

2.3.2 Agricultural Growth and Transformation

Israel's agriculture is the success story of a long, hard struggle against adverse land and climatic conditions. Its agricultural land is about 620 thousand hectares (2018), which represents about 28.7% of the land area (2.16 million hectares), consisting of only 380 thousand hectares of arable land (World Development Indicators 2019). Triggered by chronic food shortages, Israel, since its establishment in 1948, almost tripled the territory used for farming and has increased production manifold from

[5]https://data.worldbank.org/indicator/NY.GDP.MKTP.PP.CD?locations=IN.

Table 2.3 Changes in the composition of the value of agricultural production in Israel, 2000–2018 (in per cent)

	2000	2010	2018
Crops	*56*	*61*	*59*
Fruit plantations and others	26	29	31
Vegetables, potatoes and melons	18	22	19
Field crops	7	6	7
Flowers and garden plants	4	4	2
Livestock	*44*	*39*	*40*
Milk	13	9	11
Poultry	14	12	15
Eggs	7	6	6
Cattle (meat)	4	5	4
Sheep, goat, pig and others	4	5	4
Fish	*3*	*2*	*1*

Source CBS, Agricultural Produce Survey, Israel

saline soil, arid or semi-arid land with poor natural water supplies (OECD 2010). Israel's agricultural success is attributed most importantly to R&D and technological innovations (allocation to R&D is about 17% of the Israeli government's 520 million dollar budget allocation for agriculture),[6] to investments in developing alternate water sources for agriculture such as purification of sewage water and desalination of seawater (OECD 2010), and to close co-operation between farmers. It is worth highlighting that Israel's innovation of drip irrigation marked a worldwide technological revolution in the history of agriculture (Tal 2007). In addition, farming in Israel has grown technologically sophisticated over time with efficient use of water and fertilisers as well as adoption of precision agricultural methods.

Parallel to the dramatic increase in the number of settlements, the efficiency of Israeli farming operations has consistently improved. In 1955, a single Israeli farmer provided food for 15 local residents; today, an Israeli farmer produces food for over 100 local consumers. Overall, agriculture output is valued at around USD8.7 billion (2018), of which agricultural crops constitute roughly 59% with fruits and vegetable together accounting for 50% of total crop output (Israel supplies 220 kg/person fruits and vegetables annually). Livestock contributes an additional 40%, and the remaining 1% is contributed by fisheries (Table 2.3). Notwithstanding its remarkable success, agriculture at present contributes only 1.5% to the country's gross national product. Furthermore, one of the unique features of this country is that 93% of the agricultural land and all water resources are public-owned. Another important characteristic is the dominance of co-operative communities—Kibbutz and Moshav—in the country's rural sector, controlling approximately 80% of the agricultural output.

[6]https://www.factsaboutisrael.uk/.

2.3.3 The Turning Point

Israel undertook substantial economic policy reforms during the mid-1980s that marked the turning point in Israel's macroeconomic policies. These policies were introduced in the wake of the balance of payment crisis, high public debt and high rates of inflation. Major reforms in the agricultural sector also started during the same time and continued through the 2000s. These policies included reduction in price subsidies, opening up of agricultural trade, abolition of production quotas and reduction in domestic support to agriculture. Overall, these policies contributed to improved integration of the agro-food sector with global markets (OECD 2010).

These policies initiated the structural changes in the agricultural sector such as a significant decrease in the number of farms, expansion in farm size, diversification of cropping pattern towards high-value crops like fruits and vegetables and the emergence of new private enterprises serving agriculture. Although the share of agriculture in total employment as well as in GDP fell during 1990–2008, increased labour productivity led to a significant increase in total factor productivity in agriculture (it doubled between 1990 and 2006) due to innovation and the adoption of more advanced technologies.

Israel has been a net importer of agricultural products. Land-intensive crops, such as cereals, bovine meat, oilseeds, sugar and fish dominate agricultural food imports. At the same time, it is a major exporter of horticulture crops, mainly to European markets. In 2017–18, agricultural exports stood at USD2 billion while agricultural imports were USD6 billion, accounting for a share of 4% and 8%, respectively, in Israel's total exports and imports.

Chapter 9 elaborates on the technological innovation, incentive structure for farmers and institutional innovations in Israel.

References

Ahluwalia, M. S. (2020). *Backstage: The story behind India's high growth years.* Delhi: Rupa Publications India Pvt. Ltd.

ASTI. (2016). *Agricultural R&D indicators factsheet: India.* Agricultural Science and Technology Indicators (ASTI), IFPRI.

Business Standard. (2019, November 25). '*Mann ki Baat: Modi recalls Emergency, says don't take democracy for granted*'. Press Trust of India.

Economic Survey. (2019). *Entrepreneurship and wealth creation at the grassroots.* Government of India.

Ferroni, M. (2012). *Transforming Indian agriculture: India 2040.* SAGE Publications.

Ganguly, K., Gulati, A., & Braun, J. V. (2017). *Innovations spearheading the next transformations in India's agriculture.* Germany: ZEF Working Paper Series, No. 159.

Government of India. (2017). *Land use statistics at a glance.* Retrieved March 23, 2020, from Directorate of Economics and Statistics: https://eands.dacnet.nic.in/LUS_1999_2004.htm.

Government of India. (2018). *India at a glance: Profile.* Retrieved March 23, 2020, from https://www.india.gov.in/india-glance/profile.

Gulati, A., Kapur, D., & Bouton, M. M. (2019). *Reforming Indian agriculture.* Pennsylvania: Center for the Advanced Study of India and the Indian Council for Research on International Economic Relations.

Han, J. (2015). *China: Food Security and Agricultural going out, Strategy Research.* China Development Press, Beijing (in Chinese).

Hu, R., & Huang, J. (2011). The development and reform of agricultural research system: Policy evaluation and recommendations. *Science and Society, 3*, 34–40.

Huang, J. (2013). China's Agricultural Development in the New Era: Opportunities, challenges, and strategies. *Bulletin of Chinese Academy of Sciences, 3*, 295–300 (in Chinese).

Huang, J., & Ding, J. (2016). Institutional innovation and policy support to facilitate small-scale farming transformation in China. *Agricultural Economics, 47*, 309–317.

Lu, Y., Jenkins, A., Ferrier, R. C., Bailey, M., Gordon, I. J., Song, S., Huang, J., Jia, S., Zhang, F., Liu, X., Feng, Z., Zhang, B. (2015). Addressing China's grand challenge of achieving food security while ensuring environmental sustainability. *Science Advances, 1*, e1400039.

Mullen, K., Orden, D., & Gulati, A. (2005). *Agricultural policies in India: Producer support estimates 1985–2002.* IFPRI.

National Accounts Statistics. (2019). *National Accounts Statistics.* Delhi: MOSPI, CSO, Government of India.

NBSC. (2010). China Statistical Press, Beijing.

NBSC. (2019). China Statistical Press, Beijing.

OECD. (2010). *OECD Review of Agricultural Policies: Israel 2010.* OECD Publishing, Paris. https://doi.org/10.1787/9789264079397-en.

OECD, ICRIER. (2018). *Agricultural policies in India.* Paris: OECD Publishing.

Pingali, P., Aiyar, A., Mathew, A., & Rahman, A. (2019). Economic growth, agriculture and food systems: Explaining regional diversity. In P. Prabhu, A. Aiyar, M. Abraham, & A. Rahman, *Transforming food systems for a rising India.* Palgrave Macmillan.

Ramasamy, C. (2013). Indian agricultural R&D: An introspection and way forward. *Agricultural Economics Research Review, 26*(1), 1–20.

Reserve Bank of India. (2005). *Report on foreign exchanage reserves.* Mumbai: Reserve Bank of India.

Tal, A. (2007). To make a desert bloom: The Israeli agricultural adventure and the quest for sustainability. *Agricultural History, 81*(2), 228–257.

The Embassy of Israel. (2016). Israeli Democracy and Elections. https://embassies.gov.il/bucharest/AboutIsrael/State/Pages/Israeli-democracy.aspx.

United Nations Projections. (2019). *United nations world population prospects.*

Wang, X., Yamauchi, F., & Huang, J. (2016). Rising wages, mechanization, and the substitution between capital and labor: Evidence from small scale Farm system in China. *Agricultural Economics, 47*, 309–317.

World Development Indicators. (2019). *World development indicators.* The World Bank.

Zhang, F., Chen, X., & Vitousek, P. (2013). Chinese agriculture: An experiment for the world. *Nature, 497*, 33–35.

Chapter 3
Innovations in Production Technologies in India

3.1 Introduction

In agriculture, innovations in seed production could result in higher productivity, protect plants from pests and may even increase mineral, vitamin and protein content; innovation could also address how the application of water (irrigation), fertilisers, pesticides and other inputs can result in a higher value for a lower quantity/cost. There could be innovations in farming practices that not only increase productivity, but also save on costs or promote sustainable agriculture that can better withstand several abiotic and biotic stresses. In fact, innovations can make an impact beyond production technologies—in the field of institutions that ensure the effective implementation of policies; in storage, where effective logistics can avoid massive loss of food; and in better marketing of goods and services which bring higher value to its users. Thus, innovations can spread all along the agricultural value chain, from farm to fork, or, more aptly in a demand-driven system, from "plate to plough".

In this paper, we spell out the major innovations in production technology that have had a significant impact on overall productivity and production in India. We also touch upon innovations that are currently unfolding in inputs and production processes. More specifically, we will cover the following.

- Innovations in production technologies, ranging from seeds (high yielding and climate-resilient), farming practices, policies that led to the green revolution, white revolution, blue revolution, red (poultry) revolution, golden revolution and gene revolution
- The impact on agricultural total factor productivity (TFP)
- Innovations in water management—irrigation technologies, especially drip irrigation and sprinklers
- Innovations in farm mechanisation—Uberisation and custom hiring models, solar-based mobile irrigation pump sets based on a pay-per-use principle

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- Innovations in fertiliser and soil management—soil health cards (SHCs) and *neem* coating of urea (NCU)
- Innovations in precision agriculture using smart technologies—artificial intelligence, drones, Internet of things (IoT), remote sensing, etc.
- Innovations in sustainable and protected agricultural practices—soilless farming systems (hydroponics, aeroponics and aquaponics) and poly-house farming systems under the Indo-Israeli Agriculture Project
- Role of research and development and education in agriculture.

3.2 Innovations and Revolutions in Indian Agriculture: A Chronological Account

3.2.1 The Green Revolution—Innovations in Seeds, Policies and Marketing Institutions (Wheat and Rice)

India gained independence in 1947 with a challenge to feed 330 million people. Inadequate domestic production, as well as negligible foreign exchange reserves to buy grains from global markets on commercial terms, posed serious food security concerns (Gulati 2009). In 1956, Jawaharlal Nehru, the first Prime Minister of independent India, launched a heavy industrialisation strategy embedded in the Second Five-Year Plan (1956–61). It became clear that the darling of development strategy was not agriculture but heavy industry, notwithstanding Nehru's famous quote "everything else can wait, but not agriculture".[1] The situation became grim when India was hit by back-to-back droughts during the mid-1960s. Grain production plummeted by 17 million metric tonnes (MMT), from 89.4 MMT in 1964–65 to 72.4 MMT in 1965–66 (Chopra 1981). India became heavily reliant on food aid enabled by the USA's Agriculture Trade Development and Assistance Act, also known as PL-480, and underwent a "ship-to-mouth" crisis. The then Prime Minister, Lal Bahadur Shastri, called on the nation to "miss a meal" every week to cope with the dire situation (Bandyopadhyay 2016).

Against this backdrop, it was imperative to achieve self-sufficiency in food grains in a sustainable way. The then Food Minister, Chidambaram Subramaniam, steered through political hurdles, bureaucratic wrangles and public debates to advocate the import of high-yielding variety (HYV) wheat seeds, developed by Norman E. Borlaug at the International Maize and Wheat Improvement Center (CIMMYT), Mexico. He even argued that if the new technology was not supported by appropriate policies on prices, fertilisers, land ownership, water and credit, it would not work (Maitra 1991). In January 1965, the Agricultural Prices Commission (APC) and the Food Corporation of India (FCI) were established to ensure "remunerative prices" to producers and to facilitate storage, marketing and distribution of grains (Gulati 2009). Finally, in 1966, 18,000 tonnes of HYV wheat seeds—Lerma Rojo 64 and Sonora 64—were

[1] Soon after independence, in 1948, Jawaharlal Nehru remarked that "everything else can wait, but not agriculture". He said this in the context of the Bengal Famine of 1942–43 and the acute food scarcity prevailing in the country in 1947 (Swaminathan 2007).

imported and distributed to the regions of Punjab, Haryana, and the western belt of Uttar Pradesh. This ushered in the Green Revolution in India. The adaptation of imported germplasm to improve indigenous varieties like Kalyan by D. S. Athwal and Sona by M. S. Swaminathan,[2] along with extensive irrigation and fertiliser usage, aided the spread of the revolution (Gulati 2014). Around the same time, the HYV miracle rice IR8, developed by Peter Jennings and Henry M. Beachell of the International Rice Research Institute (IRRI), were imported (Dalrymple 1985). An in-house breeding programme under the All-India Co-ordinated Rice Improvement Project (AICRIP), initiated by the Indian Council of Agricultural Research (ICAR), produced Padma and Jaya, the first indigenous HYV rice seeds that formed the backbone of India's revolution in rice. About a decade later, an improved variety, IR36, developed by Gurdev Khush at the International Rice Research Institute (IRRI), also made inroads into Indian fields and became the most widely planted food crop ever grown (The World Food Prize 1996a, 1996b).[3] The international exchange of wheat and rice germplasm through an alliance with the Consultative Group on International Agricultural Research (CGIAR) network, along with better pricing and marketing policies, played a catalytic role in driving the production breakthrough in wheat and rice.

While India's population has grown more than four times, from 330 million in 1947 to 1.38 billion in 2020, wheat production has increased over 16 times (from about 6.5 MMT in 1950–51 to 106.2 MMT in 2019–20) (DoAC&FW 2020) and productivity from less than 1 tonne per hectare (t/ha) to more than 3.5 t/ha during the same time period. It is worth noting that the very first wheat harvest after the release of HYV semi-dwarf seeds in 1967–68 recorded a jump of 45% from 10.4 MMT in 1966–67 to 16.5 MMT in 1967–68. Today, India is the second largest wheat producer in the world, contributing about 13% to total wheat production, next only to China with approximately a 17% share (USDA 2018a, b). Rice production has increased 5.7 times (from 20.6 MMT in 1950–51 to 117.5 MMT in 2019–20) with a 24% increase (from 30.4 MMT to 37.6 MMT) during 1966–67 and 1967–68. Moreover, rice productivity also increased from 0.6 t/ha in 1950–51 to 2.7 t/ha in 2018–19. Today, India is the second largest rice producer in the world, accounting for approximately a 23% share in total rice production, next to China with approximately a 29% share (USDA 2018a, b). Moreover, it is also the world's largest exporter of rice with about 12.7 MMT exports in 2017–18, valued at USD7.7 billion (APEDA 2018) (Figs. 3.1 and 3.2).

Punjab, the seat of the Green Revolution, was a front runner in agriculture during the late 1960s (Verma et al. 2017). Wheat and rice production literally doubled from 2.5 MMT to 5.6 MMT and from 0.3 MMT to 0.9 MMT, respectively, between 1966–67 and 1971–72 (Figs. 3.3 and 3.4).

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[2]In 1987, M. S. Swaminathan was honoured with the first World Food Prize for spearheading the introduction of high-yielding varieties to Indian farmers (The World Food Prize 1987).

[3]In 1996, Henry M. Beachell and Dr. Gurdev Singh Khush were honoured with the World Food Prize for ensuring sufficient food supplies for rapidly growing populations in Asia and around the world (The World Food Prize 1996a, b).

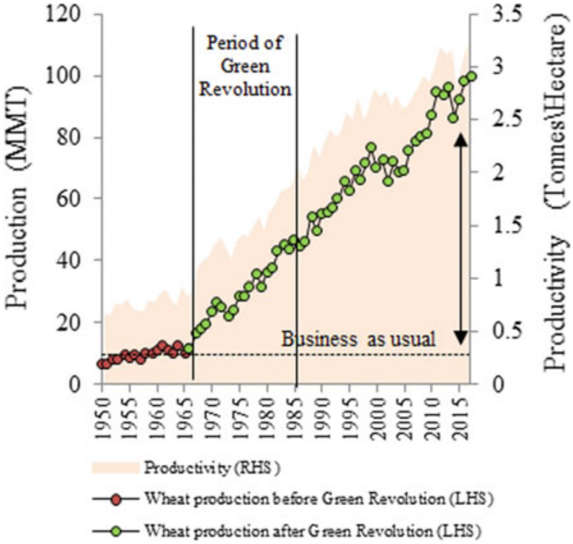

Fig. 3.1 All India wheat production and productivity. *Source* Agricultural Statistics at a Glance, Department of Agriculture, Co-operation and Farmers' Welfare (DoAC&FW), Government of India (GoI)

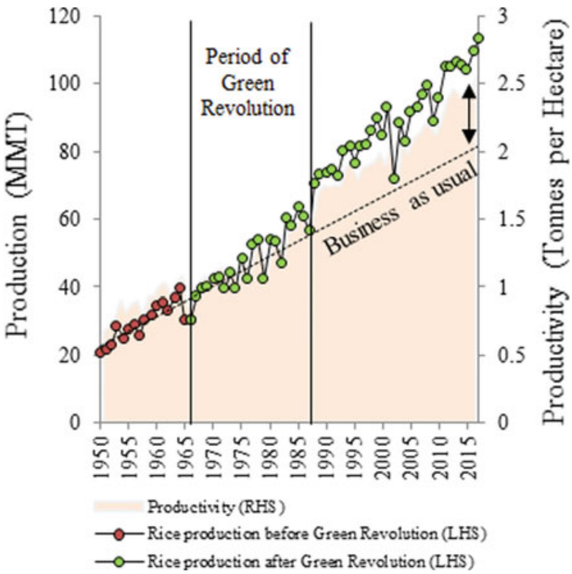

Fig. 3.2 All India rice production and productivity. *Source* Agricultural Statistics at a Glance, Department of Agriculture, Co-operation and Farmers' Welfare (DoAC&FW), Government of India (GoI)

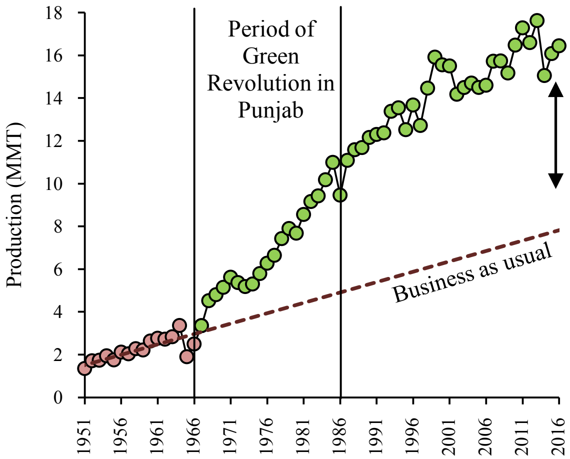

Fig. 3.3 Wheat production in Punjab, India. *Source* Bulletin on Food Statistics issued by the Economic and Statistical Adviser, Ministry of Agriculture, GoI (various issues)

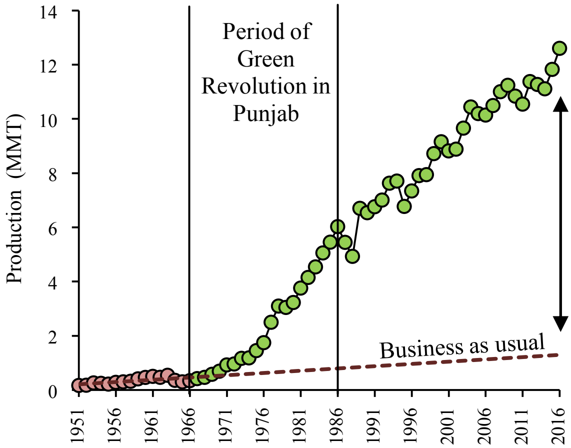

Fig. 3.4 Rice production in Punjab, India. *Source* Bulletin on Food Statistics issued by the Economic and Statistical Adviser, Ministry of Agriculture, GoI (various issues)

Basmati

Later on, between 2005 and 2013, a breakthrough in basmati rice came about through the landmark varieties—Pusa Basmati 1121[4] and Pusa Basmati 1509[5]—developed

[4]Pusa Basmati 1121 was developed by ICAR in 2003 and was first released as Pusa 1121 in 2005 vide Gazette Notification S. O. 1566(E) dated 5 November 2005. Then in 2008, it was substituted by Pusa Basmati 1121 vide Gazette Notification no. S.O. 2547(E) dated 29 October 2008.

[5]Released commercially vide Gazette Notification no. S.O. 2817(E) dated 19 September 2013.

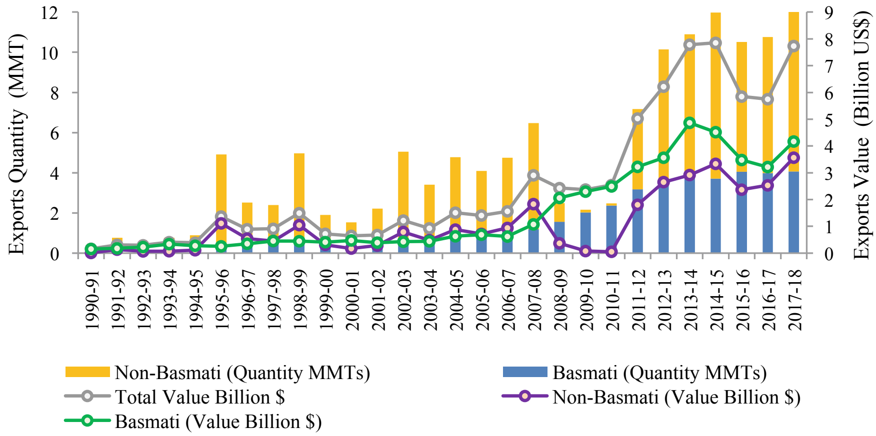

Fig. 3.5 Rice exports from India. *Source* Agricultural processing and export development authority (APEDA), GoI

by teams led by V. P. Singh, A. K. Singh and K. V. Prabhu at the Indian Agricultural Research Institute. This gave Indian rice more value with higher yields compared to traditional basmati (Fig. 3.5).

According to Singh et al. (2018), India is the largest cultivator and exporter of basmati rice in the world with 4 MMT in 2017–18 valued at USD4.17 billion, followed by Pakistan. Pusa Basmati 1121 is grown in approximately 70% of the total area under basmati cultivation in India. Moreover, the total value of exports of Pusa Basmati 1121 and domestic sales between 2008 and 2016 was estimated at USD20.8 billion, making it a highly profitable business (Singh et al. 2018).

Recent and Unfolding Innovations in Staples (Wheat and Rice) Some innovations in farming practices such as the system of rice intensification (SRI), direct seeding and zero tillage[6] hold great potential for higher yields and efficient resource management. SRI is a skill-intensive technology that saves the cost of inputs such as seeds and fertilisers and improves yields per hectare (NITI Aayog 2015). The economic impact evaluation study on SRI undertaken in Tamil Nadu and Andhra Pradesh reveals that the yield increase through SRI practices in comparison with non-SRI (conventional) was 37–39%. Further, the reduction in labour requirement per hectare was estimated to be 30–32% (Johnson et al. 2015). According to the paper based on Task Force on Agricultural Development constituted by the NITI Aayog, Government of India, "the area under SRI has increased progressively since 2000–01 and Tamil Nadu, Bihar and Tripura are the leading states that are practising the disruptive technology". Based on similar principles, the system of intensification has been extended to wheat (SWI).

[6]Zero tillage can allow farmers to sow wheat sooner after rice harvest, so that the wheat crop escapes terminal heat stress (ICAR-IARI 2018).

According to a report by ATMA (2008),[7] yields under SWI are 25–50% higher than that under conventional cultivation. It was also found that, based on SWI trials and farm-level data collected from Himachal Pradesh during 2008–09, the benefit-cost ratio under SWI was 1.81 compared to 1.16 under the conventional method (Chopra and Sen 2013). The paper brought out by the NITI Aayog titled *Raising Agricultural Productivity and Making Farming Remunerative for Farmers* stated that "the resource *(sic)* conservation technologies like zero tillage and residue management can reduce the cost of cultivation by 25–30% over conventional farming practices" (NITI Aayog 2015).

Climate change is one of the important areas of concern for our country. It is predicted that the temperature in India will rise in the range of 0.5–1.2 degree Celsius (°C) by 2020, 0.88–3.16 °C by 2050 and 1.56–5.44 °C by the year 2080. This will have a significant negative impact on crops, lowering yields by 4.5–9.0%, depending on the magnitude and distribution of warming (NICRA 2018). In order to cope with climate change, ICAR launched a flagship network project called the "National Innovations on Climate-Resilient Agriculture" (NICRA) in 2011. According to NICRA, about 60% of the net cultivated area in India is rain-fed and exposed to several abiotic and biotic stresses (ICAR-IARI 2018), due to which irrigated rice yields are projected to fall by about 4% in 2025 (2010–2039) and rain-fed rice yields by 6%. This poses a challenge of sustaining domestic food production for growing population. Therefore, developing crop varieties with higher yield potential and tolerance to climatic stresses (heat, drought, submergence, salinity) becomes imperative. Table 3.4 in the Annexure lists a few recently released climate-resilient wheat and rice varieties in India. NICRA has selected some villages based on climatic vulnerability to demonstrate climate-resilient practices and crops to enhance adaptive capacity to enable farmers to cope with climatic variability. Lessons learned from the demonstrations are then used to select the best planting lines and other management practices for further expansion.

The emergence of genomic sequencing and bioinformatics analysis further offer the potential to ramp up the process of developing crops with the desired agronomic traits, which can bring about a revolution in crop sciences, revealing avenues for economic benefits to farmers. The rice genome was decoded in 2002 and provided data to identify genetic markers for disease resistance, drought and flood tolerance and support plant-breeding strategies to develop superior varieties. Recently, in 2018, a group of scientists and breeders around the world under the International Wheat Genome Sequencing Consortium (IWGSC) have decoded the complex bread wheat genome, which is a major scientific breakthrough in the history of agriculture. It took more than a decade to decode the vast size of the genome (some five times larger than the human genome) with its highly repetitive nature (being a hybrid of three highly similar sub-genomes of earlier grasses, with more than 85% composed of repeated sequences) (IWGSC 2018). Wheat genome identification will contribute to global food security and potentially help develop highly productive, nutritious

[7] Report by Agriculture Technology Management Agency (ATMA), Nalanda with PRADAN—"Assessment, Refinement and Validation of technology through System of Wheat Intensification (SWI) in Nalanda".

and sustainable heat, water-logging and pest/disease-resistant and drought-tolerant grains. The best is yet to come!

Notwithstanding its food grain surplus, India faces a complex challenge of nutritional security. According to recent FAO estimates in *The State of Food Security and Nutrition in the World, 2018* report, 14.8% of India's total population is undernourished. Further, 38.4% of children aged below five years are stunted while 21% suffer from wasting and 51.5% of women in the reproductive age group (15–49) suffer from anaemia (FAO, IFAD, UNICEF, WFP and WHO 2018).

Several factors contribute to this, ranging from poor diets, unsafe drinking water, poor hygiene and sanitation, and low levels of immunisation and education, especially of women. However, the latest innovations in biotechnologies towards bio-fortification of major staples with micro-nutrients like vitamin A, zinc, iron, etc., can be game changers. Globally, the HarvestPlus programme of the CGIAR network is already doing a lot of work in that direction. In Uttar Pradesh, Bihar and Jharkhand, the release of high yielding zinc-rich wheat—BHU-3, BHU-6 (Chitra)—can potentially provide up to 50% of daily zinc needs, and short-duration, drought-tolerant iron pearl millet—ICTP 8203-Fe-10-2 (Dhanashakti), ICMH 1201 (Shakti-1201)—in Rajasthan and Maharashtra can potentially source 80% of daily iron needs (HarvestPlus 2017). The Indian Council of Agricultural Research (ICAR), through its independent research, has also released zinc- and iron-rich wheat (WB 02 and HPWB 01) with yields of more than five tonnes per hectare (t/ha), high protein and zinc-rich rice [CR Dhan 310 and DRR Dhan 45[8] (IET 23832)] and a fortified pearl millet hybrid with high iron and zinc (HHB 299 and AHB 1200) with yields averaging more than 3.2 t/ha. This could possibly lead to the next breakthrough in staples, making them more nutritious. Recently, a research team led by Dr Monika Garg at the National Agri-Food Biotechnology Institute (NABI), Mohali, has pushed frontiers and innovated bio-fortified coloured wheat[9] (black, blue, purple) through crosses between high yielding Indian cultivars (PBW550, PBW621, HD2967), blue wheat (TA3972) and purple wheat (TA3851) obtained from the Wheat Genetics Resource Center, Kansas State University, Kansas, USA, and black wheat obtained from Tottori University, Japan, which are exceptionally rich in anthocyanins[10] (40–140 ppm) (Sharma et al. 2018)[11] and zinc (35–38 mg per 100 g). According to nutrient requirements and the recommended dietary allowance (RDA), anthocyanins are antioxidants

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[8]DRR Dhan 45 is India's first bio-fortified semi-dwarf zinc-rich and high-yielding variety, developed at ICAR-IIRR and released in India. It is developed from the cross IR 73707-45-3-2-3/ IR 77080-B-34-3; it is a medium duration culture (~130 days) with non-lodging plant type and long slender grain that is recommended for cultivation in an irrigated ecosystem yielding 5–6 t/ha with 22 ppm zinc.

[9]It is not genetically modified (non-GMO) and has been approved for human consumption by the Food Safety and Standards Authority of India (FSSAI) as F.No.04/Std/PA/FSSAI/2018 (inputs received from NABI).

[10]Anthocyanins are the naturally occurring antioxidants that give blueberries and *jamun* their colour and come under the list of healthy nutraceuticals under Schedule VI B of FSSAI's Nutraceutical Regulations.

[11]Plant material included one white wheat (cv, PBW621), three coloured donor wheat lines (purple, blue and black) and three high-yielding coloured advanced breeding lines (purple, blue and black)

Table 3.1 Comparative composition analysis of white and coloured wheat, India

Composition	In 100 g			
	White wheat	Purple wheat	Blue wheat	Black wheat
Anthocyanins in parts per million (ppm)	5	40	80	140
Energy in calories (kcal)	322	318	318	318
Carbohydrates in grams (g)	67.8	65.8	65.8	64.8
Protein (g)	10	11	11	12
Dietary fibre (g)	11	12	12	12
Fat (g)	1.2	1.2	1.2	1.2
Moisture in percentage	10	10	10	10
Potassium in milligrams (mg)	350	350	350	350
Sodium (mg)	2.5	2.5	2.5	2.5
Calcium (mg)	35	35	35	35
Iron (mg)	38	45	45	45
Zinc (mg)	28	36	38	35

Source NABI (2018)

that prevent oxidative damage and help in delaying ageing and reducing cancer, and help prevent cardiovascular diseases, diabetes and other disorders (NABI 2018).

Table 3.1 gives a comparative composition analysis of coloured and white wheat. In June 2018, the varieties were approved for human consumption by the Food Safety and Standards Authority of India (FSSAI). More recently, under the contract farming model with private companies,[12] the purple and black varieties have been harvested in over 700 acres across India—from Patiala and Jalandhar in Punjab to Vidisha in Madhya Pradesh (Sharma 2019).

Bio-fortified crops have huge market potential. This seems to be only the beginning of a new journey, from food security to nutritional security in India. But these innovations in bio-fortified foods can help alleviate malnutrition only when they are scaled up with supporting policies, including augmented expenditure on agricultural R&D, with due accountability to deliver. If we trust science with a human face, the best is yet to come.

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selected from back-crossed filial generations (BC1F8) of cross between white and donor coloured wheat lines. They were grown and advanced in the farms of the National Agri-Food Biotechnology Institute, Mohali, Punjab, India (30°44'10" N latitude at an elevation of 351 m above sea level) in 2015–2016 (Sharma et al. 2018).

[12]Farm Grocer, Ambala; Borlaug Farm Association for South Asia, Ludhiana, Golden Agrigenetic India Ltd., Lucknow; Premier (India) Seed Company, Vidisha; Habitat Genome Improvement Primary Producer Company, Hisar; Bishwanath Agrawal (BNA), Purnea; Puddings and Pie, Mohali; Urban Platter, iStore Direct Trading LLP, Mumbai; Dayspring Foods, Porbandar; Antho Grains Pvt. Ltd., Mohali.

However, research in plant-breeding technique has broken records with the significant innovation of **golden rice**,[13] a genetically engineered and bio-fortified crop with high levels of beta carotene, the precursor to vitamin A. It is recognised by the World Health Organization that vitamin A deficiency (VAD) is a public health problem affecting about 44% children aged 6–59 months in South Asian countries where two-thirds or more of the daily calorie intake is obtained from rice; golden rice thus provides a sustainable solution for VAD at the same cost to farmers as other rice varieties (UNICEF 2019; IRRI 2018). Golden rice has been accepted as safe for human consumption by the governments of Australia, Canada, New Zealand and USA, and registrations have been applied for in the Philippines and Bangladesh (Dubock 2000). However, due to opposition by activists and non-governmental organisations (NGOs) to genetically modified crops, golden rice has not been approved in India.

3.2.2 White Revolution—Innovations in Policies, Value Chain Development and Institutional Engineering (Milk)

Another big transformational change in Indian agriculture came through the innovation "Operation Flood (OF)" that ushered in the white revolution during the 1970s through the mid-1990s. Hit by a severe milk crisis during 1945–1946, farmers in Kaira district suffered from controlled procurement and low prices due to the presence of middlemen. To end their exploitation, Sardar Vallabhbhai Patel stepped in to solve the problem of low milk prices. He gave India its first and largest milk co-operative (Anand Milk Union Limited or AMUL) and, in the process, emerged as a leader of farmers. Steered by Morarji Desai and Tribhuvandas Patel, and spearheaded by Verghese Kurien, Operation Flood transformed India's dairy industry from a drop to a flood of milk; the programme even today remains one of the largest dairy development programmes ever executed in the world (Kurien 2005). The programme was driven by three crucial principles—one, introducing co-operatives into the milk value chain; two, setting up the first processing plant at Anand to convert excess buffalo milk into milk powder, cheese, baby food and other milk products; and three, innovations in logistics such as automatic milk collection units, bulk milk coolers, rail- and road-insulated stainless steel milk tankers travelling around 2000 km from Kaira to Kolkata, bulk vending and so on—that completely revolutionised the process of milk collection, preservation and distribution.

The operation was executed by the National Dairy Development Board (NDDB) on the recommendation of Lal Bahadur Shastri in three phases during the period

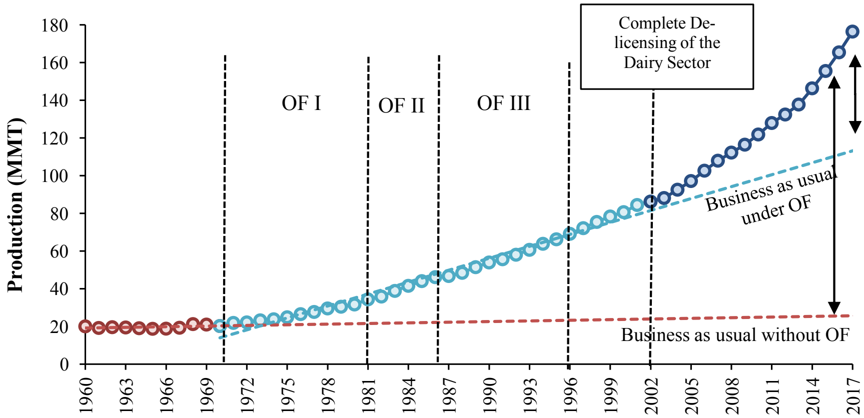
[13]The golden rice prototype was first developed in the 1990s by European scientists Ingo Potrykus and Peter Beyer independently. In early 2001, they sold the licence to the International Rice Research Institute (IRRI) in the Philippines for further development. Later, the scientists sold commercial rights to the core technology to Syngenta. Scientists made further improvements to the golden rice variety, primarily with much higher levels of beta carotene, in 2005 (Dubock 2000).

1970–1996. In phase I (1970–1980), the focus at the village level was on organising dairy co-operatives and at the union level on creating the physical and institutional infrastructure for milk procurement, processing and marketing. It started with linking 18 milk sheds to major collection centres in four metropolitan cities, namely Mumbai, Delhi, Kolkata and Chennai (NDDB 2017). During phase II (1981–85), 136 milk sheds were linked to over 290 urban markets. The sales proceeds of the grants provided by the European Commission (through the World Food Programme in the form of skimmed milk powder and butter oil), World Bank loans and internal resources of the NDDB (Gulati 2009) created a self-sustaining system of 43,000 village co-operatives covering 4.25 million milk producers by 1985 (Kurien 2004). In phase III (1985–96), around 30,000 new dairy co-operatives were added and focus was placed on augmenting the productivity of dairy animals by providing services such as artificial insemination, veterinary first-aid health care and nutritious feed to the co-operative members (NDDB 2017). By the end of the period, in 1995–96, there were 72,744 dairy collection centres in 170 milk sheds in the country with a membership of 9.3 million milk farmers (Gulati 2009).

As a result, India's milk production increased year after year and set new records. During the three phases of Operation Flood, production shot up from 20 MMT in 1970–71 to 31.6 MMT in 1980–81, then 44 MMT in 1985–86 to 69.1 MMT in 1995–96: a jump of 50 MMT in 25 years (DoAHD&F 2017a). Due to this institutional engineering, India emerged as the world's largest milk producer, surpassing the USA after 1996–97. Subsequent to the amendment of the Milk and Milk Product Order (MMPO) in 2002[14] and the entry of private entities in the dairy sector, milk production further shot up from 88.1 MMT in 2002–03 and reached a mark of 176.4 MMT in 2017–18, a massive jump of 88 MMT in just 15 years (Fig. 3.6), which is much higher than milk production in the USA (97 MMT) and mainland China (41 MMT) (FAOSTAT 2017). As a result of rapidly increasing milk production, per capita milk availability also shot up to 355 g per day in 2016–17 from less than 110 g per day in 1970–71 (DoAHD&F 2017b). Not only this, the new co-operative institutions created a much broader social and economic impact by bringing together dairy farmers from different castes and religions. It also promoted dairy co-operatives of women in a major way, by training women in modern animal husbandry practices under the Women Dairy Co-operative Leadership (WDCL) programme launched by NDDB. At present, some 2476 all-woman dairy co-operative societies (DCSs) are functioning in the country in selected states. Out of a total membership of 9.2 million in the DCS, 1.63 million are women (18%) (Dairy India 2017).

According to data from FAOSTAT, buffalo milk yields showed a significant increase from fewer than 1000 kg/animal/year in the 1960s to about 2000 kg/animal/year in 2017, whereas yields of cow increased from fewer than 500

[14]The Milk and Milk Product Order (MMPO) was first introduced in 1992 under Sect. 3 of the Essential Commodities Act, following the economic liberalisation policy of the government of India. It was last amended in 2002 when the concept of cowsheds was removed (Dairy India 2017). The MMPO helped improve the supply of quality milk and increase the share of organised players in the dairy sector (Gulat et al. 2008).



Note: OF – Operation Flood

Fig. 3.6 All-India milk production. *Source* DoAHD&F (2017b)

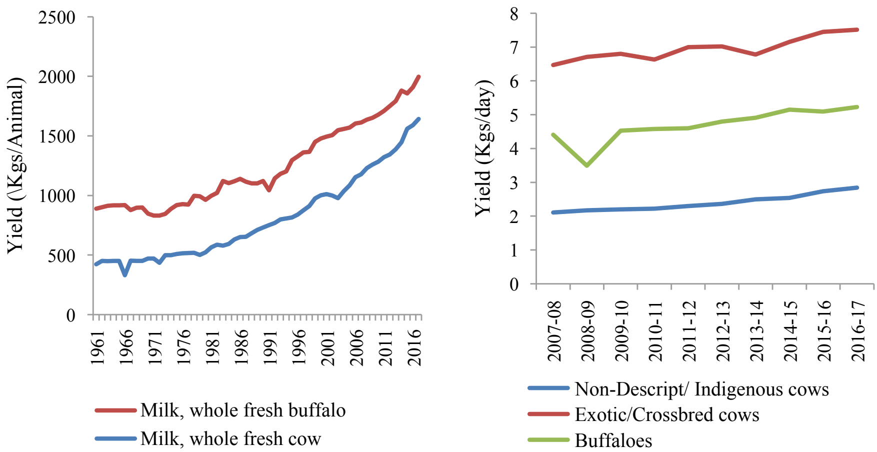


Fig. 3.7 Milk yields in India. *Source* FAOSTAT 2018 and BAHS 2017

kg/animal/year to more than 1500 kg/animal/year, mainly on account of increasing number of exotic/cross-bred cows in the period (Fig. 3.7 LHS). Basic Animal Husbandry Statistics gives milk yields in kg/day for different species. As depicted in Fig. 3.7 (RHS), exotic/cross-bred cows yield the highest milk on an average per day (more than 7.5 kg/day) followed by buffaloes (slightly more than 5 kg/day) and indigenous cows (less than 3 kg/day) DoAHD&F (2017b).

Unfolding Innovations in the Dairy Sector: India faces a challenge of a burgeoning bovine population with limited investments in productivity augmentation. According to the 19th Livestock Census, the proportion of cattle and buffalo in the total bovine population is about 64% and 36%, respectively, while the share of adult females in the total cattle and buffalo population is only 40% and 52%, respectively (DoAHD&F 2017a). Consequent to the ban on cattle slaughter, unproductive male and female cattle cannot be culled. Moreover, they consume feed and fodder that could be given to productive cattle. Therefore, ensured development of the dairy sector depends on measures such as sex-selection semen technology to increase the proportion of female cattle in the total bovine population as well as measures such as cross-breeding to improve productivity.

Selective Sex Semen Technology is about predetermining the sex of offspring by sorting X and Y chromosomes from natural sperm mix. In countries like India with less than 50% of productive cows, sexed semen innovation is of great relevance. This will reduce the dairy animal population and save rearing costs by eliminating the birth of male calves on the one hand and facilitating the production of genetically improved high-milk-producing females at a faster rate on the other (BAIF 2015). Under this strategy, the probability that the female cattle will conceive is around 45%, but if it does, then the probability of producing female progeny is more than 90%, instead of 50% as would be in the case of unsorted semen (Mohteshamuddin 2017). This sexed semen technology uses the principle of DNA concentration of X and Y chromosomes. Sperms with an X chromosome (which results in females) contain 3.8% more deoxyribonucleic acid (DNA) than Y-chromosome-bearing sperms (which result in males) (BAIF 2015). The sperms are then treated with a fluorescent dye that allows for differentiation in the amount of DNA in the sperm. Then, they are diluted and placed in droplets. During the sorting process, the droplets pass through a flow cytometer machine where a laser is used to energise the dye; X-chromosome-bearing sperms are more fluorescent. A computer quantifies the fluorescence of the sperm and assigns the sperm droplet as either X or Y, or uncertain. The sperm sequentially passes through an electromagnetic field where they are tagged by a charge (positive charge to the sperm containing an X chromosome). These charged sperms then get deflected towards the collection vessel. Sexed semen technology was originally patented by the USA-based XY Inc., which was later acquired by Sexing Technologies™ headquartered in Navasota, Texas. The commercially available sexed (sorted semen) straws are supplied by major genetic companies such as Select Sires, Genex, Accelerated Genetics, CRV, ABS Global WWS and Prime Genetics, produced using Sexing Technologies' proprietary sperm-sorting technology (Damodaran 2017).

On 15 August 2009, *Paschim Banga Go Sampad Bikash Sanstha* (PBGSBS), run by the Government of West Bengal, established the Becton Dickinson (BD) Influx cell sorter laboratory under the *Rashtriya Krishi Vikas Yojana* (RKVY) (Mumtaz et al. 2017). This was the beginning of semen sorting using a flow cytometer or high-speed semen sorter in India at the Frozen Semen Bull Station, Haringhata. The organisation reported the birth of the first male calf, "Shreyas", using sexed semen in 2011. Subsequently, some female calves were born using the technology with a conception rate of between 20 and 35% (Mumtaz et al. 2017). Under a pilot project jointly taken by the Kerala Livestock Development Board (KLDB) and the Department of Animal Husbandry, two sexed semen calves were born to Jersey cross-bred heifers and Holstein Friesian (HF) cross-bred cows, respectively, at Vakkavu in Nenmara, Palakkad, using imported frozen semen straws. Prime Bovine Genetics, in collaboration with Sexing Technologies, provides sexed semen of Holstein Friesian, Jersey, Brown Swiss and Gir cross-breeds in India. In September 2017, ABS India launched "sexed dairy genetics" in Chandigarh to provide sexed semen for indigenous cattle breeds like Sahiwal, Gir, Red Sindhi cows and Murrah buffaloes. However, the adoption of the technology in the country is not yet as robust and the biggest hindrance to its widespread adoption by farmers is the high cost involved in importing semen straws from foreign countries. Some NGOs, along with private companies including BAIF, JK TRUST and other big institutions like NDDB and AMUL, have pitched in to establish sexed semen stations in India, which could potentially bring down the cost of the semen straws. The technologies exist; the need is to ramp up R&D, extension and delivery stations to transform the dairy sector into a vibrant, competitive and more remunerative sector for farmers.

3.2.3 Blue Revolution—Fisheries

The Indian fisheries and aquaculture sector constitute an important source of nutritional security, livelihood and inclusive economic development. From a meagre 0.75 MMT in 1950–51, fish production has increased more than 15 times to 11.41 MMT in 2016–17 (MoA&FW 2017).[15] The sector at present contributes the second largest share of about 6% to global fish production, next to the largest producer China, which accounts for about 40% (FAO 2018). The sector also contributes about 1.1% to the country's gross domestic product (GDP) and around 5.3% to its agricultural GDP (Ayyappan et al. 2016). India has a long coastline that stretches over 8129 kilometres (km), encompassing an exclusive economic zone of 2.02 million sq km and varied fishery resources comprising rivers and canals (191,024 km), reservoirs (3.15 million hectare (Mha)), ponds and tanks (2.35 Mha) (NFBD 2016).[3] The country's total fish production comes from two sectors—inland and marine. The share of the inland fishery sector in total fish production has gone up from 29% (0.2 MMT) in 1950–51 to 80% (8.6 MMT) in 2016–17, while the share of marine fisheries has gone down from 71% (0.5 MMT) to 20% (2.1 MMT) during the same period[16] (Fig. 3.8). According to the National Fisheries Development Board (NFDB), the Freshwater Fish Farmers' Development Agency (FFDA) reports that freshwater productivity is 3000 kg/ha/year and the Brackish Water Fish Farmers' Development Agency (BFDA) reports that the productivity in brackish water is 1500 kg/ha/year.

In terms of exports, marine products account for the second highest share in the total value of exports from India. During 2018–19, they reached an all-time high at USD6.7 billion, as against USD4.69 billion in 2015–16 (MoA&FW 2017). The

[15]Press Information Bureau, Government of India, issued by Ministry of Agriculture & Farmers' Welfare dated 21 November 2017 (http://pib.nic.in/newsite/PrintRelease.aspx?relid=173699), accessed on 25 March 2018.

[16]Calculated using data from Handbook on Fisheries Statistics, Department of Animal Husbandry, Dairying and Fisheries; Agricultural Statistics at Glance 2016 and Indiastat, accessed on 26 March 2018.

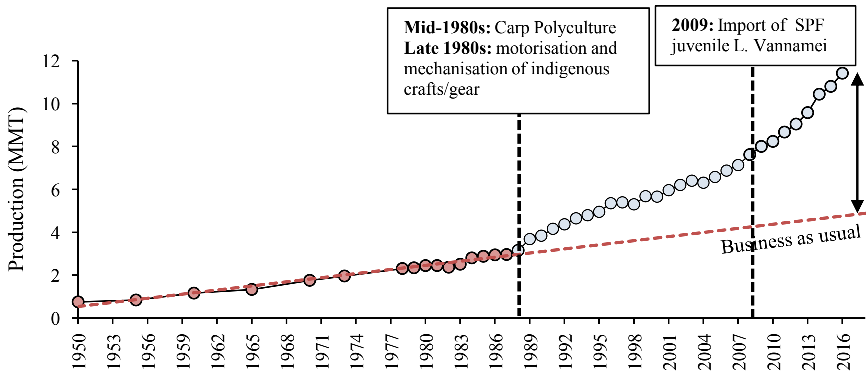


Fig. 3.8 All India Fish production. *Source* Handbook on Fisheries Statistics, DoAHD&F, Government of India; Indiastat

USA, South East Asia, the European Union and Japan are India's top export markets. Later sections give an account of innovations in breeding technologies, products and practices that revolutionised the traditional fish sector over time, turning it from being primarily capture-based into today's commercial and capital-intensive industry (Ayyappan et al. 2016).

Innovations in Farming Practice, Breeding and Diversification: The blue revolution began with a breakthrough in seed production technology through induced breeding by Hiralal Chaudhuri and K.H. Alikunhiat at the "Pond Culture Division" of the CIFRI substation (Cuttack, Odisha) in 1957. The technique of "hypophysation" and spawning of major Indian carp varieties—catla, rohu and mrigal—with induced breeding by pituitary extract was widely adopted and became an integral part of the fish culture programme (Katiha and Pillai 2004). In addition to the Indian carp, the Bangkok strain of the common carp (*Cyprinus carpio*) and other exotic species—silver carp (*Hypophthalmichthys molitrix*) and grass carp (*Ctenopharyngodon idella*)—were introduced in 1957 and 1959, respectively. The innovative composite fish culture added a new dimension to aquaculture during the late seventies and became a popular technology among farmers (Katiha and Pillai 2004). Under this technique, compatible and non-competing species (rohu, catla, mrigal, silver carp, grass carp and common carp) were cultured simultaneously using different feeding zones in a pond, to increase the total production from a unit area of water (Lekshmi et al. 2014). This was followed by the development of a carp polyculture during the mid-1980s, which contributed greatly to the transformation of inland capture fisheries to commercial aquaculture enterprise.[17] With widespread adoption in terms of area coverage and intensity of operation, production levels went up from 3–5 tonnes/ha/year to 10–15 tonnes/ha/year (Ayyappan 2005). At present, freshwater aquaculture and, more specifically, carp fish contribute about 80% of the total inland fish production (Laxmappa 2015). The Indian government has provided substantial

[17]Private hatcheries supply over 60% of the carp fingerlings for polyculture (Nair and Salin 2007).

support through a network of fish farmers' development agencies, brackish water fish farmers' development agencies and the research and development programmes at the Indian Council of Agricultural Research (ICAR). Additional support was extended by organisations and agencies like the Marine Products Export Development Authority and financial institutions (FAO 2014). As a result, total production increased by more than 50% in the five years between 1987–88 (2.9 MMT) and 1991–92 (4.37 MMT) and inland production exceeded marine production from 1988 onwards.

Notwithstanding stagnancy in the growth rate of marine fish production since the late 1980s, innovations in motorisation and mechanisation of indigenous crafts and gear, including motorised ring seine units,[18] contributed to increase fish production to the tune of 2 MMT in 1989–90 (Ayyappan et al. 2016). These motorised ring seine units are particularly efficient in catching shoaling pelagic resources such as the Indian oil sardine and the Indian mackerel. Consequently, there was an increase in production of Indian oil sardine of 113%—from 0.13 million tonnes in 1988 to 0.28 million tonnes in 1989—and an increase of 180% in the production of Indian mackerel from 0.1 million tonnes in 1988 to 0.29 million tonnes in 1989. In 1989, these two species formed nearly 26% of the total marine production of the country.[19] The Central Institute of Fisheries Technology (CIFT) further provided foundation for research to design specific fishing vessels and equipment, and emphasised "Gear Designing" so as to enhance production from mechanised vessels and diversify fishing activities. This gave birth to different harvesting equipments such as stern trawling, outrigger trawling, mid-water trawling and long lining, which increased catching efficiency[20] by 30% (Ayyappan 2005). Subsequently, several designs of small-, medium- and larger-sized mechanised boats were also introduced (Punjabi and Mukherjee 2015).

Unfolding Innovations in Fish Production: Commercial farming of shrimp picked up during the early nineties with the entry of the private sector and the opening up of trade. However, the breakthrough came in 2009, when the Coastal Aquaculture Authority granted permission to import juveniles (up to 10 g) of specific pathogen-free (SPF) Pacific white shrimp (*Litopenaeus vannamei*) from selected suppliers abroad to hatcheries in India for rearing to adult broodstock and seed multiplication and shrimp farming in India (DoAHD&F 2017).[21] *L. vannamei* is, today, the largest cultured shrimp in terms of production and productivity, farmed mainly in states like Andhra Pradesh, Gujarat, Tamil Nadu and Odisha. Because of its fast growth, low incidence of native diseases, availability of domesticated strains and high international market demand, *L. vannamei* is an attractive alternative to other prawn production (Singh and Lakra 2011). From 2009 to 2016, production levels of

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[18]Ring seine units showed an increase of 152% in terms of fishing units and 163% in terms of fishing hours from 1988 to 1989.

[19]Inputs received from A. Gopalakrishnan, Director, CMFRI, on 25 March 2018.

[20]Catch per unit effort of a specific gear and craft.

[21]*L. vannamei* is backed under two relevant acts—Livestock Importation Act, 1898 (Amended 2001), which regulates import and quarantine and the Coastal Aquaculture Authority Act, 2005, which regulates breeding and farming.

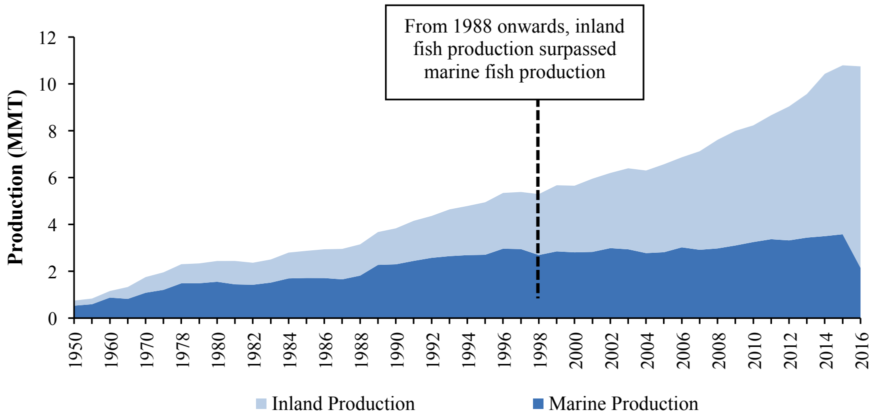

Fig. 3.9 All India inland and marine production. *Source* Handbook on Fisheries Statistics (2018), DoAHD&F, Government of India and Indiastat (2018)

SPF *L. vannamei* increased considerably, ranging between 8 and 10 tonnes/ha/year (DoAHD&F 2017). Shrimp cultivation reached 0.6 million tonnes during 2016–17, up from 28,000 tonnes during 1988–89 (Katiha and Pillai 2004). *L. vannamei* contributed a 90% share in volume and 70% share (in terms of value) to total shrimp exports (USD4.8 billion) (Kumar 2018), mainly to the USA, South East Asia, the European Union, Japan, etc. In a comprehensive study on the technical efficiency[22] of *L. vannamei* farming in India, it was found that *L. vannamei* farms achieved 90% of the maximum possible output from a given set of inputs, where stocking density, feed quantity, adoption of zero water exchange and cropping intensity were the major determinants of technical efficiency (Kumaran et al. 2017). The Government of India recently took another step towards sustainable cultivation of *L. vannamei* by permitting the culture of this species in freshwater/inland farms. Guidelines for this have already been notified under the CAA Act, 2005.

Another major activity in the aquaculture sector is the cage/pen culture in open waters, which has become very popular in recent years. It offers vast potential for inland aquaculture in the country. The production potential from sustainable cage culture for table fish production is about 50 kg/m^3 with enormous possibility for further expansion and intensification (DoAHD&F 2017a, b). Yet, there is still huge potential for large-scale cultivation of valuable fish, such as shrimp, pearl spot and sea bass since out of 1.24 million hectares of brackish water, only 15% of the area is developed for commercial cultivation (DoAHD&F 2017a, b) (Fig. 3.9).

[22]Technical efficiency measures the ability of a farmer to get maximum output from a given set of inputs.

3.2.4 Red Revolution—Poultry Meat and Egg

The poultry sector in India underwent a significant shift in structure and operation during the late 1990s—from mere backyard farming to an organised commercial industry. At present, it is one of the fastest growing sectors of Indian agriculture with the country's egg production jumping from 1.83 billion in 1950–51 to 88.1 billion in 2016–17 and poultry meat production from 0.06 MMT in 1961–62 to 3.46 MMT in 2016–17 (Fig. 3.10). India has emerged as the third largest egg producer after China and the USA and the fifth largest poultry meat producer after the USA, Brazil, China and the European Union. In India, the organised commercial poultry sector accounts for an 80% share of the total output and the unorganised backyard sector accounts for the remaining 20% (DoAHD&F 2017c). During 2016–17, India exported small quantities of poultry products (such as table eggs, hatching eggs, egg powder, live birds, frozen whole chicken and cuts) amounting to 0.5 MMT (worth USD79.51 million), mainly to the Middle East and Asia, and recently to Japan and South East Asia (DoAHD&F 2017c). Egg powder is also sent to the European Union (EU), Japan and some African countries (DoAHD&F 2017c). Innovations like the entry of private companies, import liberalisation of grandparent poultry breeding stock, and the spread of vertically integrated poultry practices, along with the contract farming model, played a catalytic role in bringing about the poultry revolution in India, as discussed in detail in later sections. Growth in the poultry sector has been engineered and dominated by the large-scale commercial private sector, which controls roughly 80% of total Indian poultry production and is concentrated in the southern states of Andhra Pradesh and Karnataka.

Innovations in Policies, Institutions and Breeding Stock: With the entry of private enterprises like Venkateshwara Hatcheries Private Limited (VH Group), Suguna Group, Rani Shaver Poultry Breeding Farms Private Limited, Kegg Farms

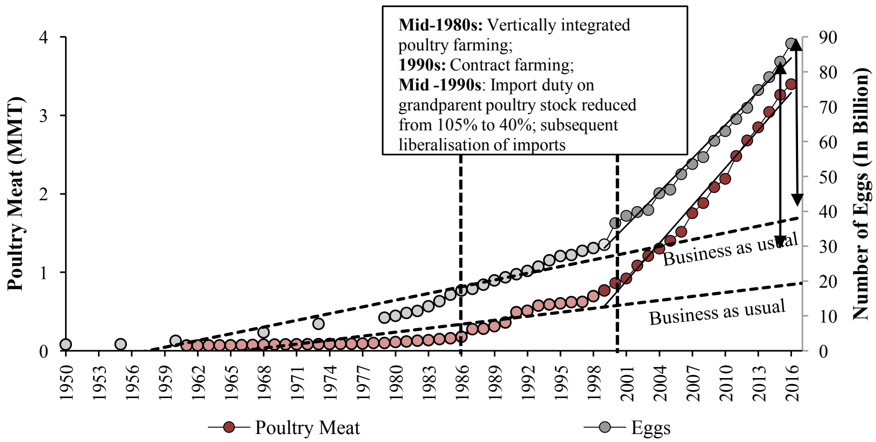

Fig. 3.10 All India poultry meat and egg production. *Source* DoAHD&F (2017b) and Food and Agriculture Organization of the United Nations (FAOSTAT)

Private Limited, Skylark Hatcheries and others, the concept of integrated poultry operations became well known in India (Manjula and Saravanan 2015).[23] These companies, through international collaborations, pooled investments and initiated the import of genetically improved breeding stock for commercial use. For instance, a joint venture between VH Group and the USA-based Cobb Vantress in 1974 initiated imports of grandparent stock of foreign breeds (Cobb strains) that kick-started the development of indigenous pure-line breeding in India (IFPRI 2003).[24] In order to achieve self-sufficiency in genetically improved germplasm, the Government of India, during the mid-1980s, took a major decision to disallow imports of grandparent stock along with other products. This split the industry into lobbies of grandparent importers and indigenous pure-line breeders (Tiwari 1990).[25] Realising that the industry was in its infancy in terms of research and development (R&D) and needed overseas support in breeding, the government revoked the decision and lifted the ban in April 1993. To encourage modernisation and diversification in agriculture, the government, in its 1993–94 budget, reduced the import duty on different agricultural items, including import duty on grandparent poultry stock, from 105 to 40% (Murty 1996).[26] Subsequently, in the budget speech of Manmohan Singh, the then Finance Minister, on 15 March 1995, it was proposed to reduce the import duty on grandparent poultry stock to 20%.[27] In 2001, all quantitative restrictions on India's imports of poultry items were dismantled and grandparent breeding stock was imported without any barriers (Mehta et al. 2008).[28] The policy resulted in a massive increase in private investment in breeding operations with the use of imported grandparent stock. It also led to the production of day-old chicks under strict bio-secure conditions leading to performance improvement in the pure-line stock of improved parent lines (Emsley 2006).

During the mid-1980s, Venkateshwara Hatcheries, which is, at present, Asia's largest fully integrated poultry group, became the first company to initiate vertically integrated poultry operations in South India, wherein they integrated different aspects of the poultry value chain from raising grandparent and parent flocks, rearing day-old chicks, compounding feed, providing veterinary services and marketing. The model gained popularity during the mid-1990s across the country and acted as a catalyst in facilitating commercial poultry growth (DoAHD&F 2017c). Currently, there are

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[23]Article titled Poultry Industry In India under a Globalized Environment—Opportunities and Challenges in International Journal of Scientific Research (https://www.researchgate.net/publication/280609553_Poultry_Industry_In_India_Under_Globalised_Environment_-_Opportunities_and_Challenges).

[24]http://www.fao.org/WAIRDOCS/LEAD/x6170e/x6170e09.htm#bm09.

[25]https://www.indiatoday.in/magazine/economy/story/19901130-poultry-industry-grows-despite-import-policy-problems-turbulent-political-situation-813333-1990-11-30.

[26]https://books.google.co.in/books?id=YY0XLt6d0BgC&printsec=frontcover#v=onepage&q&f=false, accessed on 25 March 2018.

[27]Budget (1995–96), Speech by Shri Manmohan Singh, Minister of Finance on 15 March 1995. https://www.indiabudget.gov.in/bspeech/bs199596.pdf, accessed on 15 April 2018.

[28]http://www.fao.org/tempref/AG/Reserved/PPLPF/Docs/Reports%20&%20Papers/PAP_MT_SA_UP_03_India%20Poultry%20&%20WTO_Mehta.pdf, accessed on 1 August 2018.

about 60 thousand plus poultry farms in India that function under a modern integrated management system (Hellin et al. 2015; DoAHD&F 2017c). The founder of Venkateshwara Hatcheries, Dr Banda Vasudev Rao,[29] played a pivotal role as the architect of the Indian poultry industry's growth and modernisation. To ensure that producers get remunerative prices and are free from exploitative trade practices, he brought them together under the umbrella organisation of the National Egg Coordination Committee (NECC) in 1981 and made the clarion call "my egg, my price, my life" (Frontline 2003). In the broiler segment, Rao gave birth to BROMARK in 1994 (Broiler Marketing Cooperative Society): the All India Broiler Farmers' Body registered under the Multi-State Co-operative Societies Act to promote chicken meat consumption by advertising its nutritive value and reducing the gap between producer's and consumer's price (Bhardwaj 2014).

In the 1990s, Suguna Foods Private Limited (Coimbatore, Tamil Nadu) emerged as a leading enterprise with a unique model of contract farming[30] in the south. The model emerged as a success with commitment on the part of farmers to provide reared birds in a specified quantity and of specific quality, as well as a commitment on the part of the integrator to support the farmer's production and to buy back the fully grown birds[31] (Zakir 2008). The twin institutional innovations of a vertically integrated system along with contract poultry farming contributed substantially in stimulating the commercial growth of the poultry sector. As a result, there has been an increasing trend for expansion in farm size, from less than 500 birds to an average of 7000–8000 birds, which in turn provides scope for the mechanisation of feed production, feeding and egg handling.

Recent and Unfolding Innovations in the Poultry Sector: These private enterprises have proactively taken up R&D of parent stock (both indigenous and international breeds), meat broilers and egg layers and have developed international breeds that suit Indian environmental conditions. A number of bird hybrids are reared for rapid growth, feed efficiency and higher profits. Kegg Farms has developed a hybrid, high-yielding variety bird called the Kuroiler. Another popular broiler variety—Cobb 100—more commonly known as Vencobb and owned by VH Group accounts for 65–70% of total broiler production (DoAHD&F 2017). Cobb 100 is actually an old breeding stock imported from the USA that has been acclimatised to the Indian climate and disease conditions (Landes et al. 2004). Other popular broiler breeds include Ross, Marshall, Hubbard, Hybro Avian and Anak. In the layer sector,

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[29] Also known as the "Father of Modern Poultry in India".

[30] Contact farming in poultry is broadly defined as an agreement between an integrator and farmers to produce/raise poultry birds at predetermined prices.

[31] Under the arrangement, the integrators (hatcheries) provide quality inputs, technical guidance, management skills, credit as well as knowledge of new improved technology, through intermittent supervision. Farmers, on behalf of the integrators, look after the chicks and rear them in their poultry sheds to slaughter weight while maintaining strict bio-security level. The farmers found the guaranteed returns of contract farming preferable to the vagaries of market returns as they got a fixed income, assured market, credit support, reduced risk and uncertainty. The live birds are then purchased either by the integrators for slaughter and further processing or by a wholesaler who distributes them via live markets (DoAHD&F 2017).

Babcock is the most preferred breed in India and constitutes 65% of the market share (Shukla and Nayak 2016). The strain was imported from the Netherlands-based Hendrix Genetics, while other varieties like Lohman, Bovans and Hyline are also commonly produced (DoAHD&F 2017c).

Several innovations have helped the sector to develop different varieties of eggs with specific nutritional value. Suguna Foods has developed four value-added speciality egg varieties, namely Active, Pro, Shakthi and Heart, which are enriched with special nutrients such as omega 3 fatty acids, selenium, vitamins and minerals. Kishore Farm Equipment and Dhumal Industries are leading firms that have developed auto-feeding systems, watering systems, climate control, flooring and brooding systems designed for Indian markets to ensure efficient poultry management (iBAN 2017). These innovations have led to branded shelf products, retailed at supermarkets. As a result, the feed conversion ratio for broilers has improved considerably from the ratio 2.2 in the 1990s to 1.65 in 2016–17 and the laying capacity of birds has increased from 260 to 320 plus eggs per annum (Kotaiah 2016). Moreover, according to APEDA market news (2016), per capita egg consumption has gone up from 30 to 68 and chicken from 400 g to 2.5 kg over the last five years.

However, nutritionists' recommend the consumption of 180 eggs and 10 kg chicken per year (APEDA 2016); so, there is still ample scope for production enhancement as well as increasing consumption of poultry products. India also has great potential to play a major role in the international market. India currently accounts for less than 0.5% of the global trade in poultry. Some major integrated poultry groups like Venky's (India) Ltd., Suguna Foods, Shanthi Poultry Farm (P) Ltd., etc., are selling processed branded frozen chicken that conform to stringent international quality norms to international markets including the Middle East, Europe and America, and to Indian outlets of large multinational food chains such as McDonalds, KFC, Pizza Hut and Domino's (Hellin et al. 2015). Sustained improvement in nutrition, high-quality feed, efficient utilisation of inputs and high hygiene standards are critical to remain competitive in the global market and to continue to grow to meet increasing consumer demand for eggs and meat (Hellin et al. 2015).

3.2.5 Golden Revolution—Fruits and Vegetables

After the Green Revolution in the mid-1960s and the White Revolution in the 1970s, the horticulture sector, comprising fruits and vegetables, spices and floriculture, has contributed significantly to agricultural growth in the country. In terms of production, over the last few years, there has been a voluminous increase in horticultural production overtaking food grains output in volume terms since 2012–13 (Fig. 3.11). The area under horticulture has increased by 3% per annum, and production has increased by an average of 5% per annum during the last decade. In 2016–17, production crossed the record mark of 300 MMT and is expected to reach 306.81

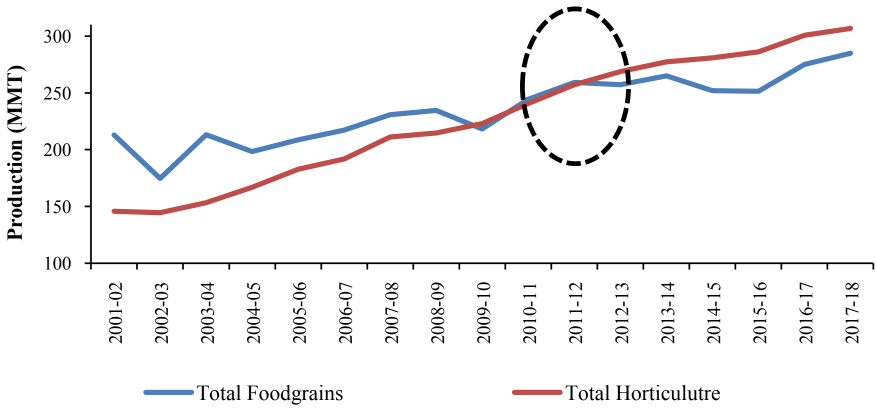

Fig. 3.11 Production of Horticulture vis-à-vis Food Grains, India. *Source* Horticultural Statistics at a Glance (2017), DoAC&FW, MoA&FW, GoI

MMT from an area of 25.6 Mha in 2017–18[32] (NHB 2018). Fruits and vegetables (F&V) account for nearly 90% share in terms of volume and about 77% in terms of value in total horticulture output. The area under F&V since the year 2001–02 has increased by 63.4% (from 10.1 to 16.6 Mha), and production has increased by 109% from 131.6 to 276 MMT (NHB 2017, 2018) during the same period. Consequently, India is now the second largest producer of F&V (with 9.3% share) in the world only next to China (with 35.4% share). The vast production base offers India good opportunities for exports, provided it is globally competitive. During 2016–17, India exported F&V worth USD1552.26 million, which comprised fruits worth USD667.51 million and vegetables worth USD884.75 million (APEDA 2017). Mangoes, walnuts, grapes, bananas and pomegranates among fruits and onions, okra, potatoes and mushrooms among vegetables constitute major portion of exports to countries like UAE, Bangladesh, Malaysia, Netherland, Sri Lanka, Nepal, UK, Saudi Arabia, Pakistan and Qatar" (APEDA 2017).[33]

The establishment of the Indian Institute of Horticultural Research (IIHR) at Bangalore and eight All-India Co-ordinated Crop Improvement Projects kick-started research and development (R&D) in several horticulture crops across the country during the Fourth and Fifth Five-Year Plans. A tremendous increase in expenditure for central sector schemes of the Department of Agriculture & Co-operation for horticulture from Rs. 250 million during the Seventh Five-Year Plan (1985–90) to Rs. 10,000 million during the Eighth Five-Year Plan (1992–97) established the road map for the golden revolution. However, the real boost came during 2005–06, when the Ministry of Agriculture and Farmers' Welfare launched the "National Horticulture Mission (NHM) to develop horticulture to its maximum potential and provide holistic growth of the sector through area-based regionally differentiated strategies, modern infrastructure for better storage management and lower post-harvest losses". Since the

[32]Third advance estimates 2017–18.

[33]According to APEDA, Ministry of Commerce and Industry, Government of India.

implementation of NHM, horticulture production has increased at a higher rate. The government also launched the Mission for Integrated Development of Horticulture (MIDH), a centrally sponsored scheme, during the Twelfth Five-Year Plan beginning in 2014–15, which subsumed earlier missions like the National Horticulture Mission (NHM), the Horticulture Mission for North East & Himalayan States (HMNEH), the National Bamboo Mission (NBM), the National Horticulture Board (NHB), the Coconut Development Board (CDB) and the Central Institute for Horticulture (CIH), Nagaland, to increase production and improve productivity of horticulture crops through various interventions.

Unfolding Innovations in Seeds and Cultivation Practices: A number of innovations implemented recently on a large scale have contributed to the production breakthrough and exports of these F&V[34] such as the adoption of crop-specific innovative planting technologies that promote crop diversification in the country, and the introduction of several high-yielding hybrid crop varieties (for instance, hybrid varieties developed using exotic mango cultivars from Florida (USA), Brazil and Peru) and the innovative farming technique of ultra-high-density plantation (UHDP)[35] contributed to the mango production breakthrough). In the case of banana, propagation of quality planting material such as "micro-propagation—tissue culture" led the boost in the country's banana production—as a result of this technique, 98% of plants bear bunches, field management is easy, and there is also uniformity in flowering and a reduction in crop duration (Chadha 2016).

In the case of potato, identification of suitable parental lines for production of true potato seed (TPS) or botanical seeds[36] by the Central Potato Research Institute (CPRI) in collaboration with the International Potato Center (CIP), Peru, and promotion of hi-tech aeroponic technology[37] for commercial adoption by CPRI has increased the rate of seed multiplication four times compared with those conventionally grown through mini-tubers (Chadha 2016). Moreover, the introduction of the short-duration, high-yielding variety "Kufri Pukhraj" in 1998 by ICAR-CPRI, which came into commercial adoption in 2005–06, had a positive impact on potato production as well as on the yield 20–40 t/ha if the crop is harvested within 60 and

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[34]Covering innovations in mango and banana production among fruits and in onion and potato production among vegetables, because mango and banana account for a 53% share in the total fruit production and onion and potato account for a 40% share in the total vegetable production.

[35]Based on closer planting of mango grafts, dwarf rootstocks and canopy architect management are key disruptions that have led to optimised use of land, nutrients and other resources. Generally, the recommended space between trees is 10 m * 10 m, but in UHDP, experts recommend only 4.5 m * 4.5 m to control growth of trees within two metres and height within six feet (Innovative Farming Solutions 2014).

[36]Under this technology, seeds are produced by transplanting seedlings raised in nursery beds or by planting seedling tubers produced in the previous season. ICAR-CPRI supplies these seeds to various state government organisations for further multiplication in three more cycles, such as Foundation Seed 1 (FS-1), Foundation Seed 2 (FS-2) and Certified Seed (CS) under strict health standards (Mustaquim 2017).

[37]Under the technology, plants are grown in an air or mist environment without the use of soil or an aggregate media. This is an alternative method of soilless culture in nutrient solutions under controlled environments (Mustaquim 2017).

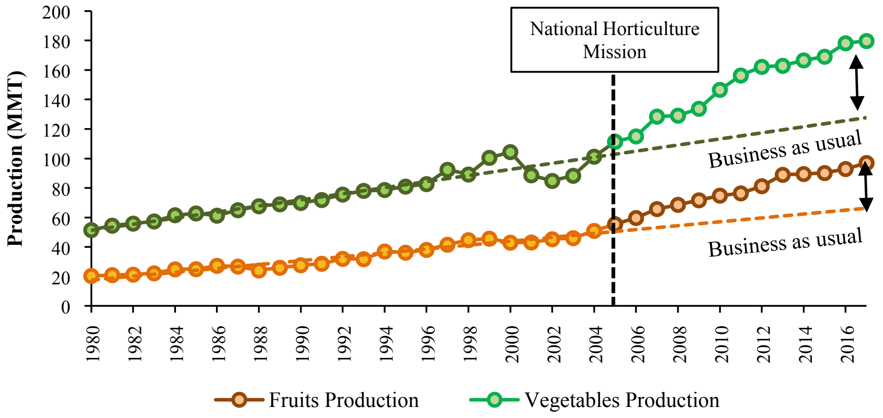

Fig. 3.12 All India fruit and vegetable production. *Source* FAOSTAT and NHB

75 days of planting, respectively.[38] At present, 33% of total potato area is under the Kufri Pukhraj variety.[39]

At the same time, in the case of onion, production was earlier confined to the *rabi* season due to low productivity during the *kharif* season. In 2001–02, the ICAR-Directorate of Onion and Garlic Research (DOGR) developed improved *kharif* production technology of raised beds with micro-irrigation, which doubled productivity during *kharif* and increased the area under onion production during the *kharif* season not only in Maharashtra but also in other states, i.e. Karnataka, Gujarat and Madhya Pradesh. Further, decanalisation of onion exports[40]in 1999 and the global demand for dehydrated onions[41] from India boosted its production.

As a result of the innovations in planting material and cultivation practices, India experienced a structural breakthrough in total fruits and vegetable production in 2005–06 compared to a "business-as-usual" scenario. Production of fruits increased from 20.4 MMT in 1980–81 to 97 MMT in 2017–18, while that of vegetables increased from 58.5 to 179.7 MMT during the same period (Fig. 3.12) (NHB 2018). However, this breakthrough is not as sharply evident as in the case of wheat during the Green Revolution and milk during the white revolution.

[38]Inputs from Dr. S. K. Chakrabarti, Director, ICAR-Central Potato Research Institute, Shimla.

[39]This variety has replaced the Kufri Jyoti as the number 1 variety and covers nearly 33% of the area under potato today.

[40]Onion exports were canalised by the National Agricultural Co-operative Marketing Federation (NAFED) until 1998 to protect domestic consumers and producers from unduly high prices and gluts. In January 1999, GoI introduced a new export–import policy and certain changes were made in the system of onion trade by including 13 state trading enterprises as canalising agencies for onion trade, namely the Maharashtra Agricultural Marketing Board, Gujarat Agro Industries Corporation, Karnataka State Co-operative Marketing Federation, Andhra Pradesh Marketing Federation, etc., so that no agency acquires a monopoly position.

[41]According to Punjabi and Mukherjee (2015), there are 100 onion dehydration units in India, of which 85 are located in Gujarat, and the remaining in Maharashtra and Madhya Pradesh. In 2016–17, India produced 50,000 tonnes of dehydrated onions and contributed approximately 40% to the

Moreover, there has been a significant increase in productivity over the decade, from 10.7 t/ha in 2001–02 to 14.3 t/ha in 2016–17 in the case of fruits, and from 14.4 to 17 t/ha in the case of vegetables (Fig. 3.13).

In the case of mango, India emerged as the largest producer with 21.2 MMT in 2017–18, up from 8.4 MMT in 1980–81, contributing about 40% (20 MMT) of total world mango production (46.2 MMT) followed by China (10%), Thailand (7.38%), Mexico (4.72%) and Indonesia (4.7%); it is also a prominent exporter. In terms of yields, India cultivated 9.2 t/ha in 2017–18, up from 5.5 t/ha in 2008–09 (Fig. 3.14). During 2016–17, India exported 52.76 thousand tonnes of mangoes, worth USD67 million, to countries such as the UAE (54%), the UK (5.7%) and Saudi Arabia (4.5%)

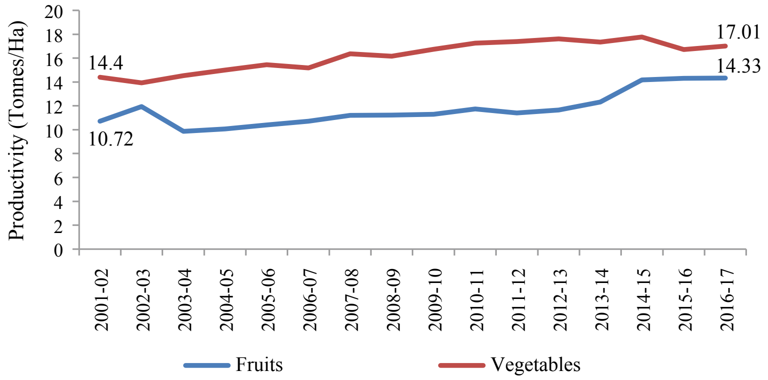

Fig. 3.13 Fruit and vegetable productivity in India. *Source* NHB (2017)

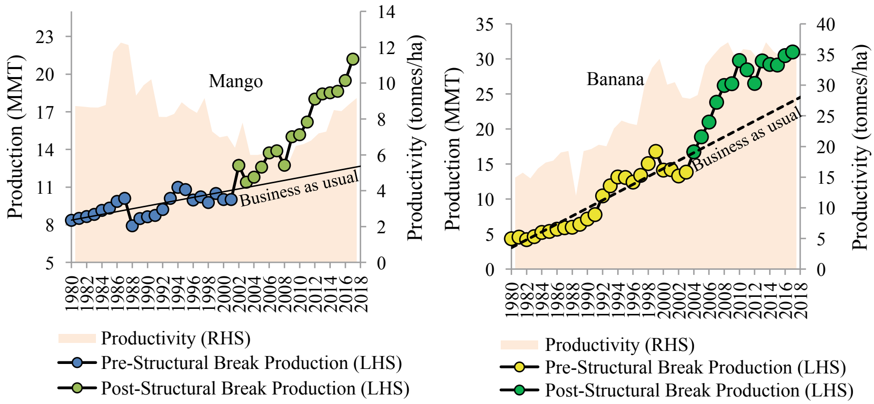

Fig. 3.14 All India mango (left) and banana (right) production and productivity. *Source* FAOSTAT and NHB

total global export of dehydrated onions, next only to the USA, which exported approximately 50%; the remainder is exported by Egypt and China. India exports to Europe, Russia, France, etc.

(APEDA 2017). In the case of bananas, production touched 31 MMT in 2017–18 from less than 5 MMT in 1980–81, contributing the largest share of 26% to total world production (FAOSTAT 2017). In terms of yields, while the world produces 20.6 t/ha on an average, India produces an average of 35.2 t/ha (FAOSTAT 2017). Additionally, in major banana-growing states like Madhya Pradesh, Gujarat, Bihar, Tamil Nadu and Maharashtra, yields are well above the country's average at 66 t/ha, 64.1 t/ha, 51.5 t/ha, 46.1 t/ha and 44 t/ha, respectively (NHB 2017). Some of the popular commercial varieties grown in India are Grand Naine (from France), Robusta, Dwarf Cavendish, Red Banana and Nendran, among others. The Grand Naine variety is extremely popular due to its tolerance to biotic stress and good-quality bunches; it is cultivated in sizable quantities in Maharashtra (Jalgaon) and Gujarat. According to a World Bank case study on Indian bananas (2011), "Unlike the rest of the world's major banana growing areas, which are dominated by large-scale commercial farms, the Indian banana industry is based on large numbers of small, independent farmers, typically cultivating less than 3 acres" (World Bank 2011).

Among vegetables, the structural break in the case of onion production is dramatic: from 2.6 MMT in 1980–81 to 22 MMT in 2017–18, with the yield increasing from 9.9 to 17 t/ha during the same period (Fig. 3.15). India is the second largest onion-growing country (contributing a 21% share) in the world next only to China (contributing a 26% share). Indian onions are famous for their pungency and are available all year round. In 2016–17, India exported 1.4 MMT of fresh onion to the world (worth USD389.36 million), including countries such as Bangladesh, Malaysia, Sri Lanka, the UAE and Nepal (APEDA 2017). In the case of potato, production increased from less than 10 MMT in 1980–81 to 48.5 MMT in 2017–18, and the yield rose to 22.7 t/ha from 12.1 t/ha during the same period. Globally, India is the second largest producer of potatoes, contributing an 11.6% share or 48.2 MMT after China (with a 26.3% share or 99.12 MMT) during 2016–17.

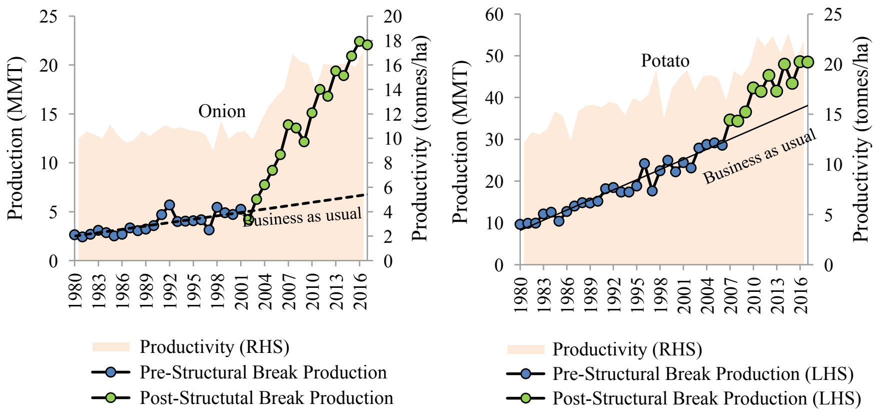

Fig. 3.15 All India onion (left) and potato (right) production and productivity. *Source* FAOSTAT and NHB

3.2.6 Gene Revolution—Cotton

Cotton (Gossypium), the "king" of fibres, is an important commercial crop of global significance. Across the world, India, China, the USA, Pakistan, Brazil and Australia are leading cotton producers, contributing about 80% of global cotton (lint[42]) production.[43] India is the only country in the world that produces all four species of cultivated cotton, i.e. *Gossypium arboreum* and *G. herbaceum* (Asiatic cotton), *G. barbadense* (Egyptian cotton) and *G. hirsutum* (American upland cotton) besides hybrid varieties.[44] Riding on the success of the Gene Revolution, India today is the largest producer of cotton with 37.2 million bales[45] in 2017–18, cultivated on 12.24 Mha (ISAAA 2017a, b, c).

Innovations in Seed Technologies and Policies: During the decade 1990–91 to 2000–01, the cotton sector was characterised by stagnation in production, heavy use of pesticides[46] and fertilisers, bollworm infestation, a decelerating trend in yield and over-reliance on imports. Repetitive use of fertiliser and insecticide gradually developed resistance in bollworm, which resulted in its consequent resurgence and massive outbreaks, which resulted in adverse ecological as well as human health effects (Gutierrez et al. 2015).[47] In 1996, the St. Louis, USA-based company, Monsanto Holdings Pvt. Ltd. introduced *Bacillus thuringiensis* (Bt) cotton seeds to grow bollworm-resistant cotton. It has since been approved for use around the world.

In India, between 1998 and 2001, Monsanto and Maharashtra Hybrid Seeds Company Pvt. Ltd. (Mahyco) conducted field trials of genetically modified seeds featuring the cry1Ac gene. However, use of GM seeds invited severe opposition from several NGOs and civil society groups due to its harmful impact on human health and environment. After long debates and consideration regarding the adoption of Bt cotton, finally on 26 March 2002, the then Prime Minister Atal Bihari Vajpayee took the bold decision to commercially introduce Bt cotton through the Genetic Engineering Approval Committee (GEAC), set up by the Ministry of Environment and Forests. Initially, three hybrids—MECH 12, MECH 162 and MECH 184 of Mahyco Monsanto—were recommended for cultivation in the central and southern cotton-growing zones (DCD 2009). With this, India became the 16th nation to commercialise

[42]Lint is cotton fibre that is removed from the seed during the cotton ginning process. From here on, cotton lint is referred to as cotton.

[43]Issued by Ministry of Textiles, Government of India, through the Press Information Bureau on 9 March 2017.

[44]Report on "Revolution in Indian Cotton" published by Directorate of Cotton Development, Department of Agriculture & Co-operation, Ministry of Agriculture, Government of India, in 2009.

[45]Million bales of 170 kg each.

[46]About 40–50% of total crop pesticide used in the country was applied just on cotton (DoAC&FW 2016).

[47]Research study on "Deconstructing Indian cotton: weather, yields, and suicides" by Andrew Paul Gutierrez, Luigi Ponti, Hans R Herren, Johann Baumgärtner and Peter E Kenmore published in Springer Open Journal (https://link.springer.com/content/pdf/10.1186/s12302-015-0043-8.pdf).

transgenic cotton seed. Atal Bihari Vajpayee, in an inaugural speech at IIT Kanpur, on 1 October 2003 said, "The next big revolution that is unfolding in the world is the biotechnology revolution. This too is going to touch the lives of ordinary people in ways that we cannot even fully imagine today. We must not lag behind others in this revolution. Indeed, India should aspire to be one of the leaders of this revolution. We must plant its healthy saplings in different parts of the country so that we can reap their fruits soon" (GOI 2003). Subsequently, the government approved six biotech events expressing versions of Cry genes, including Bollgard I or MON531 (cry1Ac gene) of Mahyco Monsanto; Bollgard II or MONN15985 (cry1Ac and cry2Ab genes) of Mahyco Monsanto; Event 1 of IIT Kharagpur and JK Agri Genetics Seeds Ltd; and GFM event (cry 1 Ab + cry Ac gene) by Nath Seeds sourced from China and BNBt LA-01 of the Indian Council of Agricultural Research and MLS9124 of the National Research Centre on Plant Biotechnology (Udikeri S. S., Kranthi, K. R., Patil S. B. and Khadi B. M.).[48]

As a result, there was a breakthrough in cotton production in 2003–04. India more than doubled cotton production from 13.6 million bales in 2002–03 to 37.2 million bales in 2017–18, surpassing China in 2014–15 to become the number one cotton-producing country in the world (DCD 2017). According to the ISAAA Report on the Global Status of Commercialized Biotech/GM Crops in 2017, 11.4 Mha is under Bt cotton cultivation, with an average rate of adoption of 93%. In addition, there are more than 2000 Bt hybrids, developed by more than 30 seed companies (mostly private), which have been approved by the GEAC for commercial cultivation (ISAAA 2017a).[49] It was the innovation and adoption of Bt cotton technology—the only commercialised GM crop in the country—and the decisions made by policymakers coupled with infrastructure (irrigation, power, roads), access to foreign markets and untiring efforts by the private sector to supply improved seed qualities which led to a major breakthrough in the sector and ushered in the Gene Revolution in India. Cotton yield also increased from 125 kg per hectare in 1960–61 to 302 kg per hectare in 2002–03 to 566 kg per hectare in 2013–14, a more than 85% increase in 10 years (Fig. 3.16) (CCI 2016–17). During this period, the area under cotton cultivation also increased by 56%, indicating production gains emanating largely from a breakthrough in productivity (CCI 2016–17).

As a result, India became a net exporter, with raw cotton export increasing from a meagre 0.09 million bales in 2002–03 to, at its the highest, 12.9 million bales in 2011–12 and 11.7 million bales in 2013–14, a 130 times increase in just 12 years (CCI 2016–17). A forthcoming study of ICRIER by Gulati and Juneja estimates the cumulative gain from import saving, extra raw cotton export and extra yarn export—compared to the business-as-usual scenario—between 2003–04 and 2019–20 at USD84.7 billion at the all-India level.

[48]ICAC Report on "Emerging Pests of Bt Cotton and Dynamics of Insect Pests in Different Events of Bt Cotton" by Udiker S. S., Kranth K. R, Pati S. B. Khad B. M. (https://www.icac.org/tis/regional_networks/asian_network/meeting_5/documents/papers/PapUdikeriS.pdf).

[49]https://www.isaaa.org/resources/publications/biotech_country_facts_and_trends/download/Facts%20and%20Trends%20-%20India.pdf.

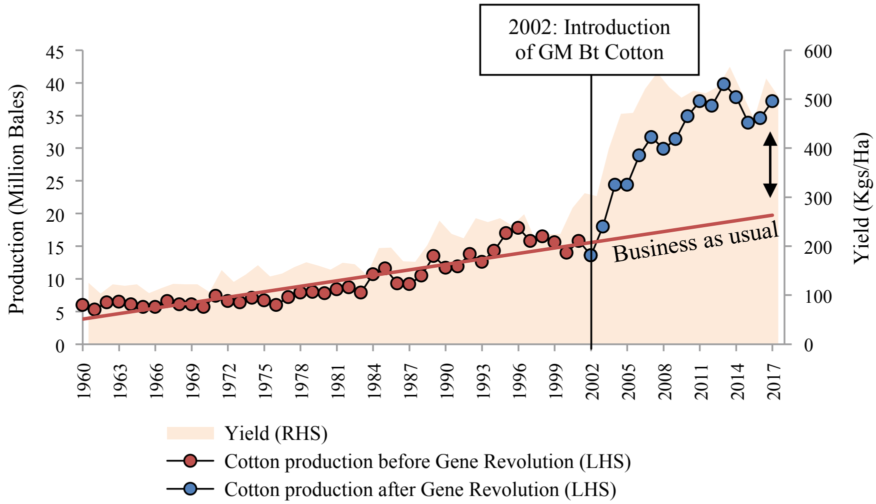

Fig. 3.16 All-India cotton production and yields.
Source United States Department of Agriculture USDA (2018a, b) and CCI (2016–17)

Unfolding Innovations and the IPR Question: Following GEAC approval for commercial cultivation of GM Bt cotton in India, Mahyco Monsanto Biotech (India) Limited (MMB) introduced Bollgard I (containing cry1Ac) in 2002 and Bollgard II (containing cry1Ac and cry2Ab genes) in 2006. Further, release of Bollgard II (with Roundup Ready Flex (RRF)) and Bollgard III with additional pest-resistant proteins (cry1Ac, cry2Ab and Vip3A), along with herbicide-tolerant (HT) RRF traits for enhanced pest resistance, was released in other countries—Australia, Brazil and the USA. Notwithstanding wide adoption of Bt cotton or Bollgard I—more than 90% in India—and ongoing field trials of improved seeds, Bollgard II RRF and Bollgard III have not yet been released, owing to widespread criticism by NGOs, political ideologues and some domestic seed companies.[50] However, in the recent report submitted by the Field Inspection and Scientific Evaluation Committee (FISEC), set up at the insistence of the Prime Minister's Office (PMO), it is reported that there was illegal cultivation of (HT) Bt cotton in states such as Andhra Pradesh, Gujarat, Maharashtra, Telangana and Punjab, to the extent of 15% during the 2017 *kharif* season.

More recently, seeing better yields and a better future with herbicide-tolerant Bt (HtBt) cotton, farmers' groups have come forward and are openly supporting cultivation of HtBt cotton in several states. They even criticise the government for

[50]The government has even stepped into private contracts and imposed price regulations as observed in March 2016, when the price of Bollgard II seed prices was controlled at Rs. 800 per 450-g pack (these had been previously selling at Rs. 830–1000 in different states) and the royalty fee or trait value paid by domestic seed firms to technology developer MMB was slashed by 70 from Rs. 183.26 earlier to Rs. 49 per packet by the government (Seetharaman 2018). Further, for the 2018 *kharif* season, GoI fixed the maximum sale price of Bt cotton seeds at Rs. 740 per packet of 450 g and reduced the royalty fee to Rs. 39 per packet (Press Trust of India 2018).

not giving commercial clearance to Bt brinjal and mustard, which had already been approved by the GEAC in 2010 and 2017, respectively. The late Sharad Joshi's outfit "Shetkari Sanghatana" was the first farmers' organisation to launch a civil disobedience movement for "Freedom of Technology", fighting for the cause of farmers' freedom to choose the best farm technologies (Gulati 2019a, b).

The government needs to provide farmers with access to the latest technologies and the freedom to exercise their prudence to be able to accept or reject a technology based on its merits. So, a careful re-examination of policies in the best interests of Indian farmers is required at this moment in order to address their concerns rather than to penalise them for being pro-technology.

3.3 Total Factor Productivity (TFP) in Agriculture

TFP in agriculture is a holistic measure of a sector's growth, defined as the share of output increase with the same amount of inputs such as fertilisers, land, labour, capital or material resources employed in production. TFP captures the effects of technological change, skills or infrastructure, as well as the increase in efficiency with which inputs are utilised in production (USDA 2018a, b; OECD/ICRIER 2018). It is calculated as the ratio of total agricultural output to total production inputs. A higher ratio implies that resources are being used efficiently (IFPRI 2018).

India's TFP growth since 2001 has been robust, reversing the slowdown of the early 1990s. Technological progress has been the main and consistent driver of TFP growth over the past two decades. The main components of technological progress in India included the use of improved seeds, as well as better infrastructure coverage and quality (irrigation, road density, electricity supply). In another study by Rada (2013), results suggested renewal of farm TFP growth in India following the economic reforms of the 1990s. The study further mentions that the transition to a more diversified production composition resulted in the renewal of TFP growth in Indian agriculture. That is, it was led primarily by horticultural and livestock products and by the southern and western regions as they benefited from higher returns from high-value commodity production following diversification (Rada 2013; OECD/ICRIER 2018) (Table 3.2).

Table 3.2 Average annual Total Factor Productivity (TFP) growth in Indian agriculture

Period	Fuglie (2018)	Rada (2013)
1961–70	0.5%	
1971–80	0.7%	
1981–90	1.3%	3.6%
1991–00	1.1%	1.32%
2001–14	2.32%	3.08% (2000–08)

Source Rada (2013), Fuglie (2018) and Lele et al. (2018)

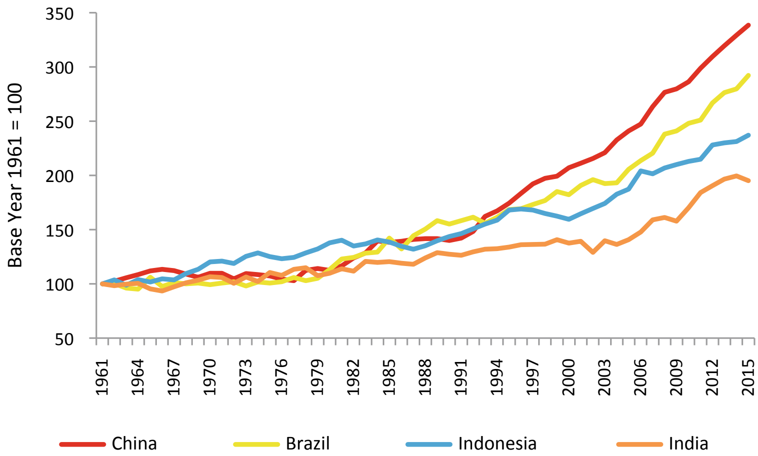

Fig. 3.17 Growth in total factor productivity in selected Asian countries, 1961–2015. *Source* Fuglie (2018). *Note* TFP growth rate is calculated as the difference between output and input growth rates

Besides this, Chand et al. (2012) also assessed the contribution of different productivity-enhancing factors to TFP growth for a variety of Indian crops and found that public investment in agricultural research constituted a significant source of TFP growth in 11 out of 15 crops. When compared to other countries such as China, Brazil and Indonesia, as per Fuglie's estimates, India's TFP growth is rising; however, since 1982, there has been an increasing gap vis-à-vis TFP growth in China, Brazil and Indonesia (Fig. 3.17). Before that, India's TFP growth was slightly better than China's (i.e. during the period of the Green Revolution); thereafter, China took off significantly by investing heavily in productivity growth, surging ahead of other countries (Lele et al. , 2018). Similarly, Brazil's TFP growth was slower than India's until it surpassed India's in the 1980s (Lele et al. 2018).

Besides, recent USDA Estimates indicate that agricultural TFP in India increased at an average annual growth of 2% during 2000–16, which is lower compared to the growth in China (3.4% per annum) and Israel (2.4% per annum) during the same period (USDA 2018a).

Thus, experts suggest that investments in infrastructure, R&D and extension services are needed to ensure sustainable agricultural productivity growth in order to keep pace with rapidly increasing consumer demand for food, feed and fibre (Global Harvest Initiative 2014).

3.4 Innovations in Irrigation Technologies

Almost 54% of agricultural area in India faces high to extreme water stress, i.e. more than 40% withdrawal of available water supply.[51] Of this, agriculture consumes more than 78% of water in India, which is well above the global average of 70%. According to the Ministry of Agriculture and Farmers' Welfare (MoA&FW), Government of India, surface water irrigation through canals accounts for 24% of the net irrigated area in the country while groundwater irrigation accounts for 63%, and tanks and other sources irrigate 13% of the net irrigated area. However, efficient water use, under surface irrigation and groundwater irrigation through conventional application practices like flood irrigation, is as low as 40%–49%. It is in this context that innovative irrigation technologies such as sprinkler and drip irrigation (micro-irrigation) improve application efficiency to about 85%–90%.

Sprinkler and Drip Irrigation: Sprinkler irrigation and drip irrigation are the two main types of micro-irrigation technologies. Up to March 2018, the area brought under micro-irrigation was about 10 Mha (15% of the net irrigated area) in India, with the area under sprinkler irrigation (SMI) spread over 5.44 Mha (53%) and drip irrigation (DMI) over 4.77 Mha (47%). Micro-irrigation has seen a steady growth rate in India over the years, increasing at the rate of 9.07% annually from 2005–06 to 2017–18[52] (Fig. 3.18).

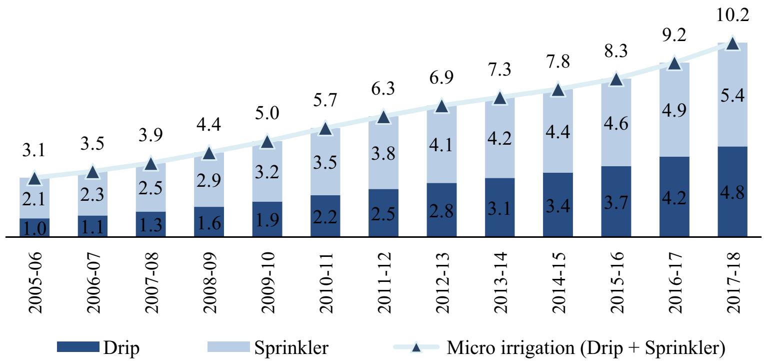

Fig. 3.18 Area under micro-irrigation (drip and sprinkler) in Mha, India. *Source* PMKSY (http://pmksy.gov.in/microirrigation/Physical_Report.aspx)

[51] http://www.wri.org/sites/default/files/india_water_tool.pdf.

[52] The Government of India implemented a centrally sponsored scheme on micro-irrigation in 2005 to improve water use efficiency in agriculture by promoting technologies like drip and sprinkler irrigation technologies. In June 2010, it was scaled up to the National Mission on Micro-Irrigation (NMMI), which continued till the year 2013–14. NMMI was integrated under National Mission for Sustainable Agriculture (NMSA) and implemented as "on-farm water management" (OFWM) during the financial year 2014–15. From 1 April 2015, the micro-irrigation component of OFWM has been included under the Pradhan Mantri Krishi Sinchayee Yojana as the "per drop more crop" component.

The overall area under micro-irrigation is at around 10 Mha, but its penetration (measured as percentage of the area under micro-irrigation to the net irrigated area or equivalent[53]) is very low (14.9%), even lower than the global average of 23.6%, and much lower than countries such as Israel (99.1%), Brazil (77.6%), South Africa (76.9%), Russia (60.7%), the USA (58.0%) and France (52.9%).[54]

Cost–benefit analysis of micro-irrigation: The benefits of micro-irrigation pertain to improving application efficiency to 85–90%, much above that achieved by flood irrigation. Studies also show that fertigation (supplying fertilisers mixed with irrigation water) and the resulting fertiliser saving are added benefit to farmers from the adoption of micro-irrigation techniques. Further, an evaluation study of the adoption of MI technology by sample farmers across states reports that owing to a reduction (saving) in the quantity of irrigation water applied, there is resultant saving in energy (electricity/diesel/solar) needed to pump irrigation water of about 30%. In addition to this, due to an improvement in the efficiency of water and fertiliser use, a significant yield improvement has also been recorded in most crops under micro-irrigation (Table 3.3).

The benefit-cost (BC) ratio of micro-irrigation systems was found to be more than one for almost all crops evaluated across states in the NMMI evaluation study. The benefit-cost estimation of the installation of drip technology in sugarcane in Maharashtra made in an ICRIER study by Gulati and Mohan (2018) showed that, subject to sensitivity analysis, the BC ratio was more than one in all cases, except where the initial investment cost was almost double the government-prescribed installation costs[55] (DoAC&FW 2017d) and farmers had to take out a loan with no subsidy. The ICRIER study also revealed that in all cases where the BC ratio is greater than 1, the

Table 3.3 Benefits from the adoption of micro-irrigation technology as estimated in an impact evaluation study on NMMI in India (2014)

Benefits	% Saving (reduction) or enhancement, as applicable
Power saving	30.65
Fertiliser saving	28.48
Yield enhancement	42.34
Irrigation cost reduction	31.93
Increase in irrigated area	8.41

Source Impact evaluation study on NMMI in India, 2014

[53]Total irrigated area: Irrigated agricultural area refers to area equipped to provide water (via artificial means of irrigation such as by diverting streams, flooding or spraying) to crops (source: FAO). For India, we have taken the net irrigated area as it was found to be the closest equivalent to FAO data.

[54]The task force on micro-irrigation (MI) set up under the Chairmanship of Shri Chandrababu Naidu (2004) estimated that the potential for micro-irrigation in India is around 69.5 Mha with DMI potential of 27 Mha and SMI potential of 42.5 Mha. Thus, the untapped potential of micro-irrigation is still quite large (around 59.3 Mha).

[55]National Mission for Sustainable Agriculture—Operational Guidelines. Ministry of Agriculture, Department of Agriculture and Co-operation, Government of India.

payback period to recover the investment made was less than three and a half years. This indicates the utility of adopting the micro-irrigation system as, in addition to the several benefits, it also ensures income enhancement through a positive BCR.

Innovative Irrigation Models

Solar Pump Sets with Micro-irrigation: The complementary benefits of energy saving and water saving can be achieved by coupling micro-irrigation[56] with other innovations such as solar pumps and underground pipelines. Across India, groundwater is the predominant source of irrigation, covering almost 63% of net irrigated area (NIA). Across the country, different sources of energy are used to pump groundwater. Based on the 5th minor irrigation survey, out of a total of 20.7 million pumps operating in the country that lift water for irrigation, electric pumps (71%) and diesel pumps (25%) dominate. To operate micro-irrigation technology, pressurised water supply is required; this is delivered through sprinklers or applied at the root zone through drippers. The per kwh cost of pumping through diesel pump sets is at least three times higher than through solar pump sets. Replacing all diesel pump sets by solar pump sets would promote cost-effectiveness and would be beneficial for business. However, the initial high capital cost of solar pump sets (about Rs. 4 lakh for a 5 HP pump) is a problem. Given that most Indian farms are small and marginal (less than 2 ha), this cost is exorbitant for them. The government has been giving subsidies to promote solar pump sets, but there is a limit on the overall subsidy funds being given.

The government has also fallen woefully short of achieving its solar power generation targets. It has set a target of 100 GW of solar power generation by 2022 under the National Solar Mission. However, till 30 June 2020, 36 GW solar power (including solar roof top) capacity has been created (MNRE 2020). Overall, up to 30 October 2019, 1.8 lakh solar powered water pumps have been installed in the country under the off-grid and decentralised solar PV application programme. In the 2018–19 budget, the Finance Minister announced a new scheme '*Kisan Urja Suraksha evam Utthaan Mahabhiyan* (KUSUM). The scheme aims to install 10,000 MW of decentralised ground-mounted solar power plants with a capacity of up to 2 megawatt (MW) and 17.50 lakh stand-alone solar-powered agriculture pumps with a capacity of up to 7.5 HP (8250 MW aggregate capacity). Integrating micro-irrigation schemes like PMKSY with the National Solar Mission and KUSUM scheme could help improve agricultural income. Moreover, innovative business models of mobile solar pump sets charging on a service-performed basis, as well as solar trees as a third crop, can make a useful contribution.

Solar as a Third Crop: The model for solar as a third crop in India should be based on a vegetation-centric approach, as maximising agriculture output is the first priority. In such cases, ground-mounted PV panels could be set up while growing cereals and other cash and horticulture crops. Incorporating solar on existing land would help provide an additional stream of income to farmers while reducing the downside

[56]Micro-irrigation techniques like drip irrigation require lower water pressure (20–25 psi) at the outlet compared to overhead systems (50–80 psi). This reduces power requirement for pumping.

risks in case of crop failure. While sales of excess solar energy generated by PV panels installed for irrigation can be a lucrative way to produce solar energy, its generation capacity can be a constraint. Hence, a separate solar generation system can be developed, which can generate enough energy to emerge as a viable source of income. While the upfront cost may be significant, a co-operative model can be developed for farmers to pool resources and limit individual liability. Solar-powered systems can be either grid-connected or stand-alone off-grid systems. In off-grid solar plants, a mechanism is required to store the energy produced such as batteries, which, having a low shelf life of two to a maximum of five years, may increase overall capital costs. As such, it is critical that any solar power system is connected to the local grid. For the concept of "solar as a third crop" to succeed, it is critical that famers are provided with net-metering[57] facilities so that they can sell excess units to the grid. This will act as an incentive for farmers to judiciously use groundwater resources.

Solar Boat and Solar Tree: Farmers in Bihar receive either low or no electric supply, forcing them to depend on expensive diesel pumps for irrigation. For this reason, the Agricultural University at Pusa (Samastipur), Bihar, has developed a boat-based solar pumping system equipped with a 2 HP submersible pump powered by a solar panel that irrigates fields in areas with river water. The university claims that the solar-powered system can irrigate 5–6 acres of land at a time; this can be doubled if micro-irrigation techniques like rain gun, sprinkler or drip irrigation systems are dovetailed with the system. This inexpensive solar irrigation system has an operation cost of about USD0.46 (or Rs. 35) per hour.[58] They have also developed a solar tree (so-named because the design resembles a tree) to save on the land required for solar panels. It has been said that each solar tree can operate a 5HP submersible pump and can normally irrigate 15 acres of land. A combination of a solar tree with a micro-irrigation system is expected to increase the irrigation area by an additional 40%.[59] The university claims that the cost of irrigation through solar tree technology comes to just one-third the cost of irrigation with a normal diesel engine.

[57]Net metering has been a success in Australia, Canada, USA, Italy, Spain and Denmark among others. In 2002, Thailand was the first country to initiate the net-metering policy in the developing world. The very small power producer (VSPP) regulations were aimed at encouraging the use of small-scale renewable generation under 1 MW. The Thailand government mandates the purchase of any surplus electricity generated through renewables at rates that are adjusted every three months. The regulations now cover generation under 10 MW.

[58]Converted in USD at the current exchange rate of USD1 = Rs. 76.62.

[59]https://timesofindia.indiatimes.com/city/patna/rau-develops-solar-tree-for-irrigation-in-areas-sans-power/articleshow/61535756.cms.

3.5 Innovations in the Fertiliser Sector and Soil Management

Backdrop to India's Urea Sector

India is the second largest producer and consumer of urea in the world, next only to China. Urea consumption in India increased from 19.2 MMT in 2000–01 to 32 MMT in 2018–19. On a per hectare (ha) basis, the consumption of urea countrywide increased from 103.5 to 149.3 kg/ha over the same period. Moreover, the price of urea in India is highly subsidised: while pricing reforms have largely (not fully) decontrolled the pricing of phosphatic (P) and potassic (K) fertilisers, urea pricing has remained almost the same for many years.[60] The underpricing of urea compared to the cost of production and imports led to a large ballooning subsidy on fertilisers, almost two-thirds of which is subsidy for urea.[61] At present, the fertiliser subsidy is the largest input subsidy in agriculture and is second only to food subsidies as the largest central subsidy. The fertiliser subsidy has shown a dramatic jump, increasing from USD3.02 billion in 2000–01 to USD10.06 billion in 2018–19. However, the biggest problem in the sector is the imbalanced use of urea in relation to P and K, which leads to soil degradation and massive inefficiency in its use. In certain states like Punjab, the situation is alarming. In addition to this, an imbalance or deficiency of soil nutrients is not limited to primary macronutrients only. Due to the concentrated emphasis on NPK in policies in the country, the deficiency of secondary macronutrients and micro-nutrients is also causing concern. Among other macronutrients, sulphur deficiency is at 41%, and among micro-nutrients, zinc deficiency is at 48%. Zinc is an essential nutrient, and its absence in food causes stunted growth. Similarly, the deficiency of boron, iron and manganese is found to be 33%, 12% and 5%, respectively. Keeping all these issues in mind, the Indian government launched two schemes—*neem* coating of urea (NCU) and soil health cards (SHCs).

[60]Compared to neighbouring countries, Brazil, Indonesia, China and South Africa and some other rice-producing countries in Asia (rice crop requires urea in large proportion), farmers in India pay the lowest price for urea. In 2017, world urea price was at USD220/MT and Indian farmers paid USD86/MT (after including an extra 5% in price for *neem* coating) while in China, Pakistan, Bangladesh, Indonesia and Philippines, urea was priced at USD253/MT, USD265/MT, USD195/MT, USD135/MT and USD362/MT, respectively. Such low prices in India have led to the misuse of urea, mainly in the form of smuggling to neighbouring countries.

[61]The subsidy on urea was calculated as the difference between retention price and the statutorily notified sale price for each urea unit individually. Under the maximum retail price (MRP) scheme of diammonium phosphate (DAP) and muriate of potash (MOP), the difference between the delivered price of fertilisers at the farm gate level and the MRP fixed by the government was paid out as subsidy. Under the nutrient-based subsidy (NBS) scheme, a fixed rate of subsidy on a Rs./kg basis is announced after taking into consideration factors like international prices, exchange rate, inventory level and the existing MRP of DAP and MOP. Subsidy being fixed, any fluctuation in international prices is reflected in the domestic price of DAP and MOP under the NBS policy. Fertiliser subsidy is mentioned in the union budget every year.

***Neem* Coating of Urea (NCU) Scheme**: For a long time, researchers have been trying to find a way to combat the damage done to Indian soil by excessive and/or disproportionate use of urea and low nutrient use efficiency (NUE). *Neem* coating of urea was found effective as this slows down the release of nitrogen from urea, reducing loss due to leaching. It thus reduced the quantity of urea required by crops. Since it reduces leaching of nitrates in groundwater aquifers, it addresses the problem of groundwater pollution as well. Prasad (1980) developed *neem* cake-coated urea in India with nitrification inhibition properties; i.e. it could slow the process of nitrogen release. Studies suggest that applying NCU increases NUE by around 10% and increases the yield of rice and wheat. On 2 June 2008, the government introduced a policy to encourage the production and availability of *neem*-coated fertilisers by allowing producers to make a maximum of 20% of their production *neem*-coated. Before that, in 2007–08, only 1.5% of the urea produced was *neem*-coated. Due to efforts by the government, in 2010–11, 5.5% of normal urea (NU) produced was *neem*-coated. The government increased the cap to 35% through a notification on 11 January 2011; consequently, neem coating jumped to 15.9% of total urea produced in 2011–12. Considering the positive effect of NCU on productivity, the government removed the cap altogether through a notification on 7 January 2015 and on 24 March 2015, the Department of Fertilisers announced that 75% of all urea produced should be *neem*-coated. Further, on 25 May 2015, the department made it mandatory to *neem*-coat 100% of the urea produced. Entire quantities of domestically produced and imported urea have been *neem*-coated since 1 September and 1 December 2015, respectively.

Impact of NCU—Recent Report: A report[62] submitted by the Agricultural Development and Rural Transformation Centre (ADRTC) under the Institute of Social and Economic Change (ISEC) to the Directorate of Economics and Statistics (DES), Ministry of Agriculture, Co-operation and Farmers' Welfare, in 2017 titled "Impact of *Neem* Coated Urea on Production, Productivity and Soil Health in India" that the application of NCU resulted in an improvement in soil health characteristics.[63] This improvement is reflected in the incremental increase in yield levels of the reference crops. The increase in yield was 38% in the case of soya bean, 34% in red gram, 8% each in paddy and maize, 5% in sugar cane and 3% in jute. The survey found the highest incremental yield in respect to paddy in Madhya Pradesh (17% = 2 quintal/acre) and the lowest in the case of Punjab (1% = 0.28 quintal/acre). NCU resulted in a cost increase of 4% in paddy and 1% in maize; however, there was a reduction in costs in the case of soya bean and jute. It also resulted in reduced costs of pest and disease control for paddy, jute, maize and soya bean. The study recorded

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[62]The study intended to analyse the impact of NCU on yield and income and document the status and implementation of the soil health card scheme. The study collected primary and secondary data from six states, namely Karnataka, Maharashtra, Madhya Pradesh, Bihar, Punjab and Assam. The reference period was the 2015 *kharif* season. The six crops considered for the study were paddy, red gram, sugar cane, maize, soya bean and jute.

[63]Nearly 52% of red gram (*tur*) farmers and 61% of paddy farmers have found improvement in soil texture, soil moisture retention, water infiltration and soil softness, and reduction in soil compaction.

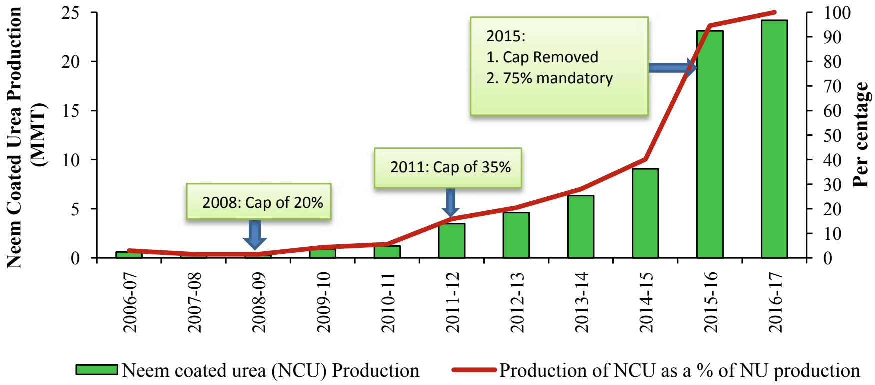

Fig. 3.19 Production of neem-coated urea in India. *Source* Constructed using the data in Fertiliser Statistics 2016–17

that the diversion of urea for non-agricultural use had stopped entirely among the farmers participating in the survey using NCU (Fig 3.19).

Soil Health Cards (SHCs) Scheme: Soil testing is a necessary prerequisite to assess the soil status and recommend fertiliser application. However, as mentioned in a report of the working group of the Twelfth Plan Period (2012–13 to 2016–17), the capacity of soil-testing laboratories was inadequate in the country[64] and "farmers' knowledge regarding the right product, dosage, time and method of application is very limited, leading to inefficient use of fertilisers". According to the report, "Extension agencies should ensure that farmers use the fertilisers in accordance with soil fertility status and crop needs. It will require strengthening of the existing soil testing laboratories by providing facilities for analyzing secondary and micro-nutrients". It also pointed out the need for a national-level centre of soil health monitoring and training under the Department of Agriculture and Co-operation (DAC), which would be equipped with a central soil-testing laboratory (STL) for monitoring the quality of samples, tested and analysed. All this took a major turn when the government announced the SHC scheme on the 19 February 2015. The scheme was approved for implementation in 2015 with an outlay of USD0.08 billion[65] (or Rs. 5.68 billion).

[64]The beginning of soil-testing laboratories in India goes back to 1955–56, when 16 soil-testing laboratories (STLs) were established under the "Indo-US Operational Agreement for Determination of Soil Fertility and Fertiliser Use". After that, 1049 STLs were set up in the country by March 2012 (Press Release 07.09.2012). In 2013–14, 15 more STLs were sanctioned (Press Release 2 January 2017). It was recognised by the working group report that for judicious use of fertiliser by farmers, the role of STLs and fertiliser recommendation is undeniable. Farmers with small holdings require these recommendations even more. Under the National Project on Management of Soil Health and Fertility (NPMSH&F) of the Department of Agriculture and Co-operation (DAC), financial assistance was provided for farmer's training and field demonstrations on balanced use of fertilisers.

[65]Converted to USD using exchange rate of USD1 = Rs. 65.46 in 2015 (RBI 2017–18).

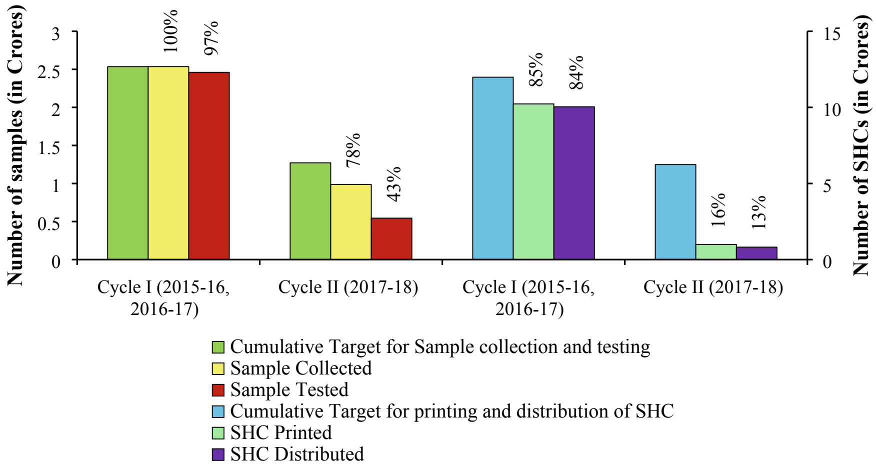

Fig. 3.20 Targets and achievements of SHC Scheme, India. *Source* SHC Website

Achievements vis-à-vis Target: The United Nations (UN) declared 2015 as the "International Year of the Soils". On that note, the government decided to complete the first cycle (sample collection, testing and SHC printing and distribution) in two years instead of three—2015–16 and 2016–17—and the second cycle started in 2017–18. According to the progress report, in the first cycle,[66] 100% of the target was collected and 97% was tested. But SHCs distributed in the first cycle were just 84% of the target. However, in the second cycle, only 13% of the target for SHCs was distributed. It would appear that the government will have to increase the pace of the process in the second cycle if the scheme is intended to be taken seriously. Figure 3.20 presents the targets and achievements of the scheme in terms of sample collection, testing, SHCs printing and distribution.

Impact of the SHC—Recent Report: The National Institute of Agricultural Extension Management (MANAGE), Hyderabad, carried out a study[67] on the "Impact of Soil Health Card Scheme" mandated by the Ministry of Agriculture and Farmers' Welfare (MOA&FW) of the Government of India, for three crops, namely: paddy, cotton and soya bean.[68] According to the report, after following the recommendations of the SHC, the area under these crops declined. This might have been the result of farmers diversifying. There was a decline in the use of fertilisers, with the use of

[66]As on 1 January 2018.

[67]To examine the design of the SHC scheme; assess the modalities of delivery; assess the level of utilisation of SHCs by farmers; and assess the impact of the SHC scheme on the judicious use of fertilisers (bio and organic) as well as cropping choice, cost reduction, farm profitability and sustainability. The study also recommends some measures to improve the overall design of the scheme.

[68]Fertiliser use and productivity before and after, following the recommendations of SHC, were compared.

nitrogenous fertilisers declining at a higher percentage than phosphatic or potassic fertilisers; this is a good sign because it signifies a move towards more balanced fertiliser application. Besides, there was a decline in costs of 8–10% for cost A_1; i.e. all actual expenses in cash and kind are incurred in production by the owner for all crops and around 4% for cost $C_{2,}$ i.e. the comprehensive cost including imputed rent and interest on owned land and capital. Crop yields have increased slightly after having SHC in all three crops at the all-India level (from 2% to 4%) although state-wise values differ. The study recommends various measures to improve the scheme including: rethinking grids considering local soil variability, the need for inclusion of water quality statements in the card, setting up more soil-testing laboratories and focusing on the quality of soil testing at acceptable market prices. Broadly, both schemes suffer shortcomings: there is lack of awareness among farmers about the benefits of using NCU and SHCs; an increase in urea prices after *neem* coating; and a lack of infrastructure and delay in soil sample collection, testing and distribution of SHCs. Although half the farmers have received SHCs on time, only a small portion of them have followed the recommendations properly. This is something that could be addressed by creating greater awareness among farmers.

3.6 Innovations in Precision Agriculture: Artificial Intelligence, Internet of Things, Remote Sensing

The use of ICT-enabled smart technologies such as the geographical information system (GIS), drones, the Internet of things (IoT), big data analytics and artificial intelligence (AI) has heralded a new technology package in Indian agriculture, which can have significant impact in due course. By interpreting the data on soil information, weather and environmental conditions for a specific piece of land, a farmer can optimise the choice of crop, and the use of pesticides, water and fertilisers, and can thus decide when and how to spray, till and harvest the crop.

Drones or unmanned aerial vehicles (UAVs) with integrated GIS mapping, sensors and digital-imaging capabilities can play an instrumental role by first analysing soil in order to plan a seed-planting pattern. After that, drone-carried devices can be used to spray the correct amounts of fertilisers, nutrients and pesticides. Time-series images captured through drones can help farmers know the precise development of a crop and reveal production inefficiencies, thus, enabling better crop management. Drones with hyper-spectral, multispectral, or thermal sensors can be used to identify parts of the field that are dry or that need improvement. By scanning the overall health of the crop using both visible and near-infrared lights, farmers can easily spot bacterial or fungal infections, further helping them to apply and monitor remedies more precisely (Mazur 2016). In a recent Pricewaterhouse Coopers (PwC) global report on the commercial application of drone technology, the market for drone-powered solutions in the agricultural sector has been estimated at USD32.4 billion.[69]

[69] https://www.pwc.pl/en/publikacje/2016/clarity-from-above.html.

In the data space, it can often be a challenge to combine and order unstructured or disparate data so that it makes sense. Through sources like the Internet of things (IoT) sensors and social networks, farmers can incorporate data collection, sensor-monitoring, the measuring and reporting of environmental elements, e.g. temperature, pressure, humidity, weather, climate, seismic activity, radiation, light, motion, proximity, etc., to form large amounts of big data. This can then be analysed from any location to lay down the action plan to be implemented in the controlled system. Some IoT application scenarios include smart agriculture, environmental monitoring and forecasting, asset management and logistics and vehicular automation. IoT can provide a means to plan, monitor and control every phase of the agricultural ecosystem.

In India, according to Agfunder.com (2016), over 50 agricultural technology-based start-ups use smart agriculture (NITI Aayog 2018). While a majority of them are in the research and development (R&D) phase, a few large-scale farmers have started implementing innovative products on their farms to improve output, thereby contributing to a booming agro-based economy (Chatterjee 2018).

CropIn Technology Solutions Private Limited, founded in 2010, provides software as a service (SaaS) to agricultural businesses through the "SmartFarm" platform, which helps farmers derive real-time insight into the standing crop based on local weather information and high-resolution satellite imagery. In addition to this, CropIn also provides "SmartSales" technological solutions for input companies to enable them to track sales orders, stocks and payments. This also helps them identify potential sales points to decide on-farm operations and output. Another service provided by CropIn is "mWarehouse" which ensures traceability to the last mile for companies engaged in exports and logistics of agri-produce, including packaging services (Ganguly et al. 2017). The start-up's clientele include PepsiCo, Mahindra & Mahindra, ITC and McCain along with banks, government bodies and development agencies. It has connected with 29 countries across South East Asia, Europe and Africa, has engaged with nearly 2 million farmers holding 3 million acres of land in farm management, crop-cycle monitoring and harvesting, and brings in produce traceability from farm to fork (Ahuja 2018).

Other start-ups have also ventured into IoT applications and are currently establishing a foothold before they begin to commercialise and scale up operations. For instance, "*Opencube Labs (OCL)*" based out of Bangalore is a start-up currently working towards creating open-source, farmer-friendly, IoT-based agricultural handheld devices to check crop health by measuring the normalised density vegetation index (NDVI), a real-time soil vital measurement system to check for soil moisture, nutrient and pH levels in the field, a semi-automated irrigation system and a smart livestock management system that gives inputs to farmers in their local language for better use of resources and predicts yields, revenues and returns on investments even before the end of the season (Chatterjee 2018). Another start-up based out of Punjab—AgNext Technologies—has developed a single solution platform by combining four technologies: IoT, AI-based image processing, weather forecasting and satellite imagery for stakeholders to monitor the occurrence of pests and diseases over a large area and build predictive models for the future. Energy Bots Private

Limited, a Gurgaon-based start-up, has introduced a smart-watering system using soil humidity and moisture sensors and a global system for mobile communication (GSM)-based IoT device. The device gets data from sensors within the controller and microcontroller to take decisions and perform actions that allow farmers to remotely switch on or switch off their motor pump either by giving a missed call or by sending a text, or by scheduling both at specific times of the day. Farmers are even alerted and notified when any action is taken by the device (Chatterjee 2018).

Artificial intelligence (AI) is a computer program in which a machine is equipped with the ability to develop the cognitive functions of a human so that it can make decisions based on interpreting, acquiring and reacting to different situations (on the basis of learning acquired) to enhance efficiency. AI and related technologies have the potential to impact productivity and efficiency at all stages of the agricultural value chain. For instance, AI solutions integrated with data signals from remote satellites, as well as local image capture on the farm, can help farmers take immediate action to restore soil health. AI can also be used to generate advisories for sowing, pest control and input control; image-classification tools combined with remote-sensed information can improve the efficiency of farm machinery. AI tools can be used to transmit more accurate supply and demand information to farmers, thus reducing information asymmetry between farmers and intermediaries. Further, predictive modelling to ensure effective price discovery can be carried out using data from e-NAM, agricultural census, AGMARKET, etc. (NITI Aayog 2018).

Recognising that efforts from the private sector may neither be financially optimal nor efficient on a stand-alone basis, the Finance Minister, in his budget speech for 2018–2019, mandated NITI Aayog to establish the National Programme on AI, to guide research and development in new and emerging technologies (NITI Aayog 2018). As a result, NITI Aayog has adopted a three-pronged approach—undertaking exploratory proof-of-concept AI projects in various areas, crafting a national strategy for building an AI ecosystem and collaborating with various experts and stakeholders. In addition to this, NITI Aayog has also partnered with several leading AI technology players to implement AI projects in critical areas such as agriculture and health.

Microsoft, in collaboration with the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), has developed an AI sowing app, which is powered by the Microsoft Cortana Intelligence Suite that includes machine learning and Power BI.[70] The app sends sowing advisories containing essential information such as the optimal sowing date, soil-test-based fertiliser application, farmyard manure application, seed treatment and optimum sowing depth to participating farmers. In addition to the app, a personalised village advisory dashboard provides important insights into soil health, recommended fertilisers and seven-day weather forecasts. In 2017, the programme was expanded to reach more than 3000 farmers across the states of Andhra Pradesh and Karnataka during the *kharif* crop cycle (rainy season) for a host of crops including groundnut, finger millet (*ragi*), maize, rice and cotton. On

[70]Power BI is a business analytics service by Microsoft. It aims to provide interactive visualisations and business intelligence capabilities with an interface for end users to create their own reports and dashboards.

average, a 10–30% increase in crop yield per ha has been witnessed in comparison with previous harvests across crops (NITI Aayog 2018). Companies such as Intello Labs have developed image-recognition software to monitor crops and predict farm yields; Aibono uses agricultural data science with AI providing solutions to stabilise crop yields, and Trithi Robotics uses drone technology that allows farmers to monitor crops in real time and provides precise analysis of their soil.

Therefore, according to the creators and system integrators in the technological ecosystem, Indian agriculture can achieve a new phase of exponential growth through IoT applications, AI, and UAVs/drones. These can revolutionise the way farmers cultivate, and have an impact on warehousing and waste reduction; they can also ensure higher revenues and profitability for the entire ecosystem (Chatterjee 2018), given that they are offered in an open source, viable and affordable platform that ensures faster adoption.

3.7 Innovations in Sustainable and Protected Agriculture

Soilless Farming Systems *Hydroponics, Aeroponics and Aquaponics*: Hydroponics is the method of growing plants in a water-based, nutrient-rich medium, without soil. This method essentially cuts down the amount of water being used compared to the traditional method of growing plants in soil. This technique is often used to grow vines, tomato, cucumber, capsicum and other crops. Aeroponics is the process of growing plants in a moist environment without soil or an aggregate medium. The plants are suspended in an enclosed setting, and water, mixed with plant food, is sprayed on to the roots. An enclosed environment like a greenhouse enables the user to regulate temperature and humidity accurately with some additional lighting (Calderone 2018). On average, plants grown using aeroponic technology were reported to yield 30% higher productivity compared to soil-growing methods (Calderone 2018). Aquaponics, on the other hand, is an integration of hydroponics (raising plants without soil) and aquaculture (rearing fish). The systems work by using the waste from fish to naturally provide nutrients to nearby water-grown plants. According to the FAO (2018), integrated agri-aquaculture farms can reduce water consumption by 90% compared to traditional agriculture. The practice is likely to benefit countries such as Oman, Algeria, Egypt or North Africa, where there is shortage of both water and good-quality soil.

An example of an emerging start-up in India that has ventured into these novel technologies and is currently at the stage of establishing its foothold is "Triton Foodworks". The company has set up over five acres of hydroponic farms across three locations in India. Their strawberry farm in Mahabaleshwar grows 20 tonnes of strawberries a year, and a 1.25-acre facility in Maharashtra's Wada district produces about 400 tonnes of tomato, 150 tonnes of cucumber, 400 heads of spinach and over 700 bunches of mint (Vaishnavi 2017). According to the company, hydroponic systems enable them to save around 0.22 billion litres of water per year compared to traditional agriculture. Another start-up—the Centre for Research in Alternative Farming Technologies (CRAFT)—has emerged as a leading service provider in alternative farming technologies. The company trains and provides consultancy to people in hydroponics, aquaponics, urban farming and the commercial aspects of the technologies (Vaishnavi 2017). A start-up named "Hamari Krishi" empowers Indian farmers to grow vegetables such as basil, coriander, lettuce, thyme, spinach, vine tomatoes, cucumbers, bell peppers, gourds and water melon throughout the year using non-soil agricultural techniques in aeroponics structures. The company manufactures poly-house and aeroponic structures to a range of specifications and also provides training programmes on how to run a farm efficiently.[71]

Poly-House Farming Systems: Indo-Israeli Agriculture Project: To achieve sustainable holistic development of Indian agriculture along with an intensification of bilateral co-operation, the Government of India and the Israeli government jointly drew up a work plan in 2006 for technology dissemination under the Indo-Israeli Agricultural Project (IIAP) implemented by the Mission for Integrated Development of Horticulture (MIDH) and MASHAV, Israel's Agency for International Development Co-operation. The project aimed to improve crop diversity, productivity, quality and resource-use efficiency through capacity building and transferring innovative applied research and technologies to farmers. To execute IIAP, "agricultural centres of excellence" (CoE) were established, the resources of which were allocated by both the Federal Government (NHM) and individual state governments after the approval of the detailed project report from the central government (MASHAV 2016). These centres of excellence are focal points for Indo-Israeli R&D in agriculture (Kumar 2014). These centres are arranged in clusters such as vegetables, mangoes, pomegranates and citrus, to provide crop-specific training and demonstrations to farmers on a variety of best practices such as protected cultivation, drip irrigation, fertigation, canopy management, nursery production and integrated pest management in order to achieve high agricultural productivity (Aluf 2014). Each cluster is headed by an Indian expert, who is usually the individual who runs the most advanced centre in the cluster. The head of a cluster works closely with their Israeli expert counterpart to adapt the technology to existing local needs (MASHAV 2016). So far, 30 centres of excellence have been sanctioned by MIDH under the Indo-Israeli Action Plan in three phases. The first action plan (phase 01) was implemented during 2008–2011 and focused on Haryana, Maharashtra, Rajasthan and Gujarat. The Action Plan for 2012–2015 (phase 02) expanded the focus to seven states, adding Karnataka, Tamil Nadu and Punjab to the list (Kumar 2014), and phase 03 (2018–2020) is currently in progress (Aluf 2014). A list of these centres is given in Table 3.5 in the Annexure.

The most significant contribution of the Indo-Israeli collaboration was in assisting Indian farmers to reduce the cost of desalination of water in addition to recycling water for irrigation purposes. Acute shortage of fresh water is one of the critical issues faced in India, yet the agricultural sector consumes nearly 78% of water drawn from freshwater sources. It is in this area that Israel has set an example. Despite having less than 200 m^3 per capita water availability (Gulati and Mohan 2018), it has emerged

[71] http://www.hamarikrishi.com.

globally as a well-established leader in water management, desalination and recycling techniques. Under the Joint Declaration for Co-operation in Water Technologies (2012) between the Indian Ministry of Urban Development and the Israeli Ministry of Industry, Trade and Labour (Kumar 2014), Israeli agricultural professionals teach and help Indian farmers in the adoption of water management practices such as drip irrigation and fertigation by demonstrating the effectiveness of these technologies in terms of higher resource-use efficiency. As a result of such countrywide efforts and the central government's micro-irrigation scheme, there has been a reasonable increase in the area under micro-irrigation from 3.1 Mha in 2005–06 to 10.2 Mha in 2017–18.[72] However, penetration is comparatively low at 14.9%, when compared with global average of 23.6%, and with other countries like Israel (99.1%), Brazil (77.6%), South Africa (76.9%), Russia (60.7%), USA (58.0%) and France (52.9%). All of this suggests that India has a long way to go in developing advanced water management technologies.[73]

Israel is also supporting India in fulfilling food requirements by exporting new crops, hybrid seeds and products, which are tested in the centres before adoption by farmers. The Indo-Israel Vegetable Centre of Excellence in Gharaunda, Haryana, has made substantial gains in terms of the annual number of seedlings grown by state farmers—from half a million in 2011 to six million in 2015[74]—using innovative plug-seedling technology[75] (MASHAV 2016). The seedlings include hybrid seeds of tomatoes, cherry tomatoes, coloured capsicum, cucumbers, eggplant, chilli peppers and more. Farmers from Punjab, Rajasthan and Himachal Pradesh also use the facility. In addition to this, the Israeli innovation of "protective cultivation" has successfully demonstrated increased crop yields, reduced pesticide use and prolonged harvesting. Protected cultivation, including structures such as the hi-tech greenhouse, naturally ventilated poly-houses (NVPH), the anti-insect net house (AINH) and walk-in tunnels, has shown a dramatic increase in crops within three years of operation. As a result, the yields in the state have increased significantly for cucumber from 3.5 t/ha to 45 t/ha, for capsicum from 12 t/ha to 72 t/ha and for tomato from 16 t/ha to 96 t/ha, along with a prolonged harvesting season: from 3 to 9 months (MASHAV 2016). In addition to the increase in crop productivity, there was a reduction of 65% in water use. At present, farmers all over Haryana grow over 1400 ha of protected vegetables, with the numbers rising annually. Although the technology, as well as construction of greenhouses and poly-houses, is expensive, government subsidies have ensured that interested farmers take the plunge (MASHAV 2016). The Indo-Israel Centre of Excellence for Sub-Tropical Fruits (ICESTF) in Ladwa, Kurukshetra,

[72]PMKSY (http://pmksy.gov.in/microirrigation/Physical_Report.aspx).

[73]Italy, France, Iran: International Commission on Irrigation and Drainage 2016-17; *Total of the 46 countries considered by ICID in their annual report 2016–17; FAO Aquastat data, DES, GOI.; China: Correspondence with CNCID—Chinese National Committee on Irrigation and Drainage; USGS (United States Geological Survey): https://water.usgs.gov/watuse/wuir.html, http://databank.worldbank.org.

[74]http://timesofindia.indiatimes.com/articleshow/53292394.cms?utm_source=contentofinterest&utm_medium=text&utm_campaign=cppst.

[75]Young plants grown in small, individual cells, ready to be transplanted into containers or a field.

established for mango in 2016, is another major success story and showcases some of the most advanced Israeli agricultural technologies adapted for Indian conditions by local experts such as new mango demonstration fields, nurseries, introducing new Israeli mango varieties like the salinity-tolerant M-13-1, Maya and Sheli, as well as demonstrating best practices such as high-density plantation, canopy management and rejuvenation of senile orchards. As a result, there has been a significant increase in output along with improved fruit quality: in just two years, the treated trees produced fruit with greater weight and better colour and harvesting was easier with fewer post-harvest losses (MASHAV 2016). Although the centres of excellence have played a key role in effectively disseminating technology through training and demonstrations, the cost-benefit analysis of such operations and technologies under IIAP still needs to be evaluated by a third party to assess its commercial viability. Moreover, its spread to farmers' fields at a respectable scale is yet to take place. Only when it has scaled up on farmers' fields, IIAP can be considered a true success story.

3.7.1 Research and Development and Education in Indian Agriculture

Agricultural research and development (R&D) is the engine for both the sector's growth and poverty reduction in the country. The evolution of R&D in Indian agriculture started with the establishment of agricultural colleges in 1905 and the Indian Council of Agricultural Research (ICAR) in 1929. This was followed by the inception of the state agricultural universities (SAUs) during the 1960s and 1970s, which marked a significant shift towards growth in state funding (Pal 2017). Today, India has one of the largest agricultural research systems in the world. Led by the ICAR, the public research system has five multidisciplinary national institutes, 45 central research institutes, 30 national research centres (NRCs), four bureaus, ten project directorates, 80 All-India Co-ordinated Research Projects (AICRPs)/networks and 16 other projects/programmes. In addition, there are 29 state agricultural universities (SAUs) and one central agricultural university, which operate through 313 research stations (Gulati et al. 2018). The AICRPs involve about 1300 centres, of which about 900 are based in agricultural universities and 200 in the ICAR institutes. They act as the main link between the ICAR and the SAUs. The ICAR also has zonal research stations (ZRSs) and 200 substations (Gulati et al. 2018). The National Academy of Agricultural Research Management (NAARM) is another institution under the ICAR; it conducts research and training in agricultural research management. The ICAR has also established eight trainers' training centres (TTCs) and 611 *Krishi Vigyan Kendras* at the district level as innovative institutional models for assessment, refinement and transfer of modern agricultural technologies (Gulati et al. 2018).

It is worth noting that India's spending on total agriculture R&D in real terms (2011 prices) has increased from USD1904 million in 2000–01 to USD3298.37 million in

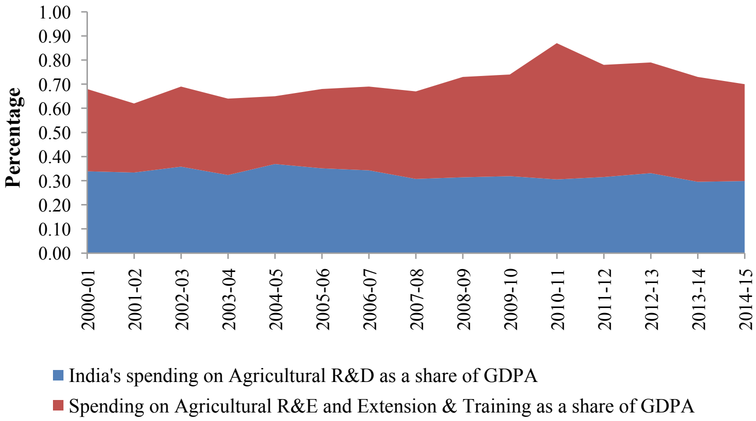

Fig. 3.21 Agriculture R&D and R&E and extension training (R&E and XT) expenditure as a share of GDPA in India. *Source* (ASTI 2016) and (Gulati et al. 2018)

2014–15 (ASTI 2016).[76] At the same time, R&D intensity, which is agricultural R&D expenditure as a percentage of gross domestic product from agriculture (GDPA), which was at 0.34% in 2000–01 increased marginally to 0.37% in 2004–05 and finally settled at 0.30% in 2014–15 (ASTI 2016). It is also observed that agriculture research and education (R&E) expenditure as a percentage of GDPA remained steady at 0.5% between 2000–01 and 2007–08; after that, it rose significantly and reached 0.7% of GDPA in 2010–11, settling down at 0.54% in 2014–15 (Gulati et al. 2018). The combined total public sector expenditure on R&E and extension and training (R&E and XT) as a percentage of GDPA stands at 0.7% of GDPA for the period 2014–15 (Fig. 3.21).

India's investment of 0.30% of the GDPA in agricultural research in 2014 compares poorly with that in countries like Bangladesh, China and Brazil. It was lower than in neighbouring Bangladesh (0.37%) and only half that invested by China (0.62%). Brazil invested a much higher share of 1.82% of GDPA in agricultural research (ASTI, IFPRI, various issues). While the government has set a target to invest 1% of GDPA on agricultural R&D, the target is unlikely to be met within the stipulated time frame (ASTI 2016) (Fig. 3.22).

Returns on R&D and Education Expenditure: The literature clearly highlights that compared to input and food subsidies, expenditure incurred on agricultural R&D and education and infrastructure is more powerful in alleviating poverty and spurring agricultural growth as this type of investment enables higher productivity. In a recent study by Perez and Rosegrant (2015) on investment in agricultural R&D, it is shown that strategies that incorporate R&D have the potential to raise agricultural total factor productivity (TFP) by 2% and lower the world prices of cereals and meat by as

[76] Data on privately performed agricultural research in India are not available; so it is excluded from the analysis.

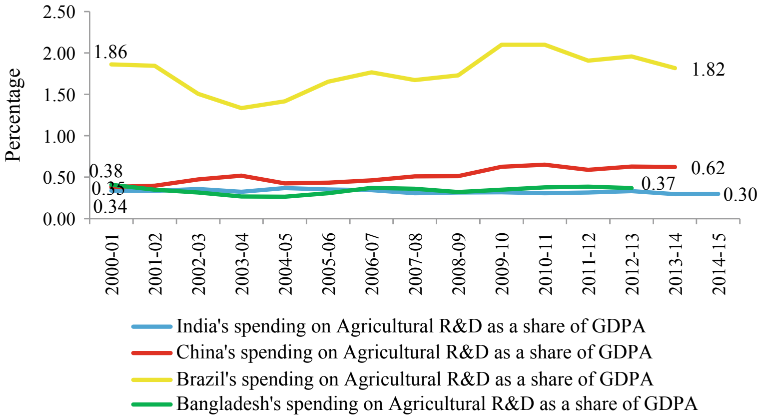

Fig. 3.22 Agricultural research intensity in India, China, Brazil and Bangladesh. *Source* ASTI, IFPRI (2016), various issues

much as 17% and 15%, respectively (Gulati and Terway 2018). Besides this, Gulati and Terway (2018), using a simultaneous equation model, discovered that marginal returns in terms of the number of people brought out of poverty to investments in research and education (R&E), roads and irrigation outweigh the benefits from input subsidies in power, fertiliser and irrigation. The number of people brought out of poverty per million rupees spent on fertiliser subsidy is only 26 compared to 328 people if an equivalent amount was to be spent on agricultural R&E. Similarly, the return on agricultural GDP per rupee spent is 0.88 for fertiliser subsidy as compared to 11.2 in agricultural R&E (Gulati and Terway 2018). Instances of enormous returns from agricultural R&D investments include Pusa Basmati 1121 and 1509, an innovation in basmati rice variety by the public research system, which yielded basmati exports of between USD4 and USD5 billion annually. Besides this, innovation of the sugar cane variety Co-0238 in Uttar Pradesh also yielded impressive returns. It led to a significant increase in the recovery ratio from about 9.2% in 2012–13 to more than 11% in 2019 (Gulati 2019a).

Role of the Private Sector in Agricultural R&D: In India, the private sector plays a vital role in agricultural transformation, accounting for 81.2% of gross capital formation (GCF) in agriculture in 2016–17 compared with an 18.8% contribution by the public sector. In a survey sponsored by the Syngenta Foundation (2011), it was found that 71 companies were active in research and agricultural product development in India: 22 in seeds, 19 in agrochemicals, ten each in fertiliser solutions and mechanisation (including irrigation), and ten in other areas, including agronomic research on specific crops. It is believed that these numbers have increased since then (Ferroni and Zhou 2018). Further, a study by Pray and Nagarajan (2012) estimated total private expenditure on agricultural R&D by local firms and multinationals in India at USD155 million and USD96 million, respectively, in 2008–09 (at 2005 prices) (Ferroni and Zhou 2018). Globally, private agri-business companies invest heavily in agricultural R&D. A study by Ferroni and Zhou (2016) estimated that the world's leading firms spend about 10% of their annual revenue in this area, of which the six largest companies spent USD7 billion on R&D in 2014. Monsanto leads the way, followed by Syngenta, Bayer, DuPont, BASF and Dow (Ferroni and Zhou 2018).[77]

Thus, given the higher marginal returns to every rupee of investment on R&D as compared to input subsidies, the government should first double the investments in agricultural R&E and infrastructure in the next five years to boost farm yields and alleviate poverty from the country in order to have a higher rate of agricultural growth on a sustainable basis. Private sector investments should also be encouraged by providing breeder's right and plant biotechnology protection with a favourable regulatory environment for widespread adoption of available technologies. This would benefit the country by unleashing innovation and the country's vast untapped agricultural potential (Ferroni and Zhou 2018).

3.8 Concluding Remarks

In this paper, we have tried to list the type of innovations in production technologies with large-scale impact on productivity that Indian agriculture has experienced in the past, and also those innovations that have been unfolding in recent years such as genome decoding, sequencing editing, precision agricultural practices, artificial intelligence, soilless farming systems, intensification in the case of rice and wheat, innovation in valuable broodstock and poultry farm management, which may influence Indian agriculture in the years to come. In particular, we have focused on innovations in seed technologies that led to the green and gene revolutions in India, innovations in institutions and technologies related to the logistics of milk that led to the white revolution and innovations in fishery and poultry, by importing high-yielding stocks and cross-breeding, and developing institutions of vertical integration and contract farming, etc., which have transformed these sectors. Further, we have looked at fruits and vegetables (F&V), especially innovations in UHDP in mangoes and bananas, and, in the case of bananas, the critical role of tissue culture that made India the largest producer of both bananas and mangoes. Similarly, in potatoes and onions, we have focused on how innovations helped increase production. These innovations have already had a large-scale impact on agricultural productivity and transformed Indian agriculture. The innovations that are now unfolding relate to the better use of water for irrigation (micro-irrigation), better use of fertilisers, especially urea; better use of farm machinery through "Uberisation" and the custom hiring model; the adoption of climate-smart, sustainable agricultural practices such as hydroponics, aeroponics, aquaponics and poly-houses; and the contribution of agricultural R&D and education in implementing these innovations. These innovations only give a flavour of what is happening in Indian agriculture. There is a

[77]Monsanto is now taken over by Bayer.

lot more on the ground where significant changes have occurred. This is reflected in the production of maize through hybrid seeds, and the “pink revolution” in the bovine meat sector that has made India the second largest exporter in the world. The bottom line is that these innovations in production technologies and institutions have turned India from a food-deficit country to one that is not only self-sufficient but also emerged as a net exporter of agricultural produce.

The innovations that have been unfolding in recent years and that are likely to accelerate in the years to come focus not only on increasing productivity and overall production, but also on better usage of water, fertilisers and farm machinery, so that efficiency can be promoted along with sustainability. Precision agriculture using UAVs/drones, the Internet of things and artificial intelligence is also making in-roads, though somewhat slowly.

Given the transformational role these innovations have played in the past and are likely to play in future, it is time for India to accord higher priority to research and development and education in the agricultural sector to allow dissemination of technologies to Indian farmers in a more systematic and affordable manner. The first step calls for an increase in investments (both public and private) in agricultural R&D and education, supported by appropriate policies and incentives. Secondly, to achieve a new phase of exponential growth, there is a need to support and adopt global technologies with conducive policies and regulations that protect innovators' interests as well as ensure farmers' access to the best technologies around the world.

Not only within India but also in a smallholder economies like Asia and Africa, where agriculture has been considered the backbone of the many countries, there is ample scope for replicating and scaling up these innovations to achieve holistic and inclusive growth in agriculture across such countries. Africa faces challenges such as diverse, rain-fed farming, far less irrigation potential and fertiliser consumption, poor infrastructure, low investment levels, limited access to markets and fragmented supply chains. Therefore, to increase productivity, ensure food security and improve cost efficiency, there is need to invest in fundamentals such as rural infrastructure, irrigation, agricultural research and extension, and climate-resilient technologies. Solar-driven irrigation models could be effective in building sustainable agriculture. The economics of solar as a third crop can be checked to enhance a farmer's income. To combat the deficiency of micro-nutrients in diets, innovations in bio-fortified staples could prove to be a game changer. Overall, to develop competitive agriculture, Africa should undergo marketing, as well as trade reforms. This will ensure better prices for farmers for their produce and enable them to cope with higher technological adaptation costs.

Appendix

See Table 3.4.

Table 3.4 Climate-resilient wheat and rice varieties released at central level

Wheat variety	Year of release/notification	Breeding institute	Characteristics	Recommended area	Source
HD 2987	2011	IARI Regional Research Station, Indore	Medium late maturing. Drought tolerance	N. Karnataka, S. Maharashtra. A.P and Tamil Nadu	https://nfsm.gov.in/StatusPaper/Wheat2016.pdf
HD 2985	2011	IARI Regional Research Station, Indore	Medium early maturing. Heat tolerance	Punjab, Haryana, Delhi, Rajasthan, Western Uttar Pradesh, parts of J & K (Jammu & Kathua Dist.) and parts of H.P. (Paonta Valley and Una Dist.	https://nfsm.gov.in/StatusPaper/Wheat2016.pdf
WH 1080	2011	CCS HAU, Hisar	Semi-dwarf, medium late, medium bold Seed rust resistance, drought tolerance	Punjab, Haryana, Delhi, Rajasthan, Western Uttar Pradesh, parts of J & K (Jammu & Kathua Dist.) and parts of H.P. (Paonta Valley and Una Dist	https://nfsm.gov.in/StatusPaper/Wheat2016.pdf
HD 3043	2012	IARI Regional Research Station, Indore	Medium late maturing, semi-dwarf, bold seed. Drought tolerance and resistance to leaf and yellow rust	Area stretching from Eastern UP onwards up to the far eastern states, viz. Bihar, Orissa, West Bengal, Assam and plains of NE region	https://nfsm.gov.in/StatusPaper/Wheat2016.pdf
AKAW 4627	2012	PDKV, Akola	Early maturing, medium dwarf, medium bold seed. Drought tolerance	Hilly regions of J & K (except Jammu & Kathua Dist.), hills of H.P. (except Paonta Valley and Una Dist.) and Uttarakhand	https://nfsm.gov.in/StatusPaper/Wheat2016.pdf

(continued)

Table 3.4 (continued)

Wheat variety	Year of release/notification	Breeding institute	Characteristics	Recommended area	Source
DBW-107	2014	DWR, Karnal	Tolerant to heat stress; higher disease resistance.	Area stretching from Eastern UP onwards up to the far eastern states, viz. Bihar, Orissa, West Bengal, Assam and plains of NE region	https://nfsm.gov.in/StatusPaper/Wheat2016.pdf
HDCSW 18	2015	ICAR	It has genetic yield potential of more than 7t/ha. It is resistant to high temperature at seedling stage. It escapes high temperature at maturity due to early seeding	NCR/Delhi state	https://icar.org.in/node/3972
Rice variety	**Year of release/notification**	**Breeding institute**	**Characteristics**	**Recommended area**	**Source**
Shabhagidhan (IR 74371-70-1-1-CRR-1)	2011	CRRI	High drought tolerance and average productivity of 3.8–4.5 t/ha	Jharkhand and Odisha	https://crri.icar.gov.in/popular_var.pdf
Jayantidhan (CR Dhan 503)	2011	CRRI	Can tolerate up to one metre water stagnation	Coastal saline area of Odisha	https://crri.icar.gov.in/popular_var.pdf
Phalguni (CR Dhan 801)	2017	ICAR	Submergence and drought tolerant	Andhra Pradesh, Telangana, Odisha, Uttar Pradesh, West Bengal	https://crri.icar.gov.in/popular_var.pdf

Source ICAR-IARI (2018), NICRA (2018)

See Figs. 3.23 and 3.24.

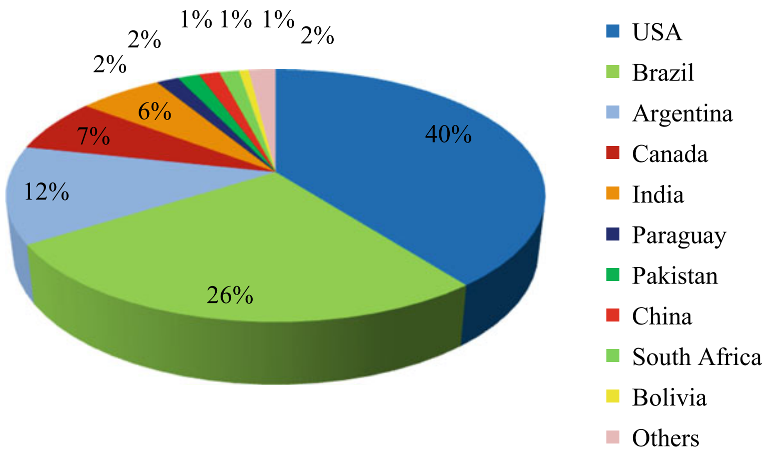

Fig. 3.23 Country-wise share of global area under biotech/GM crop. *Source* ISAAA (2017a, b, c)

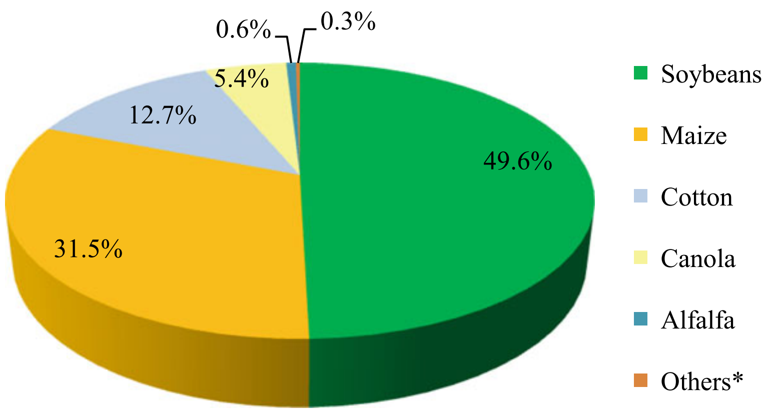

Fig. 3.24 Crop-wise share of global area under biotech/GM crops (total area under biotech/GM crops = 189.8 Mha). *Source* ISAAA (2017a, b, c). *Note* Others include biotech squash, potato, eggplant, papaya, sugar beet and apples

See Table 3.5

Table 3.5 List of agricultural centres of excellence under the Indo-Israel Agricultural Project (IIAP)

State	District	Produce
Bihar	Vaishali	Mango and litchi
	Nalanda	Vegetables
Gujarat	Junagadh	Mango
	Vadrad, Sabarkantha	Vegetable-protected cultivation
	Nani Reladi, Bhuj	Date and banana-palm post-harvest management
Haryana	Gharaunda, Karnal	Vegetables
	Mangiana	Fruits
	Kurukshetra	Beekeeping
	Hisar	Animal husbandry and milk
	Ladwa	Mango
	Hisar	Flowers
Karnataka	Kolar	Mango
	Bagalkot	Pomegranate
	Dharwad	Vegetables
Maharashtra	Dapoli	Alfonso mango
	Nagpur	Citrus
	Rahuri	Pomegranate
	Aurangabad	Kesar mango
Punjab	Ghanora and Hoshiarpur	Fruits
	Jalandhar	Vegetables
Rajasthan	Kota	Citrus
	Bassi	Pomegranate
	Jaisalmer	Date Palm
	Bassi	Vegetables
Tamil Nadu	Thally and Krishnagiri	Flowers
	Reddiyar Chathram, Dindigul	Vegetables
Uttar Pradesh	Basti	Vegetables
	Basti	Mango
	Kannauj	Vegetables

Source MASHAV (2016)

References

Ahuja, A. (2018, November 20). CropIn Technology raises $8 million from Chiratae Ventures, Gates Foundation. *The Mint*.

Aluf, D. (2014). *Indo-Israeli agricultural project (IIAP): Status report.* International Development Cooperation (Mashav) Science & Agriculture.

APEDA. (2016, March 10). *Poultry production in India—The current scenario.* Retrieved July 10, 2018, from APEDA Agri Exchange http://agriexchange.apeda.gov.in/news/NewsSearch.aspx?newsid=22055.

APEDA. (2017). Retrieved August 7, 2018, from Agricultural & Processed Food Products Export Development Authority, Ministry of Commerce and Industry, Government of India. http://apeda.gov.in/apedawebsite/six_head_product/FFV.htm.

APEDA. (2018). *India export statistics.* New Delhi: Agricultural Processing and Export Development Authority, Ministry of Commerce and Industry, Government of India.

ASTI. (2016). *Agricultural R&D indicators factsheet: India.* Agricultural Science and Technology Indicators (ASTI), IFPRI.

Ayyappan, S. (2005). *Indian fisheries and aquaculture: Present status and future prospects.* New Delhi: Indian Council of Agricultural Research (ICAR).

Ayyappan, S., Jena, J. K., Lakra, W. S., Srinivasa Gopal, T. K., Gopalakrishnan, A., Vass, K. K., et al. (2016). Fisheries Sciences. In R. B. Singh (Ed.), *100 years of agricultural sciences in India* (pp. 259–304). New Delhi: National Academy of Agricultural Sciences.

BAIF. (2015, January-March). *The BAIF Journal*, *39*(1).

BAHS. (2017). Department of Animal Husbandry and Dairying. DoAHD&F. Government of India.

Bandyopadhyay, T. (2016). *Bandhan: The making of a bank*. Gurugram, Haryana: Random House India.

Bhardwaj, K. K. (2014). A study of Indian Poultry Industry. *International Journal of Engineering Research & Management Technology (IJERMT)*, *1*(5).

Calderone, L. (2018, December 26). Growing with hydroponics, aeroponics and aquaponics. *AgriTech Tomorrow*.

CCI. (2016–17). *Cotton Corporation of India Limited*. Retrieved May 05, 2018, from www.cotcorp.org: https://cotcorp.org.in/.

Chadha, K. L. (2016). Horticultural sciences. In Singh, R. B. (Ed.), *Agricultural sciences in India* (p. 522). New Delhi: National Academy of Agricultural Sciences.

Chand, R., Kumar, P., & Kumar, S. (2012). Total factor productivity and returns to public investment on agricultural research in India. *Agricultural Economics Research Review, 25*(2), 181–194.

Chatterjee, S. (2018, December 15). Internet of things now a growing trend in India's agriculture. *Profit from IoT.com.*

Chopra, R. (1981). *Evolution of food policy in India.* Macmillan India Limited.

Chopra, R., & Sen, D. (2013). Golden wheat becomes more Golden—Extending SRI to wheat. *LEIS India 15*, *36*(3), 30–32.

Dairy India. (2017). New Delhi: P.R. Gupta.

Dalrymple, D. G. (1985). The development and adoption of high-yielding varieties of wheat and rice in developing countries. *American Journal of Agricultural Economics, 67*(5), 1067–1073.

Damodaran, H. (2017, August 16). How technology can deliver freedom from male calf. *The Indian Express*.

DCD. (2009). *Revolution in Indian cotton.* Nagpur: Directorate of Cotton Development, Ministry of Agriculture & Farmers' Welfare, Government of India.

DCD. (2017). *Status paper of Indian cotton.* Nagpur: Directorate of Cotton Development, Ministry of Agriculture and Farmers' Welfare, Government of India.

DoAC&FW. (2016a). *Agricultural statistics at a glance.* Ministry of Agriculture and Farmers' Welfare, Government of India, Department of Agriculture, Co-operation and Farmers' Welfare. New Delhi: Directorate of Economics & Statistics, Ministry of Agriculture & Farmers' Welfare, Government of India.

DoAC&FW. (2016b). *Impact evaluation & socio economic study of bt cotton.* Nagpur: Department of Agriculture Co-operation and Farmers' Welfare (DoAC&FW), Ministry of Agriculture and Farmers' Welfare (MoA&FW), Government of India.

DoAHD&F. (2017a). *Annual report 2016–17.* New Delhi: Department of Animal Husbandry, Dairying & Fisheries. Government of India.

DoAHD&F. (2017b). *Basic animal husbandry and fisheries statistics.* New Delhi: Ministry of Agriculture Co-operation and Farmers' Welfare (MoA&FW), Governmnet of India.

DoAHD&F. (2017c). *National action plan for egg & poultry—2022 for doubling farmers' income by 2022.* New Delhi: Department of Animal Husbandry, Dairying and Fisheries. Ministry of Agriculture Co-operation & Farmers' Welfare, Government of India.

DoAC&FW. (2017d). *National mission on sustainable agriculture—Operational guidelines.* New Delhi: Department of Agriculture Co-operation & Farmers' Welfare (DoAC&FW), Ministry of Agriculture, Government of India.

DoAC&FW. (2018). *Third advance estimates of production of foodgrains for 2017–18.* New Delhi: Agricultural Statistics Division, Ministry of Agriculture Co-operation & Farmers 'Welfare, Government of India.

Dubock, A. (2000, July). Golden rice: To combat vitamin a deficiency for public health. *Golden Rice Project.*

Emsley, A. (2006). *The Role of Trade in Genetic Stock in transmitting Avian Influenza.* Rome, Italy: FAO.

FAO. (2014). *National aquaculture sector overview: India.* Rome: Fisheries and Aquaculture Department, Food and Agriculture Organization of the United Nations.

FAO. (2018). *State of world fisheries and acquaculture 2018—Meeting the sustainable development goals.* Rome: FAO.

FAO, IFAD, UNICEF, WFP and WHO. (2018). *The state of food security and nutrition in the world.* Rome: FAO.

FAOSTAT. (2017). *FAO.* Retrieved May 29, 2018, from www.fao.org: http://www.fao.org/faostat/en/?#home.

FAOSTAT. (2018). Statistical Database. Food and Agriculture Organization of the United Nations. Rome.

FE Bureau. (2018, May 3). India's seafood exports up 13.7% in Apr-Jan. *The Financial Express.*

Ferroni, M., & Zhou, Y. (2018). Private agricultural R&D in India. In A. Gulati, M. Ferroni, & Y. Zhou (Eds.), *Supporting Indian farms the smart way* (pp. 269–392). New Delhi: Academic Foundation.

Frontline. (2003, March 5). Rejuvenating the poultry sector. *The Hindu*, pp. 1–14.

Fuglie, K. O. (2018). *International agricultural productivity dataset.* Washington D.C.: ERS USDA.

Ganguly, K., Gulati, A., & Braun, J. V. (2017). *Innovations spearheading the next transformations in India's agriculture.* Germany: Center for Development Research, University of Bonn.

Global Harvest Initiative. (2014). *GAP report—Measuring agricultural productivity growth in India.* Washington D.C.: Global Harvest Initiative.

GOI. (2003, October 1). *Speech by Former PM of India: Shri Atal Bihari Vajpayee.* Retrieved May 6, 2018, from Government of India: http://archivepmo.nic.in/abv/speech-details.php?nodeid=9249.

Gulati, A. (2009). Indian agriculture: Changing landscape. In *IAAE Conference* (pp. 1–20). Beijing, China.

Gulati, A. (2014). Grain of truth: The green revolution. *Agrikhalsa.*

Gulati, A. (2019a, June 10). From plate to plough: The farm-factory connect. *The Indian Express.*

Gulati, A. (2019b, June 24). From plate to plough: A farm question for Modi 2.0. *The Indian Express.*

Gulati, A., & Mohan, G. (2018). *Towards sustainable, productive and profitable agriculture: Case of rice and sugarcane.* New Delhi: Indian Council for Research on International Economic Relations (ICRIER) Working Paper No. 358.

Gulati, A., Ganguly, K., & Landes, M. R. (2008). *Toward contract farming in a changing agri-food system.* New Delhi: Researchgate.net.

Gulati, A., Sharma, P., Samantara, A., & Terway, P. (2018). *Agriculture extension system in India: Review of current status, trends and the way forward.* New Delhi: Indian Council For Research On International Economic Relations (ICRIER).

Gulati, A., & Terway, P. (2018). Impact of investments and subsidies. In A. Gulati, M. Ferroni, & Y. Zhou (Eds.), *Supporting Indian farms the smart way* (pp. 343–361). New Delhi: Academic Foundation.

Gutierrez, A. P., Ponti, L., Herren, H. R., Baumgärtner, J., & Kenmore, P. E. (2015). Deconstructing Indian cotton: Weather, yields and suicides. *Springer Berlin Heidelberg, 27(12).*

Handbook on Fisheries Statistics. (2018). Department of Fisheries. DoAHD&F. Government of India.

HarvestPlus. (2017). *India.* Retrieved October 21, 2018, from http://www.harvestplus.org: http://www.harvestplus.org/where-we-work/india.

Hellin, J., Vijesh, K. V., Erenstein, O., & Boeber, C. (2015). India's poultry revolution: Implications for its sustenance and the global poultry trade. *International Food and Agribusiness Management Review*, *18*(A).

iBAN. (2017). *Poultry: How farmers and entrepreneurs in India are developing the industry.* Retrieved October 30, 2018, from www.inclusivebusiness.net: https://www.inclusivebusiness.net/ib-voices/poultry-how-farmers-and-entrepreneurs-india-are-developing-industry.

ICAR-IARI. (2018). *National innovations in climate resilient agriculture.* Retrieved October 10, 2018, from www.nicra.iari.res.in: http://www.nicra.iari.res.in/achieve.html.

IFPRI. (2003). *Project on livestock industrialization.* FAO: Trade and Social-Health-Environment Impacts.

IFPRI. (2018). *Agricultural total factor productivity (TFP), 1991–2014: 2018 global food policy report.* Washington D.C.: IFPRI.

Indiastat. (2018). Database.

Innovative Farming Solutions. (2014, March 13). *Mangifera Indica (Mango).* Retrieved August 11, 2018, from http://richfarmerpoorfarmer.blogspot.com/2014/03/mangifera-indicamango.html.

IRRI. (2018). *Golden rice.* Retrieved March 13, 2019, from https://irri.org/golden-rice.

ISAAA. (2017a). *Global status of commercialized biotech/GM crops in 2017: Biotech crop adoption.* Ithaca, NY: ISAAA Brief No. 53.

ISAAA. (2017b). *Global status of commercialized biotech/GM crops in 2017: Biotech crop adoption surges as economic benefits accumulate in 22 years.* Ithaca, NY: ISAAA Brief No. 53.

ISAAA. (2017c, October). *India-Biotech country: Facts and trends.* Retrieved May 10, 2018, from isaaa.org: http://www.isaaa.org/resources/publications/biotech_country_facts_and_trends/download/Facts%20and%20Trends%20-%20India.pdf.

IWGSC. (2018, August 16). *The wheat code is finally cracked.* Retrieved October 30, 2018, from http://www.wheatgenome.org: http://www.wheatgenome.org/News/Press-releases/The-Wheat-Code-is-Finally-Cracked.

Johnson, B., Vijayaragavan, K., & Immanuelraj, T. K. (2015). Economic impacts of system of rice intensification (SRI) in India. *Green Farming, 6*(1), 168–171.

Katiha, P. K., & Pillai, N. K. (2004). *Evolution of fisheries and aquaculture in India.* Cochin: Central Marine Fisheries Research Institute (CMFRI), ICAR.

Kotaiah, T. (2016, March 10). *Poultry production in India—The current scenario.* Retrieved June 24, 2018, from http://www.fnbnews.com/Poultry/poultry-production-in-india-the-current-scenario-38620.

Kumar, T. (2014). *India and Israel: Reinforcing the partnership.* New Delhi: Observer Research Foundation.

Kumar, V. S. (2018, July 02). Seafood exports top $7-bn mark, frozen shrimp accounts for 69% of dollar earnings. *The Business Standard*.

Kumaran, M., Anand, P. R., Kumar, J. A., Ravisankar, T., Johnson, P., Vasagam, K. K., et al. (2017). Is Pacific white shrimp (*Penaeus vannamei*) farming in India technically efficient?—A comprehensive study. *Elsevier, 468*(1), 262–270.

Kurien, V. (2004). *India's milk revolution—Investing in rural producer organizations*. New Delhi: The Lotus Collection, an imprint of Roli Books Pvt. Limited.

Kurien, V. (2005). *I too had a dream*. New Delhi: Roli Books Pvt. Ltd.

Landes, M., Persaud, S., & Dyck, J. (2004). *India's poultry sector: Development and prospects*. USDA.

Laxmappa, B. (2015, May 06). Carp production in India: Present status and prospects. *The Acquaculturist*.

Lekshmi, N. M., Sreekanth, G. B., & Singh, N. P. (2014). *Composite fish culture in ponds*. Retrieved May 4, 2018, from krishi.icar.gov.in: https://krishi.icar.gov.in/jspui/bitstream/123456789/2706/1/Extension%20Folder%20No.%2069.pdf.

Lele, U., Agarwal, M., & Goswami, S. (2018). *Patterns of structural transformation and agricultural productivity growth*. Pune: Gokhale Institute of Politics and Economics (GIPE).

Maitra, R. (1991). How India became self-sufficient in food. In Hamerman, N. (Ed.), *Executive intelligence review (EIR)* (Vol. 18(27), pp. 22–30).

Manjula, K., & Saravanan, G. (2015). Poultry industry in india under globalised environment—Opportunities and challenges. *International Journal of Scientific Research, 4*(8), 391–393.

MASHAV. (2016). *The Indo-Israeli agricultural project*. New Delhi: Israel's Agency for International Development Cooperation.

Mazur, M. (2016, July 20). *Six ways drones are revolutionizing agriculture*. Retrieved March 22, 2019, from MIT Technology Review. https://www.technologyreview.com/s/601935/six-ways-drones-are-revolutionizing-agriculture/.

Mehta, R., Narrod, C. A., & Tiongco, M. M. (2008). *Livestock industrialization, trade and social-health-environment impacts in developing countries: A case of Indian poultry sector*. New Delhi: Research and Information System for Developing Countries.

MoA&FW. (2017, November 21). *Press information bureau, ministry of agriculture & farmers welfare, government of India*. Retrieved May 13, 2018, from http://www.pib.nic.in/newsite/mbErel.aspx?relid=173699.

Mohteshamuddin, K. (2017). Sexed semen technique: A revolution in Indian dairy industry. *Agrotechnology, 6(3)*. https://doi.org/10.4172/2168-9881.1000e117.

Mumtaz, S., Rahim, A., & Sharma, N. (2017, November 02). Sexed semen: An overview. *Pashu Sandesh*.

Murty, S. (1996). *Structural transformation of Indian economy*. New Delhi: Antlantic Publishers and Distributors.

Mustaquim, M. (2017, August 11). *Aeroponic technology: Revolutionising potato seed production*. Retrieved August 12, 2018, from Rural Marketing. https://www.ruralmarketing.in/industry/case-studies/aeroponic-technology-revolutionising-potato-seed-production.

NABI. (2018). *Biofortified coloured wheat*. Mohali: National Agri-Food Biotechnology Institute (NABI), Department of Biotechnology, GoI.

Nair, C. M., & Salin, K. R. (2007). *Carp polyculture in India: Practices, emerging trends*. New Delhi: Research Gate.

NDDB. (2017). *National Dairy Development Board*. Retrieved October 17, 2018, from www.nddb.coop: https://www.nddb.coop/about/genesis/flood.

NFBD. (2016). *About Indian fisheries*. Retrieved June 1, 2018, from National Fisheries Development Board: http://nfdb.gov.in/about-indian-fisheries.htm.

NHB. (2017). *Horticulture statistics at a glance*. New Delhi: Horticulture Statistics Division, Department of Agriculture and Farmers Welfare (DoAC&FW), Ministry of Agriculture and Farmers Welfare (MoA&FW), Government of India.

NHB. (2018). *Third advanced estimates*. New Delhi: National Horticulture Board, Government of India.

NICRA. (2018). *Research highlights (2016–18)*. Hyderabad: ICAR-Central Research Institute for Dryland Agriculture.

NITI Aayog. (2015). *Raising agricultural productivity and making farming remunerative for farmers*. New Delhi: National Institution for Transforming India (NITI) Aayog. Government of India.

NITI Aayog. (2018). *Discussion paper: National strategy for artificial intelligence*. New Delhi: NITI Aayog, Government of India.

OECD/ICRIER. (2018). *Agricultural policies in India*. Paris: OECD Publishing.

Pal, S. (2017). *Agricultural R&D policy in India: The funding, institutions and impact*. New Delhi: ICAR–National Institute of Agricultural Economics and Policy Research.

Press Trust of India. (2018, April 17). Govt to take call on Bt cotton issue after studying Delhi HC order. *The Times of India*.

Punjabi, M., & Mukherjee, A. (2015). *Supply chain for exports of dehydrated onions: Case study of jain irrigation systems limited in India*. Food and Agriculture Organisation (FAO) of the United Nations.

Rada, N. E. (2013). *Agricultural growth in India: Examining the post-green revolution transition*. USDA: Economic Research Service.

RBI. (2017–18). *Handbook of statistics on the Indian economy*. Mumbai: Reserve Bank of India.

Seetharaman, G. (2018, January 21). These two issues could put the brakes on the Bt cotton story. *The Economic Times*.

Sharma, S. N. (2019, June 01). Has India found the answer to two of its most pressing lifestyle problems? *The Economic Times*.

Sharma, S., Chunduri, V., Kumar, A., Kumar, R., Khare, P., Kondepudi, K. K., et al. (2018, April 4). Anthocyanin bio-fortified colored wheat: Nutritional and functional characterization. *PLoS ONE, 13*(4): e0194367, 1–16.

Shukla, P. K., & Nayak, S. (2016). *Evolution of poultry sector in india through policy and planning*. Dairying and Fisheries: Department of Animal Husbandry.

Singh, A. K., & Lakra, W. S. (2011). Risk and benefit assessment of alien fish species of the aquaculture and aquarium trade into India. *Reviews in Aquaculture, 3*(1), 3–18.

Singh, V., Singh, A. K., Mohapatra, T., Krishnan, G. S., & Ellur, R. K. (2018). Pusa Basmati 1121—a rice variety with exceptional kernel elongation and volume expansion after cooking. *Springer Open*, *11*(19). https://doi.org/10.1186/s12284-018-0213-6.

Swaminathan. (2007). *Agriculture cannot wait: New horizons in Indian agriculture* (Illustrated ed.). Gurugram: Academic Foundation.

The World Food Prize. (1987). *1987: Swaminathan*. Retrieved March 27, 2018, from www.worldfoodprize.org: https://www.worldfoodprize.org/en/laureates/19871999_laureates/1987_swaminathan/.

The World Food Prize. (1996a). Retrieved March 23, 2018, from www.worldfoodprize.org: https://www.worldfoodprize.org/index.cfm?nodeID=87486&audienceID=1.

The World Food Prize. (1996b). *1996: Beachell and Khush*. Retrieved March 23, 2018, from www.worldfoodprize.org: https://www.worldfoodprize.org/index.cfm?nodeID=87486&audienceID=1.

Tiwari, A. (1990, November 30). Poultry industry grows despite import policy problems, turbulent political situation. *India Today*.

Udikeri, S. S., Kranthi, K. R., Patil, S. B. & Khadi, B. M. *Emerging pests of Bt cotton and dynamics of insect pests in different events of Bt cotton*. Nagpur: University of Agricultural Sciences.

UNICEF. (2019, February). *Vitamin a deficiency*. Retrieved March 19, 2019, from UNICEF: https://data.unicef.org/topic/nutrition/vitamin-a-deficiency/.

USDA. (2018a). *International agricultural productivity*. Washington D.C.: Economic Research Service (ERS), USDA.

USDA. (2018b). *World agricultural production*. USA: Foreign Agricultural Service.

Vaishnavi, H. (2017, August 28). [Bootstrap heroes] How this startup produces 700 tonnes of fruits and vegetables without soil. *The Social Story*.

Verma, S., Gulati, A., & Hussain, S. (2017, March). Doubling agricultural growth in Uttar Pradesh: Sources and drivers of agricultural growth and policy lessons. *ICRIER Working Paper 335*.

World Bank. (2011). *Building tomorrow's markets: India banana case study*. World Bank: Unlocking the potential of the Indian Banana trade.

Zakir, S. (2008). *Management of contract farming in livestock: A case of poultry industry.*

Chapter 4
Innovations in Agricultural Technologies in China

4.1 Introduction

Since the founding of the People's Republic of China (PRC) in 1949, its agriculture has experienced roller-coaster development. After a short period of land reform and the successful implementation of the first "Five-Year Plan" in 1952–1957, China then moved to the Great Leap Forward in 1958–1960. However, this period coincided with a severe drought that led to the world's largest famine in 1959–1961. Agriculture started to recover between 1962 and the mid-1960s. Since then, ensuring food security has become the primary national development goal. However, the Cultural Revolution, which started in the mid-1960s and ended in the late 1970s, slowed economic as well as agricultural growth.

In contrast to the first three decades of the PRC, the past forty years of development and reform, initiated in 1978, have profoundly transformed both China's agricultural sector and rural areas (Huang and Rozelle 2018). The annual growth rate of agricultural GDP in real terms more than doubled from 2.2% in 1952–1978 to 4.5% in 1978–2018. While most previous studies have addressed the success of China's cereal grain production, the growth in cash crops, livestock and fishery sectors has been even faster (see Chap. 2).

While many factors have contributed to agricultural growth in the past few decades, technological change has been one of major sources of agricultural production growth and a primary source of agricultural productivity growth in the past (Fan 1997; Huang and Rozelle 1996; Jin et al. 2010). In contrast to many other developing countries where technologies have been imported from the rest of world, China developed indigenous technologies that have been adopted by its farmers. Compared with OECD countries, China's agricultural R&D expenditure intensity (the percentage of agricultural R&D in agricultural GDP) is comparatively low (about 1.23% in 2013),

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but expenditure has increased significantly recently. The growth rate of R&D expenditure in the private sector, which is much smaller than the public sector, has been high in the past decade and it has started to play an increasingly important role in agricultural innovations.[1] Chai et al. (2019) estimated that both public and private food and agricultural R&D expenditures on a purchasing power parity basis in China have exceeded those in the USA.

This chapter specifically documents major innovative technologies that have significantly increased agricultural production in the past and the promising new technologies that may affect China's agricultural productivity growth in the future. To do this, the next section focuses on the grain sector where the Green Revolution and modern breeding started in the 1960s. Section 5.3 presents the major innovations in cash crops with a focus on cotton and horticulture. Sections 5.4 and 5.5 present production and technological innovations in the livestock and fishery sectors respectively. Both sections discuss innovations in animal breeding and other major innovations that have substantially raised animal production in China. Although institutions and incentive policies are critical for innovations in both crop and animal technology and for farm technology adoption, these will be discussed in the other chapters of this book. Sections 5.6–5.8 introduce major technological developments in agricultural inputs, including irrigation, production and use of chemical fertilisers and farm machinery, respectively. It is worth noting that without technological innovations in agricultural inputs, the potential benefits promised by the modern varieties and other innovative technologies presented in Sects. 5.2 and 5.3 would not significantly increase the production levels of hundreds of millions of small farmers in China. Section 5.9 introduces some innovative farm practices that can facilitate sustainable and high-value agriculture, including both vertical (e.g. integrated crop-livestock production) and horizontal (e.g. rice–fish or shrimp culture) agricultural production systems that help farmers raise their income. Promising new technologies such as information and communication technology (ICT) and big data technologies that may significantly change agricultural production in the future are included in the last section.

4.2 From Green Revolution to Gene Revolution in Grain Production

The Green Revolution in Asia, which started in the 1960s, had dramatic impacts on rice and wheat economies. Modern varieties (MV) of rice, such as the short-statured, still-strawed and fertiliser-responsive Indica rice varieties exemplified by IR8, were first developed during 1962–1966 at IRRI (Chandler 1982) and released to farmers in 1966. By 1987, the MV adoption rates reached 32% in Bangladesh, 69% in India,

[1] However, it is worth noting that while China has generated most of its own agricultural technologies, there are pros and cons of agricultural technology innovation led by public sector. Increasing private agricultural R&D expenditure in the past decade is encouraging. Currently, China is reforming its agricultural innovation system to better integrate public and private R&D efforts.

76% in Indonesia and 85% in the Philippines (David and Ostuka 1994). The semi-dwarf wheat varieties developed by breeders led by Norman Borlaug in CIMMYT were also introduced to Asia in the 1960s. Based on the breeding materials from CIMMYT, the major varieties suitable for local production have been developed and commercialised since the late 1960s. The significant impacts of the Green Revolution in rice and wheat have been well documented in the literature (e.g. Barker and Herdt 1985; Dalrymple 1985; David and Ostuka 1994; Pingali and Heisey 1999; Estudillo et al. 2006).

While the Green Revolution was also experienced by China in the 1960s, the country is unique in its technology innovation. Unlike the Green Revolution in South and Southeast Asian countries, which was based on the technologies generated by IRRI and CIMMYT, China's Green Revolution was based on the country's own technologies. For example, in the rice sector, in addition to the nature of semi-dwarf or dwarf varieties, the revolution was accompanied by the introduction of hybrid rice. From the Green Revolution to the more recent Gene Revolution, most technologies adopted by Chinese farmers have come from the public R&D system. This section discusses the major technology innovations in rice, wheat, maize, cotton and horticulture. We start from the production trend of each commodity in the past few decades and try to link its changing trends with each of the major technological development that took place since the sixties.

4.2.1 Trends in Grain Production

During[2] the first 30 years since the start of the People's Republic of China in 1949, grain production increased nearly three times with an average annual growth rate of about 3.6%, but this growth was uneven (Fig. 4.1). In 1949, the total population was 542 million and grain production was 113 million metric tonnes (MMT). After eight years of fast recovery in production after the end of the civil war, grain production reached 198 MMT in 1958, an increase of 75% (compared with a 22% increase in population). The most significant growth during this period occurred in rice and sweet potato production, which accounted for 38 and 27% of the total increase in grain production respectively. However, grain production fell significantly during 1959 and 1961, which resulted in the "Great Famine" that caused at least 30 million deaths (Ma 2012). "Taking Grain as the Key Link" to ensure grain security at the expense of cash crops (or all crops except grain) became the key national agricultural policy thereafter.

The high growth of grain production in the 1960s and 1970s was largely due to productivity (or yield) gains from the Green Revolution, which is discussed in detail in the following sub-sections. Of course, this high growth would not have been possible without a huge investment in irrigation and fertilisers (Zhao 2016).

[2]In China, grain includes rice, wheat, maize, other cereals, beans (mainly soybeans), sweet potato and potato.

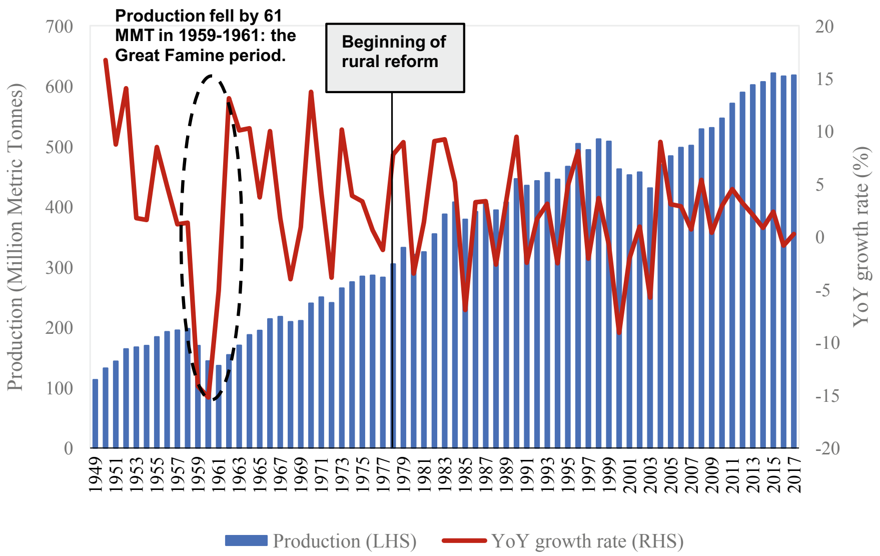

Fig. 4.1 Grain production and growth rate in China, 1949–2017. *Sources* National Statistical Bureau, China Compendium of Agricultural Statistics (1949–2008); National Bureau of Statistics of China, China Statistical Yearbook (2009–2016) and Statistical Bulletin of China National Economic and Social development (2017)

Rising productivity has been a major source of production growth in grain since reforms started in late 1978. Technology change, together with institutional reform and incentive policies, which will be discussed in Chaps. 6 and 8, raised grain production to a peak level in 1998, leading to an oversupply of grain and the accumulation of huge government grain stocks. An adjustment was made to reduce grain production and raise the production of other crops during 1998–2003. By 2004, grain production fell to its lowest level since 1990 (Fig. 4.1). As the level of government grain stocks was low by this time, China moved to becoming an importer of grain, mainly soybean. While not shown in Fig. 4.1, it is worth noting that all growth in grain production has come from an increase in yield, as the area under grain has fallen since the late 1970s. In 2017, grain production was 618 MMT, which was more than twice that in 1978 (Fig. 4.1).

4.2.2 *Technology Innovations in Rice Production*

Trends in Rice Production

Rice is the most important food crop in China's agricultural economy. While its area has been gradually falling after reaching its peak in the late 1970s, production has continued to rise in the past four decades (Fig. 4.2). Moreover, rice comprised 40% of calorie intake in China before the mid-1990s (Huang and Rozelle 1996), though its share has fallen slightly in recent periods. The rise in rice production in China

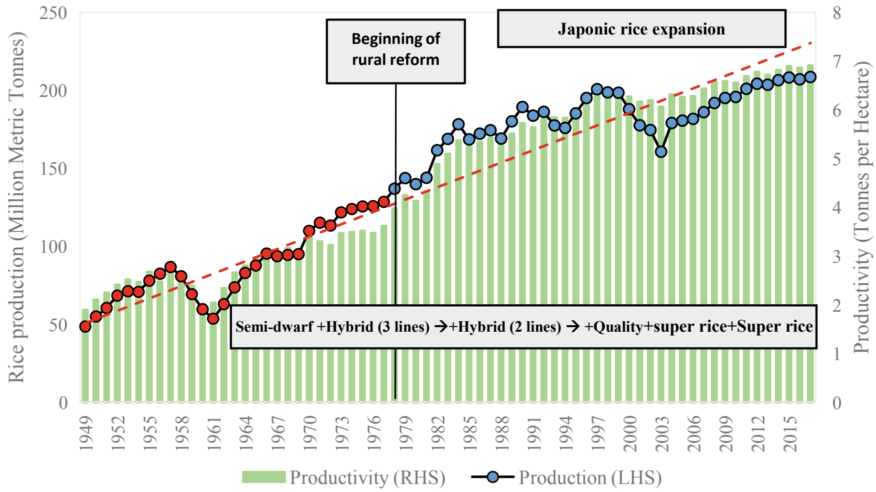

Fig. 4.2 Rice production and land productivity in China, 1949–2017. *Sources* National Statistical Bureau, China Compendium of Agricultural Statistics (1949–2008); National Bureau of Statistics of China, China Statistical Yearbook (2009–2016) and Statistical Bulletin of China National Economic and Social development (2017)

during the 1960s and 1980s is one of the most successful stories in science and technology and policymaking. Several factors contributed to the sharp increase in production (Huang and Rozelle 2018; Fan 1991). Technological changes, increasing availability of water, inorganic fertiliser and other farm chemicals have kept rice production growth exceeding population growth. Institutional change also stimulated production, particularly in the early reform period of 1979–94 (Lin 1992, Huang and Rozelle 1996).

Yield increase has been the central goal of the rice research and technology policy. China developed and extended its first fertiliser-responsive, semi-dwarf rice varieties in the early 1960s before the rest of the developing world had been introduced to Green Revolution technology, which significantly raised rice yields in the 1960s and 1970s (Fig. 4.2). A more remarkable achievement is the development and release of hybrid rice since the 1970s. By the early 1980s, more than 98% of China's rice area was planted with improved varieties (both conventional high-yielding varieties and hybrid rice cultivars) (Huang and Rozelle 1996). Disease-resistant varieties have been developed and extended since the late 1970s. Since early this century, China's rice breeding programme has moved to a stage where the key focus is on both yield and food quality. In addition, China has led R&D efforts in genetically modified (GM) rice, though the commercialisation of this technology is still facing challenges.

Hybrid Rice Since the 1970s

One of the largest breakthroughs in rice yield is the development of hybrid rice. With the successful development of semi-dwarf modern rice varieties in the early 1960s, China's rice breeders also began hybrid development in 1964 using a three-line system. Breeders led by Longping Yuan started to search for male sterile materials using wide crossing. In 1970, a rice researcher in Longping Yuan's team identified the critical rice germplasm for three-line hybrid rice—wild abortive (WA) male sterile rice—on China's Hainan Island, providing a new opportunity for the successful exploitation of rice heterosis (Li 1977).

Since 1976, China has been promoting the use of F1 hybrid rice varieties, which carry a potential 15–20% yield advantage over other modern high-yielding varieties, by farmers. But in the early 1980s, China's hybrid rice faced a number of challenges such as poor disease resistance, a single WA male sterile cytoplasm, uniform growth duration (single- and late-cropping), and low seed production yield that discouraged widespread adoption. However, hybrid rice breeders developed and released new rice hybrids to replace the first-generation, single-cropping indica hybrids. Wei-You 64, in particular, showed high-yield potential and resistance to five major rice diseases and insect pests (Yuan and Virmani 1988). The release of the new rice hybrids and the substantial increase in seed production significantly contributed to the rapid expansion of hybrid rice acreage. The area under hybrid rice expanded rapidly from 4.3 million ha in 1978 and 6.7 million ha in 1983 to 15.9 million ha in 1990, accounting for 41% of the rice-sown area (Huang and Rozelle 1996); additionally, more than half of rice and nearly all indica rice were hybrid rice by the mid-1990s.

China progressed from the three-line to the two-line hybrid rice system in the years since 1986. In 1973, Shi Mingsong discovered the source material Nong-ken 58s for the two-line system male sterile line in rice in Hubei, China (Shi 1981). From 1982 to 1986, many rice researchers studied the plant physiology, biochemistry and genetics of Nong-Ken 58s, previously dubbed "natural dual-purpose male sterile lines" and later known as Hubei photoperiod-sensitive genic male sterile rice (HPGMR). In 1987, Yuan proposed a strategy for the two-line system hybrid rice breeding using EGMS (environment-conditioned genic male sterility) materials, including Nong-Ken 58s (Yuan 1987).

The acreage grown under two-line hybrid rice increased significantly at the turn of the new millennium. In 2002, the total area under two-line hybrid rice reached 2.8 million ha, about 18% of the total hybrid rice acreage (Yuan 2004a, b; Cheng et al. 2005). In 2008, the commercial two-line hybrids occupied 3.3 million ha in China, about 11% of the total rice acreage and 22% of China's hybrid rice acreage. In terms of regional distribution, PGMS lines were mainly distributed in the Yangzte River Basin and the more northern regions that had varied day length across different seasons. Thermosensitive genic male sterile (TGMS) (thermosensitive genic male sterile) lines were mainly used in South China where day length differences were smaller (Lu et al. 1998).

Empirical studies highlight the significant role of hybrid rice in increasing yields. For example, Lin and Pingali (1994) reported that hybrid rice had about a 15% yield advantage over conventional inbred rice varieties at the farm level. He and Flinn (1989) found that the higher yields and profitability of hybrid rice were largely due to technical innovation. Huang and Rozelle (1996) also confirm that hybrid rice was one of the most important sources of rice yield increases in the past.

Japonic Rice Since the 1990s

The increasing demand for high-quality rice has a significant effect on rice production by region and the type of rice (e.g., indica and japonica) (Huang et al. 2002a). The area given over to rice production expanded rapidly in North China, a major japonica production area. North China's share of rice-sown area grew from less than 6% before the 1980s to 10% in 1990 and 14% in 2000. With the development of new japonica rice varieties, rice can be planted not only in northern China, but also along the Yangtze River Basin. Several provinces in the lower Yangtze River Basin, such as Jiangsu, Zhejiang, Shanghai and Anhui, became major japonica rice producers. Rising rice production in North China (and shifting rice production from indica to japonica cultivars in the Yangtze River Basin) has raised the share of japonica rice area from 11% in 1980 to 16% in 1990 and 27% in 2000 (Huang et al. 2002b). We estimate that japonica production has exceeded one-third of China's total rice production since 2015.

China has also tried to develop its hybrid japonica rice. Hybrid japonica rice has demonstrated strong heterosis. For example, Chang-You 1, a japonica rice hybrid, yields an average of 12.1 t/ha. The two-line system provides the opportunity to further increase the heterosis level of japonica hybrid rice and China's total rice production. In addition, there is still potential to develop superior three-line system japonica hybrid rice. For example, three-line japonica rice hybrids, such as Liao-You 5218 and Liao-You 1052, demonstrate high-yield potential (Qi et al. 2007). Challenges to further expanding the use of japonica hybrid rice in China include its relatively poor grain quality and limited disease resistance, seed production capabilities and adaptability.

Super Rice After 2000

While hybrid rice has raised yield significantly, yields of various crop varieties hit a ceiling in China during the 1990s (Cheng et al. 2004; Yang et al. 2006). To enhance the yield potential of Chinese rice further, the "super rice" breeding programme was initiated in the mid-1990s to break the yield plateau. Based on the experiences of high-yield rice breeding in China and new plant-type rice (super rice) breeding at the International Rice Research Institute (IRRI), a special collaborative research programme on super rice breeding was established by the Ministry of Agriculture (MOA), China, in 1996. The programme mainly focuses on the breeding of super hybrid rice, which is defined as the varietal type that combines harmonious plant types with heterosis and achieves super high yield through hybridisation between indica and japonica (Cheng et al. 1998). In 1996, China's MOA established yield targets for this programme (Table 4.1) (Yuan 2003, 2008). In 1998, Professor Longping Yuan proposed a strategy for developing super hybrid rice using heterosis combined with the ideotype approach in order to further increase the yield potential of hybrid rice (Yuan 2001).

Table 4.1 Yield standards (t/ha) set for China's "super hybrid rice" programme

Phase	Hybrid rice			Yield increase per cent
	Early season	Late season	Single season	
1996	7.50	7.50	8.25	0
Phase I (1996–2000)	9.75	9.75	10.50	>25
Phase II (2001–2005)	11.25	11.25	12.00	>45
Phase III (2006–2015)	NA	NA	13.50	>60

Notes It is required that grain yield should be up to standards in two consecutive years and at two locations, each location with more than 6.67 ha

Over the past 20 years, significant progress has been made in breeding super hybrid rice (Cheng et al. 2007; Peng et al. 2008; Wu 2009; Yuan et al. 2017). Through the work of Chinese rice scientists, the Phase I objective (10.5 t/ha) was achieved in 2000 and the Phase II objective (12 t/ha) was achieved in 2004, with yield increases of 25% and 45%, respectively, over the best hybrid checks before 1996. The Phase II three-line hybrid Ming-You 8 (Fujian province) and two-line hybrid P88s/0293 yielded more than 12 t/ha in Fujian province and Hunan province respectively, surpassing the Phase II yield target (Yuan et al. 2004). By 2005, China's MOA had released 34 super hybrids to production, which included 27 three-line hybrids represented by Xieyou 9308, and seven two-line hybrids represented by Liangyou Pei 9. It is estimated that all of these super hybrids were planted in a total area of 13.5 million ha during 1998–2005 (Cheng et al. 2007). Currently, 94 cultivars have been approved as super hybrid rice by MOA, China (China Rice Data Center 2018). Super hybrid rice accounted for nearly 8% of the total rice area in recent years (Huang and Zou 2018). Super hybrid rice cultivars have increased rice yield potential by more than 10% compared with ordinary hybrid cultivars (Zhang et al. 2009; Huang et al. 2011a), and this increase is likely to grow with the development of new super hybrid rice cultivars (Huang et al. 2017a).

GM Rice Since 2000s

To meet growing food demand, China has been looking at all potential measures that could increase agricultural production in more sustainable ways. Biotech is considered by national leaders as one of the major tools that could boost China's agricultural productivity and ensure national food security (Huang et al. 2002a). After China initiated its agricultural biotech programme in the mid-1980s, public investment was doubled within every four years during the late 1990s and the mid-2000s (Huang et al. 2002a, 2005). Since 2008, Chinese R&D on genetically modified (GM) crops and animals was increased by $3.8 billion of new funding from the National GM Variety Development Special Programme (GMSP) for the period of 2008–2020. By 2010, there were more than 13,000 researchers working on agricultural biotech, including GM plants, animals and microorganisms.

GM rice varieties have been ready for use by farmers since 2009 although they have not yet been approved for commercial production. China issued a production safety certificate for GM Xianyou 63 in 2009. This GM rice was created to be resistant to rice stem borers and leafrollers by the insertion of a Chinese-created Bacillus thuringiensis (Bt) gene. Unlike Bt cotton, which is used for industrial purposes, Bt rice, if commercialised, would be the first GM commercial staple food crop in China and in the world.

Huang et al. (2005) assessed the productivity and health effects of two insect-resistant Bt rice varieties that were in farm-level production trials in China. Their study showed that cultivated Bt rice, when compared to non-Bt rice, raised rice yield and significantly reduced pesticide use. Moreover, Bt rice also contributed to the improved health of farmers by reducing the probability of farmers suffering pesticide-related incidence of morbidity during the crop-growing season. The model simulations further show that the economy-wide impacts of Bt rice are substantial. Huang et al. (2004) had estimated the annual gain from Bt rice would touch $4.1 billion in 2010.

However, the growing debate on the safety of GM food has largely changed consumers' attitudes towards GM food in China. An increasing number of urban consumers perceive GM food as being unsafe for consumption; the numbers increased by more than 30% in the period 2002–2012 (Huang and Peng 2015). Major shifts occurred after 2010, a year after China issued the biosafety certificate for the production of Bt rice and Phytase maize. Public concerns about GM food obviously affected China's policy on commercialising GM technology after the late 2000s.

Given the significant socioeconomic effects of GM technologies, in recent years China has reemphasised the role of biotech in ensuring the nation's food security. National leaders have decided on a three-step development strategy: moving from non-food (e.g. fibre) to indirect food (e.g. feed) and finally to direct food (e.g. rice and wheat). Under this new strategy, China is expected to commercialise its GM maize in the near future, but it may be some time before GM is commercialised.

Quality Enhancement Since the Early 2010s

Prior to the 1980s, China sought to generate more food by increasing the quantity of rice production. This explains why the early-stage hybrid rice generally showed high yields but poor grain quality. As China moved from a low-income to middle-income society, demand for high-quality rice increased. The goal of the breeding programme started to shift to improving the quality of rice without sacrificing yield. Because of this breeding effort, China developed and released several widely used high-quality male sterile lines and hybrids, which have significantly improved the quality of hybrid rice in recent years.

Innovations in Seedlings Since the Early 2010s

Issues have arisen over the production of hybrid rice, not only in relation to quality, but also because of the costs of seedlings due to rising wages. In recent years, remarkable advances have been made in improving seed sowing machines. For example, the South China Agricultural University has invented a precision hill-drop drilling machine for direct-seeded rice production (Luo et al. 2008), and the Hunan Agricultural University has developed a mechanical single-seed sowing system for single-seedling machine-transplanted rice. It is reported that 30–75% of rice seeds can be saved by adopting these machines, and the age of seedlings can be prolonged by 7–10 days for machine-transplanted rice due to increased room for seedling growth.

Innovative uses of Foreign Germplasms

The introduction and use of foreign germplasms has played an important role in the improvement of crop varieties in China. While China does not often directly release foreign rice varieties to farmers, the germplasms from the International Rice Research Institute (IRRI) and from Japan have contributed 16.4 and 11.2% of genetic materials to China's major rice varieties during 1982 and 2011, respectively (Shi and Hu 2017). This study also shows that IRRI's materials contributed to the improvement of yield potential, growth duration, and blast and bacterial blight resistance, while Japan's materials contributed to the improvement of grain quality. Materials from other countries contributed to the improvement of resistance to diseases and insects, particularly to rice blast disease, brown plant hoppers, white-backed plant hoppers and striped stem borers.

4.2.3 Technology Innovations in Wheat Production

Trend of Wheat Production

China has the world's second-largest wheat area after India and is the world's top wheat producer. In 2016–2017, China's harvested wheat area (24 million ha) accounted for about 11% of the global wheat area, but China accounted for more than 17% (or 130 MMT) of global wheat production.[3] The national average wheat yield reached 5.41 tonnes per ha (t/ha) in 2017, well above the global average (3.45 t/ha). Within China, wheat is the second most important food crop after rice and the third most important crop overall, after maize and rice. Despite the area under wheat decreasing by 18% during 1978–2017 (NBSC 2018), yield gains resulted in a 141% increase in production over the same period (Fig. 4.3), moving China from a major wheat importer (average annual imports of 11.5 million tonnes; about 13% of domestic consumption) in the 1980s, to a net exporter by 2001. Since the early 2000s, China's wheat production has supplied from 98 to 102% of domestic demand.

Compared with rice production (Fig. 4.2), wheat production has grown even faster (Fig. 4.3). Wheat production in China has grown steadily throughout the last seven decades, especially after 1978 when rural reform started, except for a short period of stagnation from the late 1990s to the mid-2000s. In the early reform period (1978–85), wheat production increased nearly 60%. Wheat production growth slowed during 1985–97, compared to the early reform period, but was still a brisk 3.2%. Annual

[3] According to statistics from IGC (International Grains Council) (available at: http://www.igc.int/en/default.aspx), the estimated global wheat production t was 752 MMT in 2016–17.

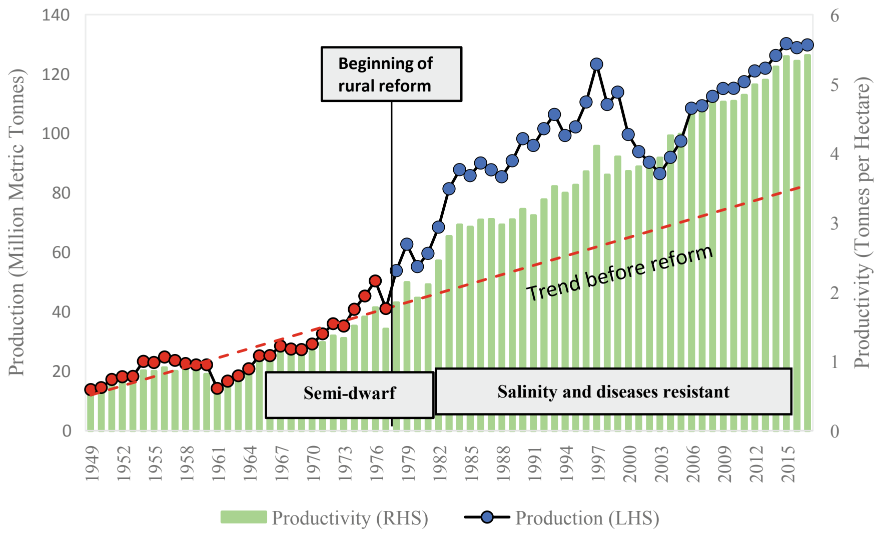

Fig. 4.3 Wheat production and land productivity in China, 1949–2017. *Sources* National Statistical Bureau, China Compendium of Agricultural Statistics (1949–2008); National Bureau of Statistics of China, China Statistical Yearbook (2009–2016) and Statistical Bulletin of China National Economic and Social development (2017)

wheat imports fell from about 15 million tonnes in the late 1980s to nearly nothing in the late 1990s, by which time there was oversupply of wheat in China (NBSC 1990–2000). The resulting expansion in domestic wheat stocks caused wheat prices to fall (Sonntag et al. 2005) and discouraged farmers from growing the crop, largely explaining the diminished wheat area and yields during the late 1990s and early 2000s (Fig. 4.3). After falling during 1998–2003, wheat production has resumed its steady growth despite a continuous reduction in the area under wheat since 2004.

Expanded wheat production has come mainly from yield growth (Fig. 4.3), which has been the central goal of policies on technology and investment for wheat and other crops. While progress in modern technology to raise productivity in wheat is similar to rice, wheat yield has increased faster than rice yield mainly due to shifting wheat production from less to more favourable areas and the expansion of irrigation for wheat production. Like in the case of rice, wheat farmers have benefitted from rapid and continual technical advancements since the Green Revolution started in China in the 1960s.

Modern Varieties

After the nationwide selection of high-yielding varieties planted by farmers in the 1950s and 1960s, Chinese wheat breeders have been developing semi-dwarf varieties since the late 1960s. Based on the successful experience of rice dwarf breeding, in the 1970s, the wheat-breeding programme reduced plant height by about 10 cm and shortened the growth period by 3–5 days. These varieties also incorporated breeding materials with rust resistance from other countries and improved wheat yield. By 1977, farmers were growing semi-dwarf wheat on about 40% of China's wheat area; by 1984, this number rose to 70% (Rozelle and Huang 2000) and, from the 1990s, it would have been difficult to find anything other than improved semi-dwarf varieties in China. As in the case of rice semi-dwarf varieties, these varieties have significantly raised wheat yield in China since the 1970s (Fig. 4.3).

After the early 1980s, a large number of modern and high-yield wheat varieties have been developed and grown in China. On average, wheat farmers grew 295 major varieties each year during 1982–2011 (Table 4.2). For the 16 provinces studied, the average number of major wheat varieties adopted annually by farmers was 24.

Exotic germplasms have also significantly contributed to China's wheat-breeding programme. While most of the wheat varieties that came to market and were rapidly adopted by farmers had been developed by Chinese wheat breeders, China has also intensively and increasingly used germplasm from CIMMYT and foreign countries (Huang et al. 2015), which has enhanced the performance of China's wheat in terms of yield potential, grain processing quality, disease resistance and early maturity.

Resistance to Diseases and Salinity

In China, wheat stripe rust is one of the most destructive diseases in wheat production and can cause severe yield losses when susceptible cultivars are grown, and weather conditions are favourable to the spread of the diseases. Wheat stripe rust most frequently affects the winter wheat-growing areas in northwest, southwest and north China, and the spring wheat-growing areas in northwest China (Wan et al. 2007; Chen et al. 2009). In this regard, in addition to high yield, the other major goal of wheat breeding was to breed disease-resistant and salinity-resistant varieties. The selection and breeding programme on high-resistance varieties started in the 1950s and was enhanced after 1980.

Table 4.2 Average annual numbers of major wheat varieties adopted by farmers and the varietal turnover, China, 1982–2011

Period	Average annual number of varieties	Average annual number of varieties per province	Varietal turnover[a]
1982–1986	251	20	0.30
1987–1991	296	24	0.24
1992–1996	263	22	0.27
1997–2001	304	24	0.33
2002–2006	296	23	0.30
2007–2011	363	31	0.27
1982–2011	295	24	0.28

Source Huang et al. (2015). The Impact of CIMMYT Wheat Germplasm on Wheat Productivity in China. CIMMYT, Mexico

Note The total number of major varieties from 16 provinces is 1873

[a]It ranges from zero (no new variety replacement) to 1 (all existing varieties were replaced by new varieties within one year)

Quality Improvement

In the past two decades, in addition to the original high yield, disease resistance, precocity and lodging resistance, China's wheat-breeding target has also started to raise wheat quality. In the field of disease-resistance breeding, it has changed from original single resistance to comprehensive multi-resistance. Like the demand for better quality rice, demand for quality and special wheat has been increasing with rise in income. In response to this demand, the opportunity to breed varieties of better quality and develop special uses of wheat has improved significantly. Adoption of these varieties has largely replaced the import of quality wheat since the early 2000s.

Promising Technologies: Hybrid Wheat and Biotech Wheat

In recent years, Chinese scientists have demonstrated significant advances in technological development and genetic engineering to improve traits such as drought tolerance, resistance to pests and diseases, specific aspects of grain quality and so on. A few projects have already led to field-trial applications. In accordance with widely used methods elsewhere, wheat transformation in China utilised mainly micro-particle bombardment, which is relatively genotype-independent and is able to introduce DNA directly into various tissues for transient gene expression studies (Rogers 1991; Altpeter et al. 1996; Vasil 2007). This method is now routine in many laboratories in China, and the transformation efficiency can reach as high as 10%.

While Chinese scientists began work on GM wheat in the late 1980s, a significant effort was made only after 2008 when China initiated the National GM Variety Development Special Programme (GMSP). Wheat is one of eight agricultural commodities under the programme. New lines on resistances to major diseases, insects, drought and salinity, as well as those with improved quality and nutrition, have been developed. Many lines have passed small field trials and are now at the stage of experimentation of environmental release.[4] The field experiment data show the yield advantage of GM wheat ranges from 10 to 15%. Although it is not expected that GM will be commercialised within a short time period, the technology does promise new tools to further raise wheat productivity in China in the future.

4.2.4 Technology Innovations in Maize Production

Trend of Maize Production

While maize used to be the third largest crop in China, it has become the largest crop since the late 2000s. In an early period, maize was used as both feed and food. Overtime, the share of maize used as feed has increased due to the rapid expansion of the livestock sector. Nowadays, maize is primarily used as feed. An increasing amount of maize is also used in processing. The increase in production has been substantial

[4]The four stages in the Chinese regulatory framework for GM crops are laboratory research, confined field tests, environmental release, and product demonstration and commercialization. The environmental release of a GM crop is important to identify potential adverse effects and stop the release into the environment.

over the past six decades though the annual increase has been much higher since rural reform (Fig. 4.4). Both yield and area have been increasing: major growth in production came from the rapid rise in maize yield (Fig. 4.4). During 1978–2017, maize yield more than doubled (2.17 times), area under maize increased by 77%, and production increased 2.85 times (Fig. 4.4). Technological innovation, institutional change, marketing policy and agricultural inputs all contributed to the growth in maize production. This chapter focuses on major innovative technologies in maize. We use hybrid maize and insect-resistant GM maize as examples to illustrate the roles played by innovative technologies that have raised maize yield in the past (e.g. hybrid maize) and are likely to do so in the future (e.g. GM maize).

Hybrid Maize Varieties

In the past six decades, Chinese maize breeders have used many outstanding inbred lines to breed many varieties of high-yield hybrid maize. The development of inbred lines initially occurred in the 1950s; in the following years, top-cross hybrids and double-cross hybrids were developed. By 1966, China released the single-cross hybrid maize for commercial production (Li 1998). Since then, many high-yield hybrid maize varieties have been developed. In the 1980s, maize farmers used more than 100 major hybrid varieties each year. This number increased to 200 in the late 1990s and nearly 1000 recently (Ministry of Agriculture (MOA) 1982–2015 2016). It is reported that nearly all maize varieties were hybrids by the middle 2000s (Bennetzen and Hake 2009). Currently, the most popular varieties adopted by farmers are Zhengdan-958 and Xianyu-335.

The genetic gain for Chinese single-cross maize hybrids has primarily been achieved by increasing yield per plant (Wang et al. 2011). The most widely used

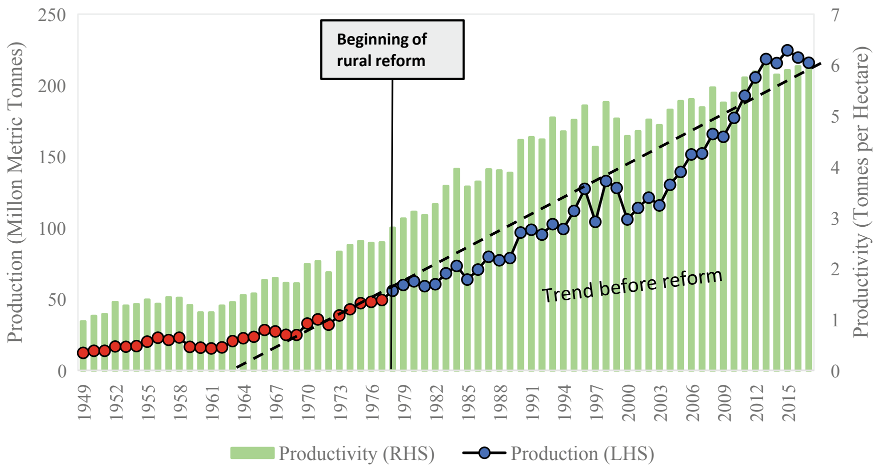

Fig. 4.4 Maize production and land productivity in China, 1949–2017. *Sources* National Statistical Bureau, China Compendium of Agricultural Statistics (1949–2008); National Bureau of Statistics of China, China Statistical Yearbook (2009–2016) and Statistical Bulletin of China National Economic and Social development (2017)

planting densities in China for maize today are: 52,500–60,000 plants per ha for spring maize regions, 60,000–67,500 plants per ha for the summer maize regions and 37,500–45,000 plants per ha for the Southwest region (Wang et al. 2011). However, a planting density of 60,000 plants per ha is still approximately only 80% of the density that is routinely used today on farms in the central Corn Belt of the USA. Improving the tolerance of Chinese hybrid maize to higher planting densities through further plant breeding could be an efficient future strategy to accelerate genetic gain and so increase the productivity of maize in China.

Promising Tech: GM Maize

Research in China on genetically modified maize began in the late 1980s and was significantly enhanced by the national GM Special Programme (GMSP) launched in 2008. The GMSP is directed towards five major crops (rice, wheat, maize, cotton and soybean) and three livestock sectors (pig, cattle and sheep). In addition to the phytase maize that was given the safety certificate for production in 2009, several new GM maize varieties have also been under environmental release or production field-trial stages. These include the varieties that have the traits with resistance to insect and herbicide developed by the public and private sectors in China. In 2019, China finally issued a biosafety certificate for insect-resistant maize. While a commercialisation decision has not been made, it is expected that farmers will be able to use this new technology in the coming years.

The potential economic gains from GM maize are substantial (Xie et al. 2017). If China decides to commercialise insect-resistant GM maize, the annual increase in maize production from GM maize will range from 5.6 MT (2.4%) to 18.1 MT (7.7%) by 2025 (Xie et al. 2017). The possible reduction in price following increased production will also help reduce livestock feed prices and, by improving the profitability of livestock production, encourage an increase in its output.

In addition, the land saved because of GM maize adoption will allow the expansion of area under other crops.

4.3 Technology Innovations in Cash Crops

In this section, we use cotton and vegetables as examples of cash crops and discuss major innovative technologies used by farmers to increase cash productivity. Cotton represents crops the area under which has declined significantly in recent years because they are less profitable vis-à-vis other cash crops. Without innovative Bt cotton to raise productivity, cotton production would have fallen more in recent years. Vegetables are much more profitable products, with both the area under and yield of vegetables having increased significantly.

4.3.1 Trends in Cotton Production

There was substantial increase in cotton production in China until the late 2000s, although it was subject to large variations in production over the past six decades (Fig. 4.5). Before the mid-1960s, as in the case of grain, cotton production recovered rapidly after the end of the civil war in 1949 and experienced a U-shape trend in the late 1950s and early 1960s (from "the Great Famine" to the recovery period). In contrast to grain crops, production and yield grew much slower during the Cultural Revolution (1966–1976) because of the national policy of "taking grain as the key link" to ensure food security, as mentioned earlier. During the initial reform period, cotton production increased from 2.17 MMT in 1978 to 6.26 MMT in 1984 (Fig. 4.5). The exceptionally high outputs in 1983–1984 were due to both area expansion and good weather conditions. By the mid-1980s, production and yield fell to a normal level.

However, after the late 1980s, with the emergence of a pesticide-resistant bollworm population, cotton yield and production stagnated and even fell for about ten years (Fig. 4.5). By the late 1990s, the bollworm problem has become so severe that farmers in the North China Plain and the middle and lower reaches of the Yangtze River, two of three major cotton production regions in China, would not have been able to continue cotton production if Bt cotton varieties had not been approved for commercial production in 1997. Bt cotton helped farmers to expand cotton area and

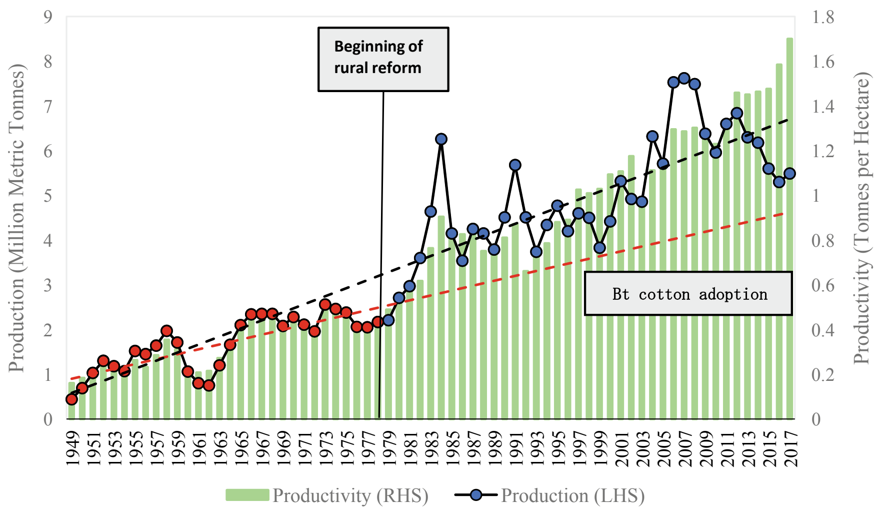

Fig. 4.5 Cotton production and land productivity in China, 1949–2017. *Sources* National Statistical Bureau, China Compendium of Agricultural Statistics (1949–2008); National Bureau of Statistics of China, China Statistical Yearbook (2009–2016) and Statistical Bulletin of China National Economic and Social development (2017)

is associated with significant yield increases and reduction in pesticide use (Huang et al. 2002b; Pray et al. 2001).

The recent fall in cotton production has been mainly due to the shifting of cotton production to other crops due to rising wages (cotton is the most labour-intensive crop in harvesting). Indeed, cotton yield has continued to grow rapidly since the late 2000s when cotton production fell significantly (Fig. 4.5).

4.3.2 Innovative Bt Cotton Technology

In response to rising pesticide use and the emergence of a pesticide-resistant bollworm population in the late 1980s, China's scientists began research on GM cotton, launching the nation's most successful experience with GM crops. Starting with a gene isolated from the bacteria, *Bacillus thuringiensis* (Bt), China's scientists modified the cotton plant using an artificially synthesised gene that was identified with sequencing techniques. Field testing began in the early 1990s. When the area under cotton declined due to pest losses in the mid-1990s, the commercial use of GM cotton was approved in 1997. During the same year, Bt cotton varieties from publicly funded research institutes and from a Monsanto joint venture (with the US seed company Delta and Pine Land and the Hebei Provincial Seed company) became available to farmers (Huang et al. 2002a, b). The release of Bt cotton began China's first large-scale commercial experience with a product of the nation's biotechnology research programme.

Bt cotton is one of the most successful cases of GM technologies in China. After its commercialisation in 1997, about 7.1 million small farmers had adopted Bt cotton by 2009, and now Bt cotton accounts for more than 85% of the total cotton area in China. Empirical studies show that the impact of Bt cotton has been impressive. On average, Bt cotton increased cotton yield by 9.6%, reduced pesticide use by 34 kg/ha, reduced labour input by 41 days/ha, and, despite higher seed costs, net profit increased by 1857 RBM (or about USD225) per hectare in major cotton producing regions in 1999–2000 (Huang et al. 2002a, b, 2003; Pray et al. 2001). Model simulations show that the economy-wide impacts of Bt cotton are substantial, and the annual gain in economic welfare from Bt cotton would reach USD1.1 billion in 2010 (Huang et al. 2004).

4.3.3 Trend in Vegetable Production

The production of vegetables has experienced a sharp increase since reform started in 1978. This helped largely diversify China's crop economy and raised farmers' income. The area under vegetables increased rapidly from 2.06 million ha in 1978 to 22.33 million ha in 2016 (Fig. 4.6). While production data before the mid-1990s are not available, the data for the last two decades show that both yield increase

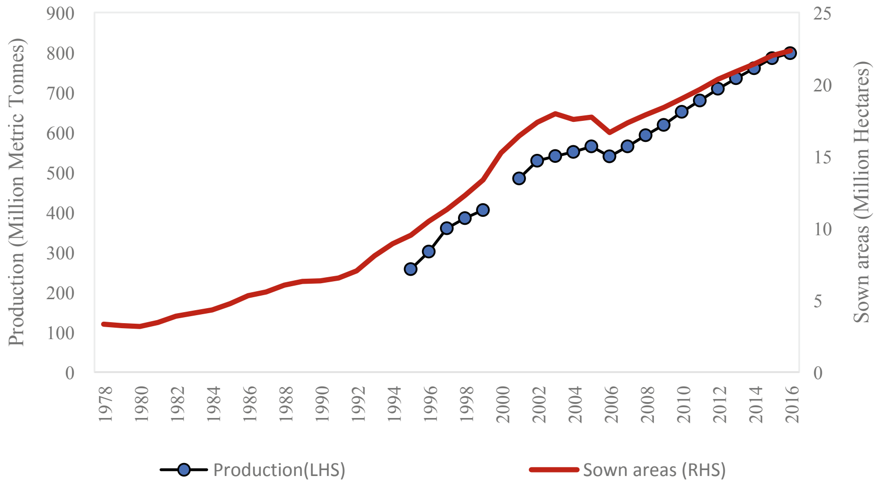

Fig. 4.6 Vegetable area, yield and production in China, 1949–2016. *Sources* National Statistical Bureau, China Compendium of Agricultural Statistics (1949–2008); National Bureau of Statistics of China, China Statistical Yearbook (2009–2016) and Statistical Bulletin of China National Economic and Social development (2017). *Note* Data before 1978 are not available

and area expansion have contributed to the growth in vegetable production since the mid-1990s (Fig. 4.6).

It is worth noting that the increase in yield and production of vegetables presented in Fig. 4.6 are part of the story of the rising vegetable sector in China. The increasing number of new vegetable varieties adopted by farmers has also improved the quality of nutrition over time. For example, Chinese cabbage (large quantity and low price) was the single or the most dominant vegetable in Northern China during the whole winter season before 1990, but now consumers in Northern China eat all types of vegetables produced in China in all seasons.

4.3.4 *Innovative Greenhouse Vegetable Production*

The rising demand for vegetables has resulted not only in a rapid expansion of open-field vegetable production but also rapid development of greenhouse technology for millions of small farmers in China, particularly in northern China. In contrast to the modern and expensive greenhouses in developed countries, where greenhouses are made of steel frame, plastic or glass walls and ceilings, and which often require energy-using heating and cooling systems, most of the greenhouses that have been developed in China are simpler and cost effective. This kind of greenhouse was first developed by farmers in Shandong province in the early 1980s. It is made of a simple bamboo frame with a clay wall, plastic-sheet roof, and a straw mat roll-out awning for cold nights. The sun warms the interior and the greenhouse is built with an orientation to maximise sunlight capture. These greenhouses have changed not only the food consumption pattern for hundreds of millions of consumers, but also vegetable farming in northern China. The vegetable greenhouse area in China reached 981,000 ha in 2016. The construction cost of this kind of greenhouse is about four dollars per square metre. This is much cheaper than modern greenhouses made of glass or plastic, which cost about 70 dollars per square metre to construct (Wang et al. 2013).

Greenhouse vegetable production differs from open-field vegetable production in the following three major ways: (1) per hectare, greenhouses allow for much greater production than open-field. Wang et al. (2013) reported that the tomato yield is about 180 tonnes/ha annually in a greenhouse compared to about 30 tonnes/ha in an open field. This high yield is due to a longer growing season, multiple harvests, and intensive production. (2) The greenhouse production season lasts for nine months during the fall and the spring, while open-field production lasts for only about three months during the summer in northern China. (3) Greenhouse vegetables are often transported to distant markets, while vegetables from the open field are usually used for local consumption.

4.4 Technology Innovations in Livestock Production

Over the past 70 years, livestock production has expanded substantially. The shortage of animal products had led China to implement the meat coupon ration for urban citizens before the 1980s. Now, per capita consumption of meat and egg in China exceeds the world average. In 2016, total meat production, including pork, beef, mutton, poultry and other meat, reached 85.4 MMT in China, while he per capita meat consumption was 62 kg in 2016 (NBSC 2018). Over time, the structure of livestock production has been shifting from a dominance of pork to one where other types of meat are gaining prevalence. By 2016, pork accounted for 62.1% of total meats, while poultry, beef and mutton accounted for 22.1%, 8.4% and 5.4%, respectively, in 2016 (NBSC 2018).

4.4.1 Trends in Red Meat Production

The production of red meat, including pork, beef and mutton, increased almost 30 times between 1949 and 2016 (Fig. 4.7). During the "Great Famine" between 1959 and 1961, meat production fell to its lowest level. While production expanded in the 1960s and 1970s, significant growth occurred only after the reform started in 1978. The biggest growth in 1979 was largely due to an increase from a low production base in 1978, while the significant "fall" in production in 1996 (−13%) reflected the official adjustment of livestock production data due to the over-reporting of livestock production in previous years (Ma et al. 2004). The growth of meat production has

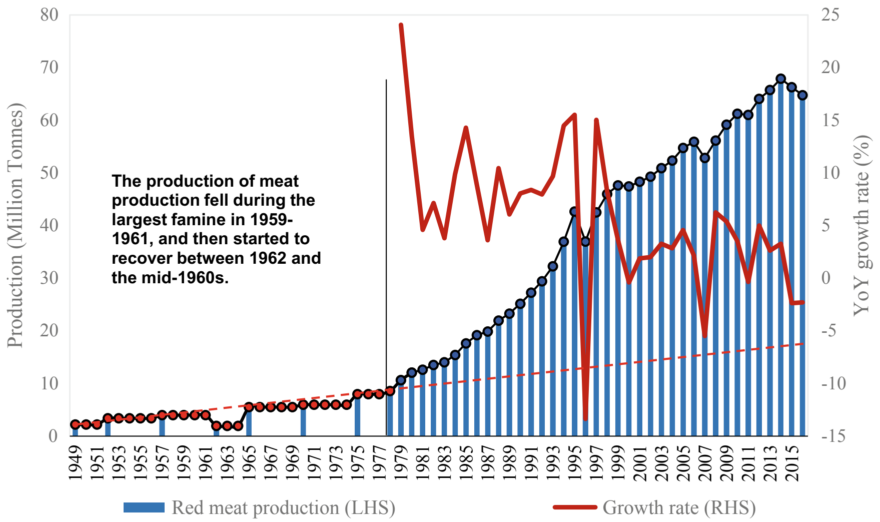

Fig. 4.7 Trend of red meat (pork, beef and mutton) production (million metric tonnes) in China, 1949–2016. *Source* Data are from the National Bureau of Statistics of China (1949–2016)

been driven by both the expansion of herd numbers and technology changes (e.g. animal breeding, nutritious feed and management).

4.4.2 Technology Innovations in Pork Production

Pork production has experienced a significant increase since 1980. In fewer than four decades, production increased by more than five times (Fig. 4.8). Except in the years 1996, 2007, 2015 and 2016, pork production has increased steadily over time. Like the overall trend in red meat production (Fig. 4.7), a sudden "fall" in production in 1996 was due to a statistical adjustment to correct for over-reporting meat production (Ma et al. 2004). The decreases in production in 2007 and 2015–2016 were mainly caused by a fall in the price ratio of pork to feed.

Varieties of Pig Breeds and Stock Breeding

China is the country with the most indigenous pig breeds in the world and has an advantage in breeding various pigs for commercialisation in different regions across the country. China has also successfully introduced foreign pigs and used exotic genetic resources of pigs in stock breeding. The major breeds of pigs include Large Yorkshire, Landrace, Duroc, Pietrain and Segher pigs. These have largely adapted to the ecological conditions found in different regions of China, and this laid a good foundation for carrying out genetic improvement of pigs over the past few decades. The improved pig breeds and varieties normally have the following characteristics:

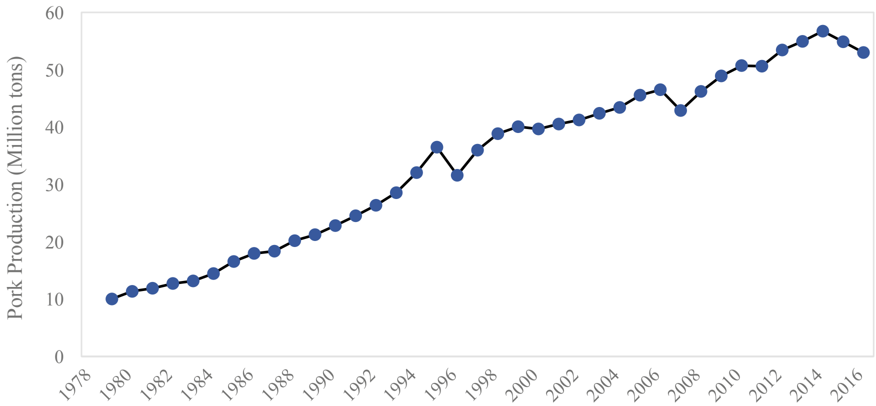

Fig. 4.8 Pork production (million metric tonnes) in China, 1978–2016. *Source* Data are from National Bureau of Statistics of China (1978–2016). Data before 1979 are not available

higher adaptability, faster growth, higher feed conversion rate and better meat quality, which has facilitated the growth of pig production and improved the quality of pork.[5]

Since 1978, China has established approximately 4.5 million large boar-breeding farms.[6] The discovery of various molecular genetic markers and the rapid development of modern breeding programmes have provided new approaches and methods for the improvement of animal genetics and breeding (Yang and Jiang 2018). Artificial insemination has been expanded continually and has covered more than 85% in recent years. The success rate of artificial insemination ranges from 85 to 95%.

Nutritious Feeding

The management of nutritious feeding improves the health of pigs so that it can benefit breeding quality and decrease the risk of epidemic diseases (Xu 2018). Because geographic and production conditions differ across regions, since 2004 national standards of pig feed have been established, which streamlines and eases the provision of technological consultancies to pig farmers. The energy feed usually includes maize and wheat bran. The protein feed includes soybean meal, rapeseed meal and fish meal. The mineral feed usually includes salt, stone powder and calcium phosphate for nutrient intakes of calcium, phosphorus, sodium, chlorine, iron, copper and selenium. The present daily ration is a mix of those feeds with vitamins and microelements, which tends to create a more precise feed according to the requirements of different pigs (Sun et al. 2015).

Productivity Gains

The rise in productivity due to technological change is reflected in the following indicators (MOA 2016). First, the feed conversion rate for fattening pigs decreased

[5] http://www.chinaswine.org.cn/piaofu/hxc/jh.php.

[6] http://www.chinaswine.org.cn.

from about more than 4.0:1 in the 1990s to less than 3.0:1 in recent years. Second, the stocking rate of pigs increased from 54% in 1978 to 132% in 2008. Third, the carcass weight increased from 57 kg in 1980 to 77 kg in 2008. Fourth, the period required for fattening pigs fell from about 300 days in 1978 to fewer than 180 days.

4.4.3 Technology Innovations in Poultry Production

Poultry production has increased even faster than pig production. It increased from 1.6 MMT in 1985 to 18.9 MMT in 2016 (Fig. 4.9). Production has continued to increase rapidly, except for a fall in 1996 (statistical data adjustment), stagnant growth during 2001–2003 and a fall in 2013–2014 due to the outbreak of influenza in humans.

The Chinese poultry industry has gradually established a complete breeding system for superior species. This system has attained a number of scientific and technological achievements, especially in chick breeding, feeding management, nutrition, disease prevention and control, product processing, etc. (Wang 2018).

Among various major technologies, it is important to take note of poultry-breeding equipment and environmental control technologies. These include widely used technologies such as nipple-drinking water technology, automatic-feeding technology, wet-curtain evaporation and cooling technology, big-air blower and longitudinal ventilation technology, welfare and healthy-breeding technology and so on. (Shen et al. 2012). In the 1980s, the representative technologies included simple and energy-saving open-type chicken houses and egg-laying cages and natural ventilation technology by using ground windows, to a large extent to meet environmental regulations that mandated energy-saving and provide a technical basis for large-scale chicken-farm production. In the 1990s, innovative research on longitudinal ventilation and

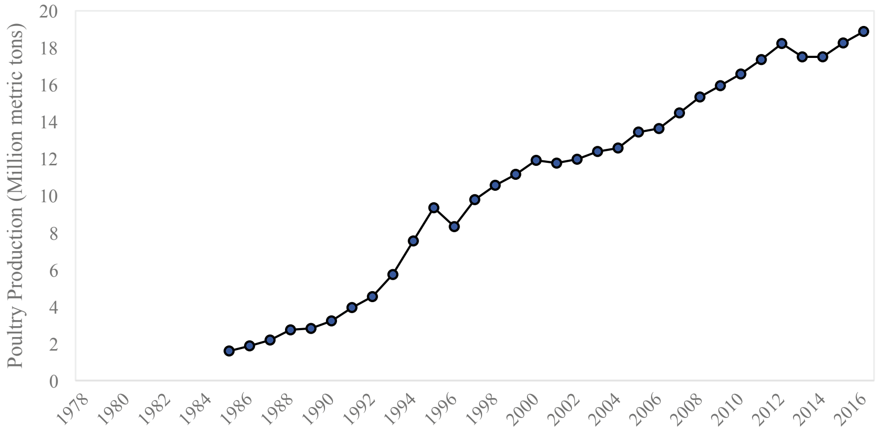

Fig. 4.9 Poultry meat production in China, 1978–2016. *Source* Data are from the National Bureau of Statistics of China (1978–2016). Data before 1985 are not available

wet-curtain cooling technology was used for building a new type of chicken house, which solved the problem of dead angle in horizontal ventilation and summer heat stress, and created a town house for chickens. In the twenty-first century, poultry breeding has also ushered in a new development stage, with the goal of improving animal welfare and animal product quality. A new technology system and modern facilities of housing have been developed and used for free-range chickens. Recently, the feed conversion rate has reached 2:1 on large-scale chicken farms.

4.5 Technology Innovations in Fishery Production

4.5.1 Trend in Fishery Production

The Chinese fishery sector plays an important role in rural livelihoods and agricultural development. During the years 1949–1978, fishery was a minor sector within agriculture (Fig. 4.10). After thirty years of growth, production was only 465 MMT in 1978. During the initial rural reform period between 1979 and 1984, an increasing number of commercial fish production bases were developed with government support across the country (Chen 1998). As a result, fishery production went up to 619 MMT in 1984. Under the influence of "The Instructions on Relaxing Policies to Accelerate the Development of the Fishery Industry" issued by the Central Government in 1985 and the "Vegetable Basket Project" (that includes fish) initiated in 1988, fishery production increased about 10 times from 705 MMT in 1985 to 6938 MMT in 2017 with an annual growth rate of 7.8% (Fig. 4.10) (Chen 1998; NBSC 2009, 2018).

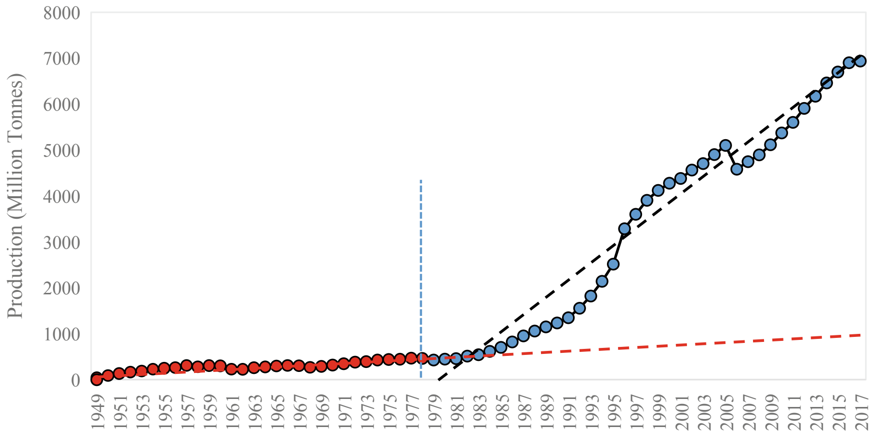

Fig. 4.10 Fishery production in China, 1949–2017. *Sources* China Compendium of Agricultural Statistics (1949–2008); National Bureau of Statistics of China (2009–2016) and Statistical bulletin of China national economic and social development (2017)

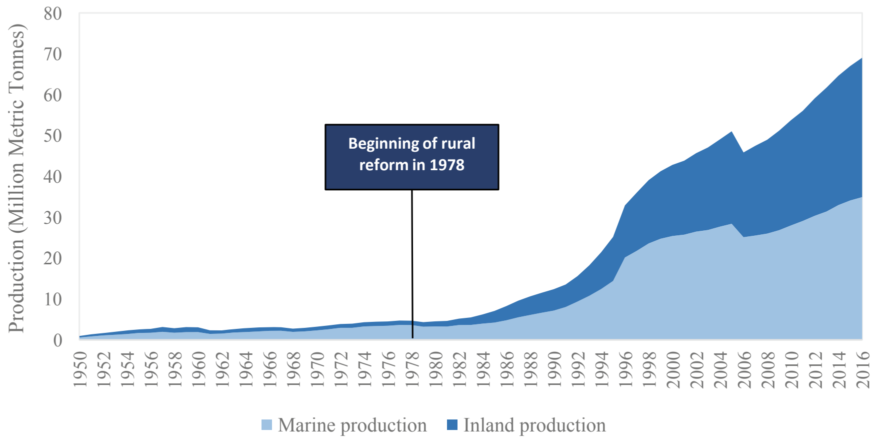

Fig. 4.11 Marine and inland fishery production in China, 1950–2016. *Sources* see Fig. 4.10

China's fishery production comes from both inland and marine production (Fig. 4.11). The 18,000-km long winding continental coastline and 3 million square km of jurisdictional sea areas with more than 20,000 species of marine life have helped the vigorous development of Chinese marine fisheries (MOA 2010). Since China's rural reform launched in 1978, marine fishing has increased rapidly. The output of marine fishery products soared nearly 10 times, from 359 MMT in 1978 to 3490 MMT in 2016 (Fig. 4.11). China also has vast inland water areas of approximately 0.2 million square km with more than 1050 species of fish. Both institutional and technical innovation, introduced by a series of policies in 1978, promoted the fast-paced development of inland fishery. According to official statistics, inland fishery production increased dramatically from 106 MMT in 1978 to 3411 MMT in 2016 at an average annual growth rate of 9.5%, higher than that of marine fishery (6.3%), and its relative contribution to total fishery production went up from 23% to nearly 50% over the same period (Fig. 4.11).

In terms of the production pattern, fishery production can be divided into two types—capture and aquaculture. From the 1950s to the 1980s, capture (increasing from less than 1 MMT in 1950 to 6.3 MMT in 1990) was greater than aquaculture production (which increased from a small amount of production to 6.1 MMT over the same period) (Fig. 4.12). In the 1990s, as coastal regions overemphasised the development of marine fishing, overfishing became a problem. Consequently, marine fishery resources deteriorated over time, and this threatened the sustainable development of the Chinese fishery industry (MOA 2010). This resulted in efforts by the Chinese government to adjust the structure of the fishing industry to increase production through aquaculture. From 1993 onwards, output from aquaculture increased (from 9.5 MMT in 1993 to 53.8 MMT in 2017), exceeding that of capture production which has remained nearly constant at about 16 MMT during the past two decades (Fig. 4.12). Over time, the share of aquaculture in total fishery production has gone up

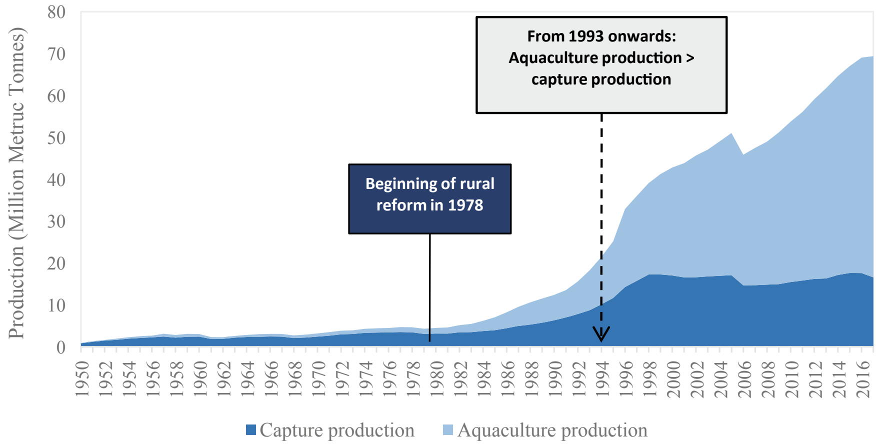

Fig. 4.12 Capture and aquaculture production in China, 1950–2017. *Sources* see Fig. 4.10

from 8% in 1950 to 76% in 2017, while the relative contribution of capture fisheries fell from 92 to 24%.

The rapid growth of fishery production has led China to be an important exporter. Exports increased from less than US$1 billion (<0.5 MMT) before the late 1970s to US$9.74 billion (3.06 MMT) in 2007 (Xu and Xu 2008; Ma 2008). From 2002, China, accounting for about 10% of total world fishery exports, was the largest fishery exporter for six consecutive years (MOA 2010). In 2017, aquatic product exports reached an all-time high of 4.34 MMT with a total value of US$ 21.15 billion (Chen 2018).

4.5.2 Innovations in Marine Fishing and Marine Culture

Sea-Farming System

Since the reforms in 1978, the development of a sea-farming system in China has been impressive. The breeding of seashell and shrimp has become one of the pillar industries in coastal regions. In the mid-1980s, the government proposed a strategy of "Revive Fishery" for sea farming to protect fishery resources and achieve the sustainable development of the marine economy. It enabled technical innovation to enter a new stage. For instance, China has successively overcome the technical difficulties in artificial breeding and culture of prawn, sea fish, sea cucumber and ormer, among others. In addition, China has developed various new breeding methods such as shallow-sea-raft breeding, three-dimensional breeding and so on, which are based on modern biotechnology such as cell engineering technology, genetic-breeding technology and sex-control technology. The output from the sea-farming system increased from 0.45 MMT in 1978 (with 0.10 million hectares of sea-farming area) to 14.16 MMT in 2006 (with 1.77 million hectares of sea-farming area) as a result in technological improvements.

Distant-Water Fishing

Since the mid-1980s, a major achievement of the Chinese fishing industry has been distant-water fishing. In March 1985, the first Chinese distant-water fishery fleet successfully entered the fishing grounds of West Africa in the Atlantic Ocean; within twenty years, China has become one of the most important distant-water fishing countries in the world. By 2008, the annual production of the distant-water fishing industry exceeded 1 MMT (NBSC 2009). Key fishing areas, including the sea areas of neighbouring countries in the South China Sea, traditional distant-water fishing areas in West Africa, the sea areas of island countries in the Pacific Ocean and Indian Ocean, and sea areas on the high seas, have been established. In 2010, there were more than 90 enterprises involved in distant-water fishing, with more than 1700 distant-water fishing vessels (MOA 2010).

Deep-Water Cage Culture

In 1998, deep-water cage culture was introduced from abroad to Hainan Province in China, and was quickly popularised in coastal provinces and cities. The first "HDPE circular double-floating over-and-under type anti-wave deep-water cage" with Chinese intellectual property rights was invented and developed in 2001. Its fishing yield can reach 14 kg per m^3 water (Guo 2006). The frame of the anti-wave deep-water cage is made of high-density polythene plastic. The mesh wire is made of new high-strength nylon. The mesh panel is produced by a computer-controlled super mesh machine and treated with anti-adhesion coating and uviol-resistant technology. It features high-tech materials, high automation level and strong anti-wave ability, and safe production can be assured in open water or in seasons with frequent typhoons. In addition, the fish are basically disease-free, so that antibiotic and other drugs are not required in order to guarantee high-quality products. The anti-wave deep-water cage culture has been considered as the direction of future fishery development by many developed countries in the world (MOA 2010). By the end of 2004, there were more than 2300 deep-water cages with 2.99 million m^3 aquaculture water and about 0.05 MMT theoretical yield in the country (Guo 2006).

4.5.3 Innovations in Fresh Water Pisciculture and Fishing/Capture

Due to the scattered distribution of fishermen in rural areas, the development of fresh water pisciculture in China was in small-scale breeding areas. In order to increase the competitive power of aquaculture in agriculture and the food processing industry, China as adopted new concepts and technologies to increase the output and quality of fishing production. In the mid-2000s, **high-standard pond-breeding**

technologies were introduced and promoted in China. Using a high-standard, fine-breeding method, the pond bottom is transformed into the shape of a pot bottom and the drain outlet is built at the centre of the pond. The dirt settles at the central drain outlet through the natural circulation of pond water and is discharged from the pond through drainage pipes by water pressure. This new breeding method has changed traditional fishery breeding practices in aspects of investment, production, management and so on. Nevertheless, there is no fixed breeding standard, and the most suitable operational method for developing pond-breeding across the whole country has yet to be established (MOA 2010).

In recent years, many other new innovative technologies have helped develop Chinese aquaculture. Some of these include the following.

(a) **Green and Healthy Pond Aquaculture** focuses on the research and application of mechanisation, intelligent management and digitalisation for highly efficient regional breeding projects.
(b) **Intensive Pond Aquaculture (IPA)** is a type of high-yielding and intensive fish culture technology. More specifically, fish are cultivated in a closed water tank with water-pushing equipment at its front and a dirt-suction device at its tail end. At present, ten aquatic species have been bred using IPA in China (Gu et al. 2016).
(c) **Paddy Field Fish Culture** is an integrated aquaculture method. During the past few years, many new integrated rice–fish aquaculture methods focusing on high-valued aquatic species have been adopted; this has resulted in significant economic, social and ecological benefits. The most popular breeding methods are the crayfish–rice co-culture and the turtle–crayfish–fish–rice aquaculture (Ma et al. 2016).

4.5.4 Moving to More Sustainable Technologies

Breeding technology plays a vital role in the Chinese fishery industry. The following describe further innovations that have recently been made in newly developing breeding technologies.

Aquatic Multi-trait Integrated Breeding Technology is an important selective breeding technology to improve multiple economic traits of aquatic animals in China. Its development was based on the introduction of the BLUP technique into the aquatic-animal breeding system in the mid-1990s (Luan et al. 2014).

Bio-flocs Technology (BFT) is an emerging technique of enhancing water quality by adding a carbon source to balance the content of carbon and nitrogen in water. The heterotrophic microorganisms in aquatic water can form bio-flocs under controlled conditions. These bio-flocs (including bacteria, organic matters, protozoa and algae) can improve water quality, save feed and strengthen the immune system of fish, which in turn, will increase fish production (Luo 2013).

Fish Sex-Control Breeding Technology, or monosex production, has become one of the most popular technologies in fish genetic breeding in China. As many fish species show apparent sex dimorphism in growth rate and body sizes, sex control in the cultivation of these species is quite important (Zhang 2012). Applying the gynogenesis technique, hormone sex reversal technique, hybridisation technique, marker-assisted selection (MAS) technique and many other genetic-breeding techniques, fish sex-control breeding increased the economic outcome of fishing by selecting the sex of the fish (Liu 1997).

Moreover, the concept of "Green Development" has been integrated into the national strategy for sustainable development of the fishery industry in China. Future innovation in technologies for harmoniously integrated and organic aquaculture will focus on industrial upgrading and precision production. More environmentally and ecologically friendly breeding techniques will be applied in Chinese aquaculture in the near future. Digital and Internet technologies in particular are expected to play an important role in aquaculture. Aiming at different breeding species, scales and methods, these innovative aquatic technologies will make full use of modern sensing technology, wireless network technology, intelligent control technology, big data technology and artificial intelligence technology to facilitate the construction of precision-breeding systems and service platforms in both marine and inland fishery production (Chen 2017). Furthermore, recreational fishery will be promoted, based on the industrial convergence of fishery and tourism (Chen 2017).

4.6 Innovations in Irrigation Technologies

The growing shortage of water for agricultural production has alarmed China. The per capital availability of water in China are less than 2100 m^3, only about one-fourth of the global average (Wang and Mei 2017). In addition, the regional distribution of water resources is extremely unbalanced; specifically, water resources in the north are poor while the water resources in the south are rich. Thus, increasing overexploitation of groundwater and land degradation is widespread in northern China (MWR 2016). Moreover, urbanisation and industrialisation have competed for water use. Therefore, China has given top priority to the development of agricultural water-saving irrigation technology. So far, various types of water-saving irrigation technologies such as canal-lining, low-pressure pipe irrigation, sprinkler, micro-irrigation and mulching have been developed and adopted and have significantly improved irrigation efficiency.

4.6.1 Trends in Irrigation–Adoption of Different Engineering Technologies

China has a long history of developing agricultural water-saving techniques. As Liu et al. (2011) point out, after the founding of the People's Republic of China in 1949, the Ministry of Water Conservancy (or the Ministry of Water Resources) together with the Ministry of Agriculture conducted research and development on agricultural water-saving technologies. To facilitate the adoptions of these technologies, China has also established water-saving demonstration counties with financial support from the government. Recently, increasing attention has been paid to popularising agricultural water-saving technologies (Table 4.3). Of the total cultivated area, the share of irrigated area rose from 45.6 to 54.2% during 2000 and 2016. Moreover, irrigated area with water-saving technologies accounted for a quarter of the cultivated area in 2016, while this number was less than 13% in 2000. Furthermore, the main water-saving technologies in China, such as sprinkler, micro-irrigation, low-pressure pipe irrigation, canal-lining and other water-saving engineering technologies, have also been increasingly adopted in the past two decades.

Table 4.3 Water-saving irrigated area (million ha) in China, 2000–2016

Year	Cultivated area	Irrigated land area	Water-saving irrigation with engineering technologies					
			Total	Sprinkler	Micro-irrigation	Low-pressure pipe irrigation	Canal lining	Others
2000	130.04	59.34	16.39	2.13	0.15	3.57	6.36	4.18
2001	130.04	60.03	17.45	2.36	0.22	3.90	6.93	4.04
2002	130.04	60.75	18.63	2.47	0.28	4.16	7.57	4.15
2003	130.04	61.06	19.44	2.63	0.37	4.48	8.07	3.89
2004	130.04	61.51	20.35	2.67	0.48	4.71	8.56	3.92
2005	130.04	61.90	21.34	2.75	0.62	4.99	9.13	3.85
2006	130.04	62.56	22.43	2.82	0.75	5.26	9.59	3.99
2007	130.04	63.41	23.49	2.88	0.98	5.57	10.06	4.00
2008	121.72	64.12	24.44	2.82	1.25	5.87	10.45	4.04
2009	121.72	65.16	25.76	2.93	1.67	6.25	11.17	3.74
2010	121.72	66.35	27.31	3.03	2.12	6.68	11.58	3.91
2011	121.72	67.74	29.18	3.18	2.61	7.13	12.18	4.08
2012	121.72	67.78	31.22	3.37	3.23	7.53	12.82	4.26
2013	121.72	69.48	27.11	2.99	3.86	7.42	12.84	
2014	135.00	70.65	29.02	3.16	4.68	8.27	12.90	
2015	135.00	72.06	31.06	3.75	5.26	8.91	13.14	
2016	134.90	73.18	32.85	4.10	5.85	9.45	13.44	

Sources National Bureau of Statistics of China. 2001–2017. China Statistical Yearbook, China Statistics Press; Ministry of Water Resources. 2017, China Water Statistical Yearbook. China Water & Power Press

Note The data on canal lining are available until 2012, "Others" are other engineering water-saving technologies except for sprinkler, micro-irrigation, low-pressure pipe irrigation and canal lining. After 2013, canal lining has been merged with "Others". Part of water-saving technologies reported under "Others" before 2013 has been excluded in the official statistics

Canal lining and low-pressure pipe irrigation are the two most widely used technologies; the irrigated area under canal lining increased from 6.36 million ha in 2000 to 12.82 million ha in 2012 while the area under low-pressure pipe irrigation rose from 3.57 million ha in 2000 to 9.45 million ha in 2016. Sprinkler and micro-irrigation technology require specific equipment, which may have slowed the rate of adoption; nevertheless, the area under sprinkler irrigation approximately doubled from 2.13 million ha to 4.10 million ha between 2000 and 2016. There was also a dramatic boom in the area under micro-irrigation during the same period—from 0.15 million ha to almost 6 million ha (Table 4.3).

4.6.2 Technologies Related to Irrigation Equipment

Sprinkler

Sprinkler irrigation technology utilises specialised equipment to irrigate the soil surface after pressurised water flows through the sprinkler head into small water droplets. Compared with flood irrigation, this technology can save water by 30% and up to 50% and has the advantages of saving labour and retaining soil and water.

Between the mid-1970s and the early 1980s, sprinkler irrigation, introduced from abroad, was firstly popularised in hilly and mountainous areas with problems of soil permeability, water shortage and drought-control irrigation. Recently, sprinklers were developed and used more in cash crops (i.e. tea, fruits, vegetable) or in relatively better off regions and high levels of productivity (Lu et al. 2016). Farmers in Gansu, Xinjiang, Shaanxi, Inner Mongolia, Henan, Anhui and Beijing also mix together chemical fertilisers and pesticides with irrigation water, which significantly reduces the need for labour (Zhang and Hu 2016). However, despite its advantage in saving water, sprinkler irrigation area covered only 4.1 million ha in 2016 (Table 4.3), about 5.6% of the total irrigated area. Equipment expenses and high operational and maintenance costs are a major deterrent to small-scale farms in adopting sprinkler irrigation.

Micro-irrigation

Micro-irrigation is a technique where there is a small flow through the pipe system and the irrigator is installed at the end of the pipe near the root of the crop. Micro-irrigation can evenly and accurately deliver water and nutrients needed for crop growth. Potted plant and soilless cultivation of fruit trees and flowers can benefit a lot from this technology. According to the classification of irrigation technology, drip irrigation, seepage irrigation and micro-sprinkling irrigation all belong to micro-irrigation (He and Liao 2014).

Drip irrigation uses special irrigation equipment to irrigate the soil in the root zone of the crop with water droplets. The common practice is to use a plastic piping system to deliver water directly to the root zone of each crop. Water is dripped directly onto the surface of the roots by each dripper, and then permeates deep into the soil and the most developed areas of the roots, saving water by 70–80%, with high automation and strong terrain adaptability.

Seepage irrigation uses the water-permeable capillary tube, built in the underground plough layer to introduce irrigation water into the tillage layer, to directly supply water to the root of the crop and only to moisten the underground part of the soil. Therefore, this technology, also known as "underground drip irrigation", can directly transport pesticides and fertilisers to the root of crops and is suitable for protecting agriculture.

Micro-sprinkler irrigation uses special sprinkler irrigation equipment to send pressurised water to the irrigation plot and spray through a micro-irrigation head installed on the pipeline. This technology, which enables localised irrigation, is a method of irrigation between sprinkler irrigation and drip irrigation. As a new type of irrigation technology, it has certain advantages and can be widely applied.

In general, micro-irrigation is the most efficient technology for the precise irrigation of crops, but its application to field crops has not yet been popularised. Despite significant expansion in the area under micro-irrigation with an increase from 0.15 million ha in 2000 to 5.85 million ha in 2016 (Table 4.3), the further expansion of this irrigation technology is limited by farmers' incentive to adopt it. In addition to the cost of adopting the technology, the likely damage to the plastic piping system by farm mechanical operations also poses a risk for farmers (Wang et al. 2005).

4.6.3 Technologies Related to Irrigation Infrastructure

Canal Lining

Materials such as stone, concrete, asphalt concrete and membrane materials are commonly used as an impermeable layer to prevent leakage of water from canals (He 2002). Compared with the traditional earth canal, lining canals can reduce water leakage by 70–90%, which greatly improves the utilisation rate of water conveyance and effectively reduces the risk of siltation and blockage of the canal (Zhou et al. 2004).

Canal lining dominates water-saving irrigation in China (Table 4.3). In ancient China, the earth canal played a vital role in transporting irrigation water from rivers or reservoirs to thousands of cultivated plots. However, leakage was a big problem, especially for plots situated far away from the canals. In order to resolve the problem, canal-lining technology with single material and single structure was developed in the late 1950s and has been widely used in irrigation, laying the foundation of irrigation channels in present day China. For decades now, composite materials and composite structures have played an increasingly important role in the selection of materials and channel construction to prolong service life and eliminate the negative impact on the environment (He and Liu 2009).

Low-Pressure Pipeline Irrigation

Low-pressure pipeline irrigation, also known as "pipe irrigation", utilises low-pressure pipelines to deliver irrigation water to farmland and irrigate the surface. This technology is simple, saving 40% of water compared with earth canals. Moreover, it is particularly convenient for farmers to master and especially suitable for regions where there are difficulties in developing sprinkler irrigation and micro-irrigation (Pang 2006).

Since the introduction of water-saving technologies from abroad in the mid-1970s failed to achieve the desired results, the government has made great efforts to develop water-saving technologies suitable to China's agricultural production conditions. During the Seventh Five-Year Plan period (1986–1990), low-pressure pipeline irrigation technology was listed as a key project deserving of the attention of the State Science and Technology Commission. This low-pressure pipeline irrigation technology was developed by 1990 and has great benefits for farmers, needing less investment, simpler equipment, is easier to operate and enables flexible management compared to sprinkler irrigation, drip irrigation and other technologies. Therefore, by the late 1990s, the sowed area had extended to more than 3 million ha within a few years. By 2016, the area under low-pressure pipe irrigation reached 9.45 million ha (Table 4.3), and this has played an important role in irrigation in northern China.

4.6.4 Other Non-engineering Water-Saving Technology

Water-saving technologies without the need for engineering/inputs have also been developed for farmers. Of these, mulching plays a major part and has been used by many farmers in dry regions. Mulching involves covering the farmland surface with materials such as straw, gravel, plastic film, and so on to reduce the evaporation of soil moisture and enhance the ability of soil–water storage and water retention. This technology can also improve the water and heat condition of the plough-layer soil, activate soil nutrients and improve the water-nutrient utilisation rate (Zhu and Wang 1996).

In Xinjiang, local farmers also developed a new water-saving technology that combines the advantages of Israeli drip-irrigation technology and domestic mulching technology, called "drip irrigation under mulch", to plant cotton, tomato, corn and other crops. However, ordinary mulch does not degrade easily. The problem of residual film recovery has not yet been effectively solved (He and Liao 2014). In addition, covering farmland with straw may cause more serious pest damage (Hu et al. 2007).

4.7 Innovations in Fertiliser Manufacture and Use Technologies

4.7.1 Trends of Fertiliser Production and Consumption

The chemical fertiliser sector was at an infant stage prior to China's rural reforms in 1978. Annual production of chemical fertilisers was only about 0.1 million tonnes of nutrients ($N + P_2O_5 + K_2O$) in the 1950s and 1.2 million tonnes in the 1960s. Meaningful production of chemical fertiliser was initiated by the Green Revolution in the 1970s, through which new cereal varieties more responsive to chemical fertiliser application were released. In 1981, when China had started its rural economic reform, total chemical fertiliser production reached 12.4 million tonnes.

In the past four decades, the scale and growth of chemical fertiliser production in China has been impressive (Fig. 4.13). Production reached 18.8 million tonnes in 1990 and was 52% higher than that in 1981. By 2000, chemical fertiliser production had grown to 30.9 million tonnes and was 64% higher than that in 1990. China has been the world's largest chemical fertiliser producer since 1992 (IFA 2014). The most dramatic increase in chemical fertiliser production occurred after 2000. Chemical fertiliser production doubled again during 2000–2015 and reached 71.6 million tonnes in 2015, accounting for 30% of global chemical fertiliser production

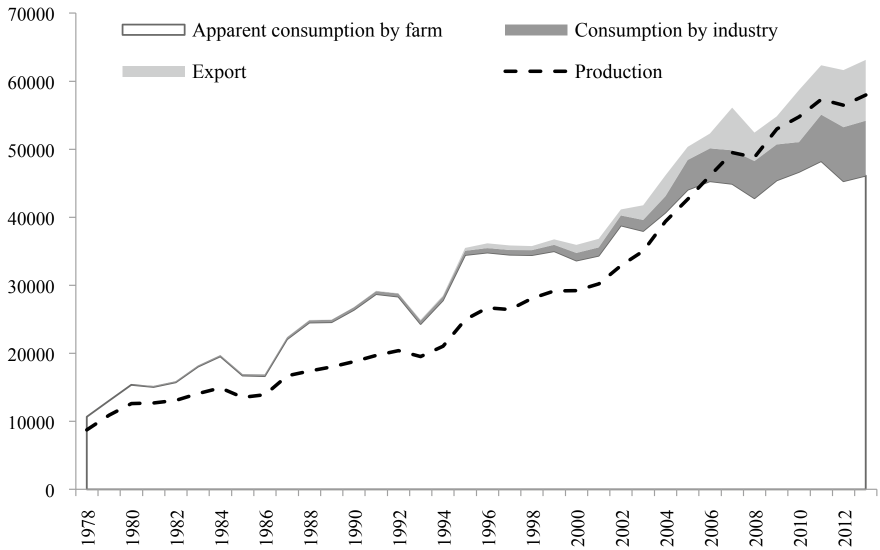

Fig. 4.13 Chemical fertiliser production, consumption and trade in China, 1978–2012 (1000 tonnes, measured in total nutrients of N, P_2O_5 and K_2O). *Source* Data on fertiliser production and industry consumption are from China Nitrogen Fertiliser Industry Association; China Phosphate Fertiliser Industry Association; Potash Branch of China National Inorganic Salts Industry Association. Trade data are from CNCIC

in 2014 (IFA 2017). With rapid growth in production, China has shifted from a major importer to a net exporter of nitrogenous and phosphoric fertilisers in recent years (Fig. 4.13). Annual fertiliser exports increased from less than 1 million tonnes in the late 1990s to nearly 16 million tonnes in 2015. Domestic chemical fertiliser production has exceeded total consumption since 2008 (Fig. 4.13), and by 2015, fertiliser exports accounted for about 22% of domestic product, while net exports (i.e. export minus import) were 13%.

The rising trend in domestic production also implied that total fertiliser consumption increased significantly in China, in particular before the mid-2000s. In less than 30 years, total consumption increased more than 2.4 times from 14.8 million tonnes in 1981 to 51.1 million tonnes in 2005. Indeed, China has become the largest chemical fertiliser consumer since 1989 (IFA 2017). Since 2005, the growth of fertiliser consumption for farming has slowed down, although due to the increasing demand for industrial use, total chemical fertiliser consumption has increased since 2010. By 2015, it was estimated that the chemical fertiliser consumption for industrial use accounted for around 14% of total fertiliser consumption, while that for farm use took up a share of about 86%. Besides, Chinese farmers used 167 kg of chemical fertiliser per hectare–about 2.4 times the world average–in 2014 (FAO 2017).

The changes in nitrogen (N) fertiliser supply and demand show China's increasing ability to meet its growing demand for N fertiliser and the changes in its role in the international market (Fig. 4.14). From 1981 to 2015, the average annual growth rate of China's N fertiliser production reached 4.5%, which was 1.3% higher than average annual growth of N fertiliser consumption (3.25%). Rising N fertiliser production shifted China from being an importer (4.6 million tonnes annually in 1990–91) to that of a net exporter by 2003. Most of the imported products are compound fertilisers. By 2015, the production of N fertiliser reached nearly 3.65 billion tonnes, which included 10 million tonnes for export. Within N fertilisers, the composition of products has changed significantly.

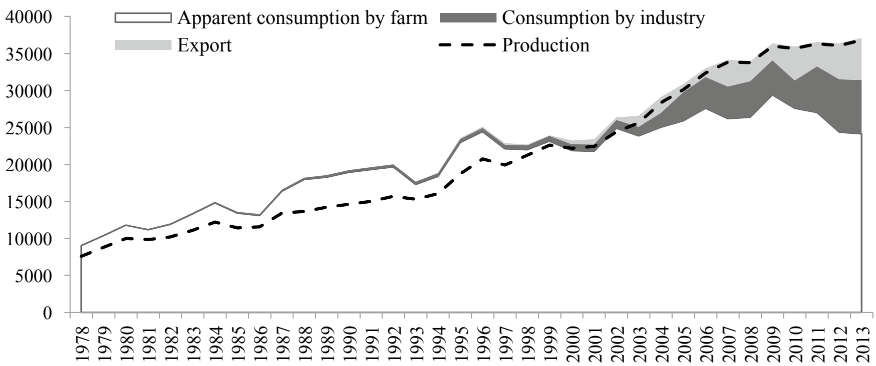

Fig. 4.14 Nitrogen fertiliser production, consumption and export (1000 tonnes) in 1978–2012 in China, on the basis of N nutrient content. *Source* Data on fertiliser production and industry consumption are from China Nitrogen Fertiliser Industry Association. Trade data are from CNCIC

4.7.2 Innovative Fertiliser Production

Rapid growth in fertiliser production has come from several sources, including the rising demand for chemical fertilisers, price and marketing reform and innovation. Three innovations have significantly affected fertiliser production in China: (1) the shift of single fertiliser from low concentration to a high concentration; (2) the shift of fertilisers from single to compound fertilisers and (3) the rising production and uses of slow-release fertiliser technology and the shift in the source of energy used in fertiliser production from coal-dominated to a more diversified production system.

The Shift of Single Fertiliser from Low Concentration to High Concentration
In the case of nitrogen fertilisers, technological changes helped China to move liquid ammonium to high concentration nitrogen fertiliser and from ammonium bicarbonate to amide urea, which significantly reduced the loss of nitrogen and increased the efficiency of utilisation. By the 1980s, more than half the nitrogenous fertilisers in China consisted of ammonium bicarbonate, while urea only accounted for about one-third. In the early 2010s, the share of ammonium bicarbonate was reduced to less than 10%, while that of urea rose to more than two-thirds. With phosphoric fertilisers, there has also been a shift from superphosphate and calcium magnesium phosphate to highly concentrated mono-ammonium phosphate and di-ammonium phosphate, which has increased the effective supply of phosphorus (P) in soil over time.

Compound fertilisers have also increased significantly over time, which has promoted the balanced use of fertilisers in China. The development of compound fertilisers has undergone a process to a uniform compound (e.g. 15–15–15 of N–P–K (potassium)) nationwide and then to a specific formula for different crops and regions. With rising market competition and farmers' awareness of the appropriate use of fertilisers, compounding technology has been improved and the formulae have in recent times provided more flexibility for farmers (Chen et al. 2014).

The production of slow-release fertilisers has been upgraded and expanded significantly. In particular, the use of nitrogen inhibitors, such as urease inhibitors and nitrification inhibitors in urea, has been increasing. These inhibitors regulate the soil nitrogen supply intensity and reduce nitrogen loss by delaying the hydrolysis of urea or slowing the conversion of ammonium nitrogen to nitrate nitrogen (Lu et al. 2018; Tian et al. 2015). In addition, the development of processes such as adding trace elements, soil conditioners and bio-stimulating hormones to a large number of elemental fertilisers has expanded the functions of chemical fertilisers, supplemented trace elements in the soil, improved the ability of crops to resist stress and improved the soil.

There has also been an effort to diversify the production of synthetic ammonia, mainly based on a coal- to gas-based chemical fertiliser industry, which lowers the environmental problems associated with the rapid expansion of the fertiliser industry. This change was largely due to government subsidies and regulations to raise natural gas use in fertiliser production. The subsidy on natural gas started in the 1980s but ended recently. During the last few decades, the share of coal-based ammonia in synthetic ammonia production decreased from 82% in 1970 to 79% in 2015, while the gas-based ammonia share increased from 11 to 21% over the same period (Table 4.4).

4.7.3 Innovations in Fertiliser Utilisation

Soil Testing for Formulated Fertilisation Programme

In response to excessive fertiliser use and low fertiliser utilisation efficiency, in 2005, the government launched the Soil Testing for Formulated Fertilisation Programme (STFFP). Soil testing for formulated fertilisation is based on crop fertiliser requirement, local soil fertility performance and fertiliser effect. Based on soil testing and fertiliser field experiment, the amount of fertilisers (e.g. nitrogen, phosphorus, potassium and trace elements), fertilisation period and application method are recommended for farmers in each village. This innovation includes soil nutrient determination, fertilisation-scheme formulation and the correct application of fertilisers in different villages. It can be divided into soil testing, formula design, fertiliser production and correct application (Gao 2005).

Through the first two years of project implementation, soil testing for formulated fertilisation has been recognised by all parties and has brought economic benefits. In 2006, 600 counties across the country implemented soil testing for a formulated fertilisation programme. The STFFP's budget rose to 900 million yuan in 2007 (7.6 yuan = 1 USD in 2007) and added 600 new project counties in the programme, to a total of 1200 counties. Through the implementation of the programme, it has provided free services to more than 40 million farmers. The programme area was extended to 42.67 million ha in 2007, which reduced fertiliser use by about 500,000 tonnes, with an average saving of more than 375 yuan per hectare (Gao 2008). At the national level, this technical service coverage in total crop area has increased from 9% in 2000 to 68% in 2013 (Zhang et al. 2017).

The STFFP plays an important role not only in grain production, but also in N_2O mitigation. According to research in Hubei Province, the programme simultaneously decreased N fertiliser use by 744 thousand tonnes and increased crop yields by 19 million tonnes. It also reduced N_2O by 22.4 thousand tonnes from reduced N fertilisation (15.7 thousand tonnes) and increased yield (6.7 thousand tonnes), respectively.

The Efforts Through the Pilot Development Programme

In 2015, China launched a pilot programme to reduce fertiliser application by improving the efficient of its use in crops such as maize, vegetables and fruits. The maize pilot programme on improving the efficiency of fertiliser use was implemented in 14 counties of the Huang–Huai–Hai region and Northeast China; the vegetable pilot programme was implemented in 20 counties in the major greenhouse vegetable production regions; and the apple pilot programme was implemented in 14 counties

Table 4.4 Production of synthetic ammonia from different raw materials in China (1000 tonnes)

Year	Coal	Naturalgas	Petroleum	Others	Total
1949					
1960					
1970	4061	574	340	5	4983
1980	7984	2912	1378	6	12,280
1981	7694	2858	1608	3	12,163
1982	8162	2761	1742	16	12,680
1983	8994	2833	1902	24	13,752
1984	9883	3096	2053	35	15,067
1985	8342	3055	2030	29	13,455
1986	8307	3019	2370	12	13,709
1987	10,096	3109	2661	35	15,901
1988	10,611	3059	2547	14	16,230
1989	10,808	3301	2846	11	16,967
1990	11,080	3408	2958	11	17,457
1991	11,516	3477	3042	17	18,053
1992	12,109	3577	3141	19	18,845
1993	11,431	3684	2955	23	18,094
1994	12,810	4078	3066	68	20,023
1995	14,808	4509	3254	0	22,572
1996	16,845	4839	3176	282	25,143
1997	15,807	5373	3068	0	24,248
1998	16,218	5571	4287	0	26,075
1999	16,975	6002	4169	90	27,236
2000	16,674	5691	2908	–	25,273
2001	17,996	6496	2486	–	26,978
2002	20,910	6501	2744	–	30,155
2003	22,000	6867	2252	–	31,119
2004	24,315	7395	2912	–	34,622
2005	27,698	8605	1661	–	37,965
2006	30,977	8732	783	–	40,491
2007	32,654	8799	865	–	42,317
2008	31,950	8589	867	–	41,406
2009	33,367	9440	854	–	43,661
2010	32,633	9633	546	–	42,812
2011	33,033	10,500	453	–	43,986
2012	37,561	11,173	218	436	49,387

(continued)

Table 4.4 (continued)

Year	Coal	Naturalgas	Petroleum	Others	Total
2013	38,799	11,160	230	631	50,821
2014	38,276	11,161	0	194	49,631
2015	43,124	11,349	205	82	54,760

Sources China Fertiliser Development Research Report (2012), China Fertiliser Development Research Report (2016)

in the Loess Plateau and the Bohai Bay region. The number of counties covered in this pilot programme increased from 48 in 2015 to 200 in 2016 and 300 in 2017. Each county received 2 million yuan annually from the central government to implement the pilot programme. The pilot programme is expected to be scaled up in the pilot counties and extended nationwide in the coming years.

In 2017, the Ministry of Agriculture initiated another new pilot programme aimed at replacing chemical fertilisers with organic fertilisers. This pilot programme for fruits, vegetables and tea production was launched with an annual budget of 1 billion yuan across 100 counties across China. Subsidies are provided to manufacturers producing organic fertilisers, which can then be sold to farmers at low/subsided prices. This pilot programme has been scaled up in more regions and, since 2017, has been expanded to other crops.

4.8 Innovations in Farm Machinery and Mechanisation

4.8.1 Trends of Agricultural Mechanisation

The number of agricultural machines increased mainly after the late 1970s. Amongst f agricultural machines, there was a remarkable increase in the number of small tractors before the early 2010s, with their numbers peaking at 17.97 million in 2012 and declining slightly afterwards (NSBC 1980–2017). The number of large and medium tractors, after a steady increase from the early 1980s to the early 2000s, started increasing rapidly after the mid-2000s, and reached 6.1 million in 2014. Along with the fast-growing large tractors, more mechanical seeders have been used in agricultural activities since the 1990s. Although irrigation and drainage machines were adopted later, their numbers increased rapidly from 7.7 million in 1996 to 23 million in 2015. Like large and medium tractors, combines have been widely adopted since the mid-2000s and the nationwide number reached 1.73 million in 2014 (NSBC 1980–2017). In 2014, the total power of large tractors exceeded that of small ones. (Institutions related to mechanisation has been discussed in detail in Chap. 8: Institutional Innovations in Accessing Land, Water, Farm Machinery and Extension Services in China's Agriculture.)

Mechanisation of agricultural production has gradually increased over time, particularly after the mid-2000s (Table 4.5). For all crops in general, ploughing and sowing are the two most mechanised production activities, with mechanisation of these activities covering 72 and 52% of the total cropped area in 2015. More than half of the sown area used mechanisation services in harvesting in 2015. Pesticide spraying was mechanised in 40% of the cropped area (Table 4.5).

4.8.2 Innovations in Farm Machinery

Hand-Held Two-Wheel Tractor

In China, where farm size is small and the land is largely fragmented, small machinery is often more practical. The promotion of small agricultural machinery and tools has become an important way to improve agricultural mechanisation and productivity. The hand-held tractor is the most representative of the small tractors (Fig. 4.15). It can be equipped with different agricultural tools, which can be used for various field operations such as ploughing, land levelling, building terraces and crushing

Table 4.5 Total crop sown area (million ha) and mechanized rate (%), 1998–2015

Year	Total crop sown area	Percentage of mechanised cropped area by activity (%)				
		Ploughing	Sowing	Irrigation	Plant protection	Harvesting
1998	155.7	38.6	24.6			
1999	156.4	39.6	25.5		21.3	16.3
2000	156.3	39.7	25.5	34.7	22.9	16.9
2001	155.7	39.6	26.1	32.8	22.9	17.0
2002	154.6	39.6	26.6	33.9	23.0	17.6
2003	152.4	40.0	26.7	31.2	23.6	18.0
2004	153.6	41.4	28.8	30.1	26.0	19.8
2005	155.5	41.9	30.3	29.5	26.6	22.0
2006	152.1	44.4	33.0	31.1	29.1	25.3
2007	153.5	46.7	34.4	31.9	30.2	27.5
2008	156.3	58.3	37.7	29.8	32.3	30.4
2009	158.6	60.3	41.0	30.1	33.6	33.7
2010	160.7	62.6	43.0	30.7	35.7	37.2
2011	162.3	65.9	44.9	31.9	36.8	40.7
2012	163.4	67.5	47.0	32.0	38.3	43.6
2013	164.6	69.1	48.8	32.3	38.9	47.0
2014	165.4	71.0	50.7	32.4	39.7	50.3
2015	166.4	72.1	52.1	32.0	40.4	52.7

Source data are from NSBC, China Agricultural Machinery Industry Yearbook (1986–2016) soil, as well as having a trailer, and can also be used for short distance transport. The hand-held tractor has many advantages, such as being lightweight and having flexible operation and strong adaptability. It is very popular in the countryside. There were only about 1000 small tractors before the 1970s with most of them being hand-held tractors. The number of small tractors has increased rapidly in the past four decades (for detail, see Chap. 8 on Institutional innovations—China).

3S Technology

Agricultural machinery can increase output and improve agricultural productivity by using the "embodied technology" contained in them (Sheng et al. 2017). At present, the adoption of "3S technology" is a new trend in the development of modern agriculture in China. 3S technology is a general term for remote sensing system (RS), geographic information systems (GIS) and global positioning systems (GPS). It is a combination of space technology, sensor technology, satellite positioning and navigation technology, computer technology and communication technology. Using machines with 3S can not only optimise agricultural production, but also protect the agricultural environment and resources (Gao et al. 2005).

GPS is a technical system that uses 24 communication satellites around the earth. It also has a receiving system on the ground that receives radio signals from several satellites. GPS can be utilised to measure the accurate geographical position of a certain point on the earth. In modern agriculture, it can determine the location of plots and then guide irrigating, fertilising and spraying in agricultural production by combining information on soil materials, diseases, and pests (Su and Liu 2014). RS can measure and analyse the nature of the target at a distance. It can collect information, which provides early prediction of crop yield (Yin et al. 2005). GIS integrates spatial information and geographical distribution. It can be used to analyse data about soil, natural conditions and crop yield combined with spatial data (He et al. 2003).

Fig. 4.15 Hand-held (two wheel) tractors. *Sources* pictures from baidu.com

China began to use RS and GIS in rice in the 1980s. From then on, experts applied them to forecast the yield of major crops (e.g. wheat, cotton and maize) and livestock (e.g. chicken, pigs and cattle). However, large-scale application of 3S technology still faces some bottlenecks. It is relatively easy to install 3S technology on large and expensive agricultural equipment but not on small farm machinery (Chen 2016).

4.9 Innovations in Sustainable and Green Agriculture

4.9.1 Moving Towards Sustainable Agriculture

Intensified agriculture with high input and output has, in the past, resulted in huge stress on limited natural resources and the rural environment. This may threaten the sustainable development of agriculture in the future. China's agricultural production greatly depends on irrigation. Currently, about half of the cultivated area is irrigated. Rising demand for irrigation water has resulted in the overexploitation of groundwater, and consequently, most of northern China is experiencing a falling groundwater table and land degradation (MWR 2016). The sustainability of irrigated agriculture is also challenged by a rising demand for water from urbanisation and ecological civilisation construction as well as water pollution. Climate change is expected to further exacerbate the water shortage (Wang et al. 2013). Although the decline in cultivated area has slowed down due to strict regulations on alternative uses of cultivated land (e.g. resolutely defend the red line of 1.8 billion mu or 120 million ha for cultivated land by 2020), soil quality degradation has been occurring in many regions. Excessive use of modern inputs (e.g. fertilisers and pesticides) has caused serious non-point pollution and soil degradation and will become one of the major factors threatening sustainable agricultural development in the future.

Recognising the resource constraints and challenges in sustainable development, the Chinese government has made a strong political commitment. For example, in recent years, China has been seeking a new development strategy, called "*Cang-liang-yu-di*" ("storage food in land,") and "*Cang-liang-yu-ji*" ("storage food in technology"). "*Cang-liang-yu-di"* primarily considers production capacity in the long run rather than current actual production; the implementation of this development strategy will have important implications on the sustainability of agriculture and the mitigation of climate change. "*Cang-liang-yu-ji*" re-emphasises the role of technology in food security.

4.9.2 Moving Towards Green Agriculture

While chemical fertilisers (and pesticides) have played an important role in increasing crop production (and reducing crops lost due to pests), the excessive use of chemicals has resulted in serious environmental and food safety problems in China. China is one of the countries that have experienced rapid growth in pesticide use in the past two decades. The excessive use of chemical fertilisers and pesticides is observed in nearly all crops and has been well documented in the literature.

Given the above challenges, China recently moved to a new policy regime aimed at reducing the use of chemicals in agriculture. Realising the environmental and food safety consequences of intensive chemical use, China in 2015 announced a plan to reach zero growth in total fertiliser and pesticide use in agriculture by 2020 and for it to fall thereafter. The plan also aims to achieve "zero discharge" of agricultural waste by 2030.

Efforts Through the Technology Innovation Programme

In 2015, China also launched a national R&D programme aimed at reducing chemical fertiliser and pesticide use. The programme is called the National Key Research and Development Plan: Comprehensive Technology Research and Development for Reducing and Improving Efficiency of Chemical Fertiliser and Pesticide Uses. Currently, this programme is for five years (2016–2020) and is targeted at major crops such as grain, major cash crops, vegetables and fruits.

Major R&D components of this programme include (1) developing the principles and standards for reducing fertiliser and pesticide use, (2) developing major technologies and innovative products and equipment to reduce fertiliser and pesticide use and (3) developing comprehensive and integrated technologies that can be used in the field. The total budget for this programme is likely to reach 4 billion yuan in 2016–2020. The budgets for the first three years has been allocated and implemented with 780, 929 and 750 million yuan budgeted for 2016, 2017 and 2018, respectively.

4.9.3 Rice–Fish/Shrimp Co-cultivation

For more than 1200 years, the Zhejiang Province of China has practised traditional rice–fish paddy land co-cultivation. Because there is a large amount of phytoplankton in paddy water, fish can feed on a nutritious biomass which includes cyanophyta, chlorophyta, bacillariophyta, euglenophyta, cryptophyta, pyrrophyta and so on, with more than 6 phyla, 38 genera and 93 species. However, this traditional method poses a higher risk of aquatic environmental degradation. When the fish density oversteps the optimal level, the chemical oxygen demand (COD) and the total phosphorus (TP) will bring about eutrophication in paddy water (Ding et al. 2013). Comparable traditional methods like "fowl-fish-lotus root", "aquatic fowl-aquaculture-aquatic feed" and "pig-bog-fruit (forest, grass, vegetables, fish)", etc., are similarly problematic.

Modern rice–fish paddy land cultivation adopts a method of precise management. For example, in Qingtian county of Zhejiang Province, a group of scientific researchers are experimenting with an optimal input–output mode. They test lower fertiliser inputs when both rice and fish yields are increased in a balanced growth mode. They have found that by feeding 55 ± 3 g per fish (Cyprinus carpio var. colour) and keeping a density of 9000 piece/hm^2 within the paddy rice land (rice density by 30 cm times 30 cm), and by using 480 kg/hm^2 of compound fertilisers can yield 1500 kg/hm^2 of fish and 7500 kg/hm^2 of rice grain (Wu et al. 2014).

Traditional rice–shrimp paddy land co-cultivation also presents a similar problem of biomass control and water eutrophication. By extending the time of co-production, ruderals can be first decreased and then increased by addressing the imbalance in the rice community and shrimp community. Recent research found rice–shrimp co-cultivation with a certain amount of soft-shelled turtle (*trionyx sinensis*) can effectively increase the yields of all production. Moreover, methods such as rice–duck and rice–fish co-cultivation can effectively decrease and control methane and nitrous oxide emissions to enable a reduction of the greenhouse gases associated with rice paddy fields.

4.9.4 Soil and Land Conservation

Agricultural modernisation and sustainable development rely on soil and land conservation. Deep ploughing over the last millennium has induced severe soil degradation in some conventional agricultural regions in China, such as the Loess Plateau. Since the 1980s, the central government has successively carried out a series of ecological projects in this region, such as a small river basin management project, a key water and soil conservation project, a project to return cultivated land to forest/grass (grain-to-green) and silt dam and sloping farmland management. Since the 2000s, on the upper and middle reaches of the Yellow River (above the Tongguan), a wide range of soil and water conservation measures have covered an area of about 14.74 million ha, including a terraced field (about 3.49 million ha), an artificial forest (about 74.7 million ha), an artificial grassland (about 2.58 million ha), a dam field (about 180,000 ha) and a stripe field for erosion control (about 1.02 million ha).

The soil and land conservation projects rely on agroforestry management. Examples of these include the state-level shelter-forest systems that have been constructed in many regions in China since the 1970s, including northern ecological protection schemes, water source conservation of the Yangtze River, and the coastal-shelter forests for the middle and lower reaches of the Yangtze River. In the 1980s, intercropping of forest-rubber-tea was developed in Hainan Province and the south of Yunnan Province. The middle and lower reaches of the Yangtze River saw the development of "pine tree and tea", "Chinese tallow tree and tea" and "paulownia and tea" in the hilly region. Later, a more complex co-cultivation system such as forest-fish-agriculture was developed in the wetlands of the Lixia River area in Jiangsu Province. In the 1990s, contour hedgerow technology was developed in the mountainous and hilly areas of southwest China. It uses a method of arranging and planting shrubs or dwarf trees along the contour line of the slope to act as hedgerows for intercropping with other things, which could effectively prevent soil erosion and improve soil fertility. Across many regions of China, other intercropping methods were also developed, such as "forest-ginseng" in northeast China, "fruit-grain" in northern China, "forest-crude medicine planting" and "forest-grass" in various regions, resulting in an improved ecological environment and improved farm incomes.

It is mainly due to biological principles that agroforestry cultivation benefits soil and land conservation, but advanced botanical techniques are expected to enrich cultivation sciences. For instance, one challenge is how to improve photosynthetic efficiency. Plant allelopathy causes competition in the root system under the soil. This happens because of the difference in nutrition intakes between shallow and deep tillage of plants. Thus, studies on factors associated with the growth cycle are crucially important to direct regional plantation structure adjustments and obtain more intercropping tips. This includes research into soil moisture, nutrients, light, temperature, humidity, plant residue decomposition, root exudation and eluviation and leaching release to the rhizosphere, as well as the permeability of plant cell membrane, absorption and transport of nutrient elements, the metabolism of organic matter, respiration in the photosynthesis process, activities of enzyme and hormone in plants, etc.

4.10 Promising ICT and Big Data Technologies

In the past decade, with the rapid increase in the rate of Internet penetration, Internet users, mobile phone subscriptions and so on, fast growth in the application of information communication technologies (ICTs) has been seen in China (ITU 2013). The rate of Internet penetration in China increased from 16% in 2007 to 55.8% in 2017. It increased from 26 to 71% in urban areas and from 7.4 to 35.4% in rural areas (CNNIC 2018). This was 4.1% higher than the global average (51.7%) and 9.1% higher than the Asian average (46.7%) by 2017 (CNNIC 2018). The number of Internet users in China reached 772 million in 2017 from a figure of only 210 million in 2007 (CNNIC 2018). The number of Internet users increased from 53 million in 2007 to 209 million in 2017 in rural areas and from 157 million to 563 million in urban areas. Compared to the globally projected 72% increase in mobile phone subscriptions during 2009–2016, this has increased from 50.4 million in 2007 to 752.7 million in 2017 (around 15 times greater) in China (Qiang et al. 2012).

ICT and big data are promising technologies that can be widely used in agriculture. In this section, we introduce some major applications of ICT to China's agriculture, including plant protection drones, the Internet of Things, and food traceability systems. For ICT used in marketing (e.g. rural e-commerce), see Chap. 6.

4.10.1 The Application of Drones in Agricultural Production

Although agricultural drones in China are much smaller and cheaper than that used by American big farms, they are suitable for the small- and medium-scale farms in China. Currently, drones are mainly used for spraying pesticides. They are often called plant protection drones. These drones use either battery or fuel powered (Lin et al. 2014). Electric-powered drones can move quickly and have the advantage of flexible operation, but a single flight is usually only 10–15 min. The fuel-powered system drone has a larger body and relatively less flexibility. It requires a certain take-off and landing time and is relatively complex in maintenance, but flight time can exceed one hour (Luo 2014). Plant protection drones have advantages in terms of operational efficiency and safety. Moreover, economic and ecological losses are obviously reduced. For example, ripe soybeans are not damaged when pesticides are sprayed by drones. They use less pesticide and employ only one-tenth of the water that is used by manual spraying.

While agricultural drone operation in China is still in the initial stage, it has increased significantly in recent years. In 2015, the number of plant protection drones reached 2324, with a total operating area of 0.77 million ha (Booz Data Center 2018). As comparison to the 695 drones and 0.29 million ha in 2014, this is an increase of 234% and 170%, respectively. The number of plant protection drones reached 5229 in 2017 (Booz Data Center 2018). Currently, agricultural plant protection in China is still dominated by semi-mechanised equipment such as manual and electric sprayers, which account for more than 90% of operations, and the proportion of drone use is less than 2%. However, with the increase in land consolidation and the development of drone custom services in China, it is expected that the proportion of drones in agriculture will rise rapidly in the future.

4.10.2 Internet of Things

The Internet of Things (IoT) is a set of technologies which includes identification, sensing and intelligence (Fan 2013). The application of IoT technology is an important means to transform traditional agriculture into modern agriculture, to achieve automatic, intelligent and information-based agricultural production, and to improve agricultural production efficiency and the quality of agricultural products. Using IoT technology is a way to accurately monitor and control light, temperature and humidity in the greenhouse to achieve precise management of agriculture. It can also help achieve precise fertilisation and save resources. Its application in remote monitoring enables greenhouse automation and intelligent management. The application of IoT technology in greenhouses has not only improved the yield and quality of crops, but also promoted the development of the greenhouse in the direction of intensification, precision, automation and intelligence, which has a broad application prospect. With the continuing development of IoT technology, it can be applied to trace agricultural products in greenhouses. Agricultural data knowledge bases and expert systems are constructed for different crops, and intelligent and low-cost terminal application technology equipment is developed to promote the rapid development of greenhouses. The application of IoT is still in its initial stages in China.

4.10.3 Food Traceability System

The food traceability system has started to apply cutting-edge technologies such as IoT, barcoding, electronic data exchange and radio frequency identification devices (RFID) to the production, packaging and identification and logistics of agricultural products to record information related to the whole agricultural supply chain. The purpose of this system is to quickly check sources and links when product quality problems occur and effectively guarantee the quality of agricultural products. In recent years, China has actively carried out research and constructed a traceability system for supervising the quality and safety of agricultural products. In Beijing, Shanghai, Tianjin and other cities, barcode technology, RFID technology and IC card technology have been adopted to establish a quality and safety traceability system focusing on the supervision of every step of agricultural production and processing. For example, Tianjin has implemented a traceability system for hazard-free[7] vegetable and launched an online vegetable-ordering service. Shouguang in Shandong Province, and other cities, have carried out research and construction into the "traceability system of pesticide-free vegetable quality" using barcodes. Nanjing has launched an agricultural product quality IC card management system with an agricultural product quality and safety website as the supervision platform.

4.11 Concluding Remarks

Understanding China's agricultural technological innovations over the past decades is relevant not only for China but also for many other developing countries. There are lessons that China can learn from its past in developing technology to raise agricultural productivity; there are also lessons that may have implications for other developing countries to facilitate their agricultural growth. This chapter has introduced major innovations in agricultural technologies adopted by farmers in the past and promising new technologies for the future in China.

One of major lessons/experiences from China is that the country has invested significantly in agricultural R&D and developed a strong technology innovation system. This system has generated in the past a wide range of innovative technologies used by hundreds of millions of small and large farms in crop, livestock and fishery production, in agricultural inputs (e.g. irrigation, chemical fertilisers and farm machinery) and in farm practices. The currently emerging technologies (e.g. ICT, big data technologies, etc.) may change the path of agricultural technology in the future.

[7]A China food standard, requiring controlled and limited use of synthesized fertilizer, pesticide, growth regulator, livestock and poultry feed additive and gene engineering technologies; no use of pesticide with high toxicity and high residue.

The other important lesson from China is that the country has developed a comprehensive agricultural extension system. This system covers all townships across the country and the extension staff work closely with farmers. While the role of the private sector in providing extension services has been rising, maintaining a strong public extension system is critical for agricultural production dominated by small farms.

China's experience also shows that innovation is one of the major sources of agricultural productivity growth in the long run and has facilitated China's agricultural transformation over the past few decades. China was one of the first developing countries to develop and extend Green Revolution technology in rice in the 1960s. Empirical studies show that the average annual growth rates of total factor productivity (TFP) in the grain sector increased from about 2–3% in 1995–2004, and the growth of TFP in cash crops and livestock was even higher, exceeding 3.5% in 1995–2005 (Jin et al. 2010). They further show that nearly all growth in TFP was the result of technological changes during 1995–2005. A recent study by Wang et al. (2019) also shows that China has maintained an annual total factor productivity growth rate of nearly 3%, and that this high rate of growth has been mainly due to China's investment in agricultural R&D and extension. With the development of new biotechnology and digital technology, we expect that technologies in boosting agricultural growth will play more important roles in the future in both China and the rest of world.

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References

Altpeter, F., Vasil, V., Srivastava, V., Stoger, E., & Vasil, I. K. (1996). Accelerated production of transgenic wheat (*Triticum aestivum L.*) plants. *Plant Cell Reports, 16,* 12–17.

Barker, R., & Herdt, R. W. (1985). *The Rice Economy of Asia.* Washington, DC: Resources for the Future.

Bennetzen, J. L., & Hake, S. C. (Eds.). (2009). *Handbook of maize: Its biology*. New York, NY: Springer.

Booz data center. (2018). *The market report and prediction of agro-chemicals spraying drones of China, 2018–2023* (pp. 28–106). Beijing.

Chai, Y., Pardey, P. G., Chan-Kang, C., Huang, J., Lee, K., & Dong, W. (2019). Passing the food and agricultural R&D buck? The United States and China. *Food Policy* (forthcoming).

Chandler, R. F. (1982). *An adventure in applied science: A history of the international rice research institute* (p. 9789711040635). ISBN: International Rice Research Institute.

Chen, C. (2016). Role of macro-decision support system research for tianshui agriculture based on 3S. *Environment and Sustainable Development, 41*(3), 189–191.

Chen, D. L. (1998). Twenty years after reform and opening-up, fishery industry developed rapidly. *Fishery Guide to be Rich, 3,* 6–7.

Chen, S. (2018). *China's import and export of aquatic products reached new peak, but narrowed in 2017*. China News (2018–03–09).
Chen, W. (2017). *These seven aquaculture models are the future direction of development*. China Aquaculture Net (2017–06–29).
Chen, M., Zhang, S., Zhong, L., Ning, M., & Wang, J. (2014). Study on the ways, models and transformation of fertilization methods of fertilizers in China. *China Agricultural Technology Extension, 30*(6), 33–46.
Chen, W., Wu, L., Liu, T., Xu, S., Jin, S., Peng, Y., et al. (2009). Race dynamics, diversity, and virulence evolution in Puccinia striiformis f. sp. tritici, the causal agent of wheat stripe rust in China from 2003 to 2007. *Plant Disease, 93,* 1093–1101.
Cheng, S., Cao, L., Yang, S., & Zhai, H. (2004). Forty years' development of hybrid rice: China's experience. *Rice Science, 11,* 225–230.
Cheng, S., Liao, X., & Min, S. (1998). Super rice research in China: Background, target and some considerations. *China Rice, 1,* 3–5. (in Chinese with an English abstract).
Cheng, S., Cao, L., & Zhan, X. (2005). *Techniques for hybrid rice seed production.* Beijing: Jindun Publishing House.
Cheng, S., Cao, L., Zhuang, J., Chen, S., Zhan, X., Fan, Y., et al. (2007). Super hybrid rice breeding in China: Achievements and prospects. *Chinese Botany Bulletin, 49*(6), 805–810.
CNNIC (China Internet Network Information Center). (2018). *Rural internet development of 2018* (pp. 55–89), Beijing, China.
CRDC (China Rice Data Center). (2018). *Super hybrid rice cultivars approved by the ministry of agriculture of China.* http://www.ricedata.cn/variety/. Accessed in May 2019.
Dalrymple, D. G. (1985). The development and adoption of high-yielding varieties of wheat and rice in developing countries. *American Journal of Agricultural Economics, 67*(5), 1067–1073.
David, C.C. & Otsuka, K. (Eds.). (1994). *Modern rice technology and income distribution.* Lynne Rienner Publishers: Boulder and London; and International Rice Research Institute, Manila.
Ding, W., Li, N., Ren, W., Hu, L., Chen, X., & Tang, J. (2013). Effects of improved traditional rice-fish system productivity on field water environment. *Chinese Journal of Eco-Agriculture, 21*(3), 308–314.
Estudillo, J. P., Sawada, Y., & Otsuka, K. (2006). The green revolution, development of labour markets, and poverty reduction in rural Philippines, 1985–2004. *Agricultural Economics, 35,* 399–407.
FAO (Food and Agriculture Organization). (2017). *FAO database.* http://faostat3.fao.org. Accessed in May 2019.
Fan, S. (1991). Effects of technological change and institutional reform on production growth in Chinese agriculture. *American Journal of Agricultural Economics, 73*(2), 266–275.
Fan, S. (1997). Production and productivity growth in chinese agriculture: New measurement and evidence. *Food Policy, 22*(3), 213–228.
Fan, T. (2013). Smart agriculture based on cloud computing and IOT. *Journal of Convergence Information Technology, 8*(2), 210–216.
Gao, X. (2005). *Soil testing and formula fertilization technology.* Beijing, China: China Agriculture Press.
Gao, X. (2008). Progress and development for fertilizing by prescription filled according to soil test result in China. *Chinese Journal of Agricultural Resources and Regional Planning, 29*(1), 7–10.
Gao, W., Zhao, R., Yang, Z., et al. (2005). Analysis of precision agricultural information system based on 3S technology. *Journal of China Agricultural Mechanization, 2005*(3), 29–32.
Gu, S., Du, X., & Yang, X. (2016). Module construction and function analysis of a recirculation raceway system with low carbon and high efficiency. *Journal of Anhui Agricultural Science, 44*(10), 312–314.
Guo, G. X. (2006). The existing problem and basic countermeasure in industrial development of deep-water net cage culture in China. *South China Fisheries Science, 2*(1), 66–70.
He, W. (2002). Development status and further research of canal anti-seepage engineering technology in China. *Journal of Water Resources and Architectural Engineering, 8*(2002), 31–33.

He, C., & Liao, N. (2014). Overview of water-saving irrigation standards system in China. *Agricultural Engineering, 4*(2014), 39–44.

He, G. T., & Flinn, J. C. (1989). Economic efficiency of hybrid and conventional rice production in Jiangsu Province, China. In *Selected papers and abstracts from the International Rice Research Conference, September 21–25, 1987*, Hangzhou, China. International Rice Research Institute, Manila, Philippines.

He, W., & Liu, Q. (2009). The present development status and trends of canal lining and seepage control techniques in China. *China Rural Water and Hydropower, 6*(2009), 3–6.

He, Y., Tan, L., Ge, X., et al. (2003). Study on the regional division system of agricultural mechanization development based on GIS. *Journal of Agricultural Engineering, 19*(3), 85–89.

Hu, S., Peng, N., Xie, X., & Wang, K. (2007). A review on water conservation in cropland with stalk cover. *Chinese Journal of Agrometeorology, 28*(1), 49–53.

Huang, J., & Peng, B. (2015). Consumers' perceptions on GM food safety in urban China. *Journal of Integrative Agriculture, 14*(11), 2391–2400.

Huang, J., & Rozelle, S. (1996). Technological change: The re-discovery of the engine of productivity growth in China's rural economy. *Journal of Development Economics, 49*(2), 337–369.

Huang, J., Hu, R., van Meijl, H., & van Tongeren, F. (2004). Biotechnology boosts to crop productivity in China: Trade and welfare implications. *Journal of Development Economics, 75*(1), 27–54.

Huang, J., Hu, R., Rozelle, S., & Pray, C. (2005). Insect-resistant GM rice in farmer fields: Assessing productivity and health effects in China. *Science, 308*(5722), 688–690.

Huang, J., & Rozelle, S. (2018). China's 40 years of agricultural development and reform. In R. Garnaut, L. Song, & F. Cai (Eds.), *China's 40 years of reform and development 1978–2018* (pp. 487–506). Australia: The Australian National University Press.

Huang, J., Rozelle, S., & Pray, C. (2002a). Enhancing the crops to feed the poor. *Nature, 418*(6898), 678–684.

Huang, J., Rozelle, S., Pray, C., & Wang, Q. (2002b). Plant biotechnology in China. *Science, 295*(25), 674–677.

Huang, J., Xiang, C., & Wang, Y. (2015). *The impact of CIMMYT wheat germplasm on wheat productivity in China.* Mexico, DF: CGIAR Research Program on Wheat.

Huang, M., Jiang, P., Shan, S. et al., (2017). Higher yields of hybrid rice do not depend on nitrogen fertilization under moderate to high soil fertility conditions. *Rice, 10*, 43. https://doi.org/10.1186/s12284-017-0182-1.

Huang, M., Zou, Y., Jiang, P., Xia, B., Ibrahim, M., & Ao, H. (2011). Relationship between grain yield and yield components in super hybrid rice. *Agricultural Sciences in China, 10,* 1537–1544.

Huang, M., & Zou, Y. (2018). Integrating mechanization with agronomy and breeding to ensure food security in China. *Field Crops Research, 224,* 22–27.

Huang, W., Qiao, F., Liu, H., Jia, X., & Lohmar, B. (2016). From backyard to commercial hog production: Does it lead to a better or worse rural environment? *China Agricultural Economic Review, 8*(1), 22–36.

IFA (International Fertilizer Industry Association). (2014). IFA database. http://ifadata.fertilizer.org/ucSearch.aspx, Accessed in May 2019.

IFA (International Fertilizer Industry Association). (2017). IFA database. http://ifadata.fertilizer.org/ucSearch.aspx. Accessed in May 2019.

ITU. (2013). *Measuring the information society.* International Telecommunication Union Annual Report. https://www.itu.int/en/ITU-D/Statistics/Documents/publications/mis2013/MIS2013_without_Annex_4.pdf. Accessed in May 2019.

Jin, S., Ma, H., Huang, J., Hu, R., & Rozelle, S. (2010). Productivity, efficiency and technical change: Measuring the performance of china's transforming agriculture. *Journal of Productivity Analysis, 33*(3), 191–207.

Li, P. H. (1977). How we studied hybrid rice. *Acta Botanica Sinica, 19,* 7–10.

Li, Y. (1998). Development and germplasm base of maize hybrids in China. *Maydica, 43,* 259–269.

Lin, J. Y. (1992). Rural reforms and agricultural growth in China. *American Economic Review, 82*(1), 34–51.

Lin, W., Sun, X., & Liu, F. (2014). Development status and trend of agricultural aerial plant protection in China. *Agricultural Equipment and Technology, 1*(2014), 6–11.

Lin, J. Y., & Pingali, P. L. (1994). Economic assessment of the potential for hybrid rice in tropical Asia: Lessons from the Chinese experience. In S. S. Virmani (Eds.), *Hybrid rice technology—New developments and future prospects. Selected papers from the International Rice Research Conference.* International Rice Research Institute, Manila, Philippines.

Liu, J. (1997). The practice and idea of hereditary breeding of Chinese freshwater aquatic fishes. *Life Science Research, 1*(1), 1–8.

Liu, Y., Wang, J., Li, Y., & Zhang, L. (2011). Study on the adoption and determinants of agricultural water saving technologies. *Journal of Natural Resources, 26,* 932–942.

Lu, Y., Nie, J., & Liao, Y. (2018). Effects of urease and nitrification inhibitor on yield, nitrogen efficiency and soil nitrogen balance under double-rice cropping system. *Journal of Plant Nutrition and Fertilizers, 24*(1), 95–104.

Lu, B., Shi, L., Wang, Y., Wang, X., Wu, W., & Li, X. (2016). Sprinkler irrigation for cash crops in hilly area. *Chinese Agricultural Science Bulletin, 32,* 178–181.

Lu, X. G., Virmani, S. S., & Yang, R. C. (1998). Advances in two-line hybrid rice breeding. In S. S. Virmani, E. A. Siddiq, K. Muralidharan (Eds.), *Advances in hybrid rice technology. Proceedings of the 3rd International Symposium on Hybrid Rice*, November 14–16, 1996, Hyderabad, India. International Rice Research Institute, Manila, Philippines.

Luan, S., Sui, J., Meng, X., Luo, K., Cao, B., & Kong, J. (2014). Optimum contribution theory and the prospect of its application in selective breeding in aquaculture. *Progress in Fishery Sciences, 35*(6), 133–140.

Luo, X. (2014). Thoughts on accelerating the development of agricultural aviation technology in China. *Agricultural Technology and Equipment, 5*, 7–15.

Luo, W. (2013). *The application of bioflocs technology for crucian carp (Carassius auratue).* Master's thesis of Shanghai Ocean University, Shanghai, China.

Luo, X., Jiang, E., Wang, Z., Tang, X., Li, J., & Chen, W. (2008). Precision rice hill-drop drilling machine. *Transactions of Chinese Society of Agricultural Engineering, 24*(12), 52–56.

Ma, G. X. (2008). The analysis and prospect of China's import and export of aquatic products in 2007. *Agricultural Outlook, 5,* 31–35.

Ma, D. W., Qian, J., Liu, J., & Gui, J. (2016). Development strategy for integrated rice field aquaculture. *Engineering Sciences, 18*(3), 96–100.

Ma, H., Huang, J., & Rozelle, S. (2004). Reassessing China's livestock statistics: An analysis of discrepancies and the creation of new data series. *Economic Development and Cultural Change, 52*(2), 445–473.

Ma, J. (2012). Data analysis and political research on great famine. In *Paper presented at China Annual Symposium on History of International Communist Movement*, Qingdao, China [in Chinese].

MOA (Ministry of Agriculture and Rural Affairs). (2010). *Featured fishery.* Beijing, China: China Statistics Press.

MWR (Ministry of Water Resources). (2016). *Monthly groundwater dynamics (May).* Beijing, China: Ministry of Water Resources.

NBSC (National Bureau of Statistics of China) (1990–2014 & 2017 & 2018). *China statistical yearbook*. Beijing, China Statistics Press.

NBSC (National Bureau of Statistics of China). (2009). *China Compendium of Agricultural Statistics (1949–2008).* Beijing, China: China Statistical Press.

NBSC (National Bureau of Statistics of China). (2018). *Statistical bulletin of China national economic and social development (2017).* Beijing, China: China Statistical Press.

Pang, H. (2006). Analysis on the status of water-saving irrigation techniques and its development trends in China. *Soil and Fertilizer Sciences in China, 5,* 1–6.

Peng, S., Khush, G., Virk, P., Tang, Q., & Zou, Y. (2008). Progress in ideotype breeding to increase rice yield potential. *Field Crop Research, 108,* 32–38.

Pingali, P. L. & Heisey, P. W. (1999). *Cereal crop productivity in developing countries: Past trends and future prospects*, Economics Working Papers 7682, CIMMYT: International Maize and Wheat Improvement Center.

Pray, C., Ma, D., Huang, J., & Qiao, F. (2001). Impact of Bt cotton in China. *World Development, 30,* 931–948.

Qi, Y., Shi, S., Yu, X., Sheng, G., & Hu, J. (2007). China's super hybrid rice breeding research progress and strategy. *Chinese Agricultural Science Bulletin, 23*(9), 263–268.

Qiang, C. Z., Kuek, S. C., Dymond, A., Esselaar, S. (2012). *Mobile applications for agriculture and rural development*. World Bank Group report:5–10.

Rogers, S. G. (1991). Free DNA methods for plant transformation. *Current Opinion in Biotechnology, 2,* 153–157.

Rozelle, S., & Huang, J. (2000). Transition, development and the supply of wheat in China. *Australian Journal of Agricultural Economics, 44,* 543–571.

Shen, L., Ma, Y., Li, X., Ma, H., & Shi, Z. (2012). Present situation and development trend of modern chicken raising equipment in China. *China Poultry, 34*(08), 4–6.

Sheng, Y., Song, L., & Yi, Q. (2017). *China's new sources of economic growth.* Beijing, China: Social Sciences Academic Press.

Shi, M. (1981). Preliminary report of late japonica natural dual-purpose male sterile line on the breeding and application in rice. *Hubei Agricultural Science, 7,* 1–3.

Shi, X., & Hu, R. (2017). Rice variety improvement and the contribution of foreign germplasms in China. *Journal of Integrative Agriculture, 16*(10), 2337–2345.

Sonntag, B., Huang, J., Rozelle, S., & Skerritt, J. (2005). *China's Agricultural and rural development in the early 21st Century*. Canberra Austria: Australian Centre for International Agricultural Research.

Su, X., & Liu, Y. (2014). Application of GPS satellite positioning and automatic navigation driving system for agricultural machinery. *Agricultural Development and Equipment, 6,* 93–94.

Sun, D., Wang, S., & Na, R. (2015). The relationship between feed nutrition and pig immunity. *Feed China, 2015*(15), 25–26.

Tian, Z., Wang, J., Liu, S., et al. (2015). Application effects of coated urea and urease and nitrification inhibitors on ammonia and greenhouse gas emissions from a subtropical cotton field of the Mississippi delta region. *Science of the Total Environment, 533,* 329–338.

Tian, F., Hu G., & Tian, F. (2006). MaiKe folklore studies. *Journal of Northwestern Polytechnical University, 2006* (02), 13–15.

Vasil, I. K. (2007). Molecular genetic improvement of cereals: Transgenic wheat (*Triticum aestivum L.*). *Plant Cell Reports, 26,* 1133–1154.

Wan, A., Chen, X., & He, Z. (2007). Wheat stripe rust in China. *The Australian Journal of Agricultural Research, 58,* 605–619.

Wang, J. (2018). Business cycle continues to rise, the institutions spotlight on white-feather chicken industry as the "money king". *Shanghai Securities News*. 7/23/2018 (A03).

Wang, H., Yu, F., Reardon, T., Huang, J., & Rozelle, S. (2013). Social learning and parameter uncertainty in irreversible investments: Evidence from greenhouse adoption in northern China. *China Economic Review, 27,* 104–120.

Wang, Q., & Mei, X. (2017). Strategies for sustainable use of agricultural water resources in China. *Journal of Agriculture, 7,* 80–83.

Wang, S., Zhang, Y., Yu, N., & Yan, W. (2005). Development status of infiltration irrigation technology and its application in protected field. *Transactions of the Chinese Society of Agricultural Engineering, 21,* 92–95.

Wang, T., Ma, X., Li, Y., Bai, D., Liu, C., Liu, Z., et al. (2011). Changes in yield and yield components of single-cross maize hybrids released in China between 1964 and 2001. *Crop Science, 51,* 512–525. https://doi.org/10.2135/cropsci2010.06.0383.

Wang, S. L., Huang, J., Wang, X., & Tuan, F. (2019). Are China's regional agricultural productivities converging: How and why? *Food Policy, 86,* 101727.

Wu, X. (2009). Prospects of developing hybrid rice with super high yield. *Agronomy Journal, 101,* 688–695.

Wu, M., Zhang, J., Hu, L., Ren, W., Sun, C., & Tang, J. (2014). Practical technology for improving rice-fish co-culture system. *Chinese Agricultural Science Bulletin, 30*(33), 51–55.

Wu, X., Mei, X., Cai, D., Zhao, Q., Zhuang, Y., & Zhao, Y. (2005). Trend and difference for development on key technology of agricultural water-saving in China and developed countries. *Chinese Journal of Agricultural Resources and Regional Planning, 26,* 28–32.

Xie, W., Tariq, A., Cui, Q., & Huang, J. (2017). Economic impact of commercializing insect-resistant GM maize in China. *China Agricultural Economic Review, 9*(3), 340–354.

Xu, G. (2018). Effects of feed nutrition on reproductive rate of pigs. *Technical Advisor for Animal Husbandry, 2018*(01), 49.

Xu, Z., & Xu, K. (2008). Fishery production history, developing process and foreign trade in China. *China Fishery Economy, 5*(26), 39–43.

Yang, C., Zhu, D., Yuan, P., Huang, Q., Zheng, X., & Yang, A. (2006). Research on relationship between traits of rice matter production and grain yield. *Southwest China Journal of Agricultural Science, 19,* 560–564 (in Chinese with an English abstract).

Yang, N., & Jiang, L. (2018). The centennial development history and research frontiers of animal genetics and breeding. *Journal of Agriculture, 2018*(1), 55–60.

Yin, J., Huang, J., & Lu, H. (2005). Comparative study of urban land use based on GIS and RS. *Agricultural Mechanization Research, 2005*(1), 119–120.

Yuan, L. (1987). Strategy for hybrid rice breeding. *Hybrid Rice, 1,* 1–3.

Yuan, L. (2001). Develop hybrid rice depending on the innovation of science and technology to ensure the food security of our country. *Review of China Agricultural Science and Technology, 3*(2), 54–56.

Yuan, L. (2003). Recent progress in breeding super hybrid rice in China. In S. S. Virmani, C. X. Mao, & B. Hardy (Eds.), *Hybrid rice for food security, poverty alleviation, and environmental protection. Proceedings of the 4th International Symposium on Hybrid Rice, Hanoi, Vietnam, May 14–17, 2002.* International Rice Research Institute, Manila, Philippines.

Yuan, L. (2004). Hybrid rice technology for food security in the world—Proceedings of the FAO rice conference: Rice is life. *International Rice Commission Newsletter, 53,* 24–25.

Yuan, L. (2008). Progress of super hybrid rice breeding. *China Rice, 1,* 1–3.

Yuan, L., & Virmani, S. (1988). Status of hybrid rice research and development. In *Hybrid rice: Proceedings of the International Symposium on Hybrid Rice, October 6–10, 1986*, Changsha, Hunan, China. International Rice Research Institute, Manila, Philippines.

Yuan, L., Q. Deng, & C. Liao. (2004). Current status of industrialization of hybrid rice technology. In *Report on China's development of biotech industries.* Beijing, China: Chemical Industry Publishing House.

Yuan, S., Nie, L., Wang, F., Huang, J., & Peng, S. (2017). Agronomic performance of inbred and hybrid rice cultivars under simplified and reduced-input practices. *Field Crops Research, 210,* 129–135.

Zhang, W., Yi, J., Zhang, F., et al. (2017). *China fertilizer development research report 2016*. Beijing, China: China Agricultural University Press.

Zhang, Q. (2012). *Practice and prospect in fish sex control*. Paper presented at Scientific Forum on Fish Seeding Engineering and Sustainable Development, Qingdao, China.

Zhang, H., Xue, Y., Wang, Z., Yang, J., & Zhang, J. (2009). Morphological and physiological traits of roots and their relationships with shoot growth in "super" rice. *Field Crops Research, 113,* 31–40.

Zhang, X., & Hu, B. (2016). Research progress of popularization and application of agricultural water-saving irrigation techniques. *Chinese Agricultural Science Bulletin, 32*(2016), 181–186.

Zhao, D. (2016). The policy and its impact of planned purchase and supply during 1966–1976. *Journal of South China Agricultural University (Social Science Edition), 2*(15), 1–11.

Zhou, W., Li, L., He, W., & Lv, H. (2004). Advances in canal seepage control techniques in China. *Advances in Science and Technology of Water Resources, 5*(2004), 60–63.

Zhu, P. (2016). A study on the dilemma and solution of the development of e-commerce in rural China. *Journal of Commercial Economics, 10*(2016), 68–69.

Zhu, W., & Wang, J. (1996). Surface mulching and conservation of soil water. *Research of Soil and Water Conservation, 3*(1996), 141–145.

Chapter 5
Innovations in Incentive Policies in Indian Agriculture

5.1 Introduction

Policies play a pivotal role in shaping the incentive structure for farmers. These incentives not only contribute to economic development but also encourage farmers to make investments to increase production and adopt new technology. Through their trade and marketing policies, both the central and the state government play a critical role in developing and administering overarching policies in Indian agriculture.

Notwithstanding the objective of the Commission for Agricultural Costs and Prices (CACP) and the Food Corporation of India (FCI) to ensure remunerative producer price as well as lower consumer prices during the Green Revolution—through policy instruments such as minimum support prices (MSPs), a subsidised ration price, restrictive trade policies and farm input subsidisation—the longstanding nature of these policies, however, has proved to be inefficient in responding to the dynamic challenges faced by the country. In reality, for most agricultural commodities, the average marketing yard (locally named as *mandi*) sale price remains 10–30% below the MSP. Further, high food subsidies, abrupt trade restrictions, bans and infrastructural deficiencies leads to depressing farm prices.

Similarly, the long-established Essential Commodities Act (ECA) and Agricultural Produce Market (Regulation) Committee Act (APMC) that were once put in place to protect producers' and consumers' interests, have impeded the functioning of agricultural markets, imposing huge intermediation costs. Even the positive support extended through subsidised farm inputs proved to have the effect of distorting the market through inefficient use of valuable resources. A joint study conducted by OECD and ICRIER quantifies the overall support provided to farmers through domestic and trade policies between 2000–01 and 2016–17 to be negative 14.4%

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of gross farm receipts[1] and concludes that the policy intervention in Indian agriculture is severely biased against farmers (in favour of consumers). This means that farmers are heavily taxed through restrictive marketing, trade policies and infrastructural deficiencies. In terms of 2017–18 prices, the study also found that farmers have effectively lost income equivalent to USD0.69 trillion[2] or Rs. 45 trillion cumulatively (between 2000–01 and 2016–17).

Thus, the looming concern at present is the direction of policymaking towards increasing MSPs to unsustainable levels and the announcement of loan waivers by several state governments at the time of assembly elections. These policy measures are not just regressive but are also highly distortionary, non-inclusive and unsustainable. Experts believe that these "band aid" solutions are nothing but atonement for siphoning income from farmers over so many years and are not aimed at reforming the agriculture sector.

This paper provides a critical review of support policies in India based on the principle of CISS: competitiveness (cost efficiency); inclusiveness; environmental and financial sustainability and, finally, scalability. It further highlights the need for structural reforms and a stable policy framework to improve incentives for farmers in a more predictable and structured manner. The paper covers unfolding innovations in the incentive policy framework—in particular, the switch towards direct income/investment support policies at the national as well as state level. It is believed that only a sustainable income support framework and investments in building efficient agricultural markets have the potential to cure India's extensive farm distress and build competitive, efficient, inclusive, sustainable and scalable agriculture. More specifically, we evaluate the following incentive policies, announced and/or recommended by the government, which are pertinent to developing structured means for farmers to realise better prices:

- ***Pradhan Mantri Annadata Aay Sanrakshan Abhiyan*** **(PM AASHA)** for price stabilisation through assured procurement and price deficiency payments.
- **Direct income (investment) support-based schemes such as *rythu bandhu* and KALIA** to induce an investment-enabling environment and provide livelihood support.
- **Reforms in marketing policies, arrangements and infrastructure** to get the markets right.

This paper is organised in eight sections. After this introductory section, in Sect. 5.2, we evaluate the output price regime based on its economic efficiency, effective implementation, inclusivity, sustainability (both financial and environmental) and scalability. In Sect. 5.3, we discuss the components of the recently announced output price support policy—PM AASHA—by the central government. This section also talks about the case study of Madhya Pradesh, which implemented a price deficiency payment scheme called *"Bhavantar Bhugtan Yojana* (BBY)". In Sect. 5.4,

[1]Gross farm receipts are measured by the value of total production (at farm gate prices), plus budgetary support.

[2]Converted to USD using current exchange rate of USD1 = Rs. 67.07 in 2016–17 (RBI 2017–18).

we evaluate the input price regime, again based on its economic efficiency, inclusivity, financial and environmental sustainability and scalability. We also discuss the need to switch from subsidies to direct benefit transfers (DBT) in the case of farm inputs. In Sect. 5.5, we discuss direct income support-based schemes recently launched by states such as Telangana, Odisha, Jharkhand and West Bengal, as well as by the central government through innovations in agricultural marketing chains, innovations in alternative marketing channels and innovations in marketing infrastructure. In Sect. 5.6, we summarise the net effect of government intervention through these policies on Indian farmers. In the final Sect. 5.7, we present concluding remarks and the way forward.

5.2 Evaluation of the Output Price Regime

In 1965, the Government of India institutionalised the Agricultural Prices Commission (APC) to implement an integrated and balanced price policy in the country. Through minimum support prices (MSPs) for products and guaranteed procurement, the government developed a long-term perspective for price policies to eliminate uncertainties for farmers at the time when they need to make decisions about crops and to improve overall price realisation for them (while, at the same time, insulating consumers against price fluctuations). In March 1985, the name of the institution was changed to the Commission for Agricultural Costs and Prices (CACP),[3] and focus was shifted towards developing a price structure that affects the production pattern in line with the overall needs of the economy (Sen and Chatterjee 2002). At present, based on the recommendations of the CACP, the Department of Agriculture, Co-operation and Farmers' Welfare, Government of India, has declared MSP for 24 crops (comprising seven cereals (paddy, wheat, maize, sorghum, pearl millet, barley and *ragi*); five pulses (*gram, arhar/tur, moong, urad*, *masur*/lentil); eight oilseeds (groundnut, rapeseed (Toria, Mustard and Sarson), soybean, sesamum, sunflower, safflower, niger seed and *toria*); and four commercial crops (copra, sugarcane, cotton and raw jute), before their sowing seasons (Gulati, Ferroni and Zhou 2018). Occasionally, the central or state governments announce a bonus over and above the MSP to incentivise the production of certain crops during specific time periods (OECD/ICRIER 2018). CACP determines the MSPs based on several factors such as demand and supply; cost of production; price trends in the market (both domestic and international); inter-crop price parity; terms of trade between agriculture and non-agriculture; and the likely implications of MSP on the consumers of that product. At the time of harvesting, government's target is to procure these crops at guaranteed support prices via the operations of public and co-operative procurement agencies, namely the Food Corporation of India (FCI), the National Co-operative Marketing

[3]CACP official website (https://cacp.dacnet.nic.in/).

Federation of India Ltd. (NAFED),[4] the Cotton Corporation of India (CCI) and the Jute Corporation of India (JCI). Notwithstanding this, in most places, MSP is effective mainly for four crops: wheat, paddy, cotton (modestly) and sugarcane (mills are legally obligated to buy cane from farmers at prices fixed by government) (Chatterjee and Kapur 2016) and influences farmers' production choices (OECD/ICRIER 2018).

- **Competitiveness (Cost Efficiency)**

One of the key challenges with a long-established procurement-backed MSP policy is that the central government may announce MSPs for 24 commodities (including fair and remunerative price (FRP) for sugarcane) on paper, but their implementation remains largely indicative in practical terms (Goklany 2016). Only wheat and rice are procured by the FCI on a continuous basis, and that too from only a few states, while procurement mechanisms for other crops—pulses, oilseeds, sugar and cotton—are largely inadequate. The implication is that the majority of farmers in the country do not really benefit from MSPs (Haque and Joshi 2018).

The FCI, along with other central and state agencies, issues procured food grains (wheat and rice) to relevant agencies at central issue prices (CIP)[5] for distribution to consumers under the targeted public distribution system (TPDS) or other welfare schemes (OECD/ICRIER 2018) and to maintain buffer stocks of food grains (mainly wheat and rice) for food security and price stability. However, the disproportionate procurement of wheat and rice by the government, as well as significantly rising MSPs, results in frequent overflowing of stocks over and above the buffer stocking norms.[6] Against the buffer norm of 31.9 MMT of rice and wheat together, total central pool stocks on 1 July 2014 were almost double this figure, at 61.03 MMT (21.2 MMT of rice and 39.8 MMT of wheat). Moreover, in line with significantly rising MSPs, stocking norms were actually raised to 41.1 MMT in 2015–16. Even after this, as of July 2018, rice and wheat stocks together were higher than the revised norms (69.38 MMT against 41.1 MMT). As shown in Fig. 5.1, over the years the FCI has held much higher stocks than required. This imposes huge costs, both in terms of locking in of resources as well as the economic cost of carrying stocks. Stagnant CIP[7] and rising economic costs in effect create a mounting food subsidy burden on the exchequer, which, at USD22.5 billion[8] (or Rs. 1453.4 billion) in 2017–18, was already pretty high (OECD/ICRIER 2018). Price signalling through MSPs and government procurement is, therefore, distortionary in the economic sense as

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[4]NAFED is a central agency for procuring oilseeds, pulses and cotton under the Price Support Scheme (PSS).

[5]CIP is set by the government and is lower than the MSP.

[6]The stocking norms are the minimum quantities of wheat and rice that must be maintained in each quarter by the central government. These comprise "food security reserves" for meeting shortfalls in procurement and "operational stocks" to meet the monthly requirements for the targeted public distribution and other welfare schemes (OECD/ICRIER 2018).

[7]CIP for wheat is Rs. 2/kg and for rice, Rs. 3/kg, under the National Food Security Act (NFSA), 2013.

[8]Converted to USD using the exchange rate of USD1 = Rs. 64.45 in 2017–18 (RBI 2017–18).

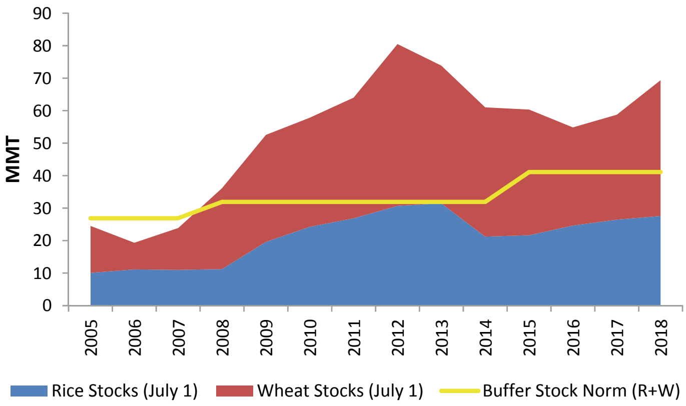

Fig. 5.1 Overflowing wheat and rice stocks compared to norms, India. *Source* Food Corporation of India

it results in an unprecedented increase in production, particularly in surplus states where farmers are effectively discouraged from diversifying into other crops. Excess production in the absence of adequate demand, lack of storage and processing facilities and the existence of restrictive export policies lead to the piling up of stocks over and above what is necessary.

It is worth highlighting that in order to increase farmers' income through assured prices, the union government in its 2018 budget announced that MSPs would be raised to 50% over and above the cost of production (i.e. the actual paid-out cost plus the imputed value of family labour, referred to as $A_2 + FL$). As a result, the hike in MSPs for 2018–19 compared to 2017–18 is quite large, ranging from 4% in the case of red gram (*arhar*) and black gram (*urad*) to 52% for finger millet (*ragi*) (see Fig. 5.2). The median hike is about 25%, which is much larger than the median hike of 3–4% in the last couple of years (Sekhar 2018). The cost-plus pricing, therefore, is more a political tool than an economic one because without demand considerations and inter-crop price parity, it is likely to cause major distortions in the functioning of markets. It can be seen from Fig. 5.2 that the MSP of sorghum (*jowar*) hybrid and finger millet increased by 43% and 52%, respectively, in 2018–19 compared to 2017–18. If these MSPs are actually implemented effectively, the farmers will find these crops relatively attractive and increase their production. The substantial increase in production without any change in demand is likely to create glut in the market and depress prices, requiring either large-scale procurement by the government at an enhanced MSP, or huge compensation for price deficiency (Gulati and Chatterjee 2018a, b). Moreover, raising cotton and paddy MSPs over and above the international reference price will eventually make India less competitive in global markets, adversely affecting exports. This will again put pressure on the domestic market to absorb higher accumulated stocks only to depress prices and cause greater inefficiency, necessitating either massive procurement or large-scale compensation for price deficiencies. Additionally, cost-plus pricing discourages farmers from improving efficiency and

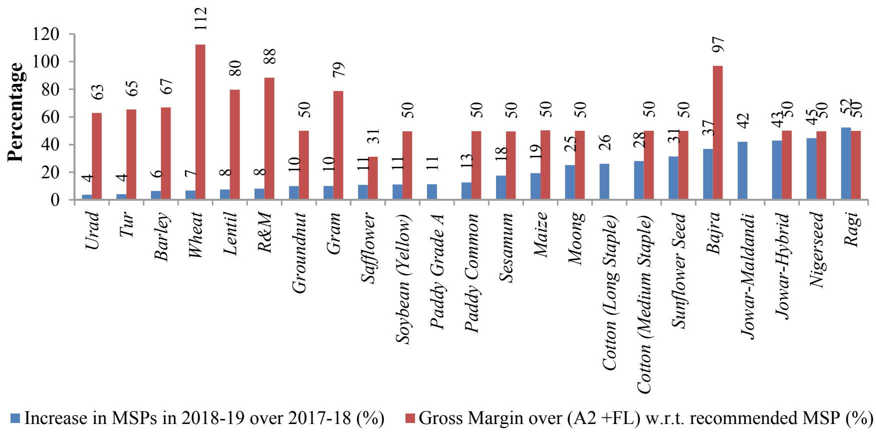

Fig. 5.2 Percentage increase in MSPs in 2018–19 over 2017–18 and gross margin of MSP over (A2 + FL) cost in 2018–19, India. *Source* (CACP, Price Policy for Kharif Crops: The Marketing Season 2018–19, 2018a; CACP, Price Policy for Rabi Crops: The Marketing Season 2018–19, 2018b)

reducing costs; that is, it locks in the highest cost of production and lets the least efficient farmers stay in business, leading to inflationary pressures (OECD/ICRIER 2018). Therefore, pursuing cost-plus pricing without any consideration of demand side is economically irrational and is likely to create higher inefficiencies in the food system.

The next challenge when higher MSPs are announced is to ensure that farmers actually receive them, especially when it is known that the government lacks the capacity to procure, store and distribute 24 commodities under the existing output price regime (Gulati and Chatterjee 2018a, b). Notwithstanding the several schemes announced by the Government of India to ensure procurement at MSP such as the market intervention schemes (MIS), price support schemes (PSS) and the price stabilisation fund (PSF) to mitigate price risks, it can be seen from Fig. 5.3 that the implementation of increased MSPs remains a distant goal. Agricultural commodities are sold 10–30% below the MSPs announced during November 1 and 30. Among others, pulses and oilseeds are the most affected crops. As a result of market signals through the procurement of pulses and oilseeds under PSF/PSS, farmers increased the production of pulses considerably from 17 and 16 MMT, respectively, in 2014–15 and 2015–16 to 23 and 24 MMT, respectively, in 2016–17 and 2017–18. The production of oilseeds also increased from 28 and 25 MMT, respectively, in 2014–15 and 2015–16 to 31 and 30 MMT in 2016–17 and 2017–18, respectively. This amounted to an increase of 43% in the production of pulses and 24% in the case of oilseeds (Gulati, Chatterjee and Hussain 2018). However, the government could not effectively adjust the import policy[9] in relation to domestic MSP policy in time. As a result, lower international prices and zero per cent duty on imports of pulses led to an influx in imports of 6.6 and 5.8 MMT, respectively, in 2016 and 2017. Record

[9]Imports were planned by the government to meet the general deficit in supplies relative to demand.

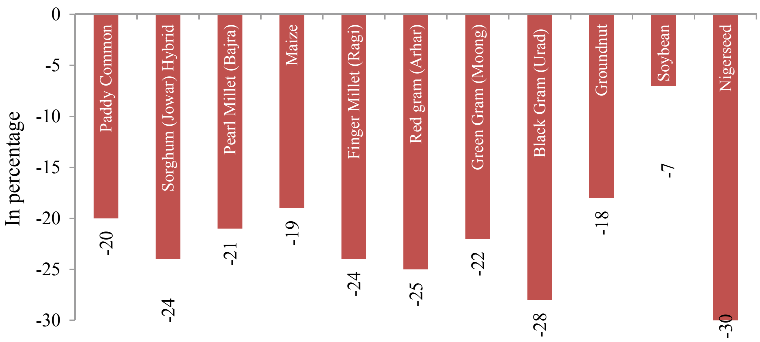

Fig. 5.3 Percentage difference in mandi prices between November 1 and 30 with respect to MSP 2018–19, India. *Source* Gulati and Chatterjee (2018a, b)

high production coupled with record high imports led to excess supply, which drove the rapidly declining domestic market prices (of pulses and oilseeds) below MSP. Further, the unstable policy environment and uncertainty regarding stocking limits discouraged traders and other stakeholders from holding stocks and participating in trading, putting pressure on the government to procure and store the excess supply (Gulati, Chatterjee and Hussain 2018).

Global experiences also reflect that higher output prices, along with ineffective procurement mechanisms and restrictive trade policies, lead to a glut in the market. For instance, the European Economic Community (EEC) in 2006 raised the prices for milk products above the international benchmark, leading to a glut in the domestic markets for butter and milk. China made the same mistake recently, raising MSPs for wheat, rice and corn significantly higher than world prices, leading to an accumulation of stocks (touching 300 MMT in 2016–17). Therefore, it is useful to learn from the mistakes of other countries and bring in policies which are market-aligned, send the right price signals to farmers and augment their incomes on a sustainable basis.

- **Inclusiveness**

It has been observed that minimum support prices (MSPs)—envisioned as an insurance mechanism for all farmers—have instead become effectively price floors, with benefits skewed in favour of medium and large farmers who grow these crops (mainly wheat, rice, cotton and sugarcane). According to data received from the Government of Odisha by CACP on paddy procurement across categories of farmers (i.e. marginal, small, semi-medium, medium and large farmers) for the *kharif* season 2016–17, marginal and small farmers (who account for 73% of operational holdings) account for only an 18% share in central procurement, while medium and large farmers (cultivating about 9% of operational holdings) account for approximately a 65% share in procurement (CACP 2018a, b). Thus, while in principle the MSP exists for most farmers for most crops, in reality its impact is limited to a very few farmers in specific states only.

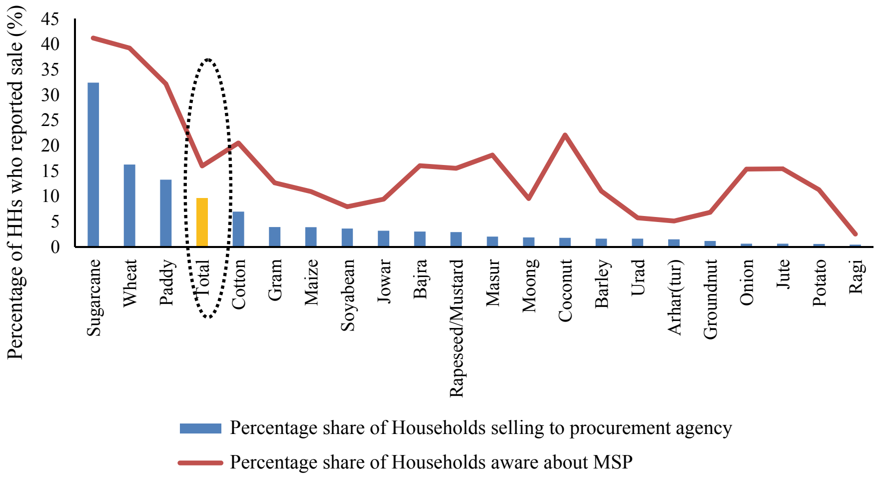

Fig. 5.4 Percentage of households (HHs) aware of MSP and selling to a procurement agency—weighted average for two seasons (July 2012 to June 2013), India. *Source* Statement 19 A&B—Key Indicators of Situation of Households in India, NSS 70th Round, NSSO

Non-inclusiveness and ineffective implementation is also reflected in the large gaps in the percentage of farmers who sold their produce at MSPs to government procurement agencies. The 70th round of the Situation Assessment Survey by the National Sample Survey Office (NSSO) for 2012–13 reveals that fewer than 10% of farmers holding stocks sold their outputs at MSPs, with widespread variations reported across crops (see Fig. 5.4). Sugarcane, wheat and rice recorded the highest percentages of farmers (selling at MSPs) at 32.4%, 16.2% and 13.2%, respectively. For most pulses and other crops, the percentage was well below 4%. This reflects the lack of reach and depth of the government's procurement mechanism.

- **Sustainability**
  - **Financial Sustainability**
    The FCI incurs an "economic cost" (the sum of MSP, procurement incidentals and distribution cost) in the procurement of grains (mainly wheat and rice) through open market operations. The difference between the economic cost and the CIP is termed "operational loss", which is reimbursed by the central government as food subsidies (OECD/ICRIER 2018). According to CACP price policy reports, the economic cost in the case of rice has increased significantly over the years from USD0.37 per kg[10] (or Rs. 17.41 per kg) in 2008–09 to USD0.51 per kg[11] (or Rs. 32.94 per kg) in 2017–18 and in the case of wheat, from USD0.3 per kg[12] (or Rs. 13.81 per kg) to USD0.37 per

[10]Converted to USD using the exchange rate of USD1 = Rs. 45.9 in 2008–09 (RBI 2017–18).

[11]Converted to USD using the exchange rate of USD1 = Rs. 64.45 in 2017–18 (RBI 2017–18).

[12]Converted to USD using the exchange rate of USD1 = Rs. 45.9 in 2008–09 (RBI 2017–18).

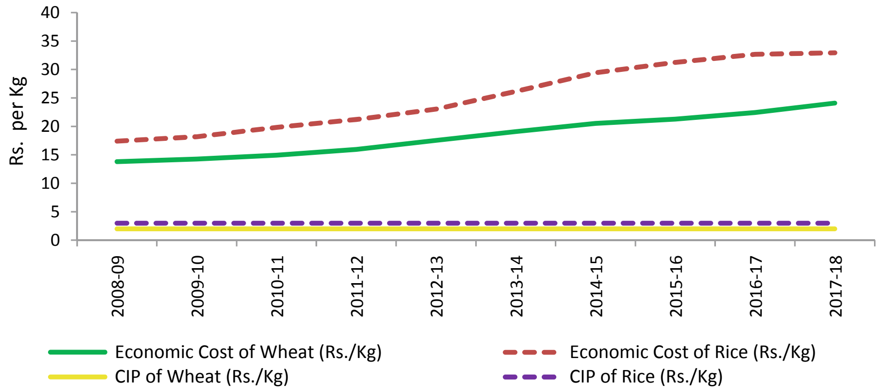

Fig. 5.5 Rising economic cost of rice and wheat and stagnant CIPs for the AAY, India. *Source* CACP (2014, 2017, 2018a, b)

kg[13] (or Rs. 24.09 per kg) during the same period (CACP 2014, 2018a, b) (Fig. 5.5). The continuously increasing statutory taxes and other incidentals levied by state governments are major contributors to rising economic costs. These statutory levies,[14] *mandi* tax, VAT, etc., are a major source of market distortions (CACP 2017).

The continuously widening gap between the economic cost (stemming from rising MSPs, procurement incidentals and distribution cost) and stagnant CIP (USD0.04 per kg for rice and USD0.03 per kg for wheat) for the *Antyodaya Anna Yojana* (AAY) led to massive budgetary pressure on the exchequer in the form of a ballooning food subsidy bill, which went from USD9.5 billion (or Rs. 437.5 billion) in 2008–09 to USD22.5 billion (or Rs. 1453.3 billion)[15] in 2017–18. Apart from these direct fiscal costs, there are also additional costs, arising from leakages (the illegal diversion of subsidised food grains from the public distribution system (PDS) to the open market) accounting for about 34.6% (as reported in 2011–12) and loss due to poor storage and transport facilities (Shreedhar et al. 2012; Himanshu and Sen 2013). But the real issue is that there are unpaid FCI food subsidy bills that have been accumulating over the years, and, as of 31 March 2018, these stood at a massive USD20.7 billion[16] (or Rs. 1.34 trillion). Additionally, there are outstanding bills for decentralised procurement (DCP) with states for which no reliable estimates are available. In total, the country's real food subsidy bill is already approaching approximately USD46.5 billion (or Rs. 3 trillion) (Gulati and Saini 2018a, b), which makes it unsustainable.

[13] Converted to USD using the exchange rate of USD1 = Rs. 64.45 in 2017–18 (RBI 2017–18).

[14] The statutory levies imposed by the states are ad-valorem and linked to the MSP.

[15] Budget Estimate.

[16] Converted to USD using the exchange rate of USD1 = Rs. 64.45 in 2018 (RBI 2017–18).

- **Environmental Sustainability**
  Farmers respond to the price signals provided by the MSPs and continue to grow predominantly crops which give them an assured price; for instance, water-intensive crops such as rice and wheat are grown mainly in the water-stressed northern and north-western regions of the country. Together, Punjab and Haryana accounted for a 15% share in total rice production and a 30% share in total wheat production in the triennium ending (TE) 2015–16 (Government of India 2016a, b) as well as a 38% share in total rice procurement and a 62% share in wheat procurement (OECD/ICRIER 2018). The existing policy framework lacks a clear incentive structure for farmers to ensure efficient and sustainable agriculture, thus exacerbating the pressures on natural resources such as water. In Punjab and Haryana (2016), 51% and 75%, respectively, of the local administrative blocks are observed to be over-exploited in terms of water use (OECD 2017). At the all-India level, the sector accounts for about 90% of water use where irrigation is predominantly based on groundwater (by tube wells), which is most suitable for fragmented holdings but leads to over-exploitation of scarce water reserves. Out of 66 million hectares of total irrigated land, 60% (i.e. about 40 million hectares) is dedicated to rice and wheat (OECD/ICRIER 2018). Highly subsidised or free power aggravates the problem as it enables farmers to continue pumping from these wells, even

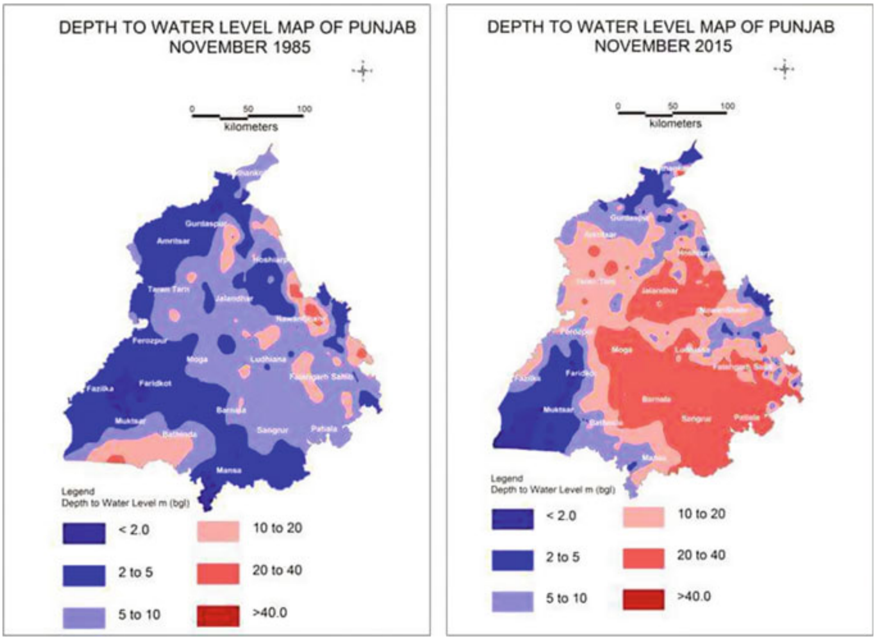

Fig. 5.6 Water crisis in Punjab, India. *Source* Water Productivity Mapping of Major Indian Crops (ICRIER-NABARD), 2018

when the underlying aquifer has reached worryingly low levels. This raises the most serious concerns in some northern, north-western and southern states, namely Rajasthan, Andhra Pradesh, Karnataka, western Uttar Pradesh, Punjab and Haryana (OECD/ICRIER 2018). Additionally, the water rates fixed for the supply of water from many major, medium and small projects funded by the government cover only a small fraction of the operating and maintenance costs, thus limiting the capacity of the states to maintain these projects (OECD/ICRIER 2018). In addition to a water crisis, agriculture contributes 18% of total greenhouse gas (GHG) emissions where the primary production stage, livestock rearing, use of chemical fertilisers, soil degradation, paddy rice cultivation and residue management practices are major contributors (IARI 2014). Therefore, price policy, like MSP, is unsustainable, both financially and environmentally (Fig. 5.6).

- **Scalability**

Price support procurement effectively operates for a limited set of crops in specific states only. The mechanism has not been scaled up, even though it has been implemented for many years. Among *kharif* crops, procurement operations are largely limited to rice with Punjab continuing to be the largest contributor to the central pool with an estimated share of about 27%, followed by Chhattisgarh (10%), Odisha (10%) and Andhra Pradesh (9%) in TE 2016–17 (CACP 2018a, b). However, in some states such as Assam, Karnataka and Tamil Nadu, which hold a reasonable share in the marketed surplus of rice, procurement operations are either absent or very limited. For example, there was almost negligible procurement of rice in Assam during TE 2016–17, even though rice is a major crop in the state. As regards West Bengal, the procurement share is only 5% although the marketed surplus share is 14%. Moreover, even market prices were below MSP in states such as Assam, West Bengal and Eastern UP, while in the case of *rabi* crops, procurement operations are largely confined to wheat. The Food Corporation of India (FCI) procures wheat at MSP, while NAFED undertakes procurement of pulses and oilseeds. In addition to this, when market prices fall below MSP, other agencies such as the National Co-operative Consumers Federation of India Ltd. (NCCF), the Small Farmers Agribusiness Consortium (SFAC) and the Central Warehousing Corporation (CWC) also procure pulses and oilseeds. However, no sizeable procurement has so far been undertaken by these agencies with the exception of the FCI (CACP 2018a, b). Additionally, the state-wise procurement pattern does not match the production pattern during TE 2017–18; out of the total wheat procurement of about 27 million tonnes, 39.9% was contributed by Punjab, 25.6% by Haryana and 22% by Madhya Pradesh. These three states account for 87.6% of total wheat procurement in the country. Uttar Pradesh, which is the largest producer of wheat in the country with an estimated share of about 28.2%, contributes about 8.3% to procurement. The share of Bihar in total wheat production is about 5%, but its share in procurement is negligible. Notwithstanding the large number of procurement centres in Bihar and Uttar Pradesh, procurement is inadequate; this is indicative of low capacity utilisation and infrastructural weaknesses.

This suggests that India's policies and related institutions are to a large extent concerned with wheat and rice only. The biggest concern, however, is the large-scale efficiency losses in agricultural markets due to higher MSPs. It is ironical that, even after 70 years of independence, the marketing system for agricultural products remains unsupportive of farmers, preventing them from discovering and realising the best possible prices for their produce across space and time (Gulati and Chatterjee 2017).

5.3 Innovations in Output Price Support Policy

Realising that merely increasing the MSPs is inadequate and that it is more important to ensure that farmers get the full benefit of the announced MSP, the present government, in September 2018, adopted a more holistic approach with the announcement of an umbrella scheme called *"Pradhan Mantri Annadata Aay Sanrakshan Abhiyan" (PM-AASHA).* The scheme aims to ensure remunerative prices to farmers for their produce as announced for 2018–19 either through a robust procurement mechanism in coordination with state governments (Government of India 2018a, b) or by compensating farmers for the difference between MSP and the received market price. The umbrella scheme comprises three sub-schemes:

1. Price Support Scheme (PSS),
2. Price Deficiency Payment Scheme (PDPS),
3. Pilot of Private Procurement and Stockist Scheme (PPPS).

The price support scheme (PSS) involves physical procurement of crops by central nodal agencies in coordination with state governments. Along with NAFED, FCI will also take up PSS operations in states/districts. The scheme groups procurement costs, storage and price loss due to procurement and suggests the financial implications of implementing it under different assumptions, taking into account price losses. For instance, for losses up to 25% of the value of MSP, the central government will bear the entire compensation cost, for losses of between 25 and 30%, the central government and the state will bear costs in the ratio of 60:40, and in the case of a price loss of between 30 and 40%, there will be a 50:50 sharing of costs between the centre and the state. The payment of price loss to farmers, however, is subject to a ceiling which may not exceed 25% of the MSP (Chand 2018).

On the other hand, the price deficiency payment scheme (PDPS) does not involve any physical procurement of crops. In this case, preregistered farmers who sell produce in the notified market yard through a transparent auction process are directly compensated for the difference between MSP and the selling/modal price. The scheme emulates Madhya Pradesh's *Bhavantar Bhugtan Yojana* (BBY), which is discussed in detail in a later section. The scheme suggests compensating for the difference between the MSP and the sale/modal price received by farmers with the central and state government each bearing half the cost if the losses to farmers amount to between 15 and 25%. However, the maximum price differential payable will have an upper limit of only 25% of the MSP value (Chand 2018).

With regard to the private procurement and stockist scheme (PPSS), the selected private agency will procure the commodity at MSP in the notified markets during the notified period from registered farmers in consonance with the guidelines whenever the prices in the market fall below the notified MSP and whenever the state/union territory (UT) authorises them to intervene (Government of India 2018a, b). The scheme provides policy and tax incentives such as those listed below to encourage the entry of private players.

- Exemption from import/export restrictions and stable trade policy environment.
- Exemption from the market fee levied under the Model Produce and Livestock Marketing Act (APML).
- Adjustment of losses in one year against profits in other years.
- Improved access to credit under priority sector lending (PSL) against collateral of procured quantity.
- Government/PSU storage facilities.

An analysis of the three schemes mentioned above, and the views of states received by *NITI Aayog*, suggests that PSS and PDPS are effective and workable options for ensuring MSP to farmers, and that the states should be given flexibility to choose among different options for different commodities. However, so far none of the states has implemented the scheme. Even Madhya Pradesh, which piloted a PDPS scheme called *"Bhavantar Bhugtan Yojana"* in *kharif* 2017, has discontinued it due to the limited coverage of production (only 23%) and a large financial burden of USD0.3 billion (or Rs. 19.44 billion). Moreover, there is no private participation as of now. Therefore, we still have a long way to go in creating structures and policies that reverse the adverse terms of trade faced by many farmers.

Bhavantar Bhugtan Yojana (BBY)—Price Deficiency Payment Scheme

In 2017, the Government of Madhya Pradesh (GoMP) introduced an innovative price deficiency payment scheme—*Bhavantar Bhugtan Yojana* (BBY)—for the 2017 *kharif* season on a pilot basis for eight crops: maize, pigeon pea, black gram, green gram, soybean, groundnut, sesamum and niger seed (Gulati, Chatterjee and Hussain 2018). Under this scheme, the difference between the average sale price (ASP) (calculated by taking the average modal prices in *mandis* in Madhya Pradesh (MP) and two other reference states) and the announced MSP is paid directly into a farmer's bank account for the quantity traded in the APMC[17] (Gulati, Chatterjee and Hussain 2018). In this way, farmers were provided with lucrative markets for their produce and protection against fluctuations in the market prices as they were able to sell their

[17]The quantity traded is up to the maximum limit of farmer's expected production where the expected production is calculated on the basis of the area sown given by a farmer at the time of registration (verified by the revenue department) and average productivity of the district of that crop. The average productivity of a crop was calculated for the three best years of the five preceding years as per crop cutting experiments (CCEs) carried out by the Revenue Department (Gulati, Chatterjee and Hussain 2018).

produce directly to traders and get the difference from the government. According to the CACP, arrivals of all registered crops in *mandis* (MP) between October 2017 and December 2017 increased by a significant quantity compared to the previous procurement season. A major increase in arrivals—of 480%—was observed in the case of pigeon pea, while there was a 228% increase in green gram and black gram and 129% in case of groundnut (CACP 2018a, b). However, the scheme involves massive financial burden on the exchequer and subject to manipulations by traders and *mandi* functionaries. Therefore, notwithstanding its impact, the GoMP gave up the scheme abruptly in the *rabi* marketing season.

Gulati, Chatterjee and Hussain (2018) also evaluated the BBY scheme in terms of its impact on market arrivals, *mandi* prices, its coverage and reach among farmers, the share of produce covered by the scheme and the cost incurred to compensate farmers (for each of the eight crops). It was observed that of the total 9.7 million hectares (Mha) of area under these eight crops, 4.3 Mha (45%) was registered under the scheme in *kharif* 2017 and covered 2.18 million farmers (Table 5.1).

The study also indicates that the BBY scheme had limited reach as overall it was able to benefit only 23% of total production. The total expenditure incurred in compensation by the GoMP was estimated to be USD0.3 billion (or Rs. 19.44 billion),[18] about 25% less than the total compensation that would have been incurred if the scheme had covered all the produce marketed below MSP, i.e. only a small share of the total produce was registered and compensated for under the scheme. The study also estimates the cost of scaling up the BBY scheme at the national level to mitigate risks, covering all crops for which MSPs are announced, i.e. paddy, wheat, sorghum, pearl millet, barley, finger millet, gram, lentil, pigeon pea, green gram, black gram, groundnut, soybean, sesamum, niger seed, sunflower, rapeseed-mustard, safflower and cotton (*kapas*)[19] (Gulati, Chatterjee and Hussain 2018). Using three hypothetical scenarios—one, when *mandi* prices are assumed to be 10% lower than MSP; two, when they are assumed to be 20% lower than MSP and three, when they are assumed to be 30% lower than MSP—the study computed the total cost which the central government would have to bear. The resulting figures were USD8.7 billion, USD17.5 billion and USD26.2 billion (or Rs. 565.18 billion; Rs. 1.13 trillion and Rs. 1.69 trillion). The highest compensation was found to be for paddy (25.5%) followed by wheat (13.5%) and cotton (*kapas*) (15.9%) (Gulati, Chatterjee and Hussain 2018).

The Government of China has also had a price deficiency payment mechanism for cotton and soybean in place since 2014. This is called "target price payments". Under this scheme, direct payments are made to farmers to compensate them for the price differential between the target price announced by the government in advance and the actual market price. It is interesting to note that earlier maize was also covered under the scheme, but due to many distortions, it was dropped from the scheme. Therefore, India could learn from the Chinese experience in keeping PDP to a minimum, say

[18]This includes compensation for soybean, groundnut, maize, *moong, urad* and expected compensations for *tur* in February 2018.

[19]Here, the costs have been computed by multiplying net available quantity with the price difference between projected MSP and projected sale prices.

Table 5.1 Crop-wise details for the Bhavantar Bhugtan Yojana (BBY) kharif 2017–18, India[a]

Crops	Maize	Black Gram *(Urad)*	Green Gram (*Moong*)	Pigeon Pea (Tur)	Soybean	Groundnut	Sesamum	Niger seed
Production (MMT)	4.91	1.77	0.16	0.8	6.94	0.34	0.2	0.02
Registered production (MMT)	1.38	0.81	0.01	0.13	3.89	0.08	0.03	0. 002
Registered market arrivals (MMT)	0.54	0.56	0.002	NA	1.28	0.014	0.0001	0.0001
Mandi prices in MP (USD/quintal)	16.9	40.06	55.76		40.2			
MSP (USD/quintal)	22.1	83.78	86.5	84.56	47.32	69.04	82.23	62.83
No. of registered farmers (Million)	0.29	0.61	0.014	0.113	1.05	0.043	0.042	0.004
Total cropped area (Mha)	1.31	1.79	0.22	0.64	5.01	0.21	0.42	0.06
Registered area (Mha)	0.44	1.2	0.01	0.11	2.48	0.04	0.03	0.004
Compensation actually paid USD billion (or Rs. billion)	0.02 (1.54)	0.20 (12.97)	0.0005 (0.03)	NA	0.07 (4.71)	0.002 (0.11)	0	0
Compensation that would have been paid if entire produce was to be covered under BBY USD billion (or Rs. billion)	0.22 (13.88)	0.63 (40.37)	0.03 (2.16)	NA	0.40 (25.47)	0.04 (2.83)	0	0

(continued)

Table 5.1 (continued)

Crops	Maize	Black Gram *(Urad)*	Green Gram (*Moong*)	Pigeon Pea (Tur)	Soybean	Groundnut	Sesamum	Niger seed
Total compensation that would have been paid for all crops USD billion (or Rs. billion)	1.31 (84.70)							

[a]Prices are converted to USD using the exchange rate of USD1 = Rs. 64.45 in 2017–18 (RBI 2017–18)
Source Gulati, Chatterjee and Hussain (2018)

one or two crops. Otherwise, market distortions and consequent efficiency losses will outweigh the support the government wants to extend to farmers (Gulati, Chatterjee and Hussain 2018).

Despite innovative incentive policies like *PM-AASHA* and PDP, the government could not make the terms of trade farmer-friendly. Most importantly, if scenarios such as ultra-high MSPs for crops (without any regard to demand or exportability) were to occur, then the production of undesirable, unexportable surpluses, leading to the accumulation of stocks in domestic markets and price depression, would aggravate farmers' distress.

5.4 Evaluation of the Input Price Regime

In order to augment productivity and meet the ever increasing demand for food, feed and fibre from limited resources, the government intervenes in the input market and offers critical farm inputs such as seeds, fertilisers, power, water for irrigation and pesticides at subsidised rates. As of 2014–15, the government spent 8.16% of GDP on input subsidies (Gulati, Ferroni and Zhou 2018). In this section, we delve deeper into the nature and degree of incentives the input price policy provides to farmers. We also evaluate the implications from various angles, from financial sustainability to its efficiency, leakages, equity and environmental risks.

Fertiliser Subsidy: India is an important player in the global fertiliser market, both as a producer and trader. Since 2001, India has been the second highest producer of nitrogenous fertilisers after China (producing 10–11% of world production) and the third highest producer of phosphatic fertilisers after China and the USA (producing around 8% of total world production in 2014). India is also the second largest consumer of fertilisers in the world after China, with about 27.3 MMT used by the agricultural sector in 2018–19. It is the second largest consumer of nitrogenous and phosphatic fertilisers after China (16% and 14%, respectively, of world consumption in 2014) and the fourth biggest consumer of potassic fertilisers after China, Brazil and the USA (7% of world consumption in 2014). The consumption of phosphatic and potassic fertilisers is met mostly or entirely by imports. India is the second highest importer of phosphatic nutrients (11% of world imports in 2014) and the fourth highest importer of potassic nutrients (8% of world imports in 2014) after the USA, Brazil and China (Gulati, Ferroni and Zhou 2018).

The fertiliser sector in India is highly subsidised by the central government and accounts for about 28% of the total centrally budgeted subsidies (Gulati, Ferroni and Zhou 2018). Under the current nutrient-based subsidy regime (excluding urea), the government sets nutrient-based subsidy rates in rupees per kilogram of nutrient (nitrogen, phosphate, potash, sulphur), which are then translated into subsidy rates per tonne of fertilisers. The rates are determined based on factors like international prices, the exchange rate and the inventory level, as well as the existing maximum retail price (MRP) of di-ammonium phosphate (DAP) and muriate of potash (MOP). The pricing is decontrolled (except for urea), so any fluctuations in international prices of DAP and MOP are reflected in domestic prices (Gulati, Chatterjee and Hussain 2018). At the same time, in the case of urea, a government-fixed selling price applies (also called the maximum retail price), where a subsidy is provided to domestic urea manufacturers to cover the difference between their cost of production and their revenue from sales at the fixed selling price.[20] Over the years, the amount of fertiliser subsidy has increased significantly, reaching USD11.4 billion[21] (or Rs. 799.9 billion) in 2019–20 Union Budget.

Irrigation and Power Subsidy: The government provides an irrigation subsidy for utilising surface water through investments in constructing and maintaining major, medium and minor irrigation projects (such as canals and dams). It also provides a subsidy on electricity to power pumps for irrigation using groundwater. State regulatory bodies set electricity rates for the sector at a much lower level than the average unit cost of power supplies. In 2013–14, the average tariff rate charged was USD0.02/Kwh[22] (or 1.64 Rs./Kwh), while the cost of supply was much higher at USD0.09/Kwh (or 5.85 Rs./Kwh). In some important agricultural states such as Punjab, Haryana and Tamil Nadu, the average tariff rate was zero (Government of India 2014).

Credit Subsidy: The government subsidises short-term institutional credit for farmers in two ways—through interest subvention to lending institutions, which enables banks to advance credit to agriculture at low levels of interest rates and through the use of an instrument called "loan waiver" in which the government

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[20] The subsidy is calculated for each individual manufacturing plant, taking into account a plant-specific fixed cost and a variable cost which largely represents the plant's cost of natural gas, which is the feedstock for urea production. Natural gas has been supplied to urea manufacturing plants at a government-determined price that is much lower than the international price, i.e. the government subsidises the difference (OECD/ICRIER 2018).

[21] Converted to USD using the exchange rate of USD1 = Rs. 61.14 in 2014–15 (RBI 2017–18).

[22] Converted to USD using the exchange rate of USD1 = Rs. 60.5 in 2013–14 (RBI 2017–18).

reimburses the lending institutions the cost of implementing the waiver. This aims to provide relief to farmers who are overburdened with debts (Gulati, Ferroni and Zhou 2018). In the wake of the food crisis in 2006–07, the first grant of subvention of two per cent was given to public sector banks, regional rural banks (RRBs) and co-operative banks for *kharif* crops in 2006–07. In 2009–10, the government introduced an additional interest subvention of one per cent to farmers who repaid their loans on or before the due date. This rate was further increased to two per cent in 2010–11, and three per cent in 2011–2012, making the total subvention five per cent (Gulati, Ferroni and Zhou 2018). In addition to this, the first loan waiver was announced in 1990, and the Agriculture and Rural Debt Relief Scheme (ARDRS) was passed. Again, in May 2008, another loan waiver scheme (both for short-term and investment loans), called the Debt Waiver and Debt Relief Scheme (ADWDRS), was announced.[23] It was followed by another loan waiver in 2014 called "*Runa Mafi*". This was announced by Andhra Pradesh and Telangana and was a significant measure for farmers who had suffered severely due to crop damage in the cyclone "Phailin". However, there is concern that this instrument is being exploited in order to win votes. Between 2014 and 2018, around ten states announced loan waivers, including Andhra Pradesh, Telangana, Tamil Nadu, Uttar Pradesh, Maharashtra, Punjab, Karnataka, Madhya Pradesh, Chhattisgarh and Rajasthan, ranging from 0.4% to 4.6% of gross state domestic product (GSDP), either before contesting the elections or immediately after coming to power, thus contributing to fiscal stress in the economy (Gulati and Chatterjee 2018a, b).

- **Efficiency**

In India, the urea subsidy has been kept out of the ambit of the Nutrient Based Subsidy Scheme (NBS), and its price has been controlled at an abnormally low level for a long time. In 2017, compared to the world price (USD220/MT) and prices in other countries such as China (USD265/MT), Pakistan (USD265/MT), Bangladesh (USD195/MT), Indonesia (USD135/MT) and the Philippines (USD362/MT), urea in India is highly under priced at USD86/MT (Gulati, Ferroni and Zhou 2018). This has resulted in market distortions, leakages and massive misuse of urea, including its diversion to non-agricultural uses and smuggling to neighbouring countries. In the Economic Survey (2016–17), it is mentioned that, in some areas, a comparison between urea subsidy allocations with estimates of actual use suggests that a large share of urea is probably being diverted for industrial use or smuggled across the borders to neighbouring Bangladesh and Nepal (Government of India 2017a, b, c). Besides, strict government control over urea prices, movement and imports leads to significant delays in the procurement and distribution processes, thus fuelling shortages during peak demand periods and imposing large costs on the exchequer

[23]Under the scheme, complete waiver was provided to small and marginal farmers (those with landholdings of up to two hectares), while a one-time relief of 25% was envisaged for other farmers (those with more than two hectares), provided they paid the balance 75% of the "eligible amount", which included interest and principal component. To qualify for the waiver, the loan had to be overdue as of 31 December 2007 (Gulati, Chatterjee and Hussain 2018).

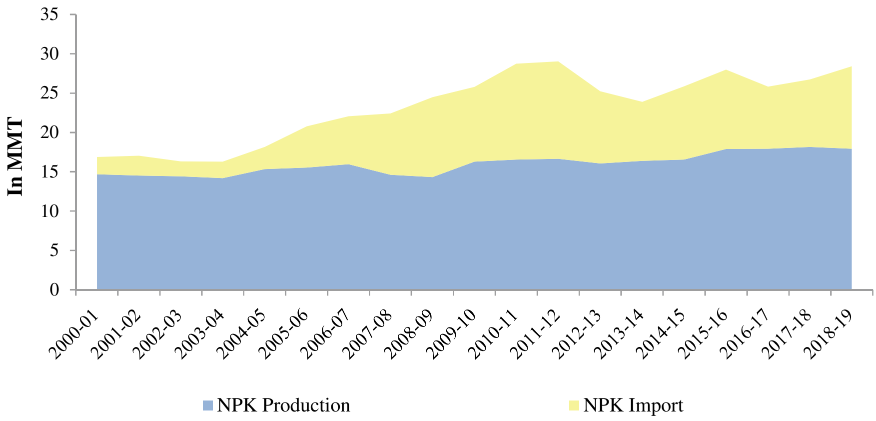

Fig. 5.7 Stagnant production and increased import dependency, India. *Source* Fertiliser Statistics 2017–18 and Annual Review of Fertilisers 2018–19

(OECD/ICRIER 2018). Influenced by massive subsidies, fertiliser consumption (in total nutrients) has increased from 16.7 MMT in 2000–01 to 27.3 MMT in 2018-19, while production of total main fertiliser nutrients has increased only marginally from 14.7 MMT in 2000–01 to 17.9 MMT in 2018-19, thus, leading to increased dependence on import (imports increased from 2.2 MMT to 10.5 MMT during the same time period) (Fig. 5.7).

Similarly, highly subsidised or free power and water has exacerbated the water shortage problem in an already water-stressed country like India. It has enabled farmers to continue pumping groundwater from tube wells even when the underlying aquifer has reached worryingly low levels. Since electricity consumption by farmers is often not metered and they pay a flat charge related to the capacity of the motor pump rather than the extent of use, there is no account of actual power consumption and associated costs. This has, in turn, serious implications for the financial position of the state electricity boards (SEBs) (Government of India 2014). In the absence of metering, it is also not clear if electricity supply to agriculture has actually been used for agricultural purposes. It is generally assumed that only 70% of the power supplied to agriculture goes to the intended sector.[24] The existing policy framework, therefore, lacks the incentive structure for efficient and sustainable use of power and water.

In the case of credit subsidy, loan waivers have serious moral hazard implications as they affect the behaviour of both borrowers and banks. It temporarily solves farmers' problems but disincentivises repayment of loans and worsens the overall credit environment. Further, repeated write-offs could be highly distortionary as

[24]It is further assumed that 30% is the overestimation in sales. This assumption was made in a 1988 domestic support notification to the WTO. The annual report on the Working of State Power Utilities and Electricity Departments (2011–12) states, "It is estimated that about 30–40% of the consumption shown against the sector is an overestimate" (p. 9) (Gulati, Chatterjee and Hussain 2018).

they encourage wilful default under the expectation of future waivers. Overall, such a policy encourages farmers to borrow to purchase and use inputs such as fertiliser, electricity and irrigation water, the prices of which are already heavily subsidised. Additionally, it adversely affects the lending activities of banks due to expectations of defaults, impeding the growth of credit in the system. Therefore, government intervention with respect to a broad range of inputs from fertilisers and power to water and credit marketed at prices lower than the cost of production is generally more distorting of production and trade than output price supports (OECD/ICRIER 2018; Dewbre et al. 2001; OECD 2001).

- **Inclusiveness**

Although the availability, access and quality of farm inputs and services (including fertilisers, seeds and credit) have improved over the past decade, their distribution across different size categories of farmers remains an issue. Informal channels are still widely present in the markets for fertilisers, resulting in several leakages. Since subsidies are routed from the government to manufacturers and importers and no direct compensation is paid to the farmers, this increases the number of levels involved in the flow of transfers, resulting in the exclusion of small and marginal farmers. In terms of water usage, there is considerable inequality among head- and tail-end users of a canal. Since head-end users get access to water first, they tend to produce more water-intensive crops like rice and consequently, less water is available for tail-end users (Gulati, Ferroni and Zhou 2018). In the case of institutional credit, provision is still inadequate compared to the needs of small and marginal farmers. Access to credit is linked to holding formal land titles; therefore, many small and marginal farmers are excluded from taking up this option. According to the All India Debt and Investment Survey (AIDIS), the 70th round conducted by the NSSO, 33.8% of cultivator households had outstanding debt from institutional sources in 2012–13. NABARD's Financial Inclusion Survey (NAFIS) estimates that 43.5% of total agricultural households took out loans between July 2015 and June 2016, of which 30.3% took loans from formal sources. Since it is accessed by only 30% of agricultural households, the implication is that the loan waiver policy has limited reach.

In addition to this, the credit system is highly iniquitous as it is only large farmers who account for a substantial proportion of credit from institutional sources. This can be seen from the Situation Assessment Survey (2013): only 49% of the credit needs of marginal farmers were met through formal sources while that of large farmers were met to the extent of 79% (Gulati and Terway 2018). This implies that mainly larger farmers receive the benefits of subsidies (provided through interest subvention and loan waivers) while small and marginal farmers remain caught in a vicious, non-institutional credit trap. There is also a paucity of medium and long-term lending due to high subsidies on short-term credit. In 2016–17, 65% of the credit advanced was short-term, while only 35% covered fixed capital formation and longer-term investments (Gulati, Ferroni and Zhou 2018).

- **Sustainability**
  - **Financial Sustainability**

    Over the years, input subsidy as a percentage of agricultural GDP has increased considerably (8.16% in 2014–15 compared to the 1980–81 level of 2.78%), while public investment as a percentage of agricultural GDP declined marginally compared to the 1980–81 level, reflecting inefficiencies in the distribution of public resources. Among input subsidies, fertiliser subsidy has been the most dominant, amounting to USD11.02 billion (or Rs. 710.76 billion) in 2014–15. Irrigation subsidy, according to government estimates (calculated as imputed irrigation charges minus depreciation of the public irrigation system), was USD5.77 billion (or Rs. 372.46 billion) in 2014–15, and power subsidy was about USD8.81 billion (or Rs. 538.89 billion). Expenditure on the interest subvention scheme was USD0.98 billion (or Rs. 60 billion) in 2014–15. Moreover, the premium subsidy on crop insurance was about USD0.42 billion (or Rs. 26 billion) in 1980–81, which has risen to more than USD3.27 billion (or Rs. 200 billion) in 2014–15. The total value of input subsidies in 2014–15, therefore, amounts to USD27.9 billion (or Rs. 1708.11 billion). Additionally, there is also the issue of unpaid subsidy bills to fertiliser plants by the government, which has adversely affected the fertiliser industry. According to the Fertiliser Association of India (FAI), a sum of almost USD4.90 billion (or Rs. 300 billion) is pending, which implies a massive fiscal burden on the exchequer. In addition to subsidies, the farm loan waiver was one of the important factors contributing to fiscal stress in the economy in 2017–18. Starting from Andhra Pradesh and Telangana in 2014–15, ten states have announced farm loan

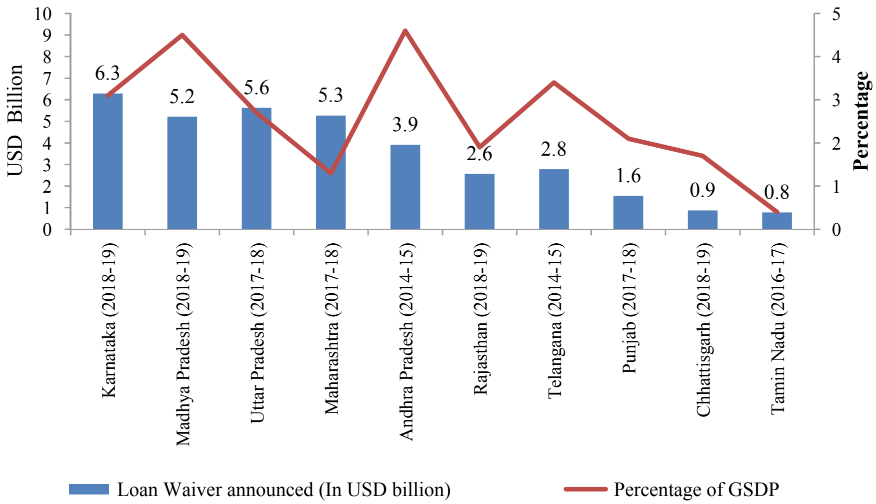

Fig. 5.8 Farm Loan Waivers Announced, India. *Source* (RBI 2018). *Note* GSDP are used for the respective announcement years

waivers, ranging from 0.4% to 4.6% of the gross state domestic product (GSDP) (see Fig. 5.8). The cumulative debt waiver since 2014 till 2018 is USD32.8 billion (or Rs. 2.3 trillion). In 2018 alone, a debt waiver of USD15.5 billion (or Rs. 1.0 trillion) was announced by four states—Karnataka, Rajasthan, Madhya Pradesh and Chhattisgarh. Such waivers announced out of budget are likely to lead to fiscal slippage or a compromise on capital expenditure leading to deterioration in the quality of expenditure (RBI 2018) (Fig. 5.8).

The debt waiver budgeted during 2017–18 for all state amounted to USD8.33 billion (or Rs. 537.0 billion) and was budgeted at USD4.91 billion (or Rs. 343.4 billion) in 2018–19. However, this does not include the farm loan waivers announced by three states (Rajasthan, Madhya Pradesh and Chhattisgarh) in December 2018, which amounted to around USD9.31 billion (or Rs. 606.0 billion), clearly indicating that actual waivers in 2018–19 were higher than the budgeted amount, imposing a greater burden on state finances (RBI 2018).

- **Environmental Sustainability**

  The fertiliser price policy followed in India does not encourage balanced application of nitrogenous (N), phosphatic (P) and potassic (K) fertilisers. This leads to soil/land degradation, water pollution, greenhouse gas emissions and other environmental damage. The Indian Council of Agricultural Research (2010) reported that 37% of the total land area (~120.4 million hectares) is affected by various types of degradation. The ideal ratio of NPK fertiliser use is considered to be 4:2:1. However, in reality, the ratio is 7.2:2.9:1 (2015–16). Highly subsidised urea has resulted in its excessive application, which has led to very disturbing usage ratios in states such as Punjab (18.6:5.4:1), Haryana (52.6:14.8:1) and Rajasthan (58.2:24.1:1) (Government of India 2016a, b). This is because a part of applied urea (i.e. fertiliser N) is lost as azane or ammonia (NH_3), nitrogen (N_2) and di-nitrogen monoxide (NOx) gases in the environment, where NH_3 after oxidation to NO_3 contributes to soil acidity, while NOx contributes to the depletion of the stratospheric ozone layer with a part of it leaching down as NO_3 to contaminate groundwater resources (Prasad 2009). One of the hazardous side effects of NO_3 contamination in groundwater is methemoglobinemia or "blue baby syndrome". Gupta et al. (2000), in a study conducted in Rajasthan, found that there was severe methemoglobinemia in all age groups of the population, especially in those under the age of one (Gupta et al. 2000).

  Enormous power subsidy for groundwater irrigation, especially in the semi-arid region of Northwest India, is creating worrying consequences for an already depleted water table as well as for the region's water quality in terms of contamination of groundwater due to the geological formation at deeper levels (or, geogenic factors). The most prominent example in recent times is arsenic and fluoride contamination in some parts of West Bengal and Gujarat. The crisis is severe in important agricultural states like Punjab, where water demand (for agriculture) is almost twice as high as total water availability. This puts water reserves under extreme pressure (OECD/ICRIER 2018). As a result, groundwater is depleting at a rapid pace, increasing the depths at which water must be pumped and hence the cost of extraction—all of which leads to acute water scarcity in summer not only for irrigation but for drinking purposes as well (Gulati, Ferroni and Zhou 2018).

This highlights how heavy subsidisation of farm inputs undermines the value of a natural resource and hinders its optimal utilisation.

- **Scalability**

Fertiliser use appears highly skewed across regions, with wide interstate and inter-district variations. As shown in Fig. 5.9, the average intensity of fertiliser use is high in states like Punjab, Haryana and Andhra Pradesh with a consumption of over 200 kg/ha, while other states like Odisha, Kerala, Madhya Pradesh, Jharkhand, Chhattisgarh and Rajasthan have consumption levels of less than 100 kg/ha (Sharma and Thaker 2010); (Gulati, Ferroni and Zhou 2018).

There also exists regional disparity in the proportion of electricity subsidy received. For instance, in TE 2013–14, the northern region received the highest share of 38.8% of total power subsidy followed by the southern and western regions, at 33.3% and 26.7%, respectively. The eastern region received the lowest share—only 1.2%. Thus, in this case, government intervention has not yet been scaled up to ensure an equitable distribution of subsidy (Gulati, Ferroni and Zhou 2018). Similarly, there appears to be interstate variation in the case of access to institutional credit. In 2013, Andhra Pradesh, with only 31% of agricultural credit needs met through institutional sources, appeared to have the least access to institutional credit while states like Kerala and Maharashtra had relatively high access with around 83% of credit needs being met by financial institutions (Gulati, Ferroni and Zhou 2018).

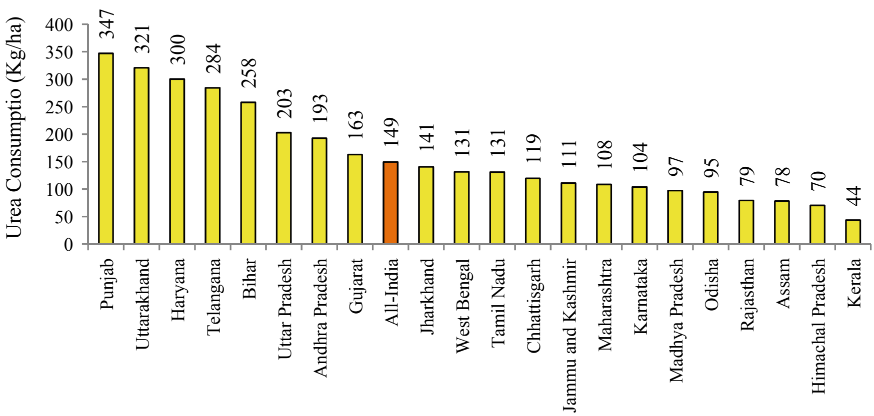

Fig. 5.9 State-wise per hectare consumption of urea (kg/ha) in India, 2016–17. *Source* Fertiliser Statistics 2016–17

Thus, input subsidies have proved to have distortionary effects, leading to inefficient use of resources and a mounting burden on the exchequer. More importantly, the transfer of subsidy through informal channels results in massive leakages and delays. It is observed that benefit transfers and subsidies from central and state government in India account for four per cent of gross domestic product (GDP), while leakages correspond to two per cent of GDP (Government of India 2016a, b).

5.5 Innovation in Income (Investment) Support Policy

The analysis above makes it apparent that policy reform is required not just on the output side of the farming equation but also on the input side. Switching from distorting price support to policies that advance income support on a per hectare basis or those which encourage investment are likely to prove economically sounder.

The experience of countries like China lends credence to this view: farm distress is best relieved by subsidising farmers through cash transfers, not by subsidising crops. In China, direct income transfer on a per acre basis has been in practice since 2004. In addition to this, two more schemes, namely comprehensive inputs subsidies and subsidies on seed variety, were launched in 2006. In 2015, the Chinese government consolidated these three area-based input subsidy schemes into a single payment scheme called the "support and protection subsidy". In 2016, the scheme was scaled up to the national level. About USD21.1 billion was allocated to provide income support to farmers on the basis of land owned by them. The scheme has now become the most critical budgetary support programme for Chinese agriculture.

The section below reviews the recently adopted innovative policy of direct income transfer by the governments of Telangana and Odisha (in 2018) and, in 2019, the central government and the governments of Jharkhand and West Bengal.

- ***Rythu Bandhu Scheme (RBS)—Government of Telangana***: In the wake of low productivity, low levels of public and private investments and a vicious circle of rural indebtedness, the Government of Telangana took the initiative and proposed an "Agriculture Investment Support Scheme" ("*rythu bandhu*") with a seed capital of USD1.86 billion (or Rs. 120 billion)[25] for both seasons (*kharif* and *rabi*) in the financial year (FY) 2018–19. Under the scheme, the government proposed to give USD62 (or Rs. 4000) per acre per farmer, before the sowing season. This was initial investment support for farmers, i.e. in the month of May for *kharif* and October in the *rabi* season, for the purchase of seeds, fertilisers, pesticides, labour and other investments in field operations, according to the choice of the farmer, as an alternative to borrowing from informal sources at exorbitant interest rates (Gulati, Chatterjee and Hussain 2018). Land records of farmers were collected by the Revenue Department in a record time of 100 days under the "Land

[25]It includes service charges payable to banks and administrative expenditure for implementing the scheme.

Records Updation Programme (LRUP)" that formed the basis for the implementation the *rythu bandhu* scheme. In *kharif* 2018–19, USD0.82 billion (or Rs. 57.34 billion) was disbursed to 5.7 million farmers covering 14.3 million acres of land (Telangana State 2018). The amount was disbursed through order cheques, which were handed over to farmers during the months of April and May 2018. The order cheques were payable at face value in all branches of designated banks in the state.[26] The vast majority (approximately 90%) of farmers who received the benefit were small and marginal farmers owning less than five acres of land. For the *rabi* season, the state government disbursed USD0.67 billion (or Rs. 47.24 billion). This time, the payment was made electronically through the "e-Kuber" government platform (with no operational costs) (Telangana State 2018).

For now, the *rythu bandhu* scheme favours only the landowners, but the state government hopes that the market will adjust land rentals for tenants. The scheme can also be improvised by making payments inversely related to landholding size, i.e. making it pro-smallholding farmers. Further, geo-tagging of farms and linking them to farmers' Aadhar number, could ensure that only those farmers who cultivate the land get the benefits (Gulati and Terway 2018). The scheme could also potentially provide a platform for the government to implement DBT for seeds, fertilisers, power, etc., instead of subsidising them. The free flow of market forces and the correct pricing of critical farm inputs will promote efficient and sustainable use of these resources.

Gulati, Chatterjee and Hussain (2018) had estimated that the total payment of the direct income scheme scaled to the national would be USD28.1 billion (or Rs. 1.97 trillion) if the income support was USD143 (or Rs. 10,000) per hectare, based on the gross cropped area (which was 197.8 million hectares in TE 2014–15). If the payment was only USD71.5 (or Rs. 5000) per hectare, then the cost of the scheme would be about USD14.3 billion[27] (or Rs. 1 trillion) (Gulati, Chatterjee and Hussain 2018). This could help avoid market distortions and promote diversification. Moreover, since direct income support involves less intervention from market participants at the lowest level, its benefits can be directly targeted to the real beneficiaries, i.e. the farmers, rather than middlemen who otherwise might extract most of the deal as happened in case of the price deficiency scheme, provided land records are upgraded (including tenant cultivators). Therefore, scaling up the untied direct cash or income support policy across India would be preferable to market-distorting policies such as higher price support and loan waivers (Kumar 2018). Even the FAO has recognised *rythu bandhu* as an important innovation to augment incentives for farmers (FAO 2019).

The Government of Telangana also established a new corporation called the *Telangana Rashtra Rythu Samanvaya Samithi* in 2018, to promote agricultural activity and improve the welfare of the farming community. It does so by increasing production and productivity of various crops and ensuring remunerative prices to farmers by intervening as and when necessary, to take up post-harvest interventions, to aim at export of produce, to promote grading, processing and value addition and to organise

[26]The farmer would have freedom to encash the cheques at any branch of that bank in the State of Telangana, payable at par.

[27]Converted to USD using the exchange rate of USD1 = Rs. 69.92 in 2018–19.

FPOs and to help in market-led extension services. Under this corporation, the authorised share capital is a minimum of USD0.03 billion (or Rs. 2.00 billion). In addition to this, the Government of Telangana has also conceptualised an innovative scheme—the Farmers' Group Life Insurance Scheme (*Rythu Bima*)—to provide financial relief and social security to family members/dependents of any farmer between 18 and 59 years of age whose life is lost for any reason. The entire premium would be paid by the government to the Life Insurance Corporation of India (Government of Telangana 2018).

- ***Krushak Assistance for Livelihood and Income Augmentation (KALIA)—Government of Odisha***: In line with Telangana's Rythu Bandhu scheme, on 21 December 2018, the Government of Odisha announced a package scheme for farmers' welfare and prosperity—the Krushak Assistance for Livelihood and Income Augmentation (KALIA)—and allocated a total budget of USD1.45 billion (or Rs. 101.80 billion) for three years (from 2018–19 to 2020–21). The support scheme aimed to cover 92%[28] of cultivators, tenants and share croppers as well as borrower or non-borrower farmers and landless labourers. The scheme was introduced with effect from the 2018–19 *rabi* season and included the following components of financial assistance:

    1. A cash grant of USD71.5 (or Rs. 5000) per farm family per cropping season for five cropping seasons spanning from 2018–19 to 2020–21. This is to induce farm investments and make purchase of agricultural inputs like seeds, fertilisers and pesticides affordable (Government of Odisha 2018a, b). This component covers 3.01 million small and marginal cultivators (landowners), which accounts for 92.9% of small and marginal farmers and, in terms of area, 74.9% of small and marginal operational holdings, at a total cost of USD1.07 billion (or Rs. 75.40 billion) over three years.
    2. One-time financial assistance of USD178.7 (or Rs. 12,500) per landless household to incentivise them to undertake allied activities and establish livelihood units such as small-scale goat rearing, dual purpose low input technology units, duck farms, fishery kits for fisherman, mushroom cultivation and bee-keeping. This component of assistance covers 1 million landless agricultural labourers at an estimated cost of USD0.17 billion (or Rs. 12.50 billion) for three years (from 2018–19 to 2010–21).
    3. Another component of the scheme provides one-time financial assistance of USD143 (or Rs. 10,000) per family to vulnerable/landless labourers and cultivators (who may not be able to work due to old age, disability, disease or other reasons), to enable them to take care of their sustenance. A total of 1 million beneficiaries are estimated to be covered over two years at a cost of USD0.14 billion (or Rs. 10 billion) (between 2018–19 and 2020–21).

[28]According to the Census 2011, there are 32.8 lakh cultivators and 24.2 lakh labourers in Odisha, who are working in agriculture and allied sectors for a major part of the reference period, i.e. 6 months. Of the total cultivators, about 30.16 lakh (92.9%) are small and marginal farmers (with landholdings of less than 2 ha).

4. Life insurance cover to farmer's family in case of farmer's death or disability at a nominal premium for all savings bank account holders aged between 18 and 50 years. Additionally, a personal accident cover (through LIC) for all savings bank account holders aged between 18 and 50 years. The two components together cover 5.7 million individuals (i.e. 3.28 million cultivators and 2.42 million landless labourers) over two years, at a cost of USD0.02 billion (or Rs. 1.70 billion).
5. Interest-free crop loans (i.e. at zero interest rate) up to USD715.1 (or Rs. 50, 000) to farmers with effect from the *kharif* season 2019 (Government of Odisha 2018a, b). This covers 2 million farmers over two years and will cost USD0.13 billion (or Rs. 2.20 billion).

The KALIA scheme is conceptually fairer and more far-reaching than the loan waiver scheme (which covers only 30% of agricultural households and provides only temporary relief) in that it addresses the agrarian crisis structurally (Swaminathan 2018). The identification of beneficiaries under the scheme was achieved through a self-declaration form, along with required documents such as *Aadhaar*, as well as through bank account details and copies of land records/agreements.

The scheme augments farmers' income and attempts to reduce poverty in a sustained manner. However, given the limited administrative capacity of the state and non-legalisation of tenancy, identifying tenants and landless agricultural labourers is a mammoth task. This poses serious challenge for the state authorities in reaching farmers at the grassroots level. Other challenges include more than one claimant for the same land (landowner as well as tenants) and division of land among independent children in order to seek a higher benefit. For example, if a farmer has two sons (independents) and five acres of land, in order to earn a higher per farm family benefit of USD71.5 (or Rs. 5000) per season, the farmer divides the land into three parts among himself and his two independent sons (1acre + 2 acres + 2 acres) and earn USD214.5 (or Rs. 15,000) per season effectively, thus, promoting land division instead of consolidation.

- ***Mukhya Mantri Krishi Aashirwad Yojana—Government of Jharkhand***: In December, 2018, the Government of Jharkhand announced financial assistance and a subsidy scheme of USD71.5 (or Rs. 5000) per acre per year to 2.27 million poor and marginal farmers, having a combined land holding/ownership of up to five acres, in total covering 4.5 million acres of cultivable land. The government has allocated USD0.32 billion (or Rs. 22.50 billion) towards the implementation of the scheme for the *kharif* season 2019–20.[29] The scheme aims to make farmers independent in terms of meeting their cultivation needs for seed, manure and other investments by transferring the assistance amount directly into the bank accounts of the beneficiaries.[30] The scheme also envisages providing interest-free crop loans to these farmers.

[29] http://cm.jharkhand.gov.in/node/9061.
[30] https://twitter.com/dasraghubar/media.

- ***Krishak Bandhu Scheme—Government of West Bengal***: Agriculture is the main livelihood of a majority of the population in West Bengal, engaging about 96% of small and marginal farmers. In January 2019, the state announced assured financial support to farmers, including Bhagchasi (sharecroppers), amounting to USD71.5 (or Rs. 5000) per acre for up to one acre of land per year in two instalments for the *kharif* and for *rabi* crops (Government of West Bengal 2019).[31] Other benefits of the scheme included an assured incomes of USD14.3 (or Rs. 1000) to landless farmers with less than one acre of land on a pro-rata basis and death benefit of Rs. 0.2 million to the nominee/family member of the deceased farmer, in the event of any type of death, including the natural death of a farmer/Bhagchasi (sharecropper) in the age group 18–60 years (Government of West Bengal 2019). A total financial outlay of USD0.64 billion (or Rs. 45 billion) has been allocated for the scheme.
- ***Pradhan Mantri Kisan Samman Nidhi (PM-Kisan) Scheme—Government of India:*** Ahead of the 2019 general elections, the Government of India, in its interim union budget (2019–2020), introduced the first ever centrally sponsored direct income support scheme—the *Pradhan Mantri Kisan Samman Nidhi* (PM-KISAN)—allocating USD10.72 billion (or Rs. 750 billion) for the financial year 2019–20. The objective of the scheme was to provide structured income support to poor landholder farmer families to procure inputs such as seeds, fertilisers, equipment, and labour and to meet other needs. Under the scheme, vulnerable landholding farmer families with a combined landholding/ownership of up to two hectares are given direct income support at the rate of USD85.8 (or Rs. 6000) per year (Ministry of Finance 2019), directly into the bank accounts of beneficiary farmers, in three equal instalments of USD28.6 (or Rs. 2000) each, every four months. The scheme covers around 0.12 billion small and marginal farmer families.

5.6 Innovations in Non-Price Support Policies

Besides switching to income support policies, government support should be refocused towards reforming agricultural marketing policies and investing in infrastructure—both to ensure better connectivity of producers to markets and for price transparency. Further, investments in agriculture infrastructure that promote sustainable productivity growth are also required. Overall, there is a need to shift away from the use of market-distorting support policies towards investment-enabling environmental policies that both improve farmers' capabilities to get the most out of markets and to respond to the changing nature of demand with quality produce. The following section focuses on some of the unfolding innovations in agricultural marketing policies that are aimed at "getting the market right" by "setting the rules of the game".

[31] http://darjeeling.gov.in/notification/kb_117ago9mnab012019.pdf.

Any benefits that flow from these will take time to materialise but they will accrue over a longer period.

5.6.1 Incentives Through Innovations in the Marketing Chain—Model Agricultural Produce and Livestock Market Act (APML) and Electronic National Agriculture Market (E-NAM)

In Indian agriculture, marketing structure is defined by two longstanding pervasive policies, which were designed by the government in the era of food scarcity to prevent hoarding and exploitation of farmers—the Essential Commodities Act, 1955 (ECA) and the Agricultural Produce Market (Regulation) Committee Acts, often also called APMC Act. ECA regulates transactions in the whole value chain across production, storage, supply, distribution, disposal, acquisition, use, consumption and pricing of essential commodities (foodstuffs and many kinds of seeds, and fertiliser). On the other hand, the APMC Acts, at the level of individual states, regulate markets at the point of first sale from the producer through to establishing and managing wholesale markets as well as regulating all aspects of marketing, including the levy of user fees for transactions taking place both on and off wholesale market yards. In other words, farmers are compelled to sell their produce in government-controlled marketing yards where these controls restrict transactions to a handful of local players and where manipulation can easily occur. Existing agricultural marketing structures in India are highly monopolistic, rent-seeking and involve heavy commissions. The evidence of fragmented markets, inadequate physical infrastructure, restrictions in licensing, high intermediation costs, market information asymmetry and so on, are indications that the market system is broken. On the one hand, this prevents private players from holding stocks and, on the other, leads to higher price volatility (Government of India 2017a, b, c, 2015a, b).

The Model Agricultural Produce Market (Regulation) Committee (APMC) Act, 2003. In order to remedy the deficiencies in market transparency, promote organised competitive marketing and most importantly, to set the right tone for agricultural marketing reforms, the Atal Bihari Vajpayee government suggested to the states the model APMC Act of 2003 (Gulati and Saini 2018a, b). In 2007, this was followed by the model APMC rules. Through amendments to the APMC Acts, the government tried to improve regulations in the marketing of produce, develop efficient systems and promote agricultural processing and exports (Government of India 2003). Only some states adopted all or some provisions of the model act, and some were quicker to do so than others, but progress remained stunted. Although 22 states adopted the model in some form, it failed to transform the agricultural marketing structure in India. It is, therefore, believed that only genuine and consistent implementation of the model APMC Act can ensure better and stable prices to farmers as well as consumers and augment farmers' incomes in a sustained manner.

The Electronic National Market (e-NAM) and the Model Agricultural Produce and Livestock Market Act (APLM). Before elections in 2014, and against the backdrop of an incomplete implementation of the model APMC, the central government announced its intention to deregulate wholesale markets and establish a unified National Market (NAM) (Government of India 2015a, b), which would foster an efficient and competitive market structure and reduce the costs of intermediation, asymmetries and wastage, thus benefitting farmers as well as consumers. In April 2016, NAM was launched as a scheme, and an electronic portal, called e-NAM, was developed to support the electronic unification of markets across the country and promote e-trading. The government budgeted USD31 million (or Rs. 2 billion) for two years in the 2017–18 budget to every marketing yard willing to join the NAM platform (Gulati and Saini 2018a, b). The portal aims to share transparent information on product arrivals and prices and the buy and sell offers made by traders; it also allows both parties to respond to trade offers made. As noted in the Dalwai Committee Report 2017–18 (Volume IV), there are close to 29,547 marketing points. Of these, 22% or 6615 are regulated markets under the APMC, and the remaining are under regional periodical markets (RPMs). The NAM scheme aimed to bring 585 markets (i.e. 9% of 6615 markets) onto its e-market platform by the end of financial year 2017–18 and, as of March 2018, all targeted *mandis*, i.e. 585 *mandis* in 16 states and 2 UTs, (Chandigarh and Puducherry), have been integrated with the NAM platform (Gulati and Saini 2018a, b). Notwithstanding commendable success in coverage, out of 0.14 billion Indian farmers, only 7%, i.e. 9 million farmers (across 585 marketing yards), have been brought onto the platform, and in terms of value, only about two per cent of the total value of output in India has been traded on the platform with minimal inter-marketing yard and interstate trading. This implies the aim of creating a truly unified NAM with an efficient price discovery mechanism is still a far-fetched dream, requiring significant investments and changes in state APMC Acts (Gulati and Saini 2018a, b).

In addition to e-NAM, the central government approved the Agricultural Produce and Livestock Market (Promotion and Facilitation) Act in 2017 to reformulate the APMC Act, focusing on promotion and facilitation and on ending the monopoly of state wholesale markets by allowing more players to set up markets and create greater competition. This would facilitate direct marketing by farmers, single licence and a single point-of-entry levy for wholesale markets and the exclusion of fruits and vegetables from the APMC Act (OECD/ICRIER 2018).

5.6.2 Incentives Through Alternative Marketing Channels—the Co-operative Model; Contract Farming Model and Futures Trading

Given the inefficient and weak functioning of output markets in India, it is imperative to develop alternative arrangements for linking farmers to markets. Such arrangements include co-operatives and contract farming that are not only useful in getting the markets right but also in ensuring transparency and improved bargaining power as well as achieving reduced costs and wastages. Another innovation in incentives to farmers could be futures trading which may protect them from wide price fluctuations and enable them to make more informed decisions related to cropping patterns and resource allocation.

Co-operative Model. In the Indian dairy industry, the co-operative model was the key driver in ushering in the white revolution during 1970s. The monopoly and monopsony of a private company in the Indian dairy sector was broken when the first co-operative incentivising small dairy farmers to supply milk directly to consumers was established by farmers in 1946 in Anand, Gujarat. Access to a lucrative market encouraged farmers to increase milk production and organise themselves into co-operative societies. As a result, the famous "Anand Model" was emulated at the national level under "Operation Flood". The model functions as a three-tiered approach which includes (1) village-level dairy co-operative societies that collect milk with quality-based payments to members; (2) district co-operative milk producers' unions (DCMPUs) that process, market and provide technical support for village-level societies and (3) the state co-operative milk-marketing federations that undertake a range of marketing, feed distribution and administrative functions. Village-level societies collect milk daily from members. The milk is chilled, aggregated and transported to a co-operative plant owned by a DCMPU. Members receive immediate payment based on the fat content of their milk and a later payment based on the overall earnings of the district and state unions. Most district unions also provide a range of inputs and services to village societies, including feed, veterinary care and artificial insemination services as well as training. This model, therefore, has placed focus on "production by the masses, not mass production", ensuring that the greatest possible share of consumers' rupees went to dairy farmers (Kurien 2004). According to 2016–17 statistics, dairy co-operatives in India include 24 state milk-marketing federations, and nearly 0.17 million village-level co-operative societies with a total membership of about 16.3 million dairy farmers procuring 4.73 million litres per day (NDDB 2016–17). Other successful co-operative models in India include *Mahagrapes*, which was established to augment the income of grape producers in Maharashtra by linking them to the export market. The development of adequate storage infrastructure played a critical role in the model's success.

The Contract Farming Model. Along with the co-operative society model, contract farming is another innovative arrangement for linking farmers to markets. The best example of this kind of model is India's own poultry industry, where the emergence of innovative "vertically integrated poultry operations" and "contract farming" catalysed the growth of the commercial system. Contact farming in poultry is broadly defined as an agreement between a hatchery (an integrator) and farmers to produce/raise poultry birds at predetermined prices. This framework requires a commitment on the part of the farmer to provide reared birds in quantity (measured in terms of mortality) and of specific quality (measured in terms of feed conversion ratio (FCR)) and a commitment on the part of the hatchery to support the farmer's production and to "buy back" the fully grown birds (Zakir 2008). The farmers are also given an incentive bonus if the FCR and/or mortality rate is better than the contracted level. Under the arrangement, the hatcheries provide quality inputs, technical guidance, management skills and credit as well as knowledge of new improved technology, through intermittent supervision. Farmers, on behalf of the hatcheries, look after the chicks and rear them in their poultry sheds until they reach slaughter weight while maintaining a strict level of biosecurity. Farmers have found the guaranteed returns of contract farming preferable to the vagaries of market returns because of the fixed income, assured market, credit support and reduced risk and uncertainty. The live birds are then either purchased by the hatcheries for slaughter and further processing or by a wholesaler who distributes them via live markets (DoAHD&F 2017). This arrangement has provided farmers with lower transaction costs, guaranteed markets, faster turnaround, more transparent pricing and better allocation of risks, while contracting firms have had the advantage of secure supplies and reasonable control over quality and other specifications. Other successful contract farming models include Pepsico, which is undertaking sustainable contract farming of potato, and Jain Irrigation, which is doing the same with onion.

Futures Trading. A futures market provides a sound incentive for farmers since it improves the transparency of market operations and helps farmers hedge against price risks and make more informed decisions related to cropping patterns and resource allocation. However, agricultural futures have gone through a roller-coaster ride since its introduction in 2003, due to an unstable policy environment and excessive regulatory government interventions in some commodities (such as higher margins or outright suspensions and bans, or frequent changes in stocking restrictions on private trade) likely to affect consumer household budgets significantly.[32] Therefore, the success of futures trading requires no government intervention in the market to influence prices (Gulati et al. 2017). China and the USA are forerunners in establishing and managing agricultural futures trading around the world, with China having the largest number of agricultural future contracts (69% in TE 2016–17) followed by the USA (18%),which is the oldest player in the futures market (Gulati et al. 2017). However, the size of each contract is much bigger in USA than in China.

[32]The highly traded commodities in India in TE-2016 include soybean complex (21%), guar gum complex (22%), *chana* (9%), castor oil complex (8%), cotton fibre (8%), rapeseed (9%) and cotton oil seed complex (7%) (Gulati et al. 2017).

5.6.3 *Incentives Through Innovations in Marketing Infrastructure—Negotiable Warehouse Receipts System (NWRS)*

Better infrastructural facilities help in expanding the markets for farmers' produce, in reducing wastage and getting better prices. When farmers get the right signals regarding price, they are incentivised to adopt modern inputs and new technology that increase production and augment yields. Therefore, when production responds to expansion in marketing infrastructure, the price response is positive and strong. An initiative to improve marketing infrastructure is the Negotiable Warehouse Receipts System (NWR), which was introduced by the government in 2010 under the regulation of the Warehousing Development and Regulatory Authority (WDRA) to promote marketing in India and help farmers realise better prices for their produce (Government of India 2018a, b). The system not only protects farmers from distress sales when prices fluctuate but also acts as a financing tool. The NWR facilitates borrowing against stocks from banks and other financial institutions. It also allows for smooth trading on different platforms such as commodity exchanges and electronic National Agriculture Markets (e-NAM) (Business Line 2011). All of this together enhances liquidity in rural areas and promotes an efficient supply chain. As of September, 2018, out of 1914 warehouses registered, 761 were active, with USD0.90 billion (or Rs. 63.6 billion) worth of commodity deposits, against which loans worth USD0.24 billion (or Rs. 17.10 billion) had been issued to farmers. In September 2017, the WDRA also set up a portal for online registration of warehouses, called the Electronic Negotiable Warehouse Receipts (e-NWRs). It set up two repositories, namely, the National Electronic Repository Limited (NERL) and the CDSL Commodity Repository Limited (CCRL) to create and manage e-NWRs. Since September 2017, over 1600 beneficiary accounts have been opened with NERL, and over 49,000 e-NWRs have been generated (with NERL) (see Fig. 5.10).

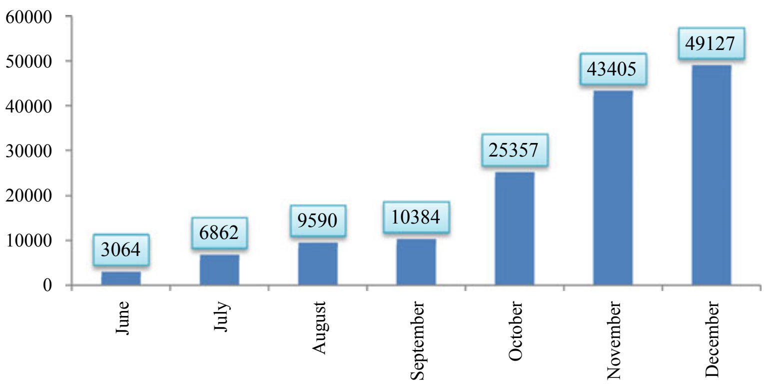

Fig. 5.10 Number of e-NWRs Generated (As on 2018) in India. *Source* Government of India (2018a, b)

5.6.4 *Incentives for the Adoption of New Technologies and Practices*

As over-exploitation of groundwater is emerging as a major concern in ensuring the environmental sustainability of agriculture, it is imperative to incentivise farmers to improve water productivity and invest in water-saving technologies. A crucial step in this direction was undertaken by introducing the "*Pradhan Mantri Krishi Sinchayee Yojana*" in 2015–16 and popularising micro-irrigation to ensure "per drop, more crop". Funding of financial assistance—under the per drop more crop (micro-irrigation) to the beneficiary—is to the tune of 35% of the total cost of installation for small and marginal farmers and 25% of the total cost for other farmers under the non-drought prone area programme/desert development programmes well as in the North-Eastern and Himalayan states. The funding is shared in the ratio of 60:40 between the central and state governments for all states except the North-Eastern and Himalayan states, where the sharing is in the ratio of 90:10. However, in the case of union territories, the scheme will be funded 100% by central government.[33] The scheme is implemented through direct benefit transfer (DBT). In the Union Budget 2017–18, a dedicated fund in the National Bank for Agriculture and Rural Development (NABARD), called the "Micro-Irrigation Fund" (MIF), was set up with an initial outlay of USD0.77 billion (or Rs. 50 billion) to encourage public and private investments in micro-irrigation (Government of India 2017a, b, c).

Further, to make agriculture more productive, sustainable, remunerative and climate-resilient, the Government of India in 2015 launched the National Mission for Sustainable Agriculture (NMSA). The NMSA promotes location-specific integrated/composite farming systems, soil and moisture conservation measures, comprehensive soil health management, efficient water management practices and the mainstreaming of rain-fed technologies. There are nine schemes under the mission: Rain-fed Area Development (RAD); Soil Health Management (SHM); Sub-Mission on Agro Forestry (SMAF); *Paramparagat Krishi Vikas Yojana* (PKVY); the Soil and Land Use Survey of India (SLUSI); the National Rain-fed Area Authority (NRAA); the Mission Organic Value Chain Development in North-Eastern Region (MOVCDNER); the National Centre of Organic Farming (NCOF) and the Central Fertiliser Quality Control and Training Institute (CFQC&TI). Efforts are directed towards developing the North-East as an organic hub. Sikkim has emerged as the first and the only fully organic state in the country. The state has adopted organic (chemical fertiliser/pesticide/insecticide-free) farming as the only farm practice and has prohibited the use of agrochemicals.[34]

Recently, however, the Punjab government proposed a direct benefit transfer scheme for inputs in which the resource is subsidised through an income-policy

[33]The subsidy payable to the beneficiary is limited to an overall ceiling of 5 ha per beneficiary and has a lock in period of 7 years (which is equivalent to the projected life of the micro-irrigation system).

[34]https://timesofindia.indiatimes.com/india/PM-envisions-the-entire-northeast-to-be-a-hub-of-organic-farming-Flags-Sikkim-model-as-an-inspiration/articleshow/50629652.cms.

approach rather than the traditional price policy approach. The state's "*Paani Bachao, Paise Kamao*" scheme to subsidise electricity is currently being piloted with six electricity feeders in three districts: Jalandhar, Hoshiarpur and Fatehgarh Sahib. As per The Energy and Resources Institute (TERI), 277 out of 940 farmers have opted for the scheme. As a next step, it has been decided to set up 1000 demonstration farms to showcase to farmers recent infrastructural and agronomic interventions. Under the scheme, metres are installed to farmers' pumps to record the amount of water saved by them. For each unit of water saved compared to the specified optimum power limit, farmers would receive a subsidy at the rate of Rs. 4 per unit directly into the bank account. This will promote efficient water and electricity use across feeders and help farmers reduce their production risk and increase farm productivity.

To achieve the target of 100 Gigawatts (GW) of solar power generation by 2022 and to enhance the income of farmers, the government of the National Capital Territory of Delhi in its 2018–19 Green Budget announced an innovative scheme named "Agriculture-cum-Solar Farm" under the *Mukhyamantri Aay Badhotari Yojana*, under which solar panels will be set up on farmers' land. Under the scheme, panels will be placed on raised structures (at a height of 3.5 m) and spaced widely enough to allow unhindered farming below. A maximum of a third of the surface area of the selected land will be used for solar installations. Farmers are neither required to make any investments, nor are they asked to sell their ownership rights. All that is required of farmers is that they provide six acres of contiguous land (the minimum space required by 1 MW plant) for a period of 25 years. The energy produced will be purchased at the rate USD119.2 (or Rs. 8333) per month per acre with an increment of 6% per annum for 25 years (Government of Delhi 2018). In addition to assured income, farmers will get free electricity from the solar plant subject to a ceiling limit of 6000 units per annum per MW plant capacity. The scheme will operate based on the Renewable Energy Service Companies (RESCO) model.[35] The solar energy produced will be stored and sold based on virtual net metering policy to government departments such as the health department and public works department, and the government agency Delhi Jal Board, which are bulk power consumers (Government of Delhi 2018).[36] By providing an additional source of income, farmers are incentivised to move towards cleaner sources of energy by cultivating solar as a third crop.

Therefore, the government is taking several initiatives to incentivise the adoption of sustainable technologies and practices in agriculture; however, the limited coverage is still a challenge that needs to be addressed in a structured manner.

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[35] RESCO model means that the Solar Power Developer (SPD) intends to take a farm/land owned by some other entity on mutually agreed term and conditions from the farm/land owner(s) and enters into PPA for supply of solar power.

[36] http://delhi.gov.in/wps/wcm/connect/79b16c8047369c4d813ccd4bb6226757/Mukhya+Mantri+Kisaan+Aay+badhotary+Yojana.pdf?MOD=AJPERES&lmod=-276071204.

5.6.5 Incentives through General Support Services (GSS)

According to the Organisation for Economic Co-operation and Development (OECD), support is defined as the annual monetary value of gross transfers to agriculture arising from government policies, regardless of their objectives and their economic impact. Support to agriculture through general services such as development and maintenance of infrastructure (particularly capital expenditure on irrigation), followed by the cost of public stockholding (for food security) and expenditure on the knowledge and innovation system (knowledge generation, education and extension) creates enabling conditions for the overall development of the sector. It does not include any transfers to individual producers. According to the report (OECD/ICRIER 2018), expenditure on the knowledge and innovation system in India has consistently amounted to about 10% of general support services (GSS) expenditure. Most of this has been for knowledge generation and extension in recent years, leaving a very small share for education.

Overall expenditure on general services as a percentage of value of production followed an increasing trend from 2000 to 2008 in the country, after which it started falling and has remained at a lower level (Fig. 5.11). This GSS percentage was 3.14% in TE 2002–03 and 3.2% in TE 2016–17, revealing that expenditure on general services to the agriculture sector has barely kept pace with the increase in the value of production. There is an increasing need to broaden economic investments in infrastructure in rural areas, both in general terms, such as roads and healthcare, and specific infrastructure that would facilitate the development of the agricultural sector.

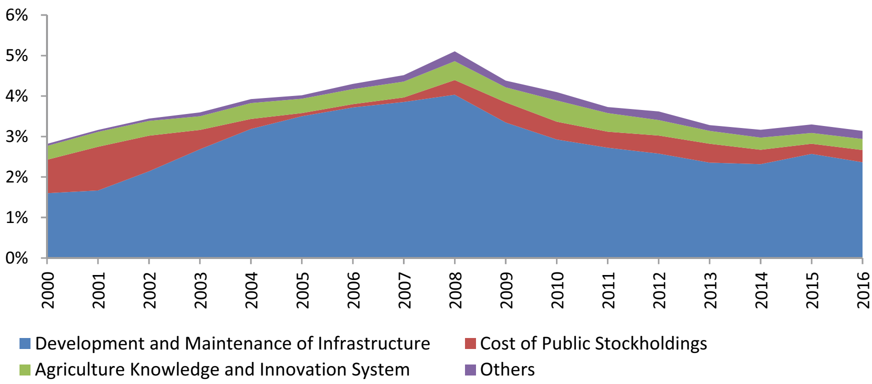
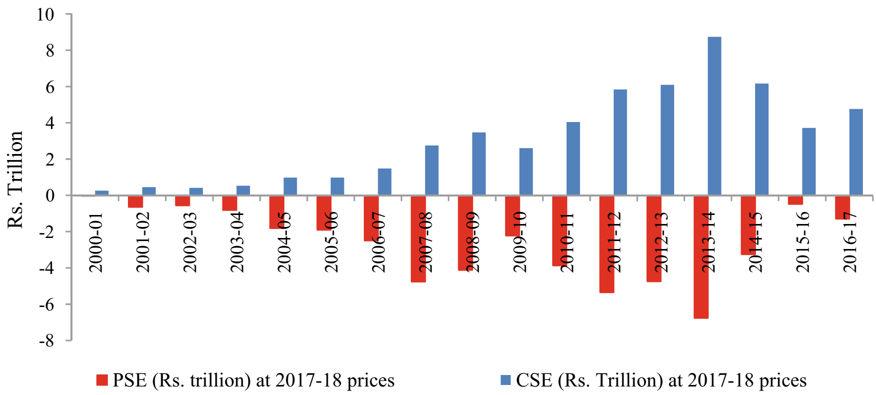


Fig. 5.11 Components of General Service Support as a percentage of Value of Production, India. *Source* OECD/ICRIER (2018). *Note* Others include expenditures on inspection and control; marketing and promotion and miscellaneous

5.7 Net Effect of Support Policies in India

The analysis above makes it apparent that India adopts policy interventions that distort production decisions and are inadequate for farmers to realise better prices. Increasing MSPs based on A2 + FL costs, while ignoring its demand side, is patently inefficient. It is not only costing the nation heavily but also creates market distortions. Moreover, the MSP policy is not inclusive due to limited reach. Even the government's recent initiative of PM-AASHA has failed to yield the expected results as none of the states have implemented the scheme. Madhya Pradesh, which had piloted the price deficiency payment scheme in *kharif* 2017, has discontinued it due to its limited reach and high costs. Therefore, price support policy cannot be a solution to farmers' distress. Although budgetary transfers through input subsidies have succeeded in achieving the objective of increasing grain production during the period of the Green Revolution, these subsidies are not free from challenges. Most critically, they have crowded out public investments in agriculture. Trends show that from 1980–81 to 2014–15, public investment in agriculture as a percentage of GDP came down from 3.9% to 2.2%, while total input subsidy as a percentage of GDP has increased from 2.8% to 8% (Gulati, Ferroni and Zhou 2018). Further, these subsidies are a major source of leakages in the system, thus adding to the financial burden on the exchequer. The relative price signals, through heavy input subsidies, mislead farmers into over-utilising limited agricultural resources, aggravating farm distress. The introduction of the loan waiver (which is currently popular) and interest subvention schemes have serious implications for the financial health of the banking system. Already, the bill for loan waivers for those state governments that have announced them is almost USD27.9 billion (or Rs. 1.8 trillion) and unpaid bills on account of interest subvention amounts to USD5.72 billion (or Rs. 350 billion).

This implies supporting Indian farmers through price policy instruments and loan waivers is highly distortionary, iniquitous and unsustainable. The government will never be able to create a stable environment for farmers to realise better prices through such policies. A major shift in policy to direct income/investment support to farmers is urgently needed. This shift will create a predictable environment for farmers to make cropping decisions of their choice and will be less distorting of the market. The joint study conducted by OECD and ICRIER quantifies the total support provided through domestic and trade policies over a period of 17 years from 2000–01 to 2016–17 to the sector. Direct support to producers is calculated as producer support estimate (PSE), which is the annual monetary value of gross transfers from consumers and taxpayers to producers, measured at the farm gate level, arising from policy measures that support agriculture, regardless of their nature, objectives or impact on farm production or income. PSE percentage combines market price support and budgetary spending benefitting farmers and expresses the total as a percentage of gross farm receipts. During the entire period of the OECD-ICRIER study (2000–2016), India's PSE has been a negative 14.4%. This is due to the combined effect of the absolute value of negative market prices and positive input subsidies. However, both support components of PSE are of the potentially most distorting type, and the distortions



Average annual value of PSE and CSE from 2000-01 to 2016-17 at 2017-18 prices stand at (negative) Rs.2.65 trillion and Rs.3.13 trillion respectively.

Fig. 5.12 Producer Support Estimates (PSE) and Consumer Support Estimates (CSE) in India. *Source* Author's calculation based on OECD/ICRIER (2018). *Note* **PSE** = Market price support + payment based on input use + payments based on current area, Animal Number, Receipts and Income (A/An/R/I), production required + payments based on non-current A/An/R/I, production required + payments based on non-current A/An/R/I, production not required + payments based on non-commodity criteria + miscellaneous payments and **CSE** = Transfers to producers from consumers of which, MPS commodities + transfers to consumers from taxpayers + other transfers excess feed cost

they create in the Indian economy do not cancel out each other (OECD/ICRIER 2018). This implies that producers/farmers in India are implicitly taxed due to abrupt trade restrictions and bans[37] as well as regressive marketing control exercised by the Essential Commodities Act (ECA) and the Agricultural Produce Market Committee Acts (APMCs), which not only prevent private participation but is the main reason behind lower incomes of the farmers. India's trade policy as currently implemented is characterised not just by relatively high barriers to imports and exports, but also by a significant degree of uncertainty. The period between 2000–01 and 2016–17 is categorised by export restrictions or export bans on wheat, non-basmati rice, chick-peas, sugar and milk, enforced to influence domestic prices. Moreover, India's PSE is amongst the lowest in the world, i.e. Indian farmers are receiving much lower prices compared to other nations. On average, Indian farmers were taxed at the rate of USD41.1 billion (or Rs. 2.65 trillion) per annum (at 2017–18 prices) during 2000–01 and 2016–17 (see Fig. 5.12). In cumulative terms, using 2017–18 prices, over USD698 billion (or Rs. 45 trillion) were drawn off from farmers' incomes between 2000 and 01 and 2016–17. India further favours its consumers to the detriment of its farmers through tendentious food and agricultural policies. As a result of suppressed agricultural prices and heavy subsidies on food, the consumer support estimate (CSE) from 2000–01 to 2016–17 was USD48.5 billion (or Rs. 3.13 trillion) per annum at

[37] India adjusts the applied tariffs downward and permits imports when domestic supplies are tight, with a view to limiting price rises. Such decisions are made on a case-by-case basis.

2017–18 prices (see Fig. 5.12). Of this, about 81% comes from farmers who cannot realise the best prices for their produce due to restrictive trade and marketing policies and the remaining amount from food subsidies for which USD28.5 billion (or Rs. 1.84 trillion) has been provided in the current budget (plus a minimum of USD18.6 billion (or Rs. 1.2 trillion) of pending FCI bills); food subsidy is provided to 67% of the population. Therefore, agriculture support policies in India are pro-consumer and implicitly tax farmers; this is in contrast to the situation in most other countries. As per recent OECD estimates released in 2018, in China and other OECD countries, PSE is positive to the tune of 15.5% and 26%, respectively.

5.8 Concluding Remarks

The negative PSE estimated for India for the last 17 years indicates that Indian farmers are in reality being net taxed. The positive support given through input subsidies is nullified by the negative market price gaps estimated for various commodities. Lower domestic market prices prevail due to policies like the ECA and APMC Acts, as well as frequent export restrictions and bans imposed from time to time. First and foremost, there has been a realisation to set the markets free and reform the agricultural economy through the effective implementation of the new model Agricultural Produce and Livestock Market Act (APML) and Electronic National Agriculture Market (e-Nam). This should be done strictly across the country on the lines of a goods and service tax (GST). Archaic ECA laws must be immediately abolished to open up the markets. Government of India has taken a bold step recently in this context and has amended the ECA Act, liberalised the APMC Act and promoted contract farming via three Acts. As per some experts, this is a positive step, similar to the delicensing of industries in 1991, towards improving farmers' competiveness. Further, to reduce post-harvest losses, the government needs to incentivise private players to invest in infrastructural facilities, including supply chain management and food-processing units. It is also necessary to establish a stable trade environment. A more predictable and open regime governing imports would permit the emergence of a multidimensional food security strategy combining domestic production in line with India's comparative advantage, along with an appropriate level of food security stocks and imports. Otherwise, farmers and private traders will be unwilling to invest in the supply chains. Thus, the need is to ensure that India is a competitive and reliable exporter of agricultural produce. Instead of potentially over-reacting by increasing the MSP of various crops, and ignoring demand considerations that could lead to a large accumulation of stocks, the government should divert such resources through investment in infrastructure and the warehouse receipt system. Given the vast leakages and inefficiencies prevailing in input subsidies, along with low marginal returns on poverty alleviation and growth, it is time policymakers shift their priority from subsidies to investment. The burgeoning subsidy bill on account of loan waivers, credit subsidy and diversion of agricultural credit to non-agricultural use calls for serious scrutiny of the scheme. Moreover, loan waivers have the potential to severely affect the credit culture and trigger a cycle of events that could lead to the drying up of institutional credit. The government needs to embrace innovations to achieve the twin objectives of providing food and nutritional security to its people as well as supporting a large number of farmers in a more predictable and structured manner. In this way, a strong case will be built for a move towards income support measures, which are less distortionary and incorporate targets in order to reach the real beneficiaries. The governments of Telangana, Odisha, Jharkhand and West Bengal, and now the central government as well, are on board and have implemented income support schemes. On the whole, the alleviation of farm distress calls for a major shift in policymaking towards direct income support, agricultural marketing reforms, rationalising subsidies and prioritising investments in line with the changing requirements of modern agriculture to make the sector more productive, competitive, inclusive and sustainable.

References

Business Line. (2011, April 26). Govt launches negotiable warehouse receipts. *The Hindu.*
CACP. (2014). *Price policy for Rabi crops: The marketing season 2015–16.* New Delhi: Department of Agriculture, Co-operation and Farmers' Welfare, Ministry of Agriculture and Farmers' Welfare, Government of India.
CACP. (2017). *Price policy for Kharif crops: The marketing season 2017–18.* New Delhi: Department of Agriculture, Co-operation and Farmers' Welfare, Ministry of Agriculture and Farmers' Welfare, Government of India.
CACP. (2018a). *Price Policy for Kharif crops: The marketing season 2018–19.* New Delhi: Department of Agriculture, Co-operation and Farmers' Welfare, Ministry of Agriculture and Farmers' Welfare, Government of India.
CACP. (2018b). *Price policy for Rabi crops: The marketing season 2018–19.* New Delhi: Department of Agriculture, Co-operation and Farmers' Welfare, Ministry of Agriculture and Farmers' Welfare, Government of India.
Chand, R. (2018). *Ensuring MSP benefit to farmers.* New Delhi: NITI Aayog.
Chatterjee, S., & Kapur, D. (2016). *India policy forum—"Understanding price variation in agricultural commodities in India: MSP, government procurement, and agriculture markets".* New Delhi: National Council of Applied Economic Research (NCAER).
Dewbre, J., Anton, J., & Thompson, W. (2001). The transfer efficiency and trade effects of direct payments. *American Journal of Agricultural Economics, 83*(5), 1204–1214.
DoAHD&F. (2017). *National action plan for egg & poultry—2022 for doubling farmers' income by 2022.* New Delhi: Department of Animal Husbandry, Dairying and Fisheries. Ministry of Agriculture & Farmers' Welfare, Government of India.
FAO. (2019, January 18). Innovating for our future of food and agriculture: How innovations are helping bring the number of hungry down to zero. *Food and Agricultural Organization of the United Nations.*
Goklany, T. (2016, March 15). Minimum Support Price: Harsh Reality vs Good Intent. *NDTV*.
Government of Delhi. (2018). *Agriculture-cum-solar farm scheme.* New Delhi: NCTof Delhi.
Government of India. (2003). *Salient features of the model act on agricultural marketing: Marketing infrastructure and agricultural marketing reforms.* New Delhi: Directorate of Marketing and Inspection, Ministry of Agriculture and Farmers' Welfare.

Government of India. (2014). *Annual report on the working of state power utilities and electricity departments*. New Delhi: Power and Energy Division, Planning Commission, Government of India.
Government of India. (2015a). *Annual Report 2014–15.* New Delhi: Department of Agriculture, Co-operation and Farmers' Welfare, Ministry of Agriculture and Farmers' Welfare, Government of India.
Government of India. (2015b). *Brief history of agricultural marketing regulation.* Directorate of Marketing and Inspection: Its Constraints and Reforms in the Sector.
Government of India. (2016a). *Agricultural statistics at a glance.* New Delhi: Directorate of Economics Statistics, Department of Agriculture, Co-operation and Farmers' Welfare, Government of India.
Government of India. (2016b). *The direct benefit transfer*. New Delhi: DBT Mission, Cabinet Secretariat, Government of India.
Government of India. (2017a). *Economic survey 2016–17*. New Delhi: Government of India.
Government of India. (2017b). *Operational guidelines of per drop more crop (micro irrigation), component of PMKSY*. New Delhi: Ministry of Agriculture & Farmers' Welfare, Government of India.
Government of India. (2017c). *Post production interventions: Agricultural marketing, volume IV, report of the committee on doubling farmers' income.* New Delhi: Department of Agriculture, Co-oporation and Farmers' Welfare, Ministry of Agriculture and Farmers' Welfare.
Government of India. (2018a, September 12). Cabinet approves New Umbrella Scheme "Pradhan Mantri Annadata Aay SanraksHan Abhiyan" (PM-AASHA). *Press Information Bureau.*
Government of India. (2018b). *Divisions.* Retrieved December 31, 2018, from Department of Food and Public Distribution: https://dfpd.nic.in/storage-intro.htm.
Government of Odisha. (2018a). *Frequently asked questions (FAQ) on KALIA.*
Government of Odisha. (2018b). *The Odisha Gazette.* Cuttak: Department of Agriculture and Farmers' Empowerment, Government of Odisha.
Government of Telangana. (2018). *Rythu Bima.* Retrieved January 18, 2019, from Government of Telangana: http://rythubandhu.telangana.gov.in/Default_LIC1.aspx.
Government of West Bengal. (2019, January 17). Notification for Krishak Bandhu Scheme. Howrah, West Bengal, India.
Gulati, A., & Chatterjee, T. (2017, August 14). From plate to plough: Getting agri-futures right is need of the hour; Here's what government needs to do. *The Financial Express.*
Gulati, A., & Chatterjee, T. (2018a, December 10). From plate to plough: Quick fix for the farmer. *The Indian Express.*
Gulati, A., & Chatterjee, T. (2018b, April 02). From Plate to Plough: The right agri-support. *The Indian Express.*
Gulati, A., & Saini, S. (2018a, May 28). Creating a national agriculture market. *The Financial Express.*
Gulati, A., & Saini, S. (2018b, April 30). From plate to plough: Reading Modi government's agri-performance right. *The Financial Express.*
Gulati, A., & Terway, P. (2018, December 24). From Plate to Plough: Loan waivers—Atonement and bait. *The Indian Express.*
Gulati, A., Chatterjee, T., & Hussain, S. (2017). *Agricultural commodity futures: Searching for potential winners.* New Delhi: Working Paper 349, Indian Council for Research on International Economic Relations.
Gulati, A., Chatterjee, T., & Hussain, S. (2018). *Supporting Indian farmers: Price support or direct income support.* New Delhi: Working Paper No. 357, Indian Council for Research on International Economic Relations.
Gulati, A., Ferroni, M., & Zhou, Y. (2018). *Supporting Indian farms the smart way*. New Delhi: Academic Foundation.

Gupta, S. K., Gupta, R. C., Seth, A. K., Gupta, A. B., Bhasin, J. K., & Gupta, A. (2000). Methaemoglobinemia in areas with high nitrate concentration in drinking water. *National Medical Journal of India, 13*(2), 58–61.

Haque, T., & Joshi, P. K. (2018). Price deficiency payments and minimum support prices: A study of selected crops in India. In U. Kapila (Ed.), *Economic developments in India* (Vol. 243). New Delhi: Academic Foundation.

Himanshu, A. S., & Sen, A. (2013). In-kind food transfers-I: Impact on poverty. *Economic and Political Weekly, 48*(45), 46–54.

IARI. (2014). *Greenhouse gas emission from Indian agriculture: Trends, mitigation and policy needs.* Center for Environment Science and Climate Resilient Agriculture.

Kumar, T. N. (2018, December 26). Farm Aid: Rhythu Bandhu or QUBIS? *The Indian Express.*

Kurien, V. (2004). *India's milk revolution—Investing in rural producer organizations.* New Delhi: The Lotus Collection, an imprint of Roli Books Pvt. Limited ISBN 9788174364074.

Ministry of Finance. (2019). *Interim budget speech 2019–2020.* New Delhi: Government of India.

NDDB. (2016–17). *Annual report.* New Delhi: GOI.

OECD. (2001). *Market effects of crop support measure.* Paris: OECD Publishing.

OECD. (2017). *Water risk hotspots for agriculture.* Paris: OECD Publishing.

OECD/ICRIER. (2018). *Agricultural policies in India.* Paris: OECD Food and Agricultural Reviews, OECD Publishing.

Prasad, R. (2009). Efficient fertiliser use: The key to food security and better environment. *Journal of Tropical Agriculture, 47*(1).

RBI. (2017–18). *Handbook of statistics on the Indian economy.* Mumbai: Reserve Bank of India.

RBI. (2018). *Farm loan waiver: An update.* Reserve Bank of India.

Sekhar, C. S. (2018). Price support to farmers: A review of recent policy initiatives. In U. Kapila (Ed.), *Economic developments in India (Volume 243).* New Delhi: Academic Foundation.

Sen, R. K., & Chatterjee, B. (2002). *Indian economy, Agenda for the 21st century: Essays in honour of Professor P.R. Brahmananda* (Vol. 243). New Delhi: Deep and Deep Publications Pvt. Ltd.

Sharma, V. P., & Thaker, H. (2010). Fertiliser subsidy in India: Who are the beneficiaries? *Economic and Political Weekly, 50*(52).

Shreedhar, G., Gupta, N., Pullabhotla, H., Ganesh, A. K., & Gulati, A. (2012). *A review of input and output policies for cereals production in India.* IFPRI Discussion Paper 1159. Washington, DC: International Food Policy Research Institute (IFPRI).

Swaminathan, S. A. (2018). *Swaminomics: Naveen Patnaik has the best idea for tackling farm distress.*

Telangana State. (2018). *Agriculture Investment Support Scheme (Rythu Bandhu).* Government of Telangana.

Zakir, S. (2008). *Management of contract farming in livestock: A case of poultry industry.*

Chapter 6
Reforms and Incentive Policies in China's Agriculture

6.1 Introduction

China's agricultural market reform started in the early 1980s. At the beginning of the reform, China did not give up a national planned economic system, but considered the free market as a supplement to the planned economy (Perkins 1994). During the course of economic reform, however, China gradually abandoned the state-planned procurement and marketing of agricultural products although the process has been going back and forth. The reform was first started in non-strategic important commodities and then gradually moved to important commodities such as rice, wheat and maize. Meanwhile, China has also invested significantly in market infrastructure to improve regional market integration.

Since the early 1990s, China has also been gradually liberalising its agricultural trade. The average import tariff of agricultural commodities declined from 42.2% in 1992 to 23.6% in 1998 and 21% in 2001 when China joined the World Trade Organization (WTO). Based on China's commitments on joining the WTO, agricultural tariff rates further fell to 12% in 2004. China also made significant commitments and major concessions in terms of domestic support and export subsidies (Anderson et al. 2004).

Gradual market reform is a unique aspect of China's market liberalisation. The path of China's market reform differs from that of many countries in Eastern Europe which rapidly abolished the planned economy and experienced a significant fall in agricultural production in the initial years of reform (Rozelle and Swinnen 2004). In contrast, China's gradual reform has facilitated its smooth transformation from a formerly centrally planned economy to a more market-oriented one (Rozelle et al. 2000; Sicular 1995).

The aim of this chapter is to have a better understanding of price and market reforms, as well as other major policies, that have affected the incentives of farmers in China over the past four decades. The experience and lessons in setting incentive policies for farmers and agriculture are important not only for future policy decisions in China, but also for their implications for other developing countries that may face

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similar problems during their own rural transformations. The rest of this chapter is organised as the follows. Section 6.2 discusses incentive reforms and policies governing the domestic agricultural market and output pricing before the early 2000s, and Sect. 6.3 presents the new incentives and reforms in agriculture after the early 2000s when China shifted its policy from taxing to subsidising; it also moved towards promoting sustainable agriculture. Section 6.4 presents China's agricultural trade policy, reform and liberalisation. The overall incentive distortions for agriculture as a whole, and major commodities over time, are presented in Sect. 6.5. The incentives governing agricultural inputs, with a focus on fertiliser and irrigation, are discussed in Sect. 6.6. Recently, emerging and innovative rural e-commerce is briefly summarised in Sect. 6.7. The last section of this chapter concludes with some major policy implications.

6.2 Agricultural Output Market Reforms and Pricing Policies Before the Early 2000s

6.2.1 Overview of Price and Marketing Reforms

Because there was no real market in the prereform era, price and market reforms were considered key components of China's strategy to shift from a socialist to a market-oriented economy. Price and market reform was first initiated in the late 1970s by raising government procurement prices. After the early 1980s, when the household responsibility system (HRS) that shifted agricultural production from collective to individual households was fully implemented, price and marketing reforms were introduced for different agricultural commodities (Box 6.1).

Box 6.1: China's Gradual and Sequential Market Reforms in Agriculture, 1978–Early 2000s

Less to more strategic importance	Period of liberalization
Horticulture	the mid-1980s
Aquaculture	the late 1980s
Minor coarse grains	the late 1980s
Livestock	the late 1980s
Sugar and edible oils	the early 1990s

Strategic importance	Period of liberalisation
Cotton	the mid-1990s
Soybean	the mid-1990s
Rice/wheat/maize	the early 1990s: nearly liberalized
	1995 and 1998-2000: Recontrolled
	the early 2000s: liberalized

Reforms began with the less important commodities and went on to the strategically important ones; for each commodity the reform was implemented gradually. Starting with the easier commodities provided an opportunity to learn from experience before moving on to more challenging reforms. This path of reform followed Deng Xiaoping's reform strategy, the so-called Crossing the River by Feeling for the Stones. For example, before the mid-1980s, the first and only products to have been liberalised were the relatively less strategically important vegetable and fruits. After the mid-1980s, price and market reform gradually moved to animal products (e.g. fish and meat) and was finally implemented for sugar, edible oil, cotton and grain—the commodities considered strategically important by China's government (Box 6.1). In the rest of this subsection, we use horticulture (vegetables and fruits) and grain as examples to illustrate how China reformed its less and most strategically important commodities during the reform period.

6.2.2 Incentive Reforms of Less Strategically Important Commodities

Horticultural price and marketing reforms started in 1978, and the completion of the phasing out of government procurement and distribution system occurred by the mid-1980s. Before 1984, reform focused on raising government procurement prices and introducing a multichannel distribution system for vegetables, fruits and other minor crops. By 1985, the government formally abolished its procurement and distribution of these commodities and shifted its effort to developing marketing infrastructure and the institutions governing these markets.

To establish a multichannel distribution system in the years 1978–1984, the government gradually reduced its procurement and distribution activities, allowing more private entities to participate in the marketing of horticultural and other minor commodities. Before 1978, state-owned commerce and the supply-and-marketing co-operatives excluded any other entity in horticultural markets and monopolised the marketing of vegetables and fruits in all urban areas; they were also in charge of selling these products to the non-agricultural population in rural areas. During the reform period, there had been rising numbers of village fairs in rural areas and farm produce markets in urban areas, as well as emerging wholesale markets in some major production counties where the products of horticulture, aquaculture and poultry were traded. After 1984, the government introduced a major initiative to develop wholesale markets for agricultural and subsidiary products in both rural production areas and urban consumption areas.

By the mid-1990s, there was concern that rising and fluctuating market prices might cause social instability with the liberalisation of horticultural markets and elimination of planned prices (or set price). To deal with this problem, the central government required local governments to invest significantly in wholesale markets, fair trade markets and retail outlets to stabilise the supply of horticultural products and other liberalised agricultural commodities. In the meantime, the Ministry of Agriculture initiated the "shopping basket programme" aimed at developing vegetable, meat, egg and other non-staple food production bases in suburban areas. With rising demand for vegetables and other non-staple foods (or non-grain food), production of these commodities expanded from suburban to rural areas that were relatively far from urban centres.

With improved market infrastructure and inter-province transportation after the late 1990s, markets for horticultural products and other liberalised products such as fish, minor coarse grains (e.g. sweet potato, millet, barley, sorghum, etc.), poultry, egg and pork have been largely integrated across China. Since the mid-2000s, China has moved to a new stage of market development aimed at improving the traceability of all agricultural products, including vegetables and fruits, though this is a challenge in small farm-dominated agriculture.

A recent study of China's fruit and vegetable value chains shows that vegetable and fruit markets are competitive and efficient (Huang and Hua 2018). This study selected apple and tomato as the representative commodities for fruits and vegetables. It traced marketing costs and price margins from farm gate to the end of marketing chain (e.g. retail) for the same commodity in real time. It was found that the horticulture markets were very competitive. For example, in 2018, the ratio of retail price to farm gate price ranged from 1.7 to 2.5 for different grades of apples that moved about 1000 km from farm gate to urban retail outlets. With tomatoes, this ratio ranged from 1.24 to 1.75 in the same year. The lower price margin for tomatoes compared to apples is because of the lower costs of sorting and packing and shorter transportation distances. The greatest price margins are explained by transportation, sorting and packaging, storage, the hiring of labour and renting costs. Total gross return on family own labour and fixed capital investment of wholesalers and retailers were only about 20% of retail prices. When accounting for the costs of family own labour and fixed capital investment, the net profit for both wholesalers and retailers is nearly zero, which indicates that the market is very competitive.

6.2.3 Incentive Reforms of Strategically Important Commodities

Among agricultural commodities, grain market liberalisation is the most important reform and has lasted for more than two decades. This is because of the national leaders' concerns about fluctuations in grain production and prices in some periods and the important implications for the consumer price index in general and food prices in particular. Because the price and marketing reforms in rice, wheat and maize were similar from the late 1970s to the early 2000s, in the following discussion, we use rice as an example to illustrate grain price and marketing reform during this period.

6.2.3.1 Overall Reform Trends

In general, China took a careful approach with regard to phasing out government procurement for strategically important commodities, using the intervening period to introduce various policy measures to incentivise the production of these commodities. Figure 6.1 shows the amount of government quota (bottom line) and negotiated rice procurement (the difference between the bottom and middle lines) as well as the amount of rice sold in the free market (the difference between the top and middle lines) between 1978 and 2003. Figure 6.2 shows the corresponding prices of government quota procurement, negotiated procurement and the free market during 1980 and 2004. Negotiated procurement prices largely followed rural market prices. Figure 6.2 also presents the trend in rice prices sold to urban consumers through a rationing system.

As Fig. 6.1 shows, in the initial reform period (1978–1984), the share of rice sold through the market was just a couple of million tonnes. The rise in the amount of rice procurement reflected the significant increase in rice production during the early reform period (see the introduction and innovative technology chapters). However, the share of the free market increased to more than half of total marketed rice by the mid-1990s and about three quarters in 2003 (Fig. 6.1). Correspondingly, since the mid-1980s, there was a significant fall in government quota procurement. By 2003, quota procurement was completely phased out.

While farmers had been heavily taxed through the government procurement system before the late 1990s, incentives to farmers had been provided by raising the

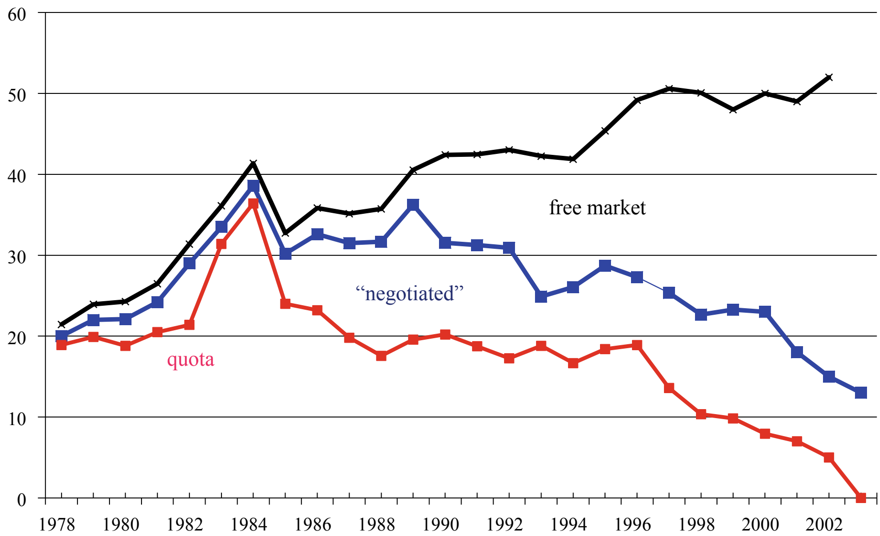

Fig. 6.1 Amount of rice procured by government and sold in free market (million tonnes), 1978–2003. *Note* Total state procurement = quota + negotiated procurement; the top line is total sale. *Source* Compiled by the author based on historical policy documents

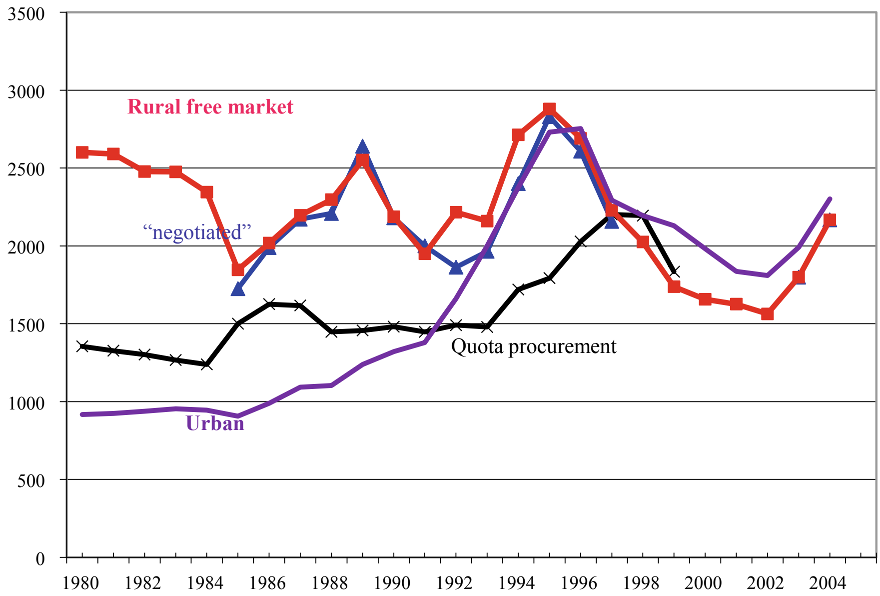

Fig. 6.2 Government rice procurement and free market prices (yuan/tonne at 2004 prices) in 1980–2004. *Source* Compiled by the author based on historical policy documents

government's quota procurement price and by increasing the amount of negotiated procurement with higher prices (Fig. 6.2). In the early reform period, the government procured grain at prices that were only about half of rural free market prices and sold at even lower prices to urban consumers in order to support China's industrialisation. Overtime, the quota procurement price was raised. By the late 1990s, it approached and was almost equal to negotiated and free market prices (Fig. 6.2).

6.2.3.2 The Forward–Retreat–Forward Path of the Reforms

It is worth noting that there were several forward–retreat–forward waves of reform in grain pricing and marketing. This reflects the importance of grain and the political economy of the grain sector. After a record growth in grain production in the early 1980s, price and market reform was announced in 1985, aimed at limiting the scope of government price and market interventions and enlarging the role of market allocation (for rice, see Fig. 6.1; this was also the case for other strategically important commodities). However, during the sharp drop in the growth rate of grain production and rise in food prices in the late 1980s (also reflected in the rise in the price of rice in this period, Fig. 6.2), the path of marketing reform slowed and even stopped. The quota procurement of rice (and wheat, maize, oil crops and cotton) was retained. For example, the amount of rice through quota procurement had been kept at nearly 20 million tonnes during 1987–1993 after a rapid fall in 1985–1986

(Fig. 6.1). To provide incentives to farmers to increase production and to encourage sales of grain to the government, quota procurement prices were raised in nominal terms over time. However, the real agricultural procurement price after accounting for the rate of inflation was almost constant until the early 1990s (Fig. 6.2).

As grain production and prices stabilised in the early 1990s, another attempt was made to abolish the grain ration system (Huang and Rozelle 2003). Government shops in urban areas discontinued sales at ration prices to consumers in early 1993. The liberalisation moved smoothly in 1993–1994. However, market liberalisation also resulted in a significant rise in price of rice (Fig. 6.1) and other types of grain, as well as prices of other food items in the economy in 1994–1995. As a result, rapid phasing out of the government compulsory quota procurement did not occur until the late 1990s, when the reform was implemented with a gradual reduction in procurement over time (Fig. 6.1). In the meantime, China started the provincial governor's "rice bag" responsibility system.[1] This policy was aimed at enhancing grain security by making provincial governors more responsible for balancing supply of and demand for grain in their provinces to stabilise local grain markets and food prices. With this responsibility system, grain-deficit provinces tended to invest more in production and make greater efforts to negotiate with grain-surplus provinces to purchase grain.

With three years of record grain production in China in the late 1990s, farmers faced difficulty in selling their grain amid falling market prices. To help farmers sell their products and stabilise the price of grain, the central government decided to take control of grain prices through government procurement, prohibiting individuals and private companies from procuring grain from farmers.[2] In contrast to past procurement arrangements, in order to raise farmers' income, the prices of grain quota procurement were for the first time set at a level higher than market prices. National leaders expected that the government (or grain bureau) would be able to sell the procured grain at even higher prices in the market because they thought the government could monopolise the grain marketing chain upstream. Under this policy, farmers' income would rise, the grain bureau would earn profit, and the government's financial burden would be reduced as there would be no need for the previous system (in which the government ran both grain procurement and distribution). Of course, consumers would have to pay higher prices for food. However, this policy did not work at all. The government was not able to stop millions of private traders from buying grain from hundreds of millions of small farmers; additionally, the grain bureau was not willing to buy grain from farmers at prices which were much higher than market prices. Not surprisingly, government grain stocks increased significantly because they were not able to sell grain at prices which were higher than their procurement prices. Meanwhile, market prices fell even further (for rice, see Fig. 6.1).

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[1]The term of "rice" in China sometime also means grain, and here it includes rice, wheat, maize and soybean.

[2]Farmers were supposed to sell all their grain to government, and private traders were supposed to buy grain from government and conduct their business in wholesale and retail markets.

After 2000, the grain price and marketing reform was reenforced. The government compulsory quota procurement system that had been implemented for several decades was formally abolished in 2000. Perhaps the most important observation is that, despite recurring cycles of reform and retreat, commodity markets have steadily strengthened in rural China. The proportion of retail commodity sales sold at market prices has continued to rise. Transaction costs have fallen while the degree of integration has risen (Park et al. 2002). Despite the forward-retreat-forward nature of the reforms, by the early 2000s, domestic markets had been gradually and largely integrated (Huang and Rozelle 2006; and more discussion later).

With the gradual reform of China's grain market, the tax burden of grain farmers through government's grain procurement programme was significantly reduced over time. The implicit tax is estimated by the amount of government grain procurement and the difference between the market price and government procurement price. Figure 6.3 shows that grain farmers, in general, had been taxed heavily by the grain procurement policy before the late 1990s. However, with marketing reform, the degree of taxation has declined significantly over time. Indeed, although China's implicit tax on farmers had been high, with the elimination of the government quota procurement since 2000 and the initiation of direct payment or subsidies to farmers since 2004, China has begun to move to a regime that has shifted from taxing to subsidising agriculture (see more discussions later).

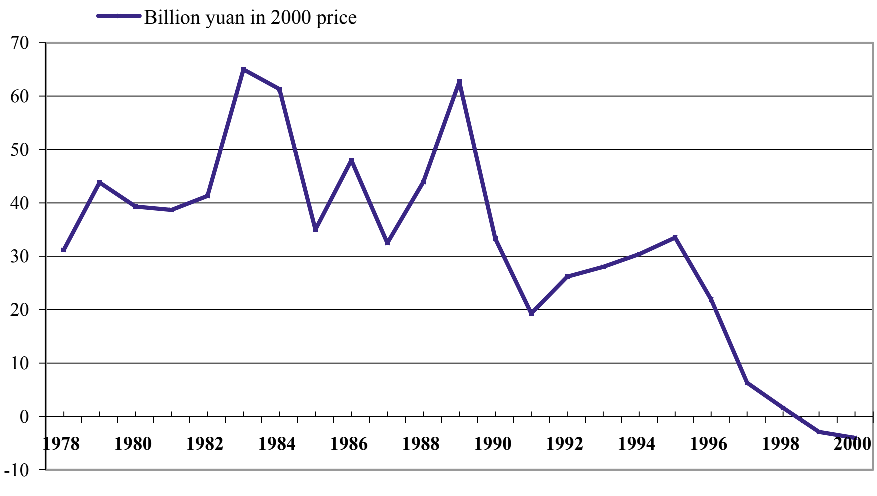

Fig. 6.3 Implicit tax on grain through government procurement, 1978–2000. *Source* Huang et al. (2006). *Developing Economies*

6.2.4 Competitiveness and Integration of Domestic Markets

Several previous studies have showed that China's agricultural markets, including grain markets, were, even by the early 2000s, among the most competitive and integrated markets in the world (Park et al. 2002; Huang et al. 2004a, b; Rozelle et al. 1997; Rozelle and Huang 2010). This section summarises the major findings of these on the grain market (as other agricultural commodities had been liberalised earlier than the grain sector).

Table 6.1 presents the results of the co-integration analysis conducted by Rozelle and Huang (2010). Their results showed that grain markets in China had been increasingly integrated after the late 1980s. During 1989–1995, when private trade started to emerge, less than 30% of grain markets across regions showed evidence of prices moving together. However, by the late 1990s, it was found that the percentages of maize, soybean and japonica rice markets with co-movement of their prices had increased to 89%, 68% and 60%, respectively (Table 6.1). After the late 1990s, more markets had been integrated. By 2002–2003, nearly all markets of either maize or soybean were integrated.

Previous studies also suggested that the cost of shipping goods across China had significantly fallen (Rozelle et al. 1997; Rozelle and Huang 2010). Much of the gain was due to both market reform and the construction of roads and improved communications. The improvements in China's market also arose from increased competition. From the mid-1990s to the early 2000s, millions of private traders had entered the commodity markets. Thousands of wholesale and retail-trading companies traded into and out of all major markets inside or around cities. This made China's grain markets competitive.

To show the empirical evidence of falling transaction costs, Rozelle and Huang (2010) examined average transportation gradients for major grains in China and the USA. They found that China's grain markets were already performing very efficiently even in 1998–2000 (Table 6.2). The transportation gradients for all crops they examined fell during 1998–2000. Although they did not analyse the exact sources of the fall in the transportation gradient, they pointed out that the patterns of changes in the transportation gradient were consistent with the marketing environment in which there was improved infrastructure and more competitive markets. The most interesting result they found was that the transportation gradients in China were very similar to those they found in the USA (Table 6.2).

Table 6.1 Percentage of market pairs in rural China that test positive for integration based on the Dickey–Fuller test, 1988–2003

Commodity	1989–1995	1996–2000	2002–2003
Maize	28	89	98
Soybeans	28	68	99
Japonica rice (Yellow River Valley)	25	60	NA

Sources Park et al. (2002) and Rozelle and Huang (2010)

Table 6.2 Percentage change in price for every 1000 km of distance from the port, 1998–2000

	Maize (%)	Soybeans (%)	Rice (%)
China 1998	−4	−10	−10
1999	−4	−11	−9
2000	−3	−8	−7
USA 1998	−5	−3.5	n.a.

Note An average transportation gradient is an indicator of the average percentage change in price for each 1000 km that a marketing site is distant from the port
Source Rozelle and Huang (2010)

6.3 New Incentive Policies and Reforms in Agriculture Since the Early 2000s

While China's agricultural growth has been impressive in the past, the country has also reached a stage of agricultural development where previous challenges have intensified and new challenges have emerged. Increased food production has been at the expense of the environment, and intensified agriculture has challenged sustainable agricultural development (Lu et al. 2015). Furthermore, recent increases in wages have significantly increased the cost of food production and lowered agricultural competitiveness in the global market, which further raises food security concerns in China (Huang and Yang 2017; Han 2015). Besides, despite steady growth in farmers' income, their average income is still low, and the rural–urban income gap remains high. How to ensure national food security, increase farmers' income and develop sustainable agriculture are the central goals of China's recent agricultural and food policy.

Recognising the challenges, the Chinese government has taken a series of strong policy measures (Huang and Yang, 2017). The most notable ones are the political commitments to *San Nong* issues (three rural issues: agriculture, rural areas and farmers). For example, in the past 15 years (2004–2018), the Number One Document, the first and most important national policy document released each year by the Central Committee of the Communist Party of China, has exclusively focused on these three issues. In the literature, several papers discuss some major policy changes in the recent decade, such as eliminating agricultural tax (Tao and Qin 2007; Liu et al. 2012), increasing agricultural subsidies (Huang et al. 2011, 2013; Yi et al. 2015), enhancing agricultural research and development expenditure (Huang and Rozelle 2014; Babu et al. 2015) and raising agricultural price and income support for farmers (OECD, 2013). The latest studies have also examined the evolution of recent policies and the objectives of policy changes (Huang and Yang 2017; Hejazi and Marchant 2017).

This section focuses on the challenges, and the responses of the Chinese government to these challenges with particular focus on the incentives to farmers.

6.3.1 New Challenges Since the Early 2000s

Challenges in Maintaining Increased Growth in Farmers' Income and Reducing the Urban–Rural Income Gap

Although average real income per capita in both rural and urban areas has increased significantly since reform was initiated in 1978, the urban–rural income gap (or ratio) had been rising since the mid-1980s and for the first time exceeded three (3.08 in 2003) (Fig. 6.4), a situation that could threaten social stability and has attracted much attention from China's policymakers. In rural areas, despite a significant increase in the opportunity to gain income from off-farm employment, agriculture still contributed to about 42% of average rural household income in 2014. In the meantime, nearly 60 million (5.3%) of the rural population were still in poverty in 2015 (NBSC 2016).

Challenges in Ensuring National Food Security

Despite remarkable achievements in ensuring national food security, recent emerging issues have raised the Chinese government's concerns regarding food security, particularly grain security. After grain production reached a historical high in 1998 (512 million tonnes), it fell to 431 million tonnes in 2003 (NBSC, various issues). Government grain stock had also successively decreased from its peak level in 1999 to its lowest level in 2004. On the other hand, with rising income, the demand for food, especially meat, has continued to rise. Cost push factors have also exerted upward pressure on food prices. Rural labour wages (or opportunity cost for agriculture) have increased at more than eight per cent annually since the mid-2000s (Li et al. 2012;

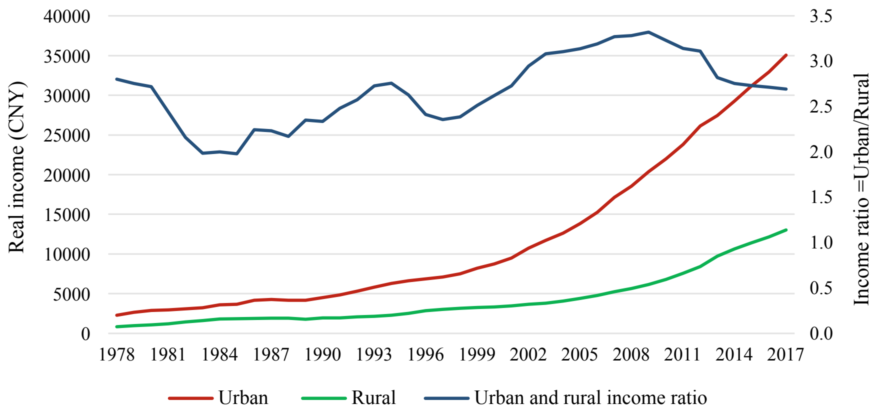

Fig. 6.4 Per capita real income in rural and urban areas in 1978–2017. Urban income is measured as per capita disposable income, while rural income is measured as per capita net income during 1978–2012 because data on disposable income for rural areas are available only after 2013. During 2013–2015, rural disposable income was about 6% higher than rural net income. Rural and urban incomes are deflated by rural CPI and urban CPI, respectively, to obtain the real income at 2015 prices ($CPI_{2015} = 100$). All data are from NBSC, various years

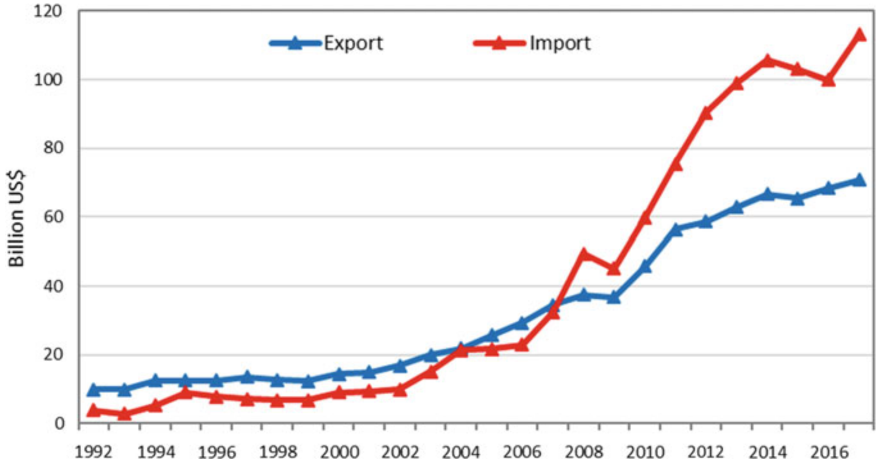

Fig. 6.5 China food import and export in 1992–2017, billion USD. *Source* UN COMTRADE. *Note* The data exclude trade of non-food commodities (e.g. cotton, silk, wool and tobacco)

Wang et al. 2011). Despite increased agricultural mechanisation (largely in response to rising rural wages), increasing labour costs still account for most of the increase in production costs in recent years (Wang et al. 2014). One of the major impacts of rising production costs is the fall of China's agricultural competitiveness in the international market. In 2004, China food imports caught up with food exports for the first time, and, since 2006, China has shifted from being a net food exporter to a net food importer; food imports have been gradually increasing since then (Fig. 6.5). Food security is likely to be further challenged by the deterioration of already very scarce land and water resources (Lu et al. 2015).

Challenges in Achieving Sustainable Agricultural Development

In the past, intensified agriculture with high input and output has resulted in a huge stress on limited natural resources and the rural environment, which may threaten the sustainable development of agriculture in the future. China's agricultural production is highly dependent on irrigation. Currently, about half the cultivated land is irrigated. Rising demand for irrigation water has resulted in an overdraft of groundwater and therefore, a falling groundwater table and land degradation in most of Northern China (MWR, 2016). The sustainability of irrigated agriculture is also challenged by rising demand for water from urbanisation and construction of ecological civilisation and water pollution. Climate change is expected to further exacerbate water shortages (Ding et al. 2006; Wang et al. 2013). In the meantime, although the decrease in cultivated land area has slowed down due to strict regulations on alternative uses of cultivated land (e.g. resolutely defend cultivated land area of 1.8 billion mu or 120 million ha by 2020), soil quality degradation has been occurring in many regions (Zhang et al. 2013; Lu et al. 2015). It is estimated that more than half the cultivated land has experienced different levels of degradation. Excessive use of modern inputs (e.g. fertilisers and pesticides) has caused serious non-point pollution and soil degradation and will become one of the major factors threatening sustainable agricultural development in the future (Lu et al. 2015).

6.3.2 *Evolution of Recent Incentive Policies Between 2004 and 2013*

Given the challenges discussed above, China's policymakers have made a strategic shift in agricultural policy since the early 2000s. Here, we present the evolution and consequences of this strategic change with particular focus on incentives to increase agricultural production and farmers' income.

6.3.2.1 Shift from Taxing to Subsidising Agriculture

Concerns about farmer income have led the Chinese government to take a series of strong policy measures since the early 2000s. The first set of policy measures comprised the abolition of all agricultural taxes and fees in 2004 (Tao and Qin 2007). These taxes included grain tax, which had remained almost constant in nominal terms and had sharply fallen in real terms and the special agricultural taxes on non-grain commodities that had increased significantly after the early 1990s (Huang et al. 2006). Fees included those collected by village committees and township governments to partially support the provision of local public goods/services and sometimes also for administration and management. In 2000, the total taxes on agricultural commodities, including grain and non-grain commodities reached 43 billion yuan (note, the official exchange rate was 8.28 yuan/USD in 2000), and the fees collected from agriculture were 16.3 billion yuan. These two together ($59.3 = 43 + 16.3$) accounted for 4.4% of the government's fiscal revenue that year (Huang et al. 2006). Agricultural taxes were eliminated in 2003, and all fees imposed on agriculture were also eliminated in 2004.

The second set of policy measures included the launch, in 2004, of direct subsidy programmes for farmers (Huang et al. 2011, 2013). These subsidies to farmers started in 2004 with the "direct grain subsidy" (in Chinese – *liangshi butie*), the "quality seed subsidy" (*liangzhong butie*) and the "agricultural machinery subsidy" (*nongjiju butie)* (Fig. 6.6).[3] When domestic chemical fertiliser and fuel prices began to rise with international prices in 2005–2006, a new aggregate subsidy programme named

[3]Except for machinery subsidies, other direct subsidies are based on the farmer's contract land area. After starting the machinery subsidy program in 2004, the subsidy budget from the central government rapidly increased and reached its peak (23.75 billion yuan) in 2014. When application for the subsided machinery is approved by the county government, a farmer can receive the amount of subsidy equal to about one-third of machinery price. Recently, the central government has allowed local government to shift part of the agricultural machinery subsidies to water-saving irrigation

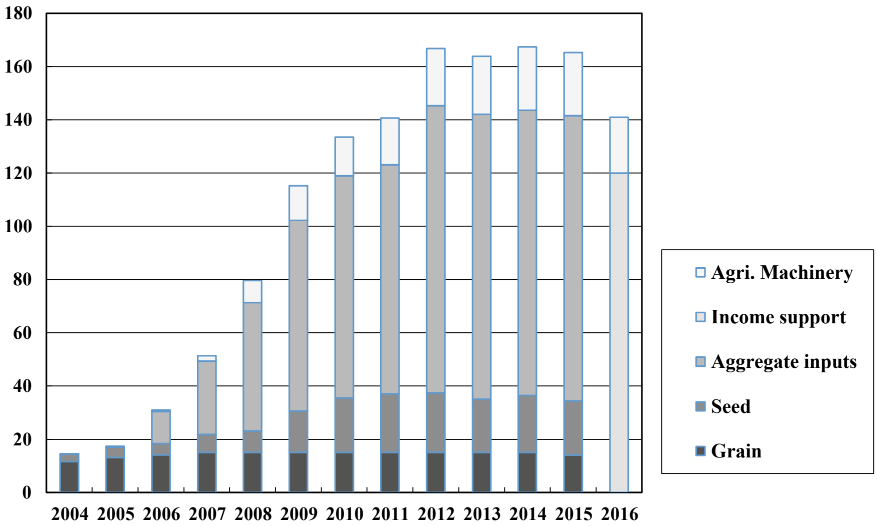

Fig. 6.6 Major agricultural subsidies in 2004–2016 (billion CNY in current price). Data are from various official documents

the "agricultural input aggregate subsidy" (*nongzi zonghe butie*) was initiated in 2006. Almost all farmers receive subsidies. The total amount of the above four major subsidies reached a peak of 164.3 billion yuan (or 26.1 billion US$) in 2012 (Fig. 6.6), about 3.13% of agricultural GDP. Beside these four major subsidies, other recent subsidies to farmers include those for agricultural insurance, credit, land consolidation and soil conservation and improvement. In 2016, direct subsidies to farmers on agricultural insurance, soil conservation and grassland ecology protection reached 15.8 billion yuan, 0.8 billion yuan and 19 billion yuan, respectively.

However, given the size of farming households, the impact of the subsidy programme on farmers' income is moderate. China has more than 200 million farm households (or rural households with land contracts), and an average household receives only about 850 CNY (or about USD130). In this regard, using an agricultural subsidy to raise farmers' income is meaningful only in terms of how politics can demonstrate the government's commitment to helping farmers.

The impact of agricultural subsidies on grain production is negligible. Using household data from a national representative survey, Huang et al. (2011) showed that subsidies were mostly being given to the land contractor, not the tiller, due to the difficulty in identifying actual crop production and input use by a household. Because the subsidies are not linked to actual production, they do not distort production.

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equipment; however, the amount of irrigation equipment subsidies for the whole country is still very minimal.

6.3.2.2 Domestic Market Intervention Policies

Although the domestic agricultural market had been fully liberalised and integrated across regions in the early 2000s, as discussed in the previous section, in response to the new challenges of farmer income and food security, China has also sought price policy support. The most important policy measures are the minimum procurement price, which has been implemented for rice since 2004 and for wheat since 2006, and the Temporary Storage Programme (TSP), which was initiated in 2008 for maize, soybean and rapeseed (Table 6.3).

While the above price support efforts increased crop production and price and therefore farmers' total income from agriculture, the urban–rural income gap still remained high and even increased from 3.21 in 2004 to 3.33 in 2009 due to higher income growth in urban areas (Fig. 6.4). To further raise farmer income, both minimum prices for rice and wheat and procurement prices for maize, soybean and rapeseed under the TSP were gradually increased until 2014 (Table 6.3). With concerns over farmers' income in cotton and sugarcane production regions, the TSP was further extended to cotton in 2011 and sugar in 2012. During 2009–2014, the ratio of urban to rural per capita income fell from 3.32 to 2.76 (Fig. 6.4); part of this change obviously came from the results of the government's price intervention policy, though this impact has not been evaluated in the literature.

While the price intervention policy has increased farmers' income, it also generated a large price gap between the domestic and international markets. Indeed, right before the global food crisis in 2007–2008, domestic prices were very close to international prices. The average rate of assistance to agriculture for import-competing commodities (or policy distortion) was only 7.5% in the early 2000s (Huang et al. 2009). During the global food crisis, China was able to prevent a significant rise in grain prices by drawing down stocks and by imposing trade controls (Yang et al. 2008). However, while global food prices fell sharply in late 2008 and have since experienced upward and downward trends after 2009, China continued to raise its domestic price in 2009–2014 (Table 6.3). The price gaps between the domestic and international markets have increased significantly since 2012. By late 2015, the wholesale price of maize was about 40% higher than the imported price (Fig. 6.7); the number reached 50% in early 2016. The domestic wholesale prices of rice, wheat and cotton were also higher than international prices, ranging from 30 to 50% in 2015.

The TSP and the minimum procurement price policies that significantly distorted the market have resulted in a series of problems in China's agricultural structure and its downstream production. Rising prices stimulated domestic production for those commodities under the price intervention programme and lowered the production of other commodities. Meanwhile, high and rising domestic maize and sugar prices had seriously hurt downstream industries such as the feed and livestock sector and the food-processing industry. Rising domestic cotton prices had also had a severe impact on production and export of, and employment in, the textile and garment industries. Although the TSP of soybean and rapeseed had little impact on their domestic prices and production (because these products have been largely liberalised

Table 6.3 Domestic intervention prices, rural CPI and exchange rates, 2004–2017

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Minimal procurement prices (CNY/tonne)														
Early indica paddy	1400	1400	1400	1400	1540	1800	1860	2040	2400	2640	2700	2700	2660	2600
Japonica paddy	1500	1500	1500	1500	1640	1900	2100	2560	2800	3000	3100	3100	3100	3000
Middle indica paddy		1440	1440	1440	1580	1840	1940	2140	2500	2700	2760	2760	2760	2720
Late indica paddy		1440	1440	1440	1580	1840	1940	2140	2500	2700	2760	2760	2760	2720
White wheat			1440	1440	1540	1740	1800	1900	2040	2240	2360	2360	2360	2360
Red and mixed wheat			1380	1380	1440	1660	1720	1860	2040	2240	2360	2360	2360	2360
Procurement price under temporary storage programme (CNY/tonne)														
Maize					1500	1500	1700	1980	2120	2240	2240	2000	–	–
Soybean					3700	3740	3800	4000	4600	4600	–	–	–	–
Rapeseed					4400	3700	3900	4600	5000	5100	5100	–	–	–
Target price (CNY/tonne)														
Soybean in Inner Mongolia and Northeast China											4800	4800	–	–
Cotton in Xinjiang											19,800	19,100	18,600	18,600
Rural CPI (2010 = 100)	83.2	85.0	86.3	90.9	96.8	96.5	100.0	105.8	108.4	111.5	113.5	115.0	117.2	118.7

(continued)

Table 6.3 (continued)

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Exchange rate (CNY/USD)	8.28	8.19	7.97	7.61	6.95	6.83	6.77	6.46	6.31	6.2	6.14	6.23	6.64	6.75

Note indicates the phased out the policy

Sources Data on prices are extracted from various policy documents and website of the National Development and Reform Commission (www.ndrc.gov.cn/); Rural consumer price index (CPI) and exchange rates are from NBSC (2018)

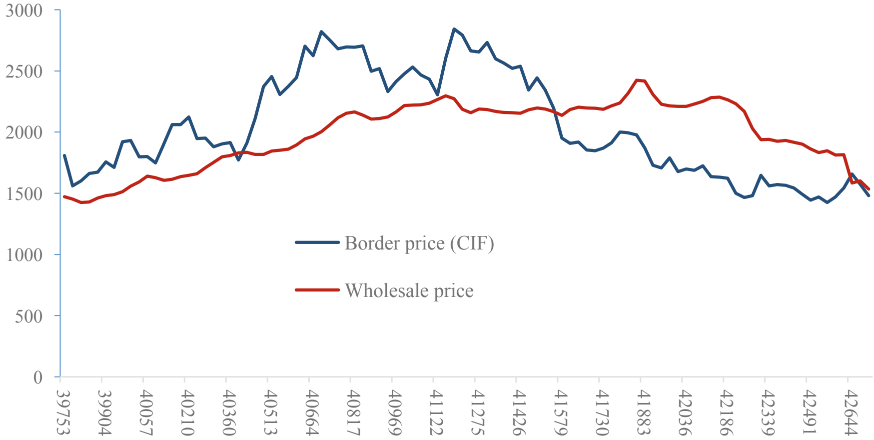

Fig. 6.7 Domestic and border prices (yuan/tonne) of maize in China, 2008–2016. *Sources* Border prices are from the General Administration of Customs monthly report; Domestic wholesale prices are from the National Grain and Oil Information Centre

and their international prices are fully transmitted into the domestic market), there has been an increasing financial burden with respect to maintaining their TSP policies.

With maize, the price policy had also significantly affected the domestic production of maize substitutes. The large price gaps between the domestic and international markets of maize increase the pressure to import. But with a tariff rate quota of 7.2 million tonnes of maize and 65% of out-of-quota tariff, the importation of large amounts of maize was not possible. Under this situation, the imports of maize substitutes (e.g. sorghum, barley and other coarse grain) that are subject to tariff-only protection emerged, which hurt the domestic production of these commodities. For example, barley imports increased from 2 million tonnes in 2011 to nearly 12 million tonnes in 2015. Over the same period, distillers' dried grains with soluble (DDGS) imports also increased from less than 2 million tonnes to nearly 7 million tonnes and sorghum imports from nearly zero to 11.8 million tonnes.

The TSP and the minimum procurement price policies also had important implications for government stock and finances. The most serious problem occurred in maize. For example, to avoid prices falling due to the increased maize supply from both domestic production and imports, the government had to continue buying maize from farmers and consequently built up a huge stockpile. While there is no official data available, the estimated size of the government's maize stock ranges from 210 million tonnes (USDA 2016) to more than 240 million tonnes from industrial sources at the end of 2015. The maize procurement was financed with government loans and holding stockpiles were subsidised by the government, which significantly increased its financial burden.

6.3.3 Recent Efforts to Adjust and Reform Current Policies

6.3.3.1 Efforts to Change the Nature of the Direct Subsidy Programme

Recognising the moderate effect on farmers' income and the failure to raise grain production, as well as the significant financial burden, there was debate among policymakers on expanding the existing subsidy programme in 2011–2012. With the fall in the growth rate of government revenues from 25% in 2011 to only 10% in 2013, due to a slowdown in economic growth (NBSC 2014), the first policy change in 2012 was to cap the total subsidy budget for 2013 and 2014 (Fig. 6.6).

The second change was to cut the direct subsidy programme and then transfer it to an income support programme. In 2016, the budget was cut by more than 20% (about 23 billion yuan); the amount saved by doing so was used as the initial special fund to support farmers who consolidated land and increased farm size through the rental market. The special fund is also used to provide loan guarantees by the government for large farms in case they lacked a mortgage when applying for bank loans for agricultural production.

A more significant shift was to merge three direct subsidy programmes into one general support programme, called "*nongye Zhichi baohu butie*" (or the agricultural support subsidy) to improve the production capacity of cultivated land. In 2016, the amount of this support was 121.24 billion yuan. It was provided to all rural households or land contractors and was decoupled from production, and hence, was more in line with the term "income support" (Fig. 6.6).

6.3.3.2 Efforts to Reduce and Phase Out Market Intervention

With rising grain stocks, particularly maize, and falling international grain prices in recent years, as well as the policy-induced challenges discussed above, China has begun to adjust its incentive policies for rice, wheat, maize, soybean, rapeseed and cotton, which were under government intervention until the recent past (Table 6.3).

The First Effort Was to Stop a Further Increase in Government Procurement prices

Both the minimum procurement prices for rice and wheat and TSP procurement prices for maize, soybean and rapeseed had increased significantly before 2013; this rising trend of procurement prices was generally capped and then reduced thereafter (Table 6.3). While not shown in Table 6.3, the amount of government procurement has also gradually been reduced for all commodities under government intervention programmes.

The Second Effort Was to Phase Out TSP for Rapeseed, Sugar, Soybean and Cotton

Despite lowering procurement prices, the price intervention programme was still difficult to maintain because international food and cotton prices continued to fall after 2013. TSP was firstly discontinued for soybean and that for cotton followed in 2014 to be replaced by the target price policy in the same year, while TSP was completely phased out for rapeseed and sugar in 2015.

The Third Effort was to Pilot the Target Price Policy for Soybean and Cotton To reduce the level of market intervention, the central government initiated a target price pilot policy in 2014. This pilot reform was implemented for soybean in major soybean production regions (Northeast China and Inner Mongolia) and for cotton in the Xingjiang Province in 2014. In these regions, soybean and cotton farmers would receive payment from the government if the market price was lower than the target price. The amount of payment would depend on the total production and the difference between the target and market prices.

Huang et al. (2015) show that the target price pilot programme for cotton achieved its major policy goals. The market price for cotton fell significantly, and the price gap between domestic and imported cotton decreased from more than 40% in 2013 to about 20% in 2015. Considering the tariff rate (5%) and value-added tax (13%) on imported cotton, the price difference between the domestic and international markets disappeared. Meanwhile, cotton farmers received the payment as planned, and textile and garment industries recovered their production due to lower cotton market prices. However, using the target price policy to raise farmers' income as one of the policy goals is also a challenge because of the huge financial burden and cost of implementing it for millions of small farmers in China (Huang et al. 2015).

In 2017, China also phased out the target price policy for soybean due to the increasing financial burden and unstable international soybean prices that had been fully transmitted into the domestic market. Recently, there have also been discussions on how to phase out the target price policy for cotton in Xingjiang, but the reform could face challenge because most farmers there belong to the Uygur minority.

The Fourth and Most Important Effort Was to Phase Out TSP for Maize Among the remaining crops under the price intervention programme (rice, wheat and maize), maize policy intervention faced the biggest challenge. Rice and wheat productions have increased only moderately under the minimal price procurement programme because of falling demand on the consumption side (Huang et al. 2015). However, the high price of maize has resulted in strong growth in maize production, partially due to the rising demand for feed. Maize production reached a historical high (225 million tonnes) in 2015. This production expansion, together with rising maize imports generated a huge increase in the government's maize stock as we discussed above. How to dispose of this massive stock has become one of the biggest problems in agriculture in recent years. Reform of maize price intervention is becoming imperative after considering the impact of restricting imports of maize substitutes through the tariff rate quota system on sorghum, barley and other coarse grains.

Recognising the problems resulting from maize price intervention (Huang and Yang 2017), the Chinese government decided to phase out its maize temporary reserve program, which had been implemented during 2008–2015, in June 2016. This reform is called *Jiabu fenli* in Chinese, that is, the separation of income support from pricing policy and allowing the price of maize to be determined by the market. Under this reform, farmers are provided with a fixed amount of subsidy (or income support) in four major maize production provinces, including all three provinces in Northeast China and Inner Mongolia, which together accounted for 44% of total maize production in 2014 (NSBC 2015). With this reform implemented, the maize price fell significantly (Fig. 6.7), which also resulted in a decrease in maize production since 2016 (NSBC 2018).

To reduce the income that maize farmers lost as a result of the reform, a moderate income compensation programme was implemented in 2016. A total budget of 39 billion yuan was allocated for this. In the four provinces mentioned above, maize farmers received about 130 yuan/mu (15 mu = 1 haThe fourth and most important). The subsidy policy continues but it is uncertain for how long it will last.

The Most Recent Efforts Have Been in Trying to Abolish the Minimum Procurement Price Policy for Rice and Wheat
After the initial and moderate reduction in the price and amount of rice and wheat procured during 2014–2017, a large policy adjustment was made in 2018. First, the minimum procurement price of rice was lowered by about 10% (to 2400, 2520 and 2600 yuan/tonne for early indica, late indica and japonica paddy, respectively) compared to 2017; for wheat it was reduced from 2360 yuan/tonne in 2017–2300 yuan/tonne in 2018. Second, the government started to procure rice or wheat from farmers only when the farm gate market prices were lower than the minimum procurement prices for three consecutive days. Third, the government would only procure rice and wheat that met the national standards of grade three (average) and above. This would significantly reduce government procurement because, in the past, farmers tended to sell low-quality grain to the government. We expect that the minimal price procurement for rice and wheat will be gradually phased out within a couple of years.

6.3.4 Incentives and Supporting Policies for Fostering Green and Sustainable Agriculture

6.3.4.1 Overall Efforts and Policy Responses

Recognising the resource constraints and challenges in sustainable development, the Chinese government has, since 2004, made a stronger political commitment towards investment in agriculture, which has generated substantial public investment in land, water and technology. The growth of investment in agriculture has been targeted to exceed that of the government's overall fiscal expenditure. During 2004–2014, while the share of agriculture in GDP fell from 13 to 9%, its share in government expenditure rose from 8 to 10% (NBSC 2015). Growth in agricultural R&D expenditure is exceptional. The annual growth rate of public agricultural R&D expenditure in real terms increased from an average of 16% in 2000–2009 to more than 20% in the early 2000s (Hu and Huang 2011). It has been estimated that public investment in agricultural R&D reached 25 billion yuan in 2015. In the water sector, China made a decision in 2011 to invest about USD630 billion in water conservation during 2012–2020. China is also planning to establish a pricing mechanism that appropriately reflects the cost of water to encourage water saving within a decade. For cultivated land, the priority is to improve land productivity through developing "high-standard farmland" that is highly drought- and flood-resistant.

A more significant and strategic change is China's attempt to mainstream sustainable agriculture into the national development goals. For example, in recent years, China has been seeking new development strategies: "*Cang-liang-yu-di*" ("storing food in land,") and "*Cang-liang-yu-ji*" ("storing food in technology"). "*Cang-liang-yu-di"* primarily considers production capacity in the long run rather than current actual production, and implementation of this development strategy will have important implications for the sustainability of agriculture and the mitigation of climate change. "*Cang-liang-yu-ji*" reemphasises the role of technology in food security.

6.3.4.2 Reducing the Use of Chemicals and Moving Towards Green Agriculture

While chemical fertiliser (and pesticide) has played an important role in increasing crop production (and reducing crop loss from pests), excessive use of chemicals has resulted in serious environmental and food safety problems in China. China is one of the countries that has experienced rapid growth in pesticide use in the past two decades. The excessive use of chemical fertilisers and pesticides is observed in nearly all crops and has been well documented in the literature. This intensive use of chemicals has raised serious concerns about its environmental consequences. For example, nitrates and phosphorous pollution occurred in nearly all major lakes, rivers and groundwater in most areas (Zhu and Chen 2002). Moreover, it was estimated that emissions from N fertiliser production, transportation and application alone accounted for nearly 30% of greenhouse gas (GHG) emissions in agriculture in 2007—equivalent to 5% of China's total GHG emissions (SAIN 2010). Excessive use of pesticides has caused not only environmental but also food safety problems.

Increasing chemical use was one of the major policies to ensure China's food security in the past. However, China has recently moved to a new policy regime aimed at reducing the use of chemicals in agriculture. Realising the environmental and food safety consequences of intensive chemical use, in 2015 China announced a plan to reach a zero growth of total fertiliser and pesticide use in agricultural by 2020 and, thereafter, a plan to achieve "zero discharge" of agricultural waste by 2030. According to newly released data, chemical fertiliser used in agriculture had declined from its peak (60.23 million tonnes in pure nutrition form) in 2015 to 56.53 million tonnes in 2018 (NSBC 2019).

6.3.4.3 Pilot Programme to Improve Soil Quality

A pilot programme on agricultural crop rotation through direct subsidy to farmers was launched in 2015 and implemented in 2016 in two major regions. One—to protect soil erosion—is in Northeast China (Liaoning, Jilin and Heilongjiang) and Inner Mongolia. The other—to solve heavy metal pollution or ecological degeneration—is in Guizhou, Yunnan, Gansu, Hunan and Hebei. The central government allocated 1.44 billion yuan to cover 6.16 million mu (15 mu = 1 ha) in 2016; this was increased to 2.56 billion yuan covering 12 million mu in 2017. It is planned to establish a national plan for crop rotation and an incentive policy support system within three to five years.

6.3.4.4 Moving Towards Sustainable Grassland Uses

Due to overgrazing, grassland degradation has been severe. While some measures to protect grasslands in China have been made over the past few decades, none of them has been significant in terms of effort or budget until recent years. In 2011, China initiated a large programme on ecological construction programmes aimed at protecting grasslands. The programme provides direct subsidies or compensation to herders to participate in the grazing ban or the forage-livestock balance projects. The programme had a budget of 13.6 billion yuan in 2011, and this was raised to about 15 billion thereafter. The total budget was 77.36 billion yuan during 2011–2015, and this is planned to increase in the next five years (2016–2020).

6.4 Agricultural Trade Liberalisation

6.4.1 Gradual Trade Reform and Liberalisation Before 2001

China has adopted a step by step reform process to liberalise agricultural trade. From 1979 to 1987, China established more than 2200 foreign trade corporations to provide more incentive for trade; meanwhile, a strict trade plan was replaced by a guidance plan. An export tax rebate policy was also implemented to promote exports from 1983 to 1991. Leaders also initiated the foreign trade contract responsibility system in 1987. The contract system increased the incentives for trade corporations to profitably engage in trade. Under the system, those firms that increased exports were allowed higher rates of retention of foreign exchange that could either be used for imports or sold in the government-managed foreign exchange market—a policy that remained effective until the unification of the exchange rate in 1994. Regarding foreign exchange policies, the real exchange rate depreciated more than 400% during 1978–1994. The foreign exchange retention system was finally abolished in 1994, and the yuan (or RMB) has been convertible on the current account since 1996.

In contrast to many other developing countries, China had aggressively and unilaterally reduced its import tariff during the reform period. China's average agricultural tariff was as high as 42.2% in 1992 (World Bank 1997). Since then, China has gradually reduced import tariffs; these were lowered to 21% in 2001 just before China joined the WTO. Border protection through non-tariff barriers has also been reduced significantly. By 1998, products that were subject to quotas, licensing and other import control measures accounted for only 5% of total import tariff lines, and most were applied to "strategically important products" such as grain, cotton, edible oils and sugar.

By the mid-2000s, most agricultural commodity prices in China almost equalled import prices at the border (Huang et al. 2009). The export of labour-intensive products (e.g. horticulture and livestock) and the import of land- and water-intensive commodities (e.g. soybeans, cotton, edible oil and sugar) have been rising, which has improved the efficiency of resource allocation and agricultural production.

6.4.2 Rapid Trade Reform and Liberalisation After Joining the WTO

China made substantial commitments to join the WTO in 2001 and significantly changed its trade institutions and policies during 2001–2005. In its most basic terms, the WTO commitments in the agricultural sector can be classified into three major categories: market access, domestic support and export subsidies. The commitments on market access have lowered tariffs for all agricultural products, increased access to China's markets by foreign producers of some commodities through tariff rate quotas (TRQs) and removed quantitative restrictions on others (Tables 6.4 and 6.5). In return, China gains better access to foreign markets for its agricultural products.

After a few years of accession to the WTO, a number of other changes have occurred. Since 2006, China has phased out its TRQ for edible oils. Since 2003, state trading monopolies have also been phased out for wools and have gradually disappeared or been reduced for most other agricultural products (Table 6.5). China has also agreed to phase out all export subsidies. Moreover, despite being a developing country, China's de minimis exemption for product-specific support is equivalent to only 8.5% of the total value of production of a basic agricultural product (compared with 10% for other developing countries).

6.4.3 The Impacts of the WTO on China's Agriculture

Numerous studies have been conducted to examine the impact of China's WTO accession. Some argued that the impact of WTO accession on China's agriculture would be substantial, adversely affecting hundreds of millions of farmers (Carter and Estrin 2001; Li et al. 1999). Others believed that, although some impact would

Table 6.4 Import tariff rates (per cent) on major agricultural products subject to tariff-only protection in China

	Actual tariff rates in 2001	Effective as of 1 January	
		2002	2004
Barley	114 (3)[a]	3	3
Soybean	3[b]	3	3
Citrus	40	20	12
Other fruits	30–40	13–20	10–13
Vegetables	30–50	13–29	10–15
Beef	45	23.2	12
Pork	20	18.4	12
Poultry meat	20	18.4	10
Dairy products	50	20–37	10–12
Wine	65	45	14
Tobacco	34	28	10

[a]Barley was subjected to licence and import quota, the tariff rate was 3% for import within the quota, and no above-quota barley with 114% tariff was imported in 2001
[b]Tariff rate was as high as 114% before 2000 and lowered to 3% after the early 2000s
Source China's WTO *Protocol of Accession*, November 2001

Table 6.5 Tariff rate quota for agricultural products

	TRQ (million tonnes)		Tariff (per cent)		Quota for non-state own enterprises (per cent)
	2002	2005	In-quota	Above-quota	2000–2005
Wheat	7.3	9.6	1	65	10
Maize	4.5	7.2	1	65	25–40
Rice	2.6	5.3	1	65	50
Cotton	0.743	0.894	–	–	67
Soybean oil	1.7	3.2	9	121	50–90

Source China's WTO *Protocol of Accession*, November 2001

be negative and even severe in specific areas, the overall effect of accession on agriculture would be modest (Anderson et al. 2004; Huang et al. 2004a, b).

China has been a member of the WTO for more than one and half decades. Now, we no longer need to look at what the projected impact of accession to the WTO found in the literature, because actual data can tell us what the impact has been. As Table 6.6 shows, the largest increase of food availability in China in 2001 and 2015 came from the rise in domestic production (columns 1 and 2). Although net imports of nearly all food and feed increased, these increases were very moderate, the exceptions being soybean, maize and dairy (columns 3 and 4).

Table 6.6 China's food and feed production and net import in 2001 and 2015

	Production (Mt)		Net import (Mt)	
	2001	2015	2001	2015
Rice	124.3	145.8	−1.6	2.2
Wheat	93.9	130.2	−0.4	2.7
Maize	114.1	224.6	−6.0	4.7
Soybean	154.1	11.6	13.7	81.7
Oilseeds[a]	28.6	35.5	−0.1	5.8
Sugar	8.5	10.6	1.0	4.8
Beef	5.1	7.0	0.0	0.5
Mutton	2.7	4.4	0.0	0.2
Pork	40.5	54.6	−0.1	0.7
Poultry	12.1	18.3	0.3	−0.1
Dairy[b]	11.2	38.9	0.3	11.1

[a]Excluding soybean
[b]A factor of 7.0 is used to convert butter, cheese, powder and other dairy products into fresh mil
Sources NSBC, various issues

6.5 Overall Incentive Distortions in Agriculture and Major Commodities

6.5.1 Incentive Distortions Before the Mid-2000s

The main purpose of this section is to document the overall incentive changes due to alterations in the policy and pricing environment in which China's agricultural sector has operated during the past four decades. The data on the differences (percentage) between international prices and domestic prices at the border (nominal protection rates or NPRs) before the mid-2000s are from Huang et al. (2009), while the data on the producer support estimates (PSEs) between 1995 and 2017 are from the OECD's database on agricultural policy support. Regarding NPRs, because input-related interventions, mainly fertilisers, will be presented separately in Sect. 6, NPRs discussed here focus on output-related distortions.

Because of incentives or policy distortions within the domestic economy, the extent of protection (or lack of protection) due to trade policies may not be the same as the real rate of protection to farmers. Huang et al. (2009) estimated the protection at both wholesale (NPRs) and farm gate levels, the latter being what they called "nominal rate of assistance for farmers" (NTAs). While both measures are used to compare the domestic prices of commodities with international prices at the border (i.e. cost, insurance and freight (CIF) in the port for importable goods; free on board (FOB) in the port for exportable ones), the NPRs measure the extent of distortions due to trade-related policies (e.g. import tariffs, export taxes and subsidies, exchange rate distortions and the many non-tariff barriers such as state trading, quotas and licences that have affected China's agricultural trade, as presented in the early part of this section), and NTAs measure both the border distortions and the domestic incentive distortions discussed in Sects. 2 and 3. That is, the differences between NPRs and NRAs are due to the subsidy or transfer payments or other distortions that cause prices received by farmers to differ from what they would receive under competitive internal market conditions.

Since the early 2000s, China has significantly changed its domestic agricultural incentive system and international trade regime (e.g. joining WTO) as we discussed in the previous section. To measure the overall distortions and support for agriculture and to compare China with other countries in the recent two decades, here we use both NPRs at wholesale level and the producer support estimates (PSEs) which the OECD has estimated for OECD countries and major non-OECD countries, including China.

Table 6.7 summarises NPRs for major agricultural commodities before the mid-2000s. These commodities accounted for about 85–90% of total agricultural production before the mid-1990s and about 65–75% thereafter. The results show that exportable commodities were, on average, taxed by about 50% in the early 1980s,

Table 6.7 Nominal protection rates for major agricultural commodities in China (percentage), 1981–2005

	1981–85	1986–90	1991–95	1996–00	2001–05
Exportable commodities					
Rice	−49.1	−36.6	−23.5	−7.8	−7.1
Fruits	−23.9	−9.9	−2.4	0.0	0.0
Vegetables	−42.1	−57.8	−13.4	0.0	0.0
Poultry	26.4	−34.6	−1.6	0.0	0.0
Pork	−70.2	−47.5	−8.9	0.0	0.0
Import competing					
Wheat	7.7	15.4	22.7	22.2	2.1
Soybeans	6.4	−3.6	10.4	26.8	15.6
Sugar	51.3	29.1	15.5	35.4	21.9
Milk	134.9	25.1	−4.1	28.3	20.7
Mixed trade status					
Maize	−27.0	−25.1	−18.6	8.5	13.3
Cotton	−30.9	−36.0	−20.8	0.8	−3.5
Weighted average of above products	−45.5	−42.4	−11.5	2.0	0.8
Standard deviation	74.4	42.3	19.8	19.7	13.2
Coverage, per cent of value of total agricultural production (at undistorted prices)	84.5	90.1	85.9	75.1	65.9

Source Huang et al. (2009)

including both taxation through depressed domestic prices resulting from border measures, and the depression of farm prices through the procurement price system. The most taxed commodities are pork, rice and fruits (column 1, Table 6.7). High overall rates of taxation persisted into the early 1990s, but declined sharply in the late 1990s, until, by 2000–05, it was essentially zero for all exportable commodities.

On the other hand, import-competing commodities were protected but changed over time. While the rate of protection for wheat rose from 7% in the early 1980s to more than 20% in the 1990s, it fell to about 2% only after China joined the WTO in 2001. By the early 2000s, the protection rates ranged from 15% for wheat to about 22% for sugar (last column, Table 6.7).

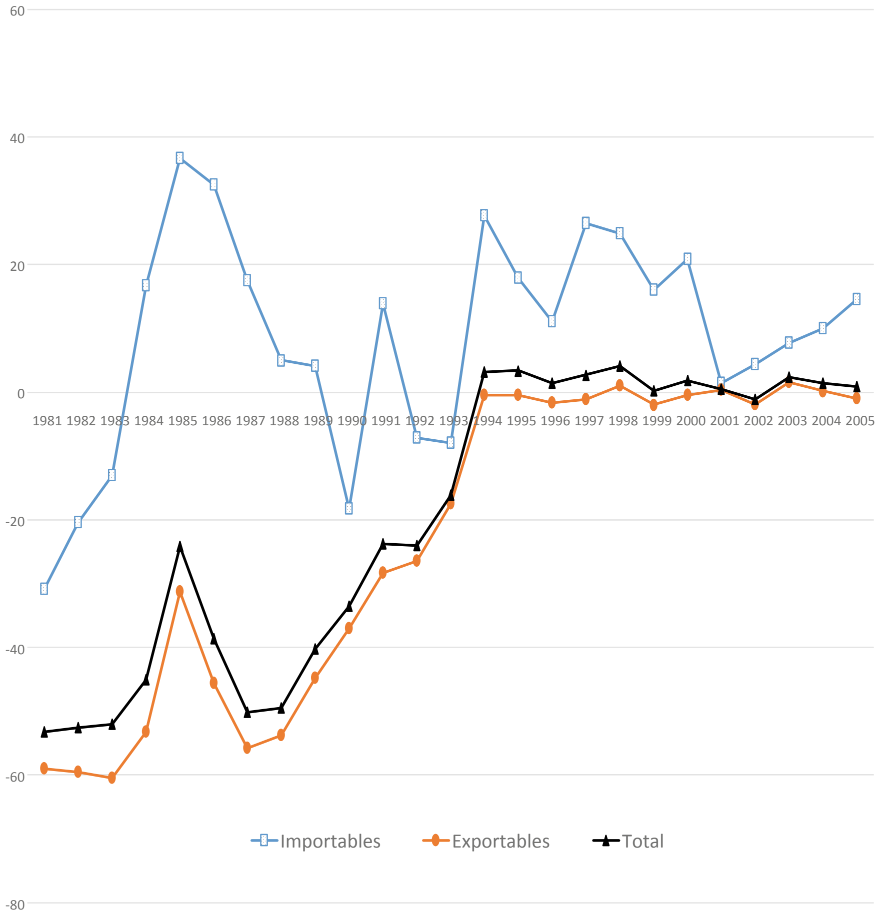

Fig. 6.8 Nominal rate of assistance for farmers in China, 1981–2005. *Source* Huang et al. (2009). *Note* Negative NPRs mean that agriculture is being taxed; positive NPRs mean agriculture is being protected

Figure 6.8 presents the overall trends in the rate of assistance to farmers for agriculture as a whole and for importable and exportable commodity groups. The commodity groups are the same as those presented in Table 6.7. For maize and cotton, they were grouped into importable or exportable, depending on the nature of net import in each period. The results show that, for agriculture as a whole, Chinese farmers were highly taxed before the mid-1990s, but distortions had nearly disappeared by the period 1995–2005 (Fig. 6.8). Overall, because output of exportable agricultural commodities accounted for a larger part of China's agriculture than those of importable commodities before the early 2000s, the trend of assistance to farmers is similar for exportable commodities and the whole of agriculture.

After 1995, the nominal rate of assistance to farmers on importable commodities fell from about 20% to less than 10%. During this period, the NRAs of exportable commodities increased, or the implicit taxes on farmers decreased, from about 40% to around 15%. When taken together, the distortions in China's agriculture fell to less than 10%. In many years, the overall assistance to farmers was between 0 and −5%. These results indicate that the combination of domestic price and marketing reforms and international trade liberalisation presented above has resulted in an agriculture that, on average, was the least distorted in the world by the early 2000s. These results also confirm that China's policies had actually taxed agriculture as a whole for most of the two decades prior to accession. The fact that protection to some import-competing sectors fell after accession is evident from the fact that protection to import-competing agriculture in 2001 was well below its average level in the 1990s, although this rate of protection rose slightly in the four years after accession.

Not all distortions to farmers have been eliminated. Over the period 2000–2005, there were still some commodities that had relatively high rates of protection (not shown in Fig. 6.8). Huang et al. (2009) show that NRAs for sugar and milk were still around 20% or greater by the early 2000s. Those for maize and soybean were around 10%. In the exportable categories, fruit, vegetables, pork and poultry had essentially zero protection, while rice appears to have been slightly negatively protected.

6.5.2 Incentive Distortion and Policy Support After the Mid-2000s

After the mid-2000s, China began market interventions to raise the income of farmers; these have provided a large incentive for farmers to increase agricultural production. The interventions through raising government procurement and purchasing price, as discussed above, together with falling international prices in recent years, had increased the price gaps of major agricultural commodities between China and the international markets. Based on an estimation by the Organisation for Economic Development and Co-Operation (OECD), the NPRs (percentage) of agriculture in China gradually increased from about zero in 2007 to a level higher than that in the OECD after 2012 and to a peak of 14% in 2014 (Fig. 6.9). In 2014, China abolished the direct market intervention policies, and this is expected to lower protection for agriculture.

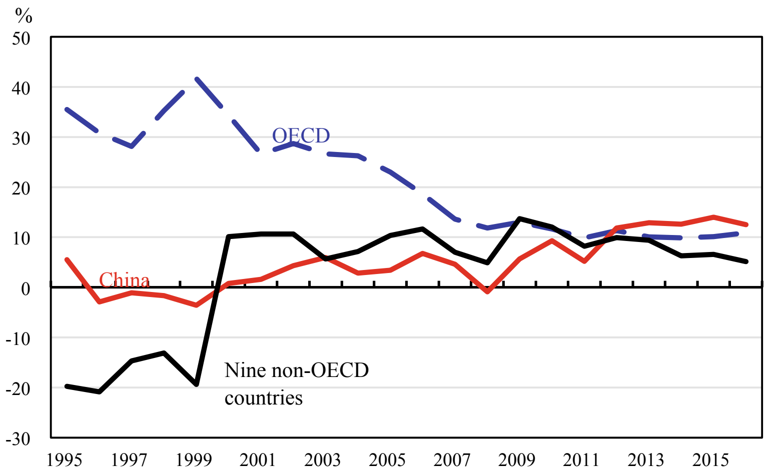

Fig. 6.9 Nominal protection rates (per cent) for agriculture in China, OECD and nine non-OECD countries, 1995–2016. *Source* OECD database, 2018, Available at: https://data.oecd.org/agrpolicy/producer-protection.htm. *Note* Nine non-OECD countries include Brazil, Colombia, Costa Rica, Kazakhstan, Philippines, Russia, South Africa, Ukraine and Vietnam

Figure 6.10 shows that despite increasing the budget allocated to the agricultural sector, the overall producer support estimates (percentage) in China have been falling since 2015. This changing trend of PSE also reflects the fact that there has been a significant reduction in market distortion in recent years. By 2017, PSE in agriculture in China reduced to 14%.

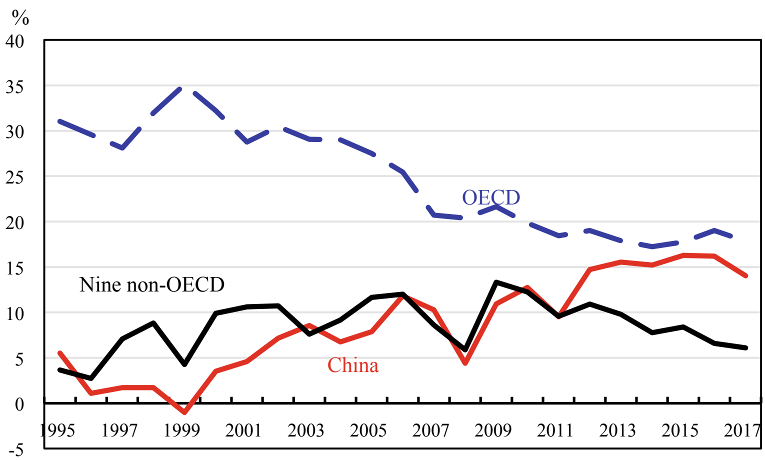

Fig. 6.10 Producer support estimates (per cent) of agriculture in China, OECD and nine non-OECD countries, 1995–2017. *Source* OECD database, 2018, Available at: http://www.oecd.org/tad/agricultural-policies/producerandconsumersupportestimatesdatabase.htm

6.6 Input Price and Market, Trade Liberalisation and Incentive Policies

Although agricultural inputs cover a wide range of products, the four major inputs are land, chemical fertilisers, irrigation and machinery and seed. The incentives related to land are mainly associated with land institutional arrangements, a central issue that is addressed in the next chapter on innovative institutional changes in China. Subsidies for agricultural machinery and subsidies for seed are based on the land area and are decoupled from production; these have been discussed in Sect. 3 of this chapter. Fertiliser and water are the most important inputs in agricultural production; they are the focus of this section. On average, fertilisers accounted for about 40% of the cash costs of crop production in China, and more than 50% of cropland now is irrigated. This section focuses on domestic price and marketing reforms, trade policy and liberalisation and other incentives governing fertiliser production and consumption. With regard to water or irrigation, the pricing of water, as in other countries, has been a challenge. However, China's recent efforts to reform irrigation prices or fees present some policy implications for China and the rest of world. This will also be presented at the end of this section.

6.6.1 Incentives Governing Fertiliser Production, Consumption and Trade

6.6.1.1 Production and Consumption of and Trade in Fertilisers

Chemical fertilisers have played an important role in increasing crop production in all countries, especially in China. After the release of the modern semi-dwarf crop varieties and improvement in irrigation in the 1970s, fertiliser consumption increased significantly. As early as 1980, China's per hectare chemical fertiliser application for crop production had already surpassed the average fertiliser use in developed countries (Heisey and Norton 2007). By 2000, fertiliser use per hectare in crop production had already reached 280 kg, nearly three times the world average (Sonntag et al. 2005). While total crop area increased by only about 6% in 2000–2015 (NBSC 2016), total chemical fertilisers used in agriculture increased by more than half, from 41.5 million tonnes to 60.2 million tonnes over the same period. Increasing use of chemical fertilisers has been possible largely because of the rapid expansion of China's fertiliser industry. Despite being one of the major importers of potassic fertilisers in the world, China has been a net exporter of total fertilisers since the late 2000s.

6.6.1.2 Fertiliser Price and Market Reform

After the early 1980s, the existing system of support to the fertiliser sector was found to be inadequate to meet farmers' demand for fertilisers, and reform started thereafter. The first market reform in the fertiliser sector was initiated in 1985 with the introduction of a dual-track pricing system. The system comprised in-quota and out-quota prices. The price for in-quota fertiliser was fixed by the government and was much lower than the out-quota price that was similar to the market price (Fig. 6.11). Meanwhile, fertiliser retailing had been gradually commercialised. By 1989, the out-quota fertilisers sold to farmers accounted for about 80% of total fertilisers sold (Jiang and Ling 1989). To ensure market supply and a stabilisation of prices, only two state-owned companies, the China National Agricultural Means of Production Group Corporation (Sino-Agri Group) and the Supply and Marketing Co-operative were allowed to operate fertiliser wholesale business in 1989–1997.

With the significant increase in fertiliser production in the 1990s, nearly all price restrictions or regulations on domestic fertilisers were phased out after the late 1990s. Rising fertiliser production also resulted in a significant fall in real fertiliser prices in the late 1990s (Fig. 6.11).

Its prices in 1989–2002 are estimated based on the growth rate of urea market retail prices over the same period; the data are from NDRC (1990–2003). Wholesale DAP prices in 2000–2013 are estimated by multiplying the retail DAP prices with a factor of 0.945 to account for the price margin between wholesale market at border and average national retail prices. The retail prices are from NATEC, MOA of China. Wholesale DAP prices in 2014–2016 are from CNCIC. Wholesale MOP prices in

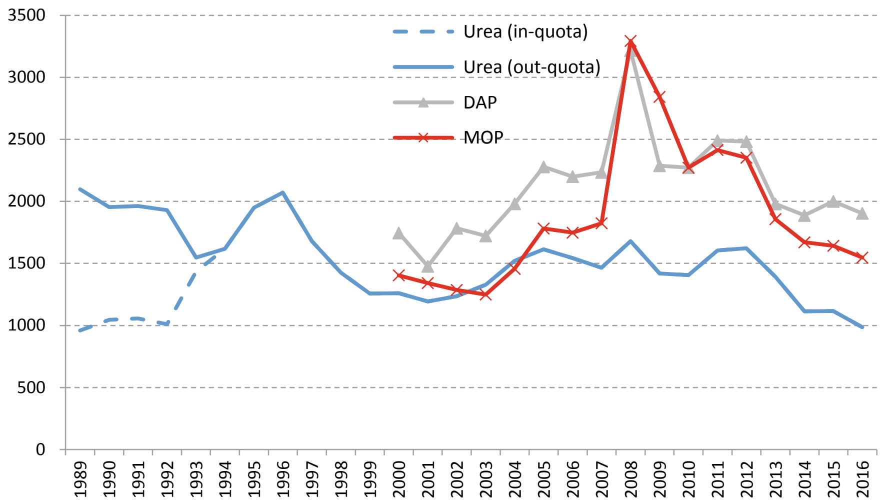

Fig. 6.11 Real wholesale prices (yuan/tonne) of urea, diammonium phosphate (DAP) and Muriate of Potash (MOP) in China, 1989–2016 (deflated by rural CPI with base year 2000). *Sources* Wholesale urea prices in 2003–2016 are from CNCIC

2006–2016 are from CNCIC. Its prices in 2000–2005 are estimated based on the growth rate of MOP market retail prices over the same period; the data are from NATEC, MOA of China. The rural consumer price index from NBSC (1991–2017) is used to deflate the fertiliser price series.

6.6.1.3 Major Subsidy and Other Support Policies for the Domestic Fertiliser Industry

In parallel with market reform, the support policies for China's fertiliser industry have also evolved over time. Policy changes were often matched with domestic fertiliser marketing and international trade reforms. There are two major sets of policies: promoting domestic fertiliser production through subsidy and other support policies and government market intervention and trade restriction policies that aim to stabilise domestic fertiliser prices and ensure adequate supply. But at each stage of fertiliser development, the policy package has differed. In the early stage, to promote domestic production, both domestic support policies and market intervention were in favour of domestic fertiliser production. In the late stage, to prevent a rise in the price of fertiliser, domestic support policies for the fertiliser industry were used to offset the industry's loss from fertiliser export restrictions.

Major support policies included a preferential taxation policy, subsidy for transportation, electricity and other inputs and storage. But all these subsides, except storage and transportation subsidies, have been phased out recently.[4] A storage subsidy through subsidised loans for off-season reserve has been implemented since 2004.

Among the supporting policies for the domestic fertiliser industry, the preferential value-added tax (VAT) policy is the major one. Depending on the market supply situation of each fertiliser, VAT (13%) could be fully exempted or partially rebated. The preferential VAT policy was first started with NPK compound fertilisers in 1994 and then gradually expanded to potassic fertilisers in 1995, monoammonium phosphate (MAP) in 1998, urea in 2005 and diammonium phosphate (DAP) in 2008. Zhang et al. (2007) estimated that the benefit to fertiliser manufacturers from the preferential VAT policy was 16 billion yuan in 2005, which was about 6.6% of the gross value of the national fertiliser products in the same year (CNCIC 2006). In a recent study, Li et al. (2013) estimated fertiliser manufacturers took gains equivalent to about 8% of the gross value of the national fertiliser products during 2004–2010. However, this taxation privilege was removed in 2015 for all types of fertilisers.

The second most important support policy for the fertiliser industry is the subsidy on railway transportation for fertilisers. The rate of the fertiliser transportation subsidy ranged from nearly 60% of freight rate in the 2000s to about 25% in recent years. Li et al. (2013) estimated that the annual subsidy on railway transportation

[4]Coal subsidy was phased out as early as 1994.

reached about 8.1 billion yuan in 2003–2010.[5] This amount of subsidy was equivalent to about 2.5% of the total output value of fertilisers in the 2000s, but this share has been falling gradually, to about 1–1.5% in 2010–2011.

Electricity and natural gas subsidies had also been implemented for several decades and have been gradually phased out since 2013. In the 2000s, fertiliser manufacturers generally paid two-thirds of the average electricity price charged from industries that were not subsidised. The subsidy on natural gas started in the 1980s but only a small portion of nitrogen fertiliser manufacturers benefited from this policy because the production of ammonia in China mainly uses coal rather than natural gas as the major raw material. It was estimated that the annual electricity subsidy for fertiliser production was about 1–3 billion yuan in 2003–2010 (Li et al. 2013). With oversupply of N and P fertilisers since the mid-2000s, China gradually phased out the electricity subsidy during 2013–2015 and has eliminated the natural gas subsidy since 2016.

The seasonal buffer stock fertiliser reserve subsidy, introduced in 2004, is a subsidy aimed at balancing the supply of and demand for fertilisers between peak and off-peak demand seasons. The government's annual budget for this fertiliser reserve programme was about 1–1.5 billion yuan in the early 2010s (Li et al. 2013). Given the excess capacity in nitrogenous and phosphatic fertiliser production, whether this policy should be continued has been debated.

6.6.1.4 Evolution of Fertiliser Trade Policy

Fertiliser trade policy is an integral part of China's fertiliser policy package and has changed over time as China's fertiliser policy package has evolved. Balancing domestic supply and demand and maintaining stable fertiliser prices have been the key factors affecting China's fertiliser import and export policies.

Fertiliser Import Policy

China has used state trading, import quotas, VAT and tariffs to regulate fertiliser imports. However, the role of each measure has changed over time. In general, import policy has evolved towards a more liberalised one.

While state trading is a major factor for China's fertiliser imports, competition has also been occurring, though it has travelled a winding path. To manage fertiliser imports, the "Sinochem Group", a state-owned enterprise (SOE), was established in 1950. To introduce competition, China provided all provincial corporations (provincial SOEs) associated with agricultural inputs with licences to import fertilisers in the 1980s and early 1990s. The "Sino-Agri Group", the largest SOE trading company in domestic agricultural inputs, has also engaged in fertiliser imports since 1998. After China joined the World Trade Organization (WTO) in 2001, further liberalisation has been introduced. Numerous trade companies, both SOEs and private companies, were given licences to import fertilisers after 2001.

[5]The average official exchange rate was 8.28 yuan per USD in 2003 and 6.77 in 2010.

VAT and tariffs are the other major trade measures and their effects on fertiliser imports have varied in different periods and by-product. The implementation of the VAT policy has mainly depended on domestic production and demand. For example, for potassic fertilisers and NPK compound fertilisers, the most deficit fertilisers in China, the government has imposed VAT only in recent years, accompanied by the cancellation of taxation privilege to the domestic fertiliser industry. On the other hand, a 13% VAT was first applied on imported urea in 1997 and DAP in 2000. With the significant increase in domestic urea production, and with China becoming a net urea exporter after the early 2000s, urea has never been exempt from VAT since 1997. Exemption from VAT for imported DAP has been effective since 2008, when China had already shifted from being a net importer to a net exporter of phosphoric fertilisers, and this was also removed in 2015.

The fertiliser import tariff was implemented in the late 1990s, but it has never become a significant part of trade policy. Before China joined the WTO, fertiliser tariffs were quite low. After China joined the WTO, imports of urea, DAP and NPK compound fertilisers were subject to a tariff rate quota (TRQ) regime, replacing quantitative import restrictions. Under the TRQ regime, the in-quota tariff was four per cent between 2002 and 2005 and has been one per cent since 2006. The above-quota tariff has been maintained at 50% during the whole period. Because imports of all fertilisers under the TRQ have never exceeded the import quota, the above-quota tariffs have not been applied. For potassic fertilisers, the tariff was only three per cent before China joined the WTO in 2001, and there has been no quantitative restriction on imports since 2001. A three per cent tariff was maintained from 2002 to 2005 and has been reduced to one per cent since 2006.

Fertiliser Export Policy

Two major measures have been employed with fertiliser exports, namely exemption of VAT and export tax. While VAT exemption had been applied to domestically produced fertiliser before 2016, only partial or no exemption from VAT had been applied to fertiliser exports. With the real prices of fertilisers rising since the early 2000s, no exemption from VAT has been implemented for the exports of N and P fertilisers since 2004 and for K fertilisers since 2006. On the other hand, China implemented export taxes and other export restrictions during the global food crisis period of 2006–2008.

6.6.2 Agricultural Aggregate Input Subsidy and an Innovative Way to Implement Policy

Agricultural aggregate input has been discussed in Sect. 3 (see Fig. 6.6). Initiation of this subsidy programme was mainly due to the government's concerns about farm incomes and the rising prices of many agricultural inputs such as chemical fertilisers and pesticides, fuel costs, plastic films and so on. Initially, this subsidy was aimed at grain producers. However, because of the difficulty in implementing this policy based on actual grain production and the amount of inputs used by farmers, nearly all rural households receive grain and aggregate input subsidies based on the amount of contracted land recorded in the late 1990s (Huang et al. 2011).

Accompanying the rising agricultural subsidies are debates on whether these subsidies have achieved their policy goals. There is consensus among scholars that agricultural subsidies lead to improved rural household incomes. They also demonstrated that there were no significant statistical difference in the amounts of agricultural subsidies obtained by different income groups of farmers. However, empirical evidence on the effect of subsides on grain production shows that there is very little impact (Du et al. 2010) or no impact (Huang et al. 2011). This is because the subsidies are decoupled from grain production or purchase of agricultural inputs (see Box 6.2). As mentioned earlier, aggregate input subsidies have been changed to income transfers since 2016.

Box 6.2: Innovative Implementation of Agricultural Aggregate Input Subsidy and Other Direct Subsidies in China All direct subsidies to farmers, except the machinery subsidy, are top-down policy programmes and have been implemented in a decoupled way. For aggregate input subsidy (and also direct grain subsidy and quality seed subsidy), because it is difficult to monitor the amount of input use (and crops produced as well as seed purchased) by millions of small farmers, after the initial years of implementation, the amount of each direct subsidy to individual households has been determined by the amount of contract land that a household had in the late 1990s, a record of which the government has. That is, the subsidies have been given to the land contractor, not the tiller (or grower) (Huang et al. 2011).

In addition, all subsidies are transferred to each household through the banking system set-up by the county's Financial Bureau. The government sets up a special account for each household in a local bank. Each household is allocated a current deposit book (card) for accessing the annual allocation of the agricultural financial subsidy funds. The funds are transferred to farm households in spring each year. Farmers can check whether their subsidies have arrived by visiting the bank.

6.6.3 Overall Impact on Fertiliser Market Distortions and the Way Forward

6.6.3.1 Measuring Distortions to the Fertiliser Market

The overall distortionary impacts of policies on fertiliser market using the differences between domestic wholesale prices and international prices at the border (nominal protection rates, NPRs) are summarised in Fig. 6.12.

Figure 6.12 provides some interesting findings. First, despite huge amounts of subsidies for both fertiliser production and consumption in the past decades, the overall impact of the government's policy intervention has been very moderate. Indeed, the results show that China's fertiliser industry has moved gradually from being highly protected to being market-driven, with its prices close to international market prices. The average rate of nominal protection was—12% for urea and only—2% for DAP in 2010–2015. Supply-side intervention polices, incentives for production and restrictions on exports have offset each other, a trade-off policy designed by policymakers. Second, on the demand side, the subsidy has been decoupled from grain production and fertiliser consumption and therefore, did not distort the market and farmers' fertiliser use. Every farmer receives the subsidy, regardless of the nature of farming. Third, there has been a shift from protected to unprotected N and P

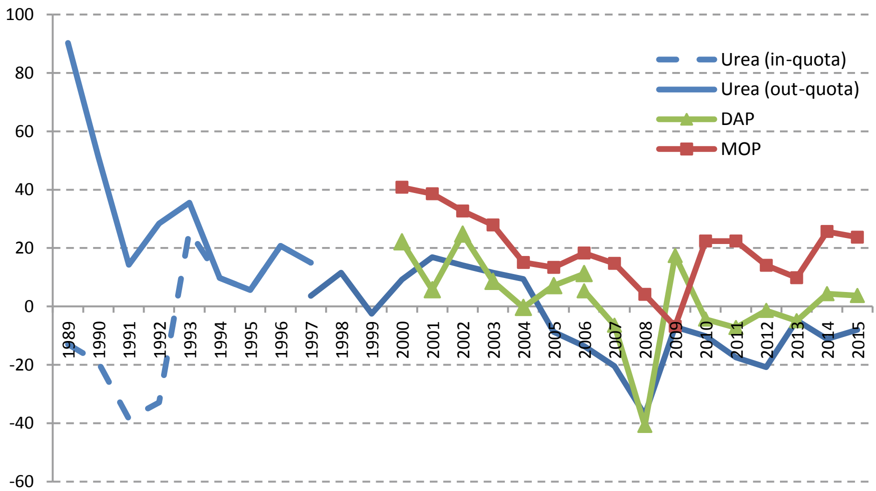

Fig. 6.12 Nominal protection rates (per cent) of urea, DAP and MOP in China, 1989–2015. *Notes* For urea, CIF is used for 1989–1997 and FOB is used for 1997–2016; For DAP, CIF is used for 2000–2006 and FOB is used for 2006–2016; For MOP, CIF is used for all the years. *Sources* Detail sources of the wholesale urea, DAP and MOP prices are provided in Fig. 6.1. FOB urea and DAP data and CIF DAP and MOP data at China border are from the GAC. CIF urea data at China border are calculated by dividing total urea import values with urea import quantity and data are from NBSC (1990–1998). Data on exchange rate are from NBSC (1990–2016)

fertiliser markets, as their domestic prices have been close to international prices in recent years. While recent lower N and P fertiliser prices might partially explain farmers' overuse of fertiliser these past few years, much of the excessive use of fertiliser by Chinese farmers has been explained by other factors, such as lack of knowledge about effective fertiliser application, small-scale farms and rising off-farm employment in the past decade (Hu et al. 2007; Huang et al. 2008, 2012; Jia et al. 2013; He et al. 2006).

As the goal of fertiliser industry development has been achieved with complex policies designed by the central government, market-oriented reform of the fertiliser industry has accelerated. All industry subsidies have been almost entirely phased out. The taxation privilege, the electricity and natural gas subsidies and the preferential price for railway transportation were abolished by 2016. Fertiliser reserves have recently declined significantly after removal of the subsidies. Meanwhile, export taxes for the main nitrogen and phosphate fertilisers were eliminated in 2017, and the tax on potassic fertilisers and NPK compound fertilisers has been much reduced in recent years. The government has also reformed the fertiliser consumption subsidy, parts of which will focus on large farmers who have cultivated appropriate-scale farmland and are an easier target for policy implementation.

This study has important policy implications for many developing countries which are suffering from both an undersupply and underuse of chemical fertilisers. Many African countries have mainly subsidised fertiliser consumption by farmers directly. However, the policy has proved to be difficult to implement due to marketing and credit constraints, deficient infrastructure and the lack of functioning distribution chains. When there is not enough foreign exchange to import fertilisers, supporting domestic fertiliser production by introducing foreign investment or international aid programmes may be an option.

6.6.3.2 New Measures to Reduce Fertiliser Use

With rising fertiliser consumption, there are growing concerns about the excessive use of fertilisers in China. For example, many studies have shown that in China, the use of N fertiliser in grain production exceeded the amount recommended by scientists by 20–60% (Chen et al. 2006; Huang et al. 2012; Jia et al. 2013), and this was even more so in vegetable production. The intensive use of fertilisers has raised serious concerns about environmental consequences, including nitrates and phosphorous pollution (which has occurred in nearly all major lakes and rivers) (Zhu and Chen 2002), soil acidification (Guo et al. 2010) and greenhouse gas emissions (SAIN 2010).

To improve farmers' incentives to reduce the use of chemical fertiliser, China has recently initiated several pilot policy support programmes and technology innovation programmes. Major pilot programmes include a development programme which, since 2015, has been aimed at reducing fertiliser use in maize, vegetables and fruits, and, since 2017, a subsidy programme to provide farmers with an incentive to replace chemical fertilisers with organic fertilisers. Meanwhile, the National Research and

Development Programme to reduce chemical fertiliser and pesticide use began in 2015. Details of these new measures to reduce fertiliser use are discussed in Chap. 4 on China's technologies.

6.6.4 Incentive Policies to Improve Irrigation Efficiency

With rising concerns about water scarcity, international communities, since the late 1980s, have begun to push the transformation of water management from the supply side to the demand side. The key issues in demand-side management are how to introduce a market mechanism into the management of water use through economic instruments such as water pricing, water rights and the water market. While progress in this area has been limited worldwide, including in China, some efforts and pilot programmes in China have had encouraging results and may have implications for other countries in providing incentives to save water and improve water use efficiency.

In China, the government has made several efforts to introduce incentive policies and reforms to improve water use in irrigation. The first effort, made in 1985, was a shift away from supplying water at almost no cost to charging a part of the supply cost. While its impact might be very moderate, it did remind farmers that they were responsible for the share of some costs of irrigation. The second effort came in 1992 and involved transferring the management of the irrigation fee from the water resource bureau to price bureaus, the implication being that water should be considered a commodity that has to be paid for. Attempts were also made to increase the water fee by charging a single irrigation fee within the basic fee, based on irrigated area, and a volumetric fee based on the amount of water used in villages with good irrigation infrastructure. Moreover, the scarcity value of water resources had begun to be an issue, with an irrigation fee through the collection of a water resources fee being piloted in some regions in the past decade. The central government selected some regions to launch pilot projects based on moving away from water resources fee to a water resources tax. In addition, in some regions, an irrigation fee by area has been replaced by time, which is closer to that by volume; this is an important improvement in collecting irrigation fee. Recently, pilot projects have been implemented in several provinces to install integrated circuit cards (IC) for directly regulating the pump rates of individual farmers.

Despite these efforts, however, progress in raising irrigation fee nationwide has been slow, and the current irrigation price is still far from the level that can effectively improve water use efficiency and cover water supply costs. For example, Wang et al. (2019) found that although the surface irrigation price in Zhangye Prefecture increased from 0.006 yuan/m^3 in 1981 to 0.216 yuan/m^3 in 2016, a35 times increase, the irrigation price could only cover 70% of the supply cost in 2016. Among the 78 pilot counties implementing comprehensive agricultural price reform funded by the Ministry of Water Resources (MWR), irrigation prices in more than 90% of the counties were lower than their supply cost (MWR 2014). Because of lack of measurement facilities and high implementation cost, it is difficult to implement the volumetric irrigation fee in many villages. Due to the high traction cost, extending IC cards from the pilot project sites to other areas is facing challenges (Wang et al. 2019). Last but not least, there is political sensitivity around raising the irrigation price as the average farmer's income is lower than the average income of non-farm families.

Given the above challenges, the other innovative reform that has addressed both the incentive and income of farmers has been piloted in Hebei Province since 2005. This pilot project is called "Increase Price and Provide Subsidy" reform for groundwater irrigation, a win-win strategy of agricultural pricing reform (Wang et al. 2016). According to the design of the reform, after the irrigation fee was raised, the collected extra irrigation fees (the amount higher than that before the reform) from all farmers would be deposited in the bank by village leaders. At the end of year, village leaders would withdraw the fund and return it to all farmers in proportion to the size of their irrigated area (same amount per ha). The result was that water used for irrigation was reduced and the extra irrigation fee paid by farmers was returned to them. In order to encourage village leaders and farmers to participate in the pilot reform projects, the local government also provided some subsidies to villages that were also evenly allocated to all farmers based on their landholding. The key mechanism of the pilot reform was that farmers received similar returns per ha but paid different irrigation fees (because the area under irrigation varies); the returned money was treated as an incentive for farmers to reduce their use of irrigation. Wang et al. (2016) show that the reform reduced irrigation water usage by 21% for both wheat and cotton.

In recent years, China has also launched a pilot to subsidise irrigation equipment to improve the efficiency of water use in agriculture. For example, irrigation equipment has been eligible for subsidy under the agricultural machinery subsidy programme in some provinces. The subsidised equipment includes water pumps and those related to sprinkler, micro-irrigation and others that contribute to saving water.

6.7 Innovations in Rural E-Commerce

Over the past decade, e-commerce has spread throughout China, including rural areas. Rural e-commerce includes farmers selling agricultural products and purchasing industrial goods. Online shopping by rural residents has been adopted quickly and successfully with rapid increases in Internet access and smartphone use in rural areas. The online selling of agricultural products by farmers is a recent trend, but it is expected to grow rapidly in coming years.

6.7.1 The Operating Modes of Rural E-Commerce in China

There are three major operating modes of rural e-commerce in China, depending on the type of e-commerce platform used for selling agricultural products:

(1) Agricultural products are directly sold by farmers, agricultural enterprises and farmer co-operatives through the most popular e-commerce platforms such as Taobao, Tmall, Jindong and Wechat. They also sell on a wholesale basis through Alibaba and other wholesale platforms. However, individual farmers hardly ever sell their products on Taobao, Tmall, Jindong and other wider platforms by themselves because of the high investment threshold and other requirements, such as official documents required to run online stores. Wechat is getting more popular for farmers who aim to sell their products because it is less expensive; however, potential consumers are limited.
(2) State-owned enterprises sell agricultural products through their own platforms, for example China Post and Supply and Marketing Co-operatives. China Post, which has the largest logistics system and is able to reach almost all villages, developed Ule in 2012. Ule co-operates with the physical groceries in the villages and establishes their platforms at the groceries. It includes help for villagers to purchase goods from the Ule website, withdraw small cash from grocery owners and pick up packages from grocers. Food enterprises and farmers' co-operatives are able to sell their products on the Ule website if they have the legal certificates that are required by Ule. Ule also collects some special agricultural products from farmers or farmers' co-operatives and sells them through self-operate shops on their platform. In addition, supply and marketing co-operatives, which were the most popular vehicle for sales in China and have been in recession since the market-oriented economy started, have developed their own platform as well. They collect agricultural products from the farmers directly and sell them through their online platform or to local restaurants offline.
(3) There are also regional platforms developed by private enterprises, which mainly serve local residents. They purchase agricultural products from the local wholesale market or farmers' co-operatives and send goods to their consumers who order from their online platform. Regional platforms developed well and quickly because of the perishability of agricultural products and the inconvenience associated with long-distance delivery.

6.7.2 The Development of Taobao Villages

The development of Taobao villages is unique in rural e-commerce. Initiated by Alibaba Group Holding Limited, Taobao's business model involves a long industrial chain and stimulates the development of various industries that specialise in activities such as processing, manufacturing and logistics. The aggregation of these workshops in rural areas has led to the development of so-called Taobao villages, which have contributed to the rapid restructuring of the rural economy. Taobao villages constitute an exciting phenomenon that has changed both the development of the rural economy

Table 6.8 presents the changes in the number of Taobao villages from 2009 to 2017. Although Taobao villages accounted for only a small fraction of China's villages, the number has expanded rapidly since 2009, reaching 2118 in 2017 (Table 6.8). Of

Table 6.8 Number of total Taobao villages and agricultural Taobao villages, 2009–2017 and the social foundation of rural daily life

Year	Taobao villages	Agricultural Taobao villages
2009	3	0
2012	16	1
2013	20	3
2014	212	8
2015	780	40
2016	1311	62
2017	2118	93

Note Authors' compilation based on the data from Alibaba and Chinese yearbook

these, agricultural Taobao villages have appeared only in the last few years. Given their rapid growth, we expect there will be more fast-moving and emerging trends in the coming years.

6.8 Concluding Remarks

China's agricultural price and market reform has been implemented gradually over the past four decades. This gradual reform approach has been adopted in both agricultural output and input markets, and it is thought to have facilitated China's smooth transformation from a planned economy to a market-oriented economy. The slow but steady reforms are also thought to have helped diversify China's agriculture during the course of agricultural transformation.

Accompanying gradual market reform has been the significant improvement in marketing infrastructure over time, which has accelerated market integration across regions. Investments in road, transportation, wholesale and retail markets and communication, as well as supporting policies to facilitate the free movement of agricultural commodities and agricultural inputs across county and provincial boundaries, have resulted in increasing integration of agricultural markets in China. By the early 2000s, grain prices in almost all markets across China moved together because their markets have been integrated. The integration of markets across the country for agricultural products other than grain has been achieved earlier than for grain because the reforms in the case of these started relatively early.

Market reforms and market infrastructural development have played important roles in agricultural growth and in raising farmers' income. Farmers have gained from more efficient use of land and labour as a result of market reform and the adjustment of the production structure according to changes in market prices (De Brauw et al. 2004; Huang and Rozelle 1996). Market reforms have also reduced the price of inputs for farmers and increased selling prices of agricultural commodities by lowering market transaction costs.

China has also steadily and significantly liberalised its agricultural trade since the early 1990s. The initial reform was implemented by relaxing trade restrictions and allowing non-state actors access to international trade. Subsequently, tariff reduction followed. Since it joined the WTO, external reform has made China one of the most liberal countries in the world with regard to agricultural trade.

China's domestic market reform and open-door policies in agriculture have enabled the integration of the nation's market into international markets. By the early 2000s, most agricultural commodity prices in China were almost equal to the price of imports at the border. The export of labour-intensive products (e.g. horticulture and livestock) and the import of land- and water-intensive commodities (e.g. soybeans, cotton, edible oil and sugar) have been rising. The nature of trade, which reflects China's comparative advantage, has improved the efficiency of its resource allocation and agricultural production.

Concerning farmer's income growth and rural poverty, China has shifted its policy regime from taxing to subsidising agriculture since the early 2000s. Like many developing countries, agriculture was taxed to support industrialisation in the early stages of development. However, China eliminated all agricultural taxes and fees in 2004. China started an agricultural subsidy programme in the same year and has implemented the subsidy programme in a way that is largely decoupled from agricultural production and input use. In terms of the total budget today, China is running the largest agricultural subsidy programme in the world. However, given the size of rural farming households, the programme's contribution to increasing farmers' income is very moderate. It also led to an increase in the financial burden on the government leading to the capping of agricultural subsidies in 2012.

China had also tried to intervene in markets to raise agricultural prices and farmers' income between 2004 and 2013. However, there is a big lesson to be learned from using price and market interventions to raise farmers' income. While price interventions increased domestic production and farmers' income, they also resulted in several serious problems, particularly the massive increase in government grain stocks. In the past decade, China has faced the twin challenges of making a decision on how to manage its price intervention policies while simultaneously ensuring national food security and increasing farmers' income.

Recent efforts to resolve the dilemma of price and market intervention are encouraging. China abolished direct market intervention policies in 2014. The overall market distortion has started to fall since 2015. With more than half the income of the average rural households coming from non-farm activities that have contributed to a significant rise in their income, more effort should be made to increase off-farm employment for rural labour in the future.

Faced with the challenges in sustainable development, the recent policies introduced by the Chinese government are encouraging. Recognising land and water constraints, since the mid-2000s, China has made a stronger commitment to sustainable agriculture through investment in land, water and technology. In addition, China is planning to establish a pricing mechanism that more appropriately reflects the cost of water to encourage water savings. It has also targeted a reduction in the use of chemical fertiliser by 2020. While an evaluation of the impact of these measures will take many years, they have significant implications not only for China's agriculture and food security in the short and long run, but also for international trade and global agriculture.

References

Anderson, K., Huang, J., & Ianchovichina, E. (2004). Will China's WTO accession worsen farm household incomes? *China Economic Review, 15*(4), 443–456.

Babu, S. C., Huang, J., Venkatesh, P., & Zhang, Y. (2015). A comparative analysis of agricultural research and extension reforms in China and India. *China Agricultural Economic Review, 7*(4), 541–572.

Carter, C. A., & Estrin, A. J. (2001). Market reforms versus structural reforms in rural China. *Journal of Comparative Economics, 29*(3), 527–541.

Chen, X. P. F. S., Zhang, F., Römheld, V., Horlacher, D., Schulz, R., Böning-Zilkens, M., et al. (2006). Synchronizing N supply from soil and fertilizer and N demand of winter wheat by an improved N min method. *Nutrient Cycling in Agroecosystems, 74*(2), 91–98.

China National Chemical Information Centre (CNCIC). (2006). *China chemical industry yearbook*. China National Chemical Information Centre: Beijing.

De Brauw, A., Huang, J., & Rozelle, S. (2004). The sequencing of reform policies in China's agricultural transition. *Economics of Transition, 12*(3), 427–465.

Ding, Y. H., Ren, G. Y., Shi, G. Y., Gong, P., Zheng, X. H., Zhai, P. M., et al. (2006). National assessment report of climate change (I): Climate change in China and its future trend. *Advances in Climate Change Research, 2*(1), 3–8.

Du, H., Zhang, M., & Chen, C. (2010). The confusion and solution of China's new agricultural subsidy system: Rational reflection of its six years' practice. *China Soft Science, 7,* 1–7 (In Chinese).

Guo, J. H., Liu, X. J., Zhang, Y., Shen, J. L., Han, W. X., Zhang, W. F., et al. (2010). Significant acidification in major Chinese croplands. *Science*, 1182570.

Han, J. (2015). China: Food security and agricultural going out. *Strategy Research* (in Chinese).

He, H., Zhang, L., & Li, Q. (2006). Farmer's fertilizer use and agricultural non-point pollution. *Journal of Agrotechnical Economics, 6,* 2–10.

Heisey, P., & Norton, G. (2007). Chapter 53 Fertilizers and other farm chemicals. In R. Evenson & P. Pingali (Eds.), *Handbook of agricultural economics* (Vol. 3, pp. 2741–2777). Elsevier

Hejazi, M., & Marchant, M. A. (2017). China's evolving agricultural support policies. *Choices, 32*(2), 1–7.

Hu, R., & Huang, J. (2011). The development and reform of agricultural research system: Policy evaluation and recommendations. *Science and Society, 3,* 34–40 (in Chinese).

Hu, R., Cao, J., Huang, J., Peng, S., Huang, J., Zhong, X., et al. (2007). Farmer participatory testing of standard and modified site-specific nitrogen management for irrigated rice in China. *Agricultural Systems, 94*(2), 331–340.

Huang, J. & Hua, Y. (2018). *An analysis of China's fruit and vegetable value chains: The case of apples and tomatoes*. Working paper. Peking University, CCAP.

Huang, J., & Rozelle, S. (2003). The impact of trade liberalization on China's agriculture and rural economy. *SAIS Review, 23*(1), 115–131.

Huang, J., & Rozelle, S. (1996). Technological change: The re-discovery of the engine of productivity growth in China's rice economy. *Journal of Development Economics, 49*(2), 337–369.

Huang, J., & Rozelle, S. (2006). The emergence of agricultural commodity markets in China. *China Economic Review, 17,* 266–280.

Huang, J., & Rozelle, S. (2014). Agricultural R&D and extension. In S. Fan, R. Kanbur, S.-J. Wei, & X. Zhang (Eds.), *The Oxford companion to the economics of China* (pp. 315–319). London: Oxford University Press.

Huang, J., & Yang, G. (2017). Understanding recent challenges and new food policy in China. *Global Food Security, 12,* 119–126.

Huang, J., Hu, R., Cao, J., & Rozelle, S. (2008). Training programs and in-the-field guidance to reduce China's overuse of fertilizer without hurting profitability. *Journal of Soil and Water Conservation, 63*(5), 165A–167A.

Huang, J., Liu, Y., Martin, W., & Rozelle, S. (2009). Changes in trade and domestic distortions affecting China's agriculture. *Food Policy, 34,* 407–416.

Huang, J., Rozelle, S., & Chang, M. (2004a). Tracking distortions in agriculture: China and its accession to the World Trade Organization. *The World Bank Economic Review, 18*(1), 59–84.

Huang, J., Rozelle, S., & Chang, M. (2004b). The nature of distortions to agricultural incentives in China and implications of WTO accession. *World Bank Economic Review, 18*(1), 59–84.

Huang, J., Rozelle, S., & Wang, H. (2006). Fostering or stripping rural China: Modernizing agriculture and rural to urban capital flows. *The Developing Economies, 44*(1), 1–26.

Huang, J., Wang, D., & Hu, J. (2015). Some reflections on implementing target price policy for agricultural products in China: A study based on cotton target price pilot reform in Xinjiang Uygur Autonomous Region. *Chinese Rural Economy, 5,* 10–18 (in Chinese).

Huang, J., Wang, X., & Rozelle, S. (2013). The subsidization of farming households in China's agriculture. *Food Policy, 41*(2013), 124–132.

Huang, J., Wang, X., Zhi, H., Huang, Z. & Rozelle, S. (2011). Subsidies and distortions in China's agriculture: Evidence from producer-level data. *The Australian Journal of Agricultural and Resource Economics*, *55*, 53–71.

Huang, J., Xiang, C., Jia, X., & Hu, R. (2012). Impact of training on farmers' nitrogen use in maize production in Shandong, China. *Journal of Soil and Water Conservation, 67*(4), 321–327.

Jia, X., Huang, J., Xiang, C., Hou, L., Zhang, F., Chen, X., et al. (2013). Farmer's adoption of improved nitrogen management strategies in maize production in China: An experimental knowledge training. *Journal of Integrative Agriculture, 12*(2), 364–373.

Jiang, R., & Ling, L. (1989). Fertilizer market and price in China. *Prices Monthly, 12,* 5–11 (In Chinese).

Li, H., Li, L., Wu, B., & Xiong, Y. (2012). The end of cheap Chinese labour. *Journal of Economic Perspectives, 26*(4), 57–74.

Li, S., Zhai, F., & Wang, Z. (1999). *The global and domestic impact of China joining the world trade organization.* A Project Report. Development Research Centre, the State Council, China.

Li, Y., Zhang, W., Ma, L., Huang, G., Oenema, O., Zhang, F., et al. (2013). An analysis of China's fertilizer policies: Impact on the industry, food security, and the environment. *Journal of Environmental Quality, 42*(4), 972–981.

Liu, M., Xu, Z., Su, F., & Tao, R. (2012). Rural tax reform and the extractive capacity of local state in China. *China Economic Review, 23,* 190–203.

Lu, Y., Jenkins, A., Ferrier, R. C., Bailey, M., Gordon, I. J., Song, S., et al. (2015). Addressing China's grand challenge of achieving food security while ensuring environmental sustainability. *Science Advances, 1*(1), e1400039.

MWR (Ministry of Water Resources). (2016). *Monthly groundwater dynamics (May).* Beijing, China: Ministry of Water Resources.

National Bureau of Statistics of P.R. of China (NBSC). Statistical Yearbook, various years from 2010 to 2018. Beijing: China Statistical Press.

Organization of Economic Co-operation and Development (OECD). (2013). *Agricultural policy monitoring and evaluation 2013: OECD countries and emerging economies*, OECD Publishing, Paris, available at https://www.oecd-ilibrary.org/agriculture-and-food/agricultural-policy-monitoring-and-evaluation-2013_agr_pol-2013-en.

Organization of Economic Co-operation and Development (OECD). (2018). *Online database, review of agricultural policies in OECD and non-OECD countries.* https://data.oecd.org/agrpolicy/producer-protection.htm. Accessed in May 2019.

Park, A., Jin, H., Rozelle, S., & Huang, J. (2002). Market emergence and transition: Arbitrage, transition costs, and autarky in China's grain market. *American Journal of Agricultural Economics, 84*(1), 67–82.

Perkins, D. H. (1994). Completing China's move to the market. *Journal of Economic Perspectives, 8*(2), 23–46.

Rozelle, S., & Huang, J., (2010). The marketization of rural China: Gain or pain for China's two hundred million farm families? In J. C. Oi, S. Rozelle, & X. Zhou (Eds.), *Growing pains: Tensions and opportunity in China's transformation* (pp. 57–85). Walter H. Shorenstein Asia-Pacific Research Center.

Rozelle, S., Park, A., Huang, J., & Jin, H. (1997). Liberalization and rural market integration in China. *American Journal of Agricultural Economics, 79*(2), 635–642.

Rozelle, S., & Swinnen, J. F. (2004). Success and failure of reform: Insights from the transition of agriculture. *Journal of economic literature, 42*(2), 404–456.

Rozelle, S., Park, A., Huang, J., & Jin, H. (2000). Bureaucrat to entrepreneur: The changing role of the state in China's grain economy. *Economic Development and Cultural Change, 48*(2), 227–252.

SAIN. (2010). UK-China sustainable agriculture innovation network: Policy brief 1. http://www.sainonline.org/English.html. Accessed in May 2019.

Sicular, T. (1995). Redefining state, plan and market: China's reforms in agricultural commerce. *The China Quarterly, 144,* 1020–1046.

Sonntag, B., Huang, J., Rozelle, S. & Skerritt, J., (2005). *China's agricultural and rural development in the early 21st century*. CCICED Task Force, Australian Centre for International Agricultural Research.

Tao, R., & Qin, P. (2007). How has rural tax reform affected farmers and local governance in China? *China & World Economy, 15*(3), 19–32.

Wang, J., Huang, J., & Yan, T. (2013). Impacts of climate change on water and agricultural production in ten large river basins in China. *Journal of Integrative Agriculture, 12*(7), 1267–1278.

Wang, J., Zhu, Y., Sun, T., Huang, J., Zhang, L., & Guan, B. (2019). *40 years of irrigation development and reform in China.* Working paper, CCAP, Peking University.

Wang, J., Zhang, L., & Huang, J. (2016). How could we realize a win–win strategy on irrigation price policy? Evaluation of a pilot reform project in Hebei Province, China. *Journal of Hydrology, 539,* 379–391. https://doi.org/10.1016/j.jhydrol.2016.05.036.

Wang X., Yamauchi, F., Otsuka. K. & Huang, J., (2014). *Wage growth, landholding and mechanization in Chinese agriculture.* World Bank, Policy Research Working Paper, WPS7138.

Wang, X., Huang, J., Zhang, L., & Rozelle, S. (2011). The rise of migration and the fall of self-employment in rural China's labour market. *China Economic Review, 22*(4), 573–584.

World Bank. (1997). "China Engaged: Integration with the Global Economy" in China 2020, *The World Bank*, Washington D.C.

Yang, J., Qiu, H., Huang, J., & Rozelle, S. (2008). Fighting global food price rises in the developing world: The response of China and its effect on domestic and world markets. *Agricultural Economics, 39,* 453–464.

Yi, F., Sun, D., & Zhou, Y. (2015). Grain subsidy, liquidity constraints and food security—Impact of the grain subsidy program on the grain-sown areas in China. *Food Policy, 50,* 114–124.

Zhang, W., Gao, L., Ma, J., Ma, W., Xu, X., & Zhang, F. (2007). Evaluation on the reform effectiveness of fertilizer industry policy in China. *Phosphate and Compound Fertilizer, 22*(1), 5–9 (In Chinese).

Zhang, W., Zhang, F., Li, Y., Huang, G., & Wu, L. (2013). *Research report 2012 on China's fertilizer development*. Beijing: China Agricultural University Press (In Chinese).

Zhu, Z. L., & Chen, D. L. (2002). Nitrogen fertilizer use in China—Contribution to food production, impact on the environment and best management strategies. *Nutrient Cycling in Agroecosystems, 63*(2–3), 117–127.

Chapter 7
Institutional Innovations in Accessing Land, Water, Farm Machinery and Extension Services in Indian Agriculture

7.1 Introduction

Institutions represent the "rules of the game" that enable a given system to function. They can be designed for running a country (typically as enshrined in the constitution), the economy as a whole, a sector such as agriculture or industry, or a sub-sector. Observers tend to view institutions as "good" or "bad" according to their short, medium and long-term consequences. The quality of those consequences, the system's outcomes, is in turn judged according to appropriate parameters.

This chapter looks at the sub-systems behind four key farm inputs: land, water, machinery and extension. We examine the embedded institutions and the quality of their outcomes in Indian agriculture. We focus on institutional innovations that can improve the outcomes.

This chapter has six sections, including this introduction. Section 7.2 looks at institutions related to land, the most fundamental factor of agricultural production. We discuss how the institutions—in other words, policies—have evolved, how they affect land access and use, and what innovations could produce better outcomes. Section 7.3 evaluates institutions governing the development and use of water resources, again judging their effects on access (especially by small and marginal farmers), and on the efficiency and sustainability of use. This section further highlights institutional innovations that can help manage India's water resources better. In Sect. 7.4, we

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study farm mechanisation and its if evolution, with prime focus on the innovations of custom hiring and "Uberisation". Section 7.5 examines the evolution of India's agricultural extension system and innovative models designed to take research results to farmers.

A central theme of this chapter is the need for farmer-centric institutions that improve their access to the four inputs. Better use of land, water, machinery and extension policy raises farm productivity and income sustainably. This is reflected in the concluding section, which charts a way forward.

7.2 Institutional Framework Governing Agricultural Land Use

India covers a total geographical area of 328.7 million hectares (Mha), of which some 157 Mha is the agricultural area. The net sown area is about 140.1 Mha, and the gross cropped area about 198.4 Mha.[1] At independence in 1947, land revenue and ownership systems varied across the country. However, India's agrarian structure was essentially feudal. There was a sizeable concentration of land in the hands of a few and a high proportion of tenant cultivators[2] (Appu 1996). Three major land tenure systems were called *Zamindari*, *Ryotwari* and *Mahalwari* (Government of India 1976).

Almost all state governments regarded the institutions at independence as inefficient, unequal and unjust and carried out comprehensive reforms (NITI Aayog 2016). Their objective was to distribute agricultural land more equally and encourage self-cultivation and efficient land use. The three main institutional thrusts aimed to (i) abolish intermediaries and reform tenancy, (ii) introduce landholding ceilings and distribute surplus land and government wastelands to farmers and (iii) consolidate landholdings (Deshpande 2003; Srivastava et al. 2007).

Unlike China and Israel, land in India is privately owned by individuals. In today's federal structure, however, it remains subject to control by the states, whose laws on farmland usage rights and ownership vary. An interesting restriction in several states is that "no sale, gifts and exchange of any land will be valid in favour of a person who is not an agriculturist. An 'agriculturist' is a person who cultivates the land personally" (Hassan 2016).

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[1] In the Agricultural Census 2015–16, the agricultural area included both cultivated and currently uncultivated land put to agricultural production at some stage during the reference period. The net sown area (NSA) is the actual area under crops in that year. Gross cropped area (GCA) includes those parts of the NSA sown more than once during the reference period. GCA/NSA reflects the cropping intensity, which is about 141% in India, indicating that about 41% of NSA is double cropped.

[2] A tenant cultivator/farmer works someone else's land and pays rent in cash or kind.

7.2.1 Lay of the Land: Evolution of Land Institutions in India

The differences in tenancy reforms between states are considerable (Deshpande 2003). Jammu and Kashmir, Kerala and Manipur prohibit leasing out agricultural land, with no exceptions. Bihar, Karnataka, Madhya Pradesh, Chhattisgarh, Uttar Pradesh, Uttarakhand, Himachal Pradesh, Tripura and Odisha permit exceptions. They allow leasing out by certain categories of land owners, such as those suffering from physical or mental disability, widowed, unmarried, separated or divorced women, members of the armed forces, privileged *raiyats* like Lord Jagannath in Odisha, or recognised trusts of a public nature (NITI Aayog 2016). Punjab, Haryana, Gujarat, Maharashtra and Assam do not ban leasing out of agricultural land but give tenants the right to purchase it after a set period. In Punjab and Haryana, the period is six years of tenancy. In Assam, the tenant can purchase the leased-in land for 50 times the rate of revenue after at least three years' consecutive tenancy (NITI Aayog 2016). In Gujarat and Maharashtra, tenancy by a member of a scheduled caste or scheduled tribe cannot be terminated. In Andhra Pradesh, Tamil Nadu, Rajasthan and West Bengal, there are no restrictions on land leasing, but there are several restrictive clauses. In the scheduled tribe areas of Andhra Pradesh, Bihar, Odisha, Madhya Pradesh and Maharashtra, transfer of land from tribals to non-tribals, even on a lease basis, can be permitted only by a competent authority (Mani 2016).

Unfortunately, bans and restrictions on agricultural land leasing have led to informal and concealed tenancy. According to the Expert Committee on Land Leasing (2016), "tenants in India are the most insecure and inefficient people, as they lack legal sanctity, access to institutional credit, insurance and other support services. In addition, the restrictions reduce the occupational mobility of many landowners. Hence, the institutional framework of land reforms undertaken post-independence had an adverse impact on agricultural growth, equity and investments" (NITI Aayog 2016).

Land ceiling legislation was introduced in the 1950s and early 1960s. It imposed limits on landholdings based on the size of farm that can be operated with personal resources, with certain exemptions[3] (Srivastava et al. 2007). The ceiling area varied from state to state (Venkatasubramanian 2008). For instance, Uttar Pradesh limited it to 40 acres, but West Bengal to 25. In Punjab, it varied from 27 to 100 acres, in Rajasthan from 22 to 336 acres and in Madhya Pradesh from 25 to 75 acres. The basis for determining the ceiling also varied. Andhra Pradesh, Assam, Bihar, Punjab,

[3]Exemptions from land ceiling laws include tea, coffee, rubber, cocoa and cardamom plantations, land used for palm, *kesra, bela*, jasmine or roses when the holders have no land for any other cultivation (U.P.); sugarcane growing; co-operative gardens, colonies, tank fisheries, orchards up to four hectares (Punjab and Haryana); land held by co-operative farming and other co-operative societies, including land mortgage banks; land awarded for gallantry; land held by religious, charitable and educational institutions, sugarcane factories, state or central government, a public sector or industrial or commercial undertaking, and land vested in *gram sabha, bhoodan* or *gramdan* committees; land situated in any area specified as reserved for non-agricultural or industrial development under the relevant tenancy law (Gujarat); specified farms engaged in cattle breeding, dairy production or wool-raising; several other categories of land including research farms and private forests.

Haryana, Uttar Pradesh, West Bengal, Madhya Pradesh and Maharashtra defined it as the area that could be farmed by a "land holder"; the other states based this on a "family" (Table 7.1).

The first phase of land ceiling introduction met with limited success. This was partly because of a lack of political will to enforce ceilings. Ambiguous definitions, retrospective transfers, numerous exemptions (see note 3) and states' different bases for fixing ceiling limits contributed to widespread manipulation and evasion. Mearns (1999) writes that "exemptions and loopholes left by individual states allowed landlords to retain control over land holdings, most infamously through *benami* (nameless entity) transactions, whereby village record keepers (*patwaris*) could be bribed to register holdings in the names of deceased or fictitious persons" (Mearns 1999).

Table 7.1 State ceilings on landholdings

States	Ceiling laws	Landholding ceiling (acres)
Andhra Pradesh	Andhra Pradesh Ceiling on Agricultural Holdings Act 1961	27–324
Assam	Assam Fixation of Ceiling on Land Holdings Act 1956	50
Bihar	Bihar Land Reforms (Fixation of Ceiling Area and Acquisition of Surplus Land) Act 1961	20–60
Gujarat	Gujarat Agricultural Lands Ceiling Act 1961	19–132
Kerala	Kerala Land Reforms Act 1963	15–36
Madhya Pradesh	Madhya Pradesh Ceiling on Agricultural Holdings Act 1960	25–75
Madras	Madras Land Reforms (Fixation of Ceiling on Land) Act 1961	24–120
Maharashtra	Maharashtra Agricultural Lands (Ceiling on Holdings) Act 1961	18–126
Mysore	Mysore Land Reform Act 1965	27[a]
Orissa	Orissa Land Reforms Act 1960	20[a]
Punjab	Punjab Security of Land Tenures Act 1953	30[b]
Rajasthan	Rajasthan Land Reforms Act 1960	22–336
Uttar Pradesh	Uttar Pradesh Zamindari Abolition and Land Reforms Act 1950 (U.P. Act 1 of 1951)	40
West Bengal	West Bengal Estates Acquisition Act 1953	25
Himachal Pradesh	Himachal Pradesh Abolition of Big Landed Estates and Land Reforms Act 1953	30

Source Authors' compilation from Planning Commission (1966), https://planningcommission.nic.in/reports/publications/pub1966land.pdf

[a]Standard Acres (one standard acre means 1–3 ordinary acres)

[b]Punjab Government has the power to utilise surplus lands held by a person under personal cultivation in excess of the permissible limit for resettlement of tenants, ejected or to be ejected in exercise of the land owners' right of resumption. The landowners will retain ownership of the surplus area and be entitled to receive rent from the tenants

To bring uniformity into the ceiling legislation, a new policy evolved in 1971–72 (Venkatasubramanian 2008). Its main features were the following:

1. Lower ceilings were recommended, 28 acres of wetland and 54 acres of un-irrigated land.
2. The unit for determining ceilings was fixed as a "family" instead of "individual landholder", with some provision for raising the ceiling in line with additions to the family.
3. All exemptions were removed, with some compensation.
4. The application of the law for declaring *benami* transactions null and void was enforced with retrospective effect.
5. There was no scope to move a court on grounds of infringement of fundamental rights.

The 1972 national guidelines specified the ceilings as 10 acres of best land, 18–27 of second-class land and 27–54 acres for the rest, with a slightly higher limit in hill and desert areas (Venkatasubramanian 2008). By March 2002, around 3 Mha (about 7.5 million acres)[4] were declared surplus, some two per cent of the cultivated land. Of these 3 Mha, about 2.63 Mha (i.e. 88.2%) were occupied by the government, of which some 2.18 Mha were distributed to the rural poor. The remaining 0.45 Mha were the subject of varied litigation (Srivastava et al. 2007).

The third set of reforms focused on consolidation of landholdings. They aimed at integrating small and fragmented parcels of agricultural land into contiguous holdings (Maitreesh and Roy 2007). The *Zamindari* Abolition and Land Reform Act passed in 1951 led to the implementation of the 1953 Consolidation of Holdings Act in various states.[5] These included Punjab, Uttar Pradesh, Bombay, Rajasthan, Madhya Pradesh, Haryana, Gujarat, West Bengal and Kerala. During the 1970s, similar laws were enacted in Bihar, Assam, Andhra Pradesh, Himachal Pradesh and other states (Anupama and Thomas 2009).

Government initiatives to consolidate landholdings included prohibition of transfer or partition of land in ways that created small fragments, as well as acquisition of fragmented land in exchange for compensation. A further measure was to rearrange plots into consolidated units and reallocate them to farmers whose land had been acquired. However, variation in land quality across plots made this difficult to implement (Anupama and Thomas 2009). Consolidation of land holdings made better progress in northern states than elsewhere.

At the time of the second Five-Year Plan (1956–61), about 23 million acres had been consolidated and work was in hand on another 13 million. By the beginning of the Seventh Five-Year Plan (1985), about 128 million acres (51.8 million hectares) had been consolidated, some 33% of the cultivatable land (Venkatasubramanian 2008). Consolidation stemming from land reforms represented the most far-reaching

[4]One hectare equals 2.47 acres.

[5]East Punjab Holdings (Consolidation and Holding) Act, 1948; the UP Consolidation of Holdings Act, 1953; Bombay Prevention of Fragmentation and Consolidation of Holdings Act, 1948; Rajasthan Holdings (Consolidation and Prevention of Fragmentation) Act, 1954; Madhya Pradesh Land Revenue Code, 1959, etc.

change in land systems at that time. By bringing together fragmented pieces of land, it reduced farming costs and made land use more efficient. The United Nations' Food and Agriculture Organisation (FAO), after studying the status of land consolidation in Punjab and Uttar Pradesh, remarked, "A significant reduction in the cost of cultivation, increased cropping intensity and a more remunerative cropping pattern were developed in these two states" (Venkatasubramanian 2008).

7.2.2 Land Institution: Assessing Impact

With nearly half its population dependent on agriculture for employment and income, good distribution of land among various classes of farmers is highly important for India. The landholding structure determines the way in which rural workers make their livelihoods and influences the organisation of production (Srivastava et al. 2007). Average landholding size influences the nature of technological change, input costs and final income (Srivastava et al. 2007; Government of India 2018a).

The average size of an Indian farm fell from 2.28 ha in 1970–71 to 1.55 ha in 1990–91. By 2015–2016, it was 1.08 ha (Fig. 7.1). The simultaneous decline in the number of medium and large farms has been a matter for concern (Government of India 2017a). Eighty-six per cent of holdings are small and marginal (less than two hectares), and together account for 47% of operated land. The question remains: How do owners of such small holdings eke out an existence and survive under global competition? (Gulati and Jain 2012). As highlighted in the Committee Report on Doubling Farmers' Income, "fragmented and scattered land holdings do not allow efficient utilisation of farm resources and technology adoption by the farmers, and thus reduce economic productivity" (Government of India 2017b).

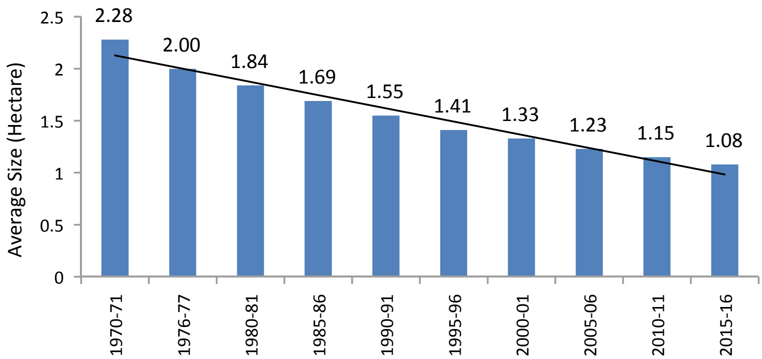

Fig. 7.1 Average size of operational holdings in each agriculture census. *Source* Agriculture Census, 2015–16

According to the report of the Expert Committee on Land Leasing, “most state governments have either legally banned or imposed restrictions on agricultural land leasing. Restrictive land leasing laws have forced tenancy to be informal, insecure and concealed” (NITI Aayog 2016). A Planning Commission discussion paper notes that at independence, “almost half of the arable land was cultivated by tenants” (Saxena 2013). Virtually, all states banned leasing in order to encourage owner-cultivation and give security of tenure to sharecroppers and tenants. The area under tenancy dropped as a result (Saxena 2013). In the 1953–54 National Sample Survey (NSS), leased-in land accounted for 20.6% of the total; by 2002–03, it was 6.6% (Table 7.2). The national average share of leased-in area then apparently suddenly increased; by 2012–13, it had reached ten per cent. However, several studies point out that NSS data underestimate the real figures due to considerable concealment of tenancy and the practice of oral leasing. The NSS does not fully reflect the extent of informal tenancies (Saxena 2013; Appu 1996).

It is very difficult to determine the exact level of tenancy in India. Comparisons over 60 years reflect not only the impact of legislation but also the dynamics of population pressure. However, it seems that three states bucked the general trend. On a national average, recorded tenancy roughly halved between 1953 and 2013. In Andhra Pradesh, however, the proportion increased from 21.2% to 33.7, in Bihar from 12.4% to just over 21 and in Odisha from 12.6 to 16.2%. Exploration of the possible reasons goes beyond the scope of this chapter. The important question here is what impact tenancy has on efficient, productive and sustainable use of the scarce and fundamental resource called land.

The report of the Expert Committee on Land Leasing declared that “informal tenants are insecure and inefficient”. Their situation is precarious. They neither have legal status nor are they recognised as farmers, which deprives them of access to government-sponsored programmes, relief support in case of calamities, and to institutional credit. This limits the productivity of the land they cultivate and negatively affects agricultural growth and farmers’ welfare (Government of India 2018b; NITI Aayog 2016).[6]

The insecure nature of tenure provides a disincentive to invest long term in improving the land or cultivating it effectively (Saxena 2013). This can result in low capital formation and thus low farm productivity, affecting the overall efficiency of the sector (Planning Commission 2007). Fear of eviction discourages tenants from adopting technological innovations, for example, in efficient use of inputs. Restrictions on leasing also reduce landowners’ occupational mobility. Many would be keen and able to work outside agriculture, but feel forced to stay put for fear of losing ownership rights. As a result, many landowners prefer to keep their lands fallow or underused. The fact that across the country about 16% of land remains fallow is a matter of concern (Government of India 2017c).

[6]Tenants either have short oral leases or they get rotated from plot to plot each year so that they cannot prove continuous possession of any particular piece of land for any specified period, which could give them occupancy rights (NITI Aayog 2016).

Table 7.2 State-wise proportion of leased area (%)

NSSO reports	Report 36 (8th round)	Report 215 (26th round)	Report 330 (37th round)	Report 388 (48th round)	Report 492 (59th round)	Report NSSO key indicators (70/18.1) (70th round)
States	1953–54	1972–73	1981–82	1992–93	2002–03	2012–13
Andhra Pradesh	21.2	9	6.2	9.6	9.97	33.7
Assam	43	16.7	6.4	8.9	5.06	4.21
Bihar	12.4	14.5	10.3	3.9	11.76	21.04
Gujarat	19.4	3.9	2	3.3	5.08	5.63
Haryana	39.8	23.3	18.2	33.7	14.38	14.90
Himachal Pradesh	n.a	15.9	3.2	4.8	2.87	5.20
Jammu & Kashmir	22.1	8.1	2.5	3.7	0.32	0.15
Karnataka	21.5	15.9	6	7.4	3.68	6.71
Kerala	20.2	8.6	2.1	2.9	4.18	8.55
Madhya Pradesh	19.8	7.5	6.6	6.3	2.83	5.05
Maharashtra	19.7	6.2	5.2	5.5	4.59	3.40
Odisha	12.6	13.5	9.9	9.5	13.15	16.16
Punjab	39.8	28	16.1	18.8	17.84	24.62
Rajasthan	21	5.3	4.3	5.2	2.81	7.76
Tamil Nadu	27	13.1	10.9	10.9	6.1	13.87
Uttar Pradesh	11.4	13	10.2	10.5	3.49	7.56
West Bengal	25.4	18.8	13.4	10.4	9.42	14.25
All India	20.6	10.6	7.2	8.3	6.6	10.10

Source (i) For data from 1953–54 to 1992–93 (Mani 2016) (ii) 2002–03 NSSO Report 492 (59th round) (iii) 2012–13 (NITI Aayog 2016). National Commission for Enterprises in the Unorganised Sector (2008), "A Special Programme for Marginal Farmers" based on NSSO. https://mospi.nic.in/sites/default/files/publication_reports/492_final.pdfhttps://mospi.nic.in/sites/default/files/publication_reports/492_final.pdf. Based on NSS Key Indicators of Land and Livestock Holdings in India (70/18.1) (70th round).

Bans and restrictions not only reduce the land available on the leasing market. They also disadvantage poor tenants by forcing them into informal arrangements, in contravention of the rules, and by restricting their access to land (Haque 2001; Deininger et al. 2008). Overall, restrictive tenancy laws have proved bad for growth and bad for the poor (NITI Aayog 2016).

7.2.3 Innovations in Land Institutions

7.2.3.1 Opening up of the Land Lease Market

In 2015, NITI Aayog set up an Expert Committee to review states' agricultural tenancy laws and suggest appropriate improvements. Chaired by T. Haque, the committee concluded that legalisation of leasing would be highly egalitarian, making more land available for the rural poor. Such a step would benefit landless and marginal farmers in several ways. Poor families could increase their income by farming more land, as well as using other farm, off-farm and non-farm employment opportunities. Official recognition of tenants' or sharecroppers' land leases would additionally enable them to access institutional credit, insurance, disaster relief and other government support, while still fully protecting the owners' land rights. The overall results would be less poverty and better social status (NITI Aayog 2016).

In consultation with states and other stakeholders, including farmers' organisations and civil society groups, the Expert Committee also proposed a "Model Agricultural Land-Lease Act, 2016" (NITI Aayog 2016). According to the Committee Report on Doubling Farmers' Income (2018), "the Model Act offers an appropriate template for states and union territories to draft their own legislation in line with local requirements, and to adopt an enabling Act" (Government of India 2018c). More leasing will improve the use of land and labour and increase tenants' and landowners' income.

7.2.3.2 Digitisation of Land Records

The importance of land makes it essential that land records be authentic, tamper-proof and easily accessible (Government of India 2015). To improve transparency, the government in the mid-1980s initiated the creation and maintenance of land records under two national schemes: computerisation of land records and strengthening of revenue administration and upgradation of land records. Both ran for some 20 years (Government of India 2015). In 2008–09, they were rationalised and merged into the National Land Records Modernisation Programme (NLRMP). The Department of Land Resource maintains an online dashboard for continuous monitoring of this programme's progress across different states.[7]

The NLRMP's main objective is to modernise India's land records system with integrated, up-to-date, real-time documentation. Since April 2016, the Digital India Land Records Modernisation Programme has been part of the Digital India Initiative. Considerable efforts have gone into computerising land records, but progress varies widely between states. By December 2018, Tripura, Odisha, Sikkim, Himachal Pradesh, Karnataka, Madhya Pradesh, Jharkhand, Telangana and Tamil Nadu had computerised 99–100% of land records. Nagaland, Mizoram, Arunachal Pradesh and Meghalaya were yet to start the process (Government of India 2018a).

[7] https://dilrmp.gov.in/faces/common/dashboard.xhtml.

Overall, 22 states and union territories have begun issuing digitally signed records of rights (RoRs), in a total of 36% of villages. RoRs show how owners' land rights are derived and record property transactions. Twenty states have started linking RoRs to cadastral maps showing the area, ownership and value of land in over 34% of villages. Goa, Odisha, Tripura and West Bengal have completed more than 90% of the process. Progress on some other components of the scheme has been slow. As of December 2018, computerisation of land records had been completed in 89% of villages. However, "mutation" (transfer of ownership) records had been computerised for only 58%.[8]

Maps form an important component of land records, as they show property boundaries and thus the exact limits of ownership. Only about 52% of cadastral maps have been digitised so far.[9] Spatial data have been verified in just 45% of the villages; survey and re-survey work, which helps update spatial records, has been carried out in just 12%.[10] Only about 22% of villages have started real-time updating of RoRs and maps. This suggests that although records have been digitised, they may not be up to date. Only 11 states have integrated land records with the banking systems and only four with the courts. Eighteen states have started linking RoRs with *Aadhaar* (national identity) cards, but the process has been completed in only 5% of villages.[5] Government needs to accord high priority to accelerate land record improvement.

7.2.3.3 Geo-Tagging of Agricultural Land

"Geo-tagging" is the process of adding geographical identification features such as latitude and longitude to land records. It provides information about the location, size and other characteristics of each holding (Ministry of Agriculture and Farmers' Welfare 2017). Linking land records with geo-tags and *Aadhaar* will provide comprehensive information to insurance companies, potential lenders and the government. This would facilitate a number of financial processes in rural areas. For instance, farmers with damaged crops can send their insurers geo-tagged pictures. Suitable software can estimate the damage, and where appropriate, sanction compensation payment straight into farmers' bank accounts, keeping overheads to a minimum (Zainulbhai and Roy 2018). Digitised land records, combined with geo-tags and weather data, can help provide rapid relief where it is needed.

[8] https://dilrmp.gov.in/faces/rptstatewisephysical/rptComputerizationOfLandRecord.xhtml.

[9] https://dilrmp.gov.in/faces/rptstatewisephysical/rptMapDigitization.xhtml.

[10] https://dilrmp.gov.in/faces/rptPhysicalHome/rptStateGenericDetail.xhtml?id=./../master/physical.xhtml.

7.2.3.4 Innovations in Land Institutions—Examples of Andhra Pradesh and Kerala

Some states in India have taken innovative approaches to improving land institutions and the use of scarce agricultural land. Andhra Pradesh and Kerala provide helpful examples.

The Licensed Cultivators Act, 2011: Government of Andhra Pradesh. Many tenant farmers in Andhra Pradesh (AP) cultivate lands on an "oral lease" basis. There are no written agreements for tenancy and no noting of tenancy particulars in government records.[11] To protect the interests of informal tenants, AP in 2011 passed the Land Licensed Cultivators Act. This provides for annual loan eligibility cards (LEC) for farmers using land with the explicit or implied permission of the owners. AP is the first state to take this step. With the LEC, farmers can access cheap or even interest-free credit, input subsidies, crop insurance and compensation for crop damage. During 2018–19, more than 613,000 LEC recipients stood to benefit from easier access to institutional credit. However, the future now looks less certain. The 2019 Andhra Pradesh Crop Cultivators Rights Act has now replaced the 2011 legislation (Mohan 2019). The new AP government has not yet made it clear how tenant farmers will be accommodated under the new law.

Women's Group Leasing and Joint Liability Groups: Kudumbashree, Kerala. In 1998, the Government of Kerala initiated a community-based poverty eradication and women's empowerment programme. This *Kudumbashree* Mission[12] focuses on women as participants of change. Over the last two decades, the programme has played a critical role in women's collectivisation and empowerment, using collateral-free credit to encourage sustainable livelihood practices. It is regarded as one of the world's largest women's networks.[13] One of its initiatives is revitalising Kerala's farming culture by mobilising women to take up agriculture through a collective approach. Since 2006, this initiative has included "lease land farming". The majority of group members are landless, but this approach motivates them to take up land on lease. The programme has gained momentum over the years; women in Kerala are now seen as farmers and not just as labourers. Today called "collective farming", the programme focuses on raising production by bringing fallow and cultivable wastelands into agricultural use.[14]

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[11] https://www.apagrisnet.gov.in/2018/Agri%20Action%20Plan%202018-19%20(English)/Action-Plan-2018-19-English-Final-149-156.pdf.

[12] In the Malayalam language, *kudumbashree* means "prosperity of the family". The *Kudumbashree* Mission uses a three-tier structure for its women community network. The neighbourhood groups (NHGs) operate at the primary level, followed by area development societies (ADS) at the ward level, and community development societies (CDS) at the local government level (https://www.kudumbashree.org/pages/171).

[13] At present, there are more than four million women members associated with the programme. More than USD50 million have been pooled among the women, who have accessed USD150 million in bank credit, without any collateral (MANAGE Report 2018).

[14] https://kudumbashree.org/storage//files/qzp9h_rakhi%201.pdf.

Kudumbashree has enabled the conversion of women's collective farming groups into joint liability groups, ensuring access to agricultural credit from NABARD and other banking institutions. Direct control over the means of production and access to formal credit help women increase their returns from farming. The groups have 4–10 members and farms between half an acre and 12.35 acres (NITI Aayog 2016). In 2018, there were 63,101 joint liability groups involving 285,871 women farming 52,490 ha. The *Kudumbashree* experience points to the significant benefits of liberalising land leasing.

7.2.4 Concluding Remarks

As the average size of landholding declines, an overwhelming majority has become so small as to seriously limit farmers' ability to run them as a profitable business. Restrictive land policies aimed for equity by banning tenancy, imposing a landholding ceiling and redistributing land. However, they actually worked against the interests of landless and marginal farmers by restricting their access to land as well as reducing agricultural efficiency. Tenants felt perpetually insecure and vulnerable. Such restrictions discourage them from making long-term investments in land, while the habit of oral agreements deprives tenants of access to institutional credit, insurance and other benefits. Landowners also feel a sense of insecurity while leasing land, with many consequently choosing to leave it fallow or underused. There is an urgent need for reform of land laws, freeing up the lease market and revoking restrictions such as the area ceiling. The aim must be to encourage a viable size of holdings and allow farmers to choose how to make the best possible use of their land. Liberalisation of this type will encourage investments in land and raise farmers' productivity and incomes. The experience of Andhra Pradesh with its Licensed Cultivators Act, loan eligibility cards and protection of land ownership rights seems a good basis on which to build. Digitising and geo-tagging land records together with group leasing akin to Kerala's *Kudumbashree* can all contribute to improving farmer livelihoods. Rapid implementation of the recommendations of the T. Haque Expert Committee seems advisable but will require political will and a suitably composed agricultural reforms council.

7.3 Water Institution in Indian Agriculture

In India, about 78% of available fresh water goes into agriculture (2010 figure). Paradoxically, about half the gross cropped area nonetheless depends on erratic rainfall (Gulati and Mohan 2018). The amount of water available per person and year decreased from about 5200 m^3 in 1951 to 1544 m^3 in 2011 (CWC 2014). That is markedly below the "Falkenmark Water Stress Indicator" volume of 1700 m^3

(MOSPI 2018). India is already designated a "water-stressed region". With a 2019 population of 1.37 billion, likely to surpass China by 2027[15] and estimated to grow to 1.6 billion by 2051, it is predicted that per capita water availability will fall to 1140 m^3 by 2050. Thereafter, India will soon become a "water-scarce region", as annual freshwater volumes fall below 1000 m^3 per capita. Water shortages will become more acute and widespread unless corrective mechanisms are put in place well in time.

India's irrigation has undergone a dramatic transition. Instead of state-owned canal systems using surface water, irrigation now depends heavily on drawing groundwater via boreholes, tube wells and pumps owned and operated by individual farmers (Shah 2010). In 2014–15, the 68.38 million irrigated hectares represented almost half the net sown area. Some 63% (43 Mha) was irrigated using groundwater sources, primarily from tube wells. Of the remainder, 26% (18 Mha) came from surface water sources such as canals and tanks, and 11% (7.5 Mha) from other sources (DES 2018).

Our three main questions in this chapter are: (a) why does Indian agriculture still depend heavily on rainfall, (b) what institutions led to the shift from surface water to groundwater exploitation and (c) is the current irrigation system efficient, inclusive and sustainable? We also look at innovations in irrigation that can improve water use efficiency, sustainability and equity.

7.3.1 Irrigation Water Institution in India

Since independence, India has considered irrigation an integral element of the basic infrastructure for agriculture and rural development. The earlier commercial drive for full cost recovery has given way to an emphasis on irrigation's social role in protecting farmers from recurring droughts and enabling resilient agricultural growth. However, limited public resources created only limited public irrigation via reservoirs and canals, leaving large parts of agriculture dependent on rainfall.

For a couple of decades, irrigation development was extensively supported by borrowing, primarily from the World Bank but also from the USA, the European Community and Japan. However, relaxation of repayment obligations from the states to the central government resulted in a sharp downturn in cost recovery (Svendsen et al. 2006). In addition, NGO agitations against large dams increased, mainly because of inadequate compensation and resettlement of people ousted from submerged areas. The World Bank reacted with a dramatic reduction in loans for major and medium irrigation schemes, which correspondingly shrank sharply.

Despite many inefficiencies in old style surface irrigation, it still helped conventional Indian farming, especially during the dry winter. However, the onset of the Green Revolution in the late 1960s with high-yielding rice and wheat varieties put much greater pressure on water resources. By law, landowners had the right to access the groundwater under their land. There was, therefore, a massive increase in tube well irrigation, not only in the well-watered Ganga–Brahmaputra Basin, but also in

[15] UN's 2019 World Population Prospects report.

hard-rock peninsular India (Shah 2010). Millions of farmers became owners of tube wells and small pumps. They took irrigation into every corner of the country. Tube well use shot up in certain regions, notably in the Punjab–Haryana belt of north-western India. Shah (2010) likens this process to the international democratisation of personal computers. He notes that "until 1960, Indian farmers owned just a few tens of thousands of mechanical pumps using diesel or electricity to pump water and today India has over 20 million modern water extraction structures. Every fourth cultivator household has a tube well; and two of the remaining three use purchased irrigation services supplied by tube well owners" (Shah 2010). The 5th Minor Irrigation Census (2013–14) found 18.85 million groundwater extraction units. About 73% (13.7 million) are electric pumps and 25% (4.7 million) run on diesel (Government of India 2017a).[16] The remainder are solar, wind and manual/animal pumps. According to more recent figures from the Council on Energy, Environment and Water, "there are nearly 30 million irrigation pumps in use throughout the country where about 70% run on grid electricity and 30% are powered by diesel" (Raymond and Jain 2018). As Fig. 7.2 shows, there is a heavy concentration of diesel pumps in Uttar Pradesh, Bihar and Assam.

The model groundwater regulation bill (1970s) added some state control over groundwater but failed to address the key issue of landowners' unbridled access (Cullet 2017).[17] To make matters worse, the rising political influence of large farmers led to flat rates for electricity supplied to agriculture. In the 1970s, Karnataka, Andhra Pradesh and then numerous other state electricity boards dismantled the metered tariff regime. With cheaper power rates, exploitation of groundwater for irrigation surged (Dabadge et al. 2018). The share of irrigation using public surface water systems continued to fall.

It nonetheless took some considerable time before state agriculture departments introduced co-ordinated implementation of irrigation and command area development projects.[18] The National Water Policy[19] was first drafted in 1987. It stipulated that farmers should take over operation and maintenance of irrigation systems, and that, the state should focus on improving water systems management. This led to the emergence of participatory irrigation management, in which farmers' water users associations managed part or all of their surface irrigation systems (Gandhi and Namboodiri 2011).

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[16]Operated with one source of energy.

[17]https://www.thehindu.com/opinion/op-ed/a-gathering-crisis-the-need-for-groundwater-regulation/article19446507.ece.

[18]The Command Area Development (CAD) programme included construction of field channels and drains, enforcement of *warabandi* water allocation, land levelling and shaping, realignment of field boundaries/consolidation of holdings, introduction of suitable cropping patterns, strengthening of extension services, etc. From 2015–16 onward, the CAD and water management programme have been implemented as part of *Pradhan Mantri Krishi Sinchai Yojna* (PMKSY)—*Har Khet Ko Pani*, implementing 99 prioritised accelerated irrigation benefits programme (AIBP) projects.

[19]Later revised in 2002 and again in 2013 by the National Water Board.

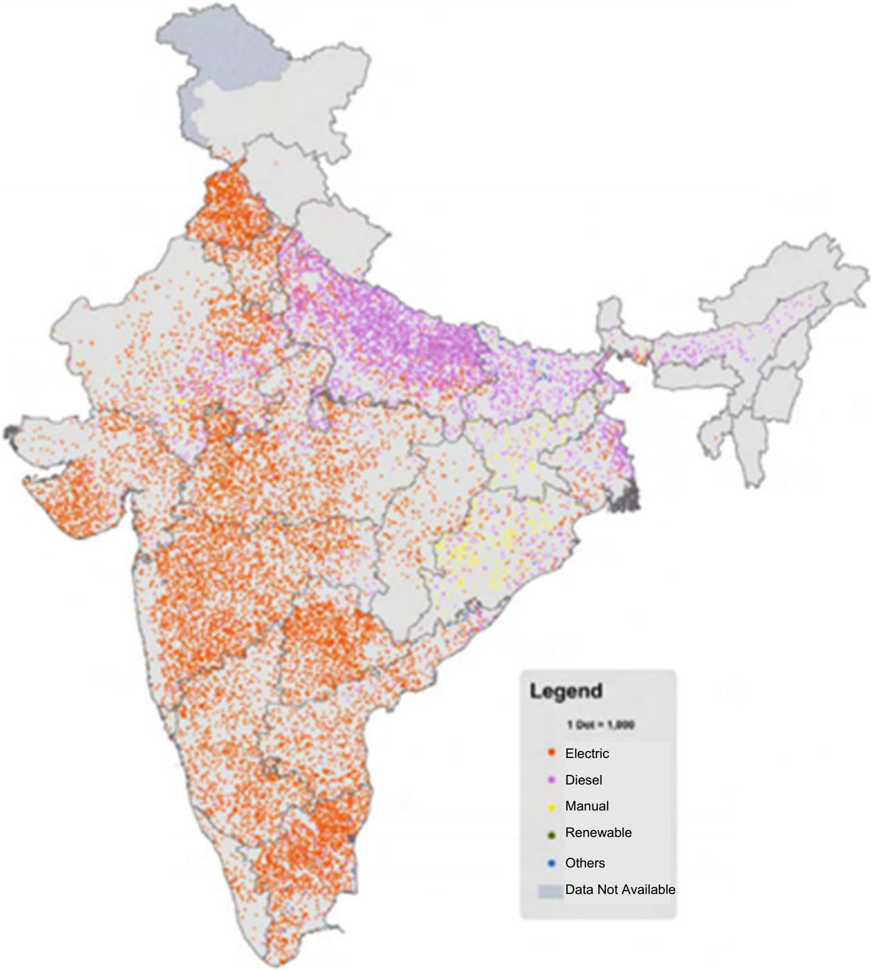

Fig. 7.2 Energy sources in Minor Irrigation Schemes (5th MI Census). *Source* Government of India (2017a, b, c)

Over the years, reforms have created new departments, structures, responsibilities and institutions for water management (Fig. 7.3). However, these changes have had only a marginal impact on cropping systems and water management (Svendsen et al. 2006). There remains a strong need for more fundamental reforms that sustainably improve irrigation efficiency.

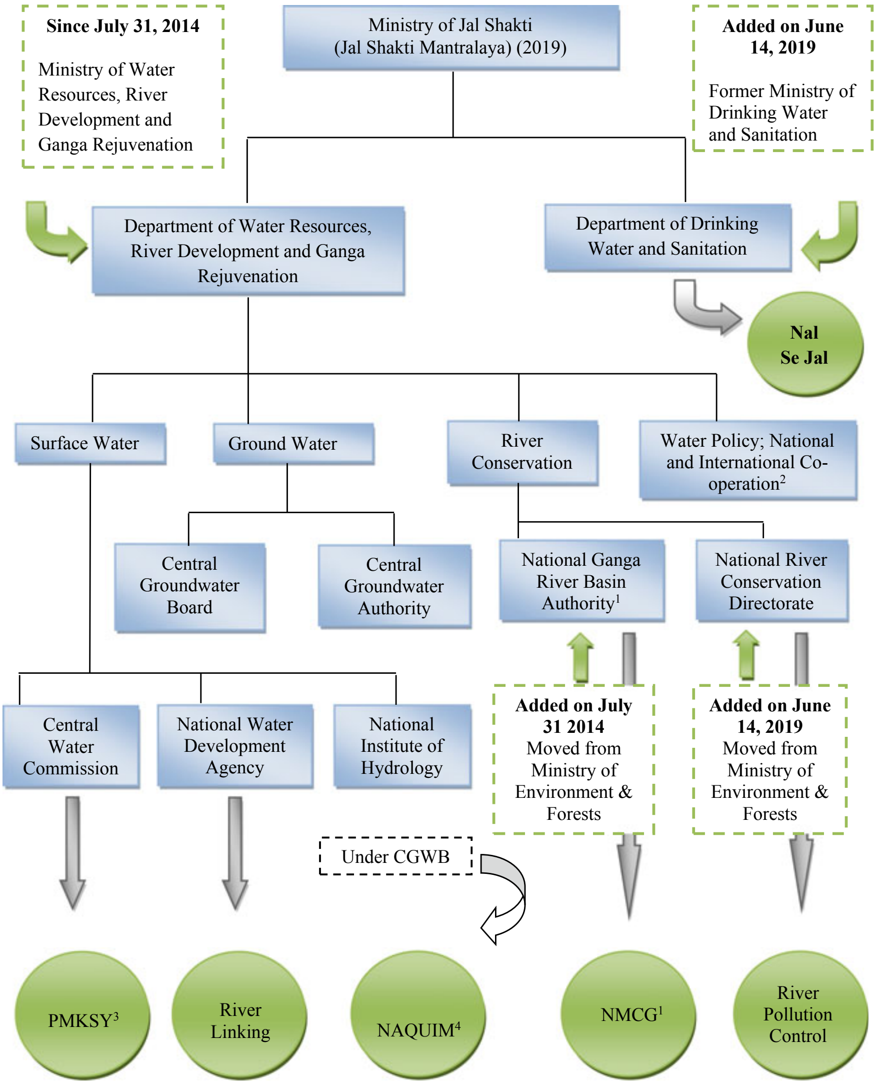

Fig. 7.3 Organisation of Irrigation Systems (2019). *Source* Second Schedule, Allocation of Business Rules 2019, Cabinet Secretariat. *Notes* (1) Includes the Mission Directorate, National Mission for Clean Ganga (NMCG) and related aspects of Ganga Rejuvenation. (2) Organisations under this theme are: (a) Farakka Barrage Project and Control Board; (b) Ganga Flood Control Commission; (c) Sardar Sarovar Construction Advisory Committee; (d) Brahmaputra Board; (e) Narmada Control Authority; (f) Betwa River Board; (g) Bansagar Control Board; (h) Tungabhadra Board; (i) Upper Yamuna River Board; (j) Central Soil and Material Research Station; (k) Central Water and Power Research Station. 3. PMKSY: *Pradhan Mantri Krishi Sinchayee Yojana* (implemented jointly by MoWR, RD&GR; MoA&FW and DoLR). 4. NAQIM: National Project on Aquifer Management.

7.3.2 Irrigation Policies and Institutions: Assessing Impact

This section assesses irrigation policies and institutions with respect to water use efficiency, user coverage and sustainability.

7.3.2.1 Efficiency

With shared resources such as water, a major issue is open access versus selfishness, often referred to as the "tragedy of the commons". Commercialisation of commons results in conflicts and inefficient use. These negative aspects are typically compounded by increasing scarcity, distorted policies and inadequate institutions. In India, for instance, lack of property rights and free or highly subsidised electricity encouraged runaway extraction of groundwater (Pal et al. 2003).

Unless bold policy decisions are taken to augment water supplies for agriculture and use them more efficiently, there will not be enough water to meet water future demand from all sectors. According to the National Commission for Integrated Water Resources Development, total water withdrawal for all uses in 2010 was 710 billion cubic metres. Irrigation accounted for 78%, followed by domestic use (6%), industry (5%) and power (3%). The remaining 8% represented evaporation losses, environmental and navigational requirements (CWC 2014).

The current operating efficiency of surface water irrigation is as low as 30%. Groundwater scores better at 55%,[20] but still compares poorly with Israel's 77% water use efficiency (Ahluwalia 2019). The main reasons for India's low performance are inefficient operations, poor maintenance, use of the flood irrigation method and water

Table 7.3 Efficiency of different irrigation systems

Irrigation method	%
Conveyance	
Through unlined canal, surface water	55–60
Through lined canal, surface water	70–75
Application for both surface and groundwater	
−Flood irrigation	65
−Furrow irrigation	80
−Sprinkler	85
−Drip	90
Overall efficiency for surface water system	30–65
Overall efficiency for groundwater system	65–75

Source CWC (2014)

[20] Note: The present efficiency of various systems is based on a range of studies and reports. CWC has assessed surface water use efficiency for 30 major and medium-sized irrigation projects. Efficiency of groundwater irrigation systems is derived from CGWB reports (CWC 2014).

charges based on irrigated area instead of quantity supplied. There is scope to improve the efficiency of surface irrigation systems by 30% and, in the case of groundwater, by about 20% (CWC 2014). To increase efficiency, it is important that the price of water reflects associated economic cost and different innovative water-saving technologies are promoted through the right institutions (see Table 7.3).

7.3.2.2 Inclusiveness

India suffers from significant inequities in crop water use. Almost half of its agriculture still depends on the erratic monsoons, resulting in poor productivity and profitability (Gulati and Mohan 2018). In surface canal irrigation, upstream users often grow water-intensive crops, leaving tail-end users much less water than would be equitable. This is one reason for the wide gap between "irrigation potential created" (IPC) and "irrigation potential utilised" (IPU). The gap has been widening over time (Fig. 7.4) and reached 29% in the Eleventh Plan, 2007–12. The figure is even higher for major and medium-sized projects. Inefficient flood irrigation leads to 60–65% water loss—in other words, only one-third of the water released from the dam actually reaches farmers' fields (CWC 2014).

If used rationally, groundwater irrigation can help overcome these problems, as it supplies the right quantity to the right users at the right time (Gulati and Banerjee 2018; Pal et al. 2003).

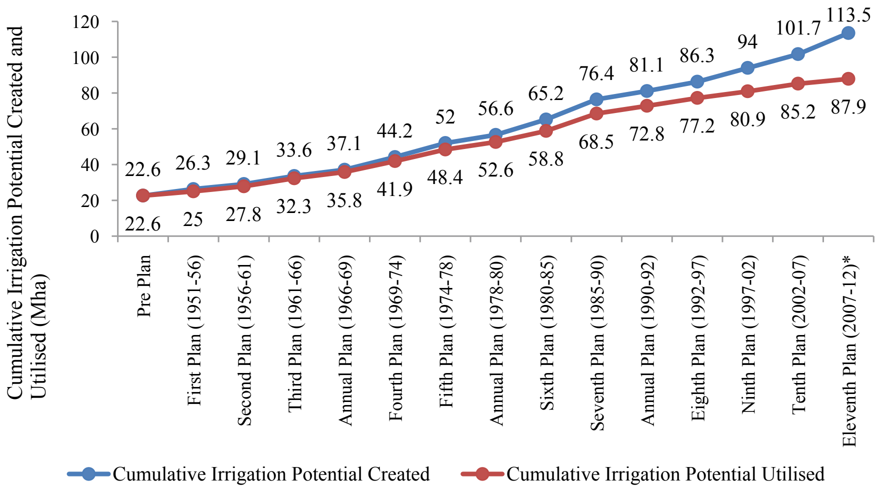

Fig. 7.4 Gap between irrigation potential created and utilised. *Source* Gulati and Banerjee (2018)

7.3.2.3 Sustainability

In a market economy, rational pricing of a resource signals its efficient allocation across and within sectors. However, heavy subsidies for water and power, as well as assured sales of water-intensive crops in dry regions, make farmers wasteful and discourage them from moving to higher value uses of water.[21]

In March 2013, the Central Ground Water Board (CGWB) reported that in about 39% of analysed wells across the country, the groundwater table was falling. Figure 7.5 shows a more recent assessment of water status in 6584 units (blocks, *mandals, talukas* or *firkas*). This categorised 1034 as "over-exploited",[22] 253 as "critical"[23] and 681 as "semi-critical"[24] (CGWB 2017). The over-exploited areas are mostly in three regions. North-western India, including parts of Punjab, Haryana, Delhi and western Uttar Pradesh, has abundant replenishable sources, but indiscriminate withdrawals of groundwater continue. On the western side of the country, particularly in parts of Rajasthan and Gujarat, the arid climate limits groundwater replenishment. In southern peninsular India, including parts of Karnataka, Andhra Pradesh, Telangana and Tamil Nadu, water replenishment is restricted by poor aquifer properties (CGWB 2017).

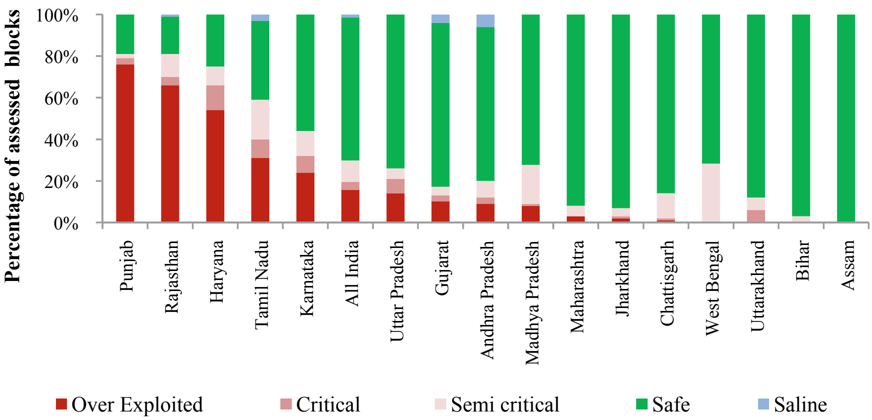

Fig. 7.5 Groundwater status across India. *Source* CWGB (2017)

[21]Gulati & Mohan (2018) estimated that paddy, wheat and sugarcane (the three "guzzler" crops) consume about 80% of available irrigation water. These crops are often cultivated in unsuitable regions, e.g. sugarcane in water-stressed parts of Maharashtra, or rice and wheat in Punjab, leaving most other crops there water-deprived.

[22]Annual groundwater extraction exceeds net availability, and there is a significant long-term decline in groundwater levels either before or after the monsoon, or both.

[23]Extraction is above 90% of net annual availability, and there is a significant long-term decline in groundwater levels both before and after the monsoon.

[24]Extraction is above 70% and there is a significant long-term decline in groundwater levels either before or after the monsoon.

7.3.3 Innovations in Irrigation Institutions

In June 2019, India created the Ministry of *Jal Shakti*. The new body unites the former Departments of Drinking Water and Sanitation and of Water Resources, River Development and Ganga Rejuvenation. Its goal is to integrate water resources management under one roof. Among the objectives are renovation of water bodies and bore well recharge structures, watershed development and better rainwater harvesting.

It remains to be seen, however, what impact this amalgamated ministry will have. Institutional innovation is no guarantee of social change. The CGWB's 2016 Model Bill to regulate and control the development and management of groundwater is an example. It prohibits, or allows only with a permit, the construction of new groundwater structures in 162 "critical" and "over-exploited" areas. These are spread across Haryana, Punjab, Andhra Pradesh, Rajasthan, Madhya Pradesh, Gujarat, West Bengal, Uttar Pradesh, Karnataka, Tamil Nadu, the National Capital Territory of Delhi and the union territories of Puducherry and Diu. So far, however, the Bill has not been widely adopted. Even where it has, lack of effective implementation has allowed continued unsustainable extraction of groundwater and lowering of the water table.[25]

The drive for innovative improvements continues nonetheless, in response to sheer necessity. In Punjab, for example, some 76% of blocks assessed by the CGWB are in areas of over-exploitation (Gulati et al. 2019). Groundwater is receding by 70–110 cm per annum. Some 1.4 million tube wells run for eight hours a day, pumping out approximately 480 million litres of water (Sirhindi 2018).[26] In response, the Punjab government in 2018 used its powers under the state's 2009 Preservation of Sub-Soil Water Act and delayed the annual sowing of paddy by five days. Instead of June 15, transplantation is now only allowed from the June 20 onwards. The intention is to align sowing with the onset of the monsoon and to reduce the time between paddy harvest and wheat sowing.

In the same year, the Punjab government launched *Paani Bachao, Paise Kamao*, meaning "save water, earn money". This scheme incentivises farmers to use less power and water and encourages large-scale adoption of corresponding technologies and practices. Pilot projects began around six electricity feeders in selected districts of Jalandhar, Hoshiarpur and Fatehgarh Sahib. The scheme is now being upscaled and expanded to other states such as Rajasthan.[27] The government has also decided to set up 1000 demonstration farms of up to one acre to display efficient water and electricity use, allocating a budget of about Rs. 600 million (approximately eight million dollars at March 2020 rates). Dissemination and extension will use a "field school" approach, linking farmers with researchers. If successful, these institutional innovations could have important consequences for many other states.

[25] https://mowr.gov.in/sites/default/files/Model_Bill_Groundwater_May_2016_0.pdf.

[26] https://timesofindia.indiatimes.com/city/chandigarh/punjab-issues-notification-to-delay-paddy-sowing-by-five-days/articleshow/63898321.cms.

[27] The scheme is being piloted jointly by the World Bank and the Government of Punjab.

In July 2015, the National Democratic Alliance government launched the *Pradhan Mantri Krishi Sinchayee Yojana* (PMKSY) to expand irrigation coverage in line with the slogan "*Har khet ko paani"* and improve water use efficiency to get "more crop per drop". The scheme targeted rapid completion of 99 irrigation projects that had remained unfinished for almost two decades. Since 2006, central government subsidies have been available for farmers adopting drip and sprinkler technology. Since July 2015, PMKSY has mandated that micro-irrigation be used on at least ten% of its command area (Gulati and Mohan 2019).

The past three decades have also produced some success stories from irrigators' co-operative societies and water user associations (WUAs) in the command area of river basins (Pal et al. 2003). Successful management of canal irrigation systems requires good design and enforcement of societies' internal arrangements for equitable and efficient water distribution. Recovery of irrigation fees, proper maintenance and reliable repairs are also crucial (Mahapatra and Rajput 2002; Marothia 2002).

Co-operative management of the commons/WUAs has shown mixed results. Co-operatives are often dominated by government nominees and lack both resources and popular participation (Singh and Ballabh 1996). Andhra Pradesh provides a positive example to the contrary. The state's 1997 Farmers' Management of Irrigation Act created a WUA system with three tiers: hydraulic, distributary and project. More than 10,000 WUAs were formed with clearly defined roles, responsibilities and powers as well as financial assistance supplementing water fees for major and medium-sized irrigation systems (Reddy and Reddy 2006). This institutional innovation helped to shift the responsibility for water delivery and maintenance services from the state to farmers' WUAs. However, it lacked financial transparency and accountability (Svendsen et al. 2006).

Another institutional innovation for governance of the commons is participatory irrigation management (PIM) with clear rights and responsibilities for stakeholders (Chopra et al. 1990). In April 1987, the Ministry of Water Resources issued guidelines for farmers' participation in water management, primarily for areas under the centrally sponsored Command Area Development Programme (MOWR 2018). Legislation to involve farmers in irrigation management followed in 16 states.

Successful operation of co-operatives/WUAs and participatory irrigation management (PIM) requires strong links between government, user organisations, voluntary groups and individuals. There must also be adequate incentives for people to participate in the management of the commons. Transparent rules, credible enforcement and mechanisms for conflict resolution can further contribute to success.

7.3.4 Concluding Remarks

Numerous innovations could help Indian agriculture use its scarce water resources more efficiently, equitably and sustainably. They can be grouped under four main tasks.

Set values correctly. For judicious and sustainable use of water and power, prices need to reflect their scarcity and economic value. Consumption must be metered and charged. Market forces will determine the value of groundwater and ensure greater efficiency and sustainability (Gulati and Mohan 2018). To compensate farmers for losing access to almost free power, government needs to move towards direct income support per hectare.

Regulate unsustainable extraction. Government can create the institution that regulates spacing of tube wells, identification of aquifers, size of pumps and the overall rate of exploitation. This should be accompanied by institutional arrangements governing rights over water, land tenure, users' relationships, financial incentives, etc. Today, unfortunately, ownership of groundwater and land is tied together and landowners have the right to extract unlimited groundwater. This traditional dominance of private property demands serious rethinking. Water use limits should be based on field area, and farmers should be financially incentivised to consume less. China, for example, began strictly regulating water use per unit of irrigated area in the 1990s (Chaudhuri 2018).

Improve efficiency and investments. Government should promote practices that save energy and water. These include prohibition of flood irrigation for paddy cultivation[28] and adoption of micro-irrigation for water-intensive crops like paddy and sugarcane. Ensuring underground piped water and canal-based micro-irrigation systems could significantly improve conveyance efficiency and "last mile" delivery. With canal irrigation, the gap is widening between created and utilised potential, and even more so with regard to social and economic benefits. Government should explore opportunities such as public–private partnerships for management of water distribution and bulk-vending to farmer-managed irrigation co-operatives (Gulati and Banerjee 2016). Morocco, for example, ran an innovative irrigation PPP in 2008 in the Souss Massa Draa region, particularly around the city of El Guerdane. The project included water mobilisation, supply and management. At present, the system provides water to 10,000 ha of highly lucrative citrus fruit plantations (Houdret and Bonnet 2013).

Shift cropping patterns: The present irrigation and marketing environment encourages farmers to cultivate water-intensive crops in unsuitable places. This leads to over-exploitation of groundwater. New policies are needed that favour sugarcane and rice production in the water-richer eastern states (Gulati et al. 2019) and encourage farming of less thirsty crops in dryer states. Farmers can also be incentivised to adopt more climate-resilient and water-saving varieties.

[28]One can irrigate paddy every three or four days and fully use the standing water before the next round. This can save almost a quarter of irrigation water and reduce power use.

7.4 Farm Mechanisation

Indian agriculture faces many challenges. Some could be well tackled by greater mechanisation. Examples include farmers' low production efficiency and profitability, as well as rising labour costs and a declining agricultural workforce. The Committee Report on Doubling of Farmers' Income notes that "agricultural mechanisation can contribute a cut in cultivation cost by 25% and can raise productivity by 20%, thereby increasing farm income by 25–30%" (Government of India 2018a, b, c). Farm mechanisation also aids diversification and sustainable intensification via multiple-cropping, making agricultural land more commercially viable (Government of India 2018a, b, c). However, the market for farm machinery and related services remains underdeveloped.

7.4.1 Evolution of Farm Mechanisation

The progress of agricultural mechanisation has been closely linked with overall development in production techniques. The amount of available agricultural power from all sources is measured in kilowatt (kW) or horsepower (hp) per hectare (Government of India 2018a). In India, this figure increased from about 0.25 kW/ha in 1951 to about 1.35 kW/ha in 2001; by 2017, it had reached 2.02 kW/ha (Fig. 7.6). Major sources of farm power are agricultural workers, draught animals, tractors, power tillers, diesel engines and electric motors. The combined share of agricultural workers and draught animals has fallen over the years and that of tractors and electric motors has increased. In 2012–13, over 90% of farm power came from mechanical sources, with tractors and power tillers together providing 47% (Fig. 7.7).

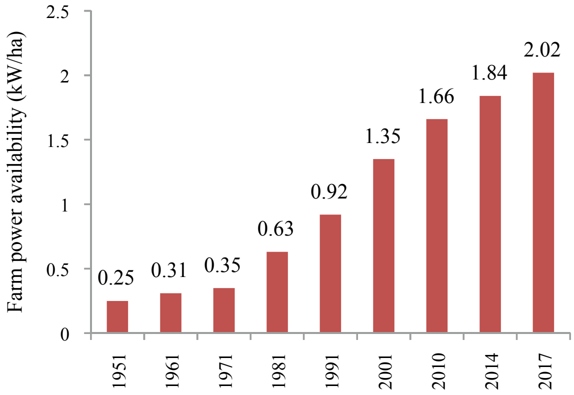

Fig. 7.6 Farm power availability (kW/ha), 1951–2017. *Source* Government of India (2018a) and Directorate of Economics & Statistics (2017)

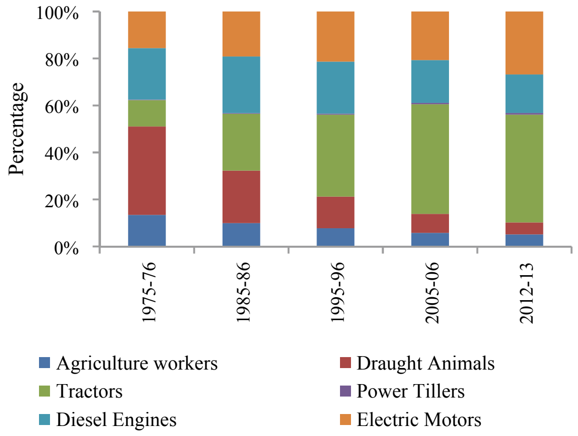

Fig. 7.7 Percentage of farm power from various sources, 1975–76 to 2012–13. *Source* Government of India (2018) and Directorate of Economics & Statistics (2017)

Another measure of the progress of farm mechanisation is the sales of tractors and power tillers. As Fig. 7.8 shows, these increased strongly for about 10 years after 2004–05, but have since flattened.

The size of the machinery market and the density of mechanisation both vary markedly between states. Figure 7.9 gives a snapshot of the tractor market in 2015–16. Uttar Pradesh accounted for 15.5% of all tractor sales. The next three largest markets were Madhya Pradesh (11.9%), Rajasthan (11.4%) and Andhra Pradesh (8.5%). Unsurprisingly, farms in hillier and/or smaller states had fewer tractors. A better indication of mechanisation levels is tractor density (Fig. 7.10). This presents quite a different picture, although Uttar Pradesh and Andhra Pradesh again scored well.

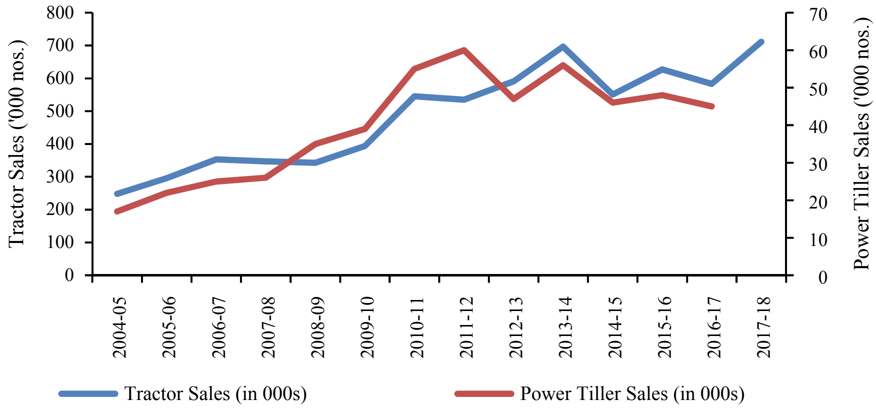

Fig. 7.8 Sales of tractors and power tillers, 2004–05 to 2017–18. *Source* Directorate of Economics & Statistics (2017)

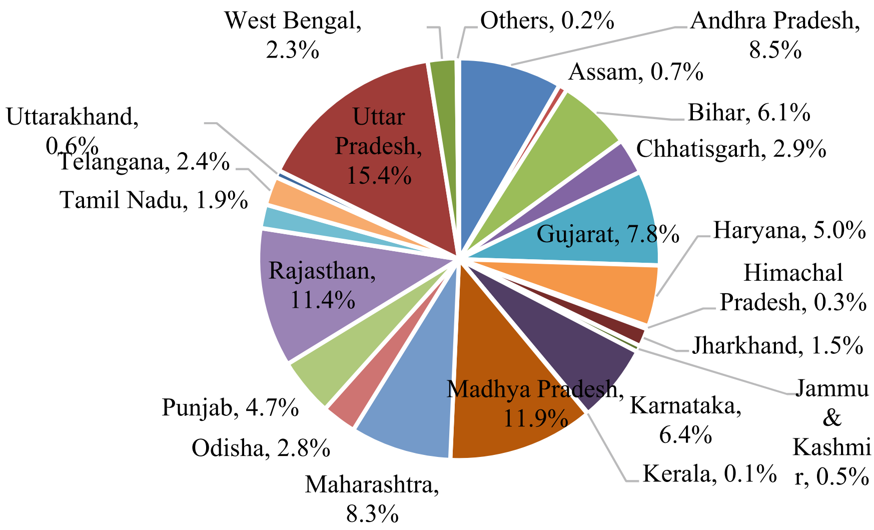

Fig. 7.9 Tractor sales by state as a percentage of national sales, 2015–16. *Source* Tractor Manufacturers Association

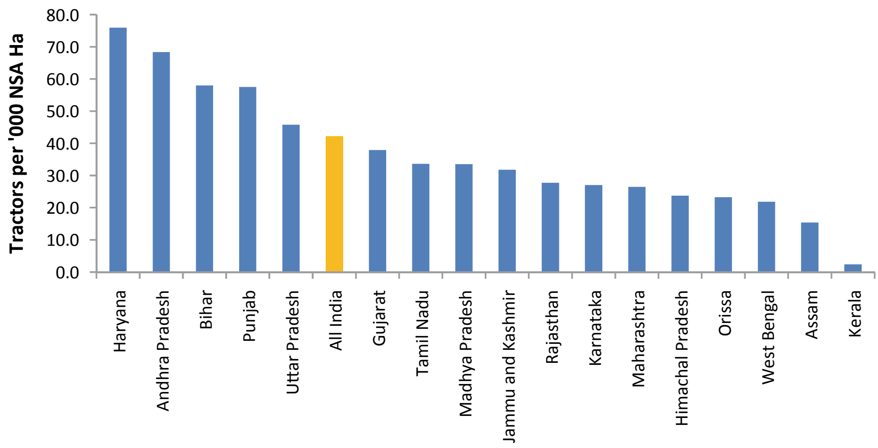

Fig 7.10 Tractor density by state (tractors per '000 NSA hectares), 2017–18. The tractor density in 2017–18 has been calculated by adding domestic sales of tractors between 2008–09 and 2017–18 (under the assumption that the average life of a tractor is 10 years) and then dividing them by the gross cropped area (GCA) in 2015–16. For simplicity, authors have assumed replacement demand as 10 years because the exact life of tractor is not known with certainty. It may vary somewhere between 8 and 15 years, as per different studies. *Note* Tractor density is calculated by dividing the total unit sales from 2007–2008 to 2017–2018 by the net sown area (assuming the average life of a tractor is 10 years). *Source* Tractor Manufacturers Association

Some states' tractor density is well above the national average; others lag far behind. These considerable differences reflect several factors. They include the main farming systems practised (e.g. field crops, horticulture, livestock), crop types, farm sizes, relevant skill levels and the availability of fuel or power. However, it is important to note that tractors provide just one measure of mechanisation. Overall machine use across all farm activities is estimated to be between 40 and 45% in the country, which is relatively poor when compared with, for example, the USA (95% mechanisation), Brazil (75%) or China (57%) (Government of India 2018a).

7.4.2 Farm Mechanisation: Efficiency, Inclusiveness and Financial Sustainability

7.4.2.1 Efficiency

India's agricultural mechanisation process is hampered by increasing fragmentation of land. As shown earlier in Fig. 7.1, average holding sizes more than halved between 1970–71 and 2015–16. Individual ownership of agricultural machinery became correspondingly less feasible, especially for farmers with fragmented plots. This trend is likely to continue (Mehta et al. 2014). A tractor is generally considered economically viable only if it operates for at least 1000 h per year. Most Indian studies suggest that actual use is only about 50–60% of this figure, indicating that farms are overcapitalised. In addition, underuse of tractors raises the per unit cost of production. It also makes it harder for farmers to repay their purchase debts. This is an important consideration, as more than 90% of tractors are bought on credit.

Real daily farm wages have risen by more than 50% since the start of the century. At constant 2011–12 prices, they increased from Rs. 125 in 2000–01 (or USD2.6) to Rs. 196 in 2017–18 (or USD3) (Fig. 7.11). Such a rise in labour costs tends

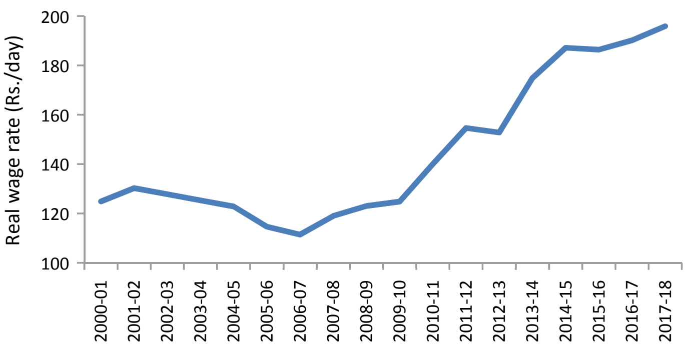

Fig. 7.11 Average real farm wages across India, 2011–12 prices (Rs./day). *Source* Labour Bureau, Shimla and the Agricultural Census 2015–16

to accelerate the process of mechanisation, particularly in more labour-intensive operations. The small size of Indian holdings has acted as a brake. Nevertheless, as shown in Figure, machinery sales did rise from 2005–06 onwards. Tractor sales, for example, increased from 296,000 in 2005–06 to 711,000 in 2017–18.

7.4.2.2 Inclusiveness

The great majority of Indian farmers run small and marginal operations. Purchase of machinery and equipment is a significant investment and locks them into debt for a long period. Furthermore, one piece of machinery is not enough for all tasks in the crop cycle. Smallholders cannot afford to buy all the required items. Farm machinery ownership is thus much less inclusive than, for example, the purchase of seeds or fertilisers. An additional challenge is that India's wide range of cropping systems and farming terrain requires numerous different machines. Without good advice, farmers can easily invest in unsuitable technology for their local conditions. India, therefore, needs to ensure a sound mechanisation policy, planning and direction for all its farmers (Mehta et al. 2014).

7.4.2.3 Financial Sustainability

As noted above, financing of agricultural machinery is an area of concern. At the New Holland dealership in Faridabad (Haryana), for example, 35 hp and 55 hp tractors are the most commonly sold. The 35 hp model costs around Rs. 485,000 (or USD7447.7), a 55 hp Rs. 755,000 (or USD11,593.9). Smallholders lack the necessary capital. There is a need for institutional innovations to enable them to mechanise cost-effectively. This is particularly true for more expensive items such as combine harvester, sugarcane harvesters, potato combines, paddy transplanters, laser-guided land levellers and rotavators (Mehta et al. 2014).

7.4.3 Institutional Innovations in the Provision of Farm Machinery Services

Large, contiguous and geographically straightforward farms enable machinery users to achieve considerable economies of scale. When farm sizes continue to shrink, as in India, individual ownership of even one piece of agricultural machinery becomes progressively less economical. Owning different farm machines and equipments is entirely beyond smallholders' means.

Alternatives include an attractive institutional innovation of "Uberisation". Custom hiring of this type, with payment per use, makes equipment affordable even for quite small operations. Well-timed short-term rental can boost farm income by

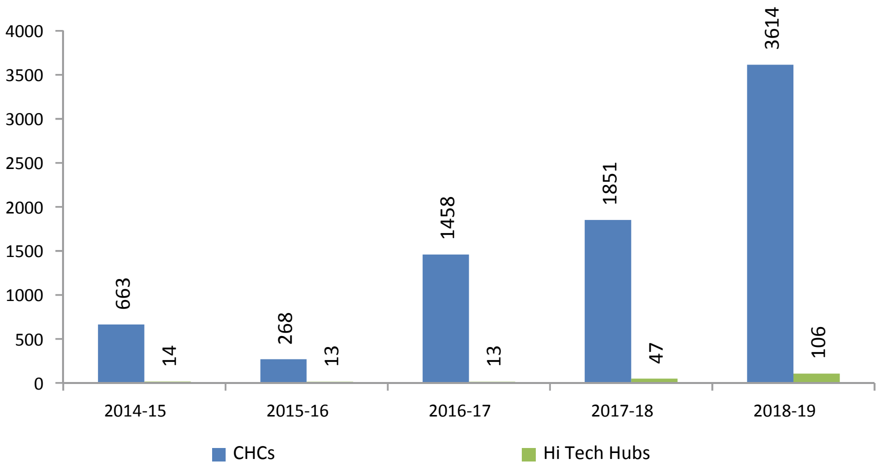

Fig. 7.12 Number of new CHCs, and hi-tech equipment hubs established between 2014–15 and 2018–19 (as of October, 2019). *Source* GoI Live Dashboard, https://agrimachinery.nic.in/GraphReport/SMAMFmtti/SMAMFmtti.aspx

cutting labour costs, increasing crop output and often reducing post-harvest losses. Custom hiring not only makes more machine power available, but also helps level out the disparities among states and farmers, and removes much of the drudgery associated with certain tasks. It enables new machines to be used at maximum capacity and puts the latest technology within smallholders' reach without prohibitive upfront costs.

With all this in mind, the Government of India in 2014–15 initiated a Sub-Mission on Agricultural Mechanisation (SMAM) under the National Mission on Agricultural Extension and Technology. The programme promotes the establishment of custom hiring centres (CHCs), with a 40% subsidy to farmers, entrepreneurs and societies willing to set up one (Ministry of Agriculture and Farmers' Welfare 2018). Financial assistance is also available to promote the use hi-tech equipment hubs, dealing with high-end technological agricultural farm implements and specialised machinery (Ministry of Agriculture and Farmers' Welfare 2018). The pattern of assistance for establishing CHCs and hi-tech equipment hubs is given in the Annexure.

Figure 7.12 gives the status of CHCs and hi-tech equipment hubs established between 2014–15 and 2018–19. Further, to assess the SMAM, the Ministry of Agriculture and Farmers' Welfare commissioned a survey[29] run by the public sector enterprise WAPCOS during 2016–17. The survey showed that a majority of CHCs belong to rural entrepreneurs (62.3%). Smallholder groups own 17.2 and farm producer organisations 4.1%. The remainder belonged mainly to NGOs, co-operative societies, KVK public extension centres or the corporate sector (Ministry of Agriculture and Farmers' Welfare 2018). The survey also found that an average CHC provides

[29]Field data collected between September 2016 to June 2017; 202 CHCs (14.22%) were evaluated for performance and impact.

Table 7.4 Examples of custom hiring rates (2019, Rs./h except for brush cutters)

Equipment	Local market	CHC
Tractor with rotavators	1200	950
Tractor with cultivators	800	650
Tractor with seed drill	800	700
Power tiller	600	500
Thresher	1000	850
Paddy Combine	1400	1200
Brush cutter without fuel	350 per day	300 per day

Source Ministry of Agriculture and Farmers' Welfare (2018)

machinery services within 10 to 20 kms of the village in which it is established. Each employs two to three people, typically a driver, helper and centre assistant. The main operations covered are land levelling, ploughing, seeding, harvesting and threshing. CHCs also arrange field machinery demonstrations and provide on-site servicing.

It is worth mentioning that the private sector is increasingly engaged in providing rental farm machinery and related services. Examples include major tractor companies such as Mahindra and Mahindra or Tractors and Farm Equipment Limited. One notable model is that of EM3 AgriServices, which brokers access to equipment and technology for an hourly or acreage-based fee. It enables farmers who own tractors, harvesters and other machines to rent these out to colleagues with smaller operations, often in remote areas. EM3 co-ordinates supply and demand through mechanisation and call centres as well as village representatives. The company's 1240 *Samadhan* "farming as a service" centres in Rajasthan, Madhya Pradesh, Gujarat and parts of Uttar Pradesh serve more than 8000 farms.

Table 7.4 compares the CHCs' very competitive hiring rates with average market figures. Farmers in the SMAM survey reported that hourly CHC charges were Rs. 100–200 (i.e. 15–20%) lower than those of local competitors. Farmers also appreciate the flexibility of paying cash for land preparation and seeding but in kind for threshing, as well as being able to repay credit at the time of crop sale (Ministry of Agriculture and Farmers' Welfare 2018).

At first sight, the lower CHC prices are good news for farmers. However, the centres receive 40% subsidies on capital equipment. This skewing of the market threatens to put informal local competitors out of business and leave the whole system dependent on subsidies. Many private sector providers may be tempted to turn their machinery ventures into CHCs in order to benefit. Robust evaluation, therefore, is required of CHCs' machinery use efficiency, their viability with lower or no subsidy and the size of farms they are serving. As there is a serious concern that extending use of farm machinery with 40% capital subsidy may not lead to an effective use of machinery. Thus, the model needs to be monitored closely.

The SMAM programme represents an important step towards "last mile" delivery of farm mechanisation to small and marginal farmers (Ministry of Agriculture and Farmers' Welfare 2018). But, according to experts, India is yet to see intermediate custom hiring interventions in the crop cycle, encompassing land preparation, sowing operations till harvesting, which are missing at present (Ministry of Agriculture and Farmers' Welfare 2016). Business models are still at an early stage of development and need fuller evaluation before attempting further scale-up.

7.4.4 Concluding Remarks

The innovative idea of supplying farm machinery services to small and marginal farmers at affordable cost through CHCs and "Uberisation" platforms is commendable. The initial 40% subsidisation of capital for a sufficiently large number of pilot CHCs seems reasonable. But before further scaling up, thorough evaluation is required of the system's efficiency, reach and financial sustainability with lower or no subsidies.

To stay in business, rental entrepreneurs will need machinery that is location-specific, easy to manage and in every other respect "farmer-friendly". Availability of machines should match local conditions, topography, production systems, crop area and cropping intensity. Greater mechanisation will improve productivity and timely production and mitigate a number of natural and man-made constraints on agriculture.

Greater access to mechanised tools for small parcels of land is best achieved by developing them as "common use assets" via CHCs and hi-tech equipment hubs. As demand develops, the centres can offer a wider range of equipment and supporting services (Government of India 2018a, b, c). The Committee on Doubling Farmers' Income (DFI Committee) proposes a three-level structure for "mechanisation inclusion". There should be at least one CHC in every large village (a role to be assumed by the *gram panchayat*/local council in small ones). At the district level, provision should be through CHCs, complemented by service centres at the regional or state level. The DFI Committee further suggests that the government should use the brand equity of professional service providers and expand agricultural mechanisation via the franchise route. We see considerable promise in this approach.

Further, it is worth highlighting that mechanisation expansion can generate local employment. Farmers with appropriate skills can earn additional income as operators for their neighbours—a familiar model in other countries worldwide; for example, Syngenta Foundation through the CEMA Model, a centre for mechanised services, is working closely with rice farmers in Senegal and Mali, Africa, to improve production and productivity amidst weed and water stress. The foundation is basically promoting establishment of mechanised service centres by farmers' co-operatives or produce aggregators to provide a package of custom services that would otherwise be unaffordable because of the considerable upfront investment needed. The model also promotes agribusiness and generates employment by encouraging the young to establish such service centres and the use of digital applications for managing machines, storage, processing and giving advice to farmers (Syngenta Foundation 2018a).

7.5 Institution of Agricultural Extension System

The DFI Committee also puts great emphasis on agricultural extension. It describes extension as "an empowering system of sharing information, knowledge, technology, skills, risk and farm management practices, across agricultural sub-sectors and along all aspects of the agricultural supply chain, so as to enable the farmers to realise higher net income on a sustainable basis" (DFI 2017).

India has a well-established system of agricultural extension and education. It involves some 113 research centres/institutes of the Indian Council of Agricultural Research (ICAR) and 77 state agricultural universities (SAUs), as well as central agricultural universities, water and land management institutes, the research institutions of various commodity boards, 700 *krishi vigyan kendra* (KVKs, literally "farm science centres") and more than 50,000 agricultural scientists. Together, they cover multiple aspects of the agricultural value chain from preproduction to output marketing (DFI 2017).

7.5.1 Evolution and Spread of Agricultural Extension System

India has three main sources of extension. The public sector combines the efforts of agricultural ministries and departments as well as research centres. The private sector is divided into non-profit and for-profit providers. The former include local and international non-governmental organisations (NGOs), foundations, community boards and associations, as well as bilateral and multilateral aid projects and other non-commercial associations. In the for-profit segment, extension is on offer from input manufacturers and distributors, agro-marketing and processing firms, trade associations, or consulting and media companies. A further for-profit source is commercial farmers or farmer group enterprises, whose members are both users and providers of the information (Syngenta Foundation 2018b).

Paroda (2018) traces the current public agricultural extension system back to the community development programme (CDP), started in 1952. The CDP was later strengthened by the Intensive Agriculture District Programme (1961–62), the Intensive Agriculture Area Programme (1964–65) and the High Yielding Varieties Programme and Farmers' Training and Education Programme (both 1966–67). These ran in collaboration with international public research institutes working on maize and wheat (CIMMYT) and rice (IRRI). Overall, the programmes improved farmers' access to modern inputs and technologies and generated major improvements in farm productivity (Paroda 2018; Ferroni and Zhou 2018).

In 1974, ICAR introduced an institutional innovation called the frontline extension approach and established the first KVKs. In the mid-1970s, successful pilots took place in Madhya Pradesh and Rajasthan of the "training & visit" extension system. This spreads across India from 1984 to 1995 in the National Agricultural Extension Project, supported by the World Bank. In 1998, the National Agricultural Technology

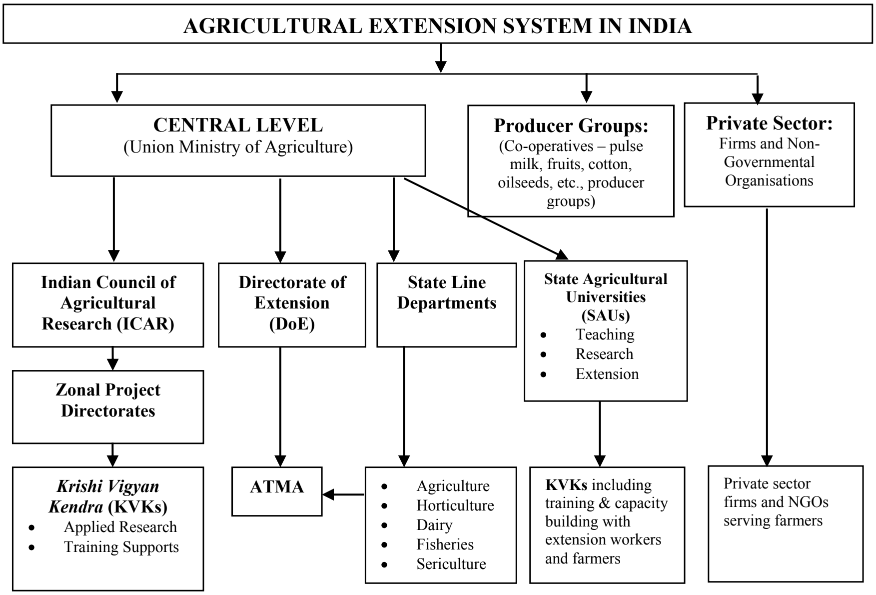

Fig. 7.13 Agricultural Extension System in India. *Source* Meena, M. S., K. M. Singh & B. E. Swanson. https://mpra.ub.uni-muenchen.de/49107/1/MPRA_paper_49107.pdf (Source will come below the figure)

Project united all public extension under the Agricultural Technology Management Agency. ATMA is still the main driver of that extension today (DFI 2017) (Fig. 7.13).

The strong growth in private extension followed economic reforms in the early 1990s, resulting in India's hybrid seed and biotechnology revolution (DFI 2017). By 2016–17, the private sector accounted for 81.2% of gross capital formation in agriculture (Central Statistics Office 2018). In 2017–18, the largest companies (Bayer/Monsanto, Corteva and Syngenta) together spent around six billion dollars on agricultural research and development. India benefits from global investments of this type and from the companies' many innovations in seeds, crop protection and extension services.

India's national budget for 2019–20 allocated Rs. 80.7 billion (or USD1.23 billion) to the Department of Agricultural Research and Education (DARE). This represents an almost 10% increase from 2018–19, but at slightly over a billion dollars, is still far less than the agricultural R&D expenditure of Bayer alone (Gulati 2019). In 2014–15, India spent roughly 0.7% of agricultural GDP on the two areas of research and education, and extension & training. About three-quarters of that spending went to research and education (Gulati et al. 2018). In 2018–19, however, India spent only 0.37% of agricultural GDP in this area. That figure is far below the 1% recommended for a sustainable increase in farm productivity and incomes in developing countries (Gulati 2019).

NGOs play a large role in delivering extension services. India has numerous agricultural NGOs implementing a wide range of programmes. Leading examples include the BAIF Development Research Foundation (the former Bharatiya Agro-Industries Federation), Action for Food Production, Professional Assistance for Development Action (PRADAN) and the Foundation for Ecological Security. They work in several states on livestock development, water resource management, environmental conservation, livelihood development and other initiatives (Rasheed 2000).

7.5.2 *Efficacy, Inclusiveness and Financial Sustainability*

This section examines three aspects of India's agricultural extension system. Our first question is how far the country's intellectual property rights (IPR) regime encourages investment in this area. The second is one of inclusiveness: how far does technology transfer also benefit "the bottom of the pyramid"? The third aspect is that of financial sustainability and related policies.

7.5.2.1 Efficacy

There are several components to the efficiency—and efficacy—of an extension system. One is its focus on the market, helping farmers to produce what customers want. It is important for farmers to know what products are in high demand in the market and the quality specifications that they should achieve to get good value for their output. Optimally, they should have this information before making production decisions.

Another important concern is to provide the knowledge to find solutions for the diverse problems that farmers face. That is, farmers not only need to know the best practices and technologies for crop production, but also need information on post-harvest aspects including processing, marketing, storage and handling. Therefore, this requires both serious efforts in research prioritisation and targeted technology development along with an efficient extension system.

Yet another concern is whether enough technically competent extension staff are available, who are ready to work in remote areas. At least, graduation in agriculture should be the minimum essential qualification for extension staff.

According to the empirics, at present, there is lack of grass root level extension workers at the *panchayat* or village level. Thus, given the fast changing agricultural scenario, the current extension system in the country is inadequate to address the challenges faced by farmers. Thus, there is a need to incentivise and motivate these workers to ensure their long-term retention (Babu et al. 2013).

One major bottleneck here is the non-conducive IPR regime and uncertain policy environment in the country, because some innovations stay in the laboratory only without benefiting farmers. This, in turn, discourages private sector investment in agricultural innovation. GM crops provide an unfortunate example. Apart from cotton, India has kept such innovations on hold for a very long time. Large-scale field trials are severely restricted, even after approval by the regulators (Ferroni and Zhou 2018). As a result, a leading domestic seed company, Mahyco, has cut GM research expenditure by more than 60% (Fernandes 2019). If the regulatory environment prevents access to new technologies, it severely affects farmers' productivity, efficiency and competitiveness. Thus, the inter-linkage between research and extension has to be strengthened by supportive policies and effective management.

7.5.2.2 Inclusiveness

For greater inclusiveness, several changes are necessary. Both public and private sector extension typically bypasses Indian smallholders. Private extension is more active in irrigated areas with more intensive and commercial crops. It tends to focus on big farmers and product promotion. Small and marginal farmers, especially in rain fed and remote areas, are left unattended. Public extension should focus more on their needs (DFI 2017). The DFI Committee proposes greater use of dealers in agricultural inputs and primary agricultural credit societies (PACSs) as extension delivery points. Farm schools could be an innovative idea, where farmers are both pupils and teachers reporting on their experience with particular technologies. Further, tailor-made technologies for small and marginal farms need to be prioritised.

In her July 2019 budget speech, the Finance Minister announced the formation of 10,000 new farmer producer organisations. The extension system will need to start catering to these FPOs. Other shifts are also required. According to the DFI Committee, in 2014–15, around 70% of agriculture research and education (R&E) expenditure was for crop-growing. Only 10% went to animal husbandry and dairy development, even though the livestock sector accounts for 27% of the gross output value from agriculture and allied activities (Gulati et al. 2018). Thus, the livestock sector needs much greater attention in extension services as it is more inclusive of small holders and women farmers.

7.5.2.3 Financial Sustainability

It is important to ensure that adequate funds are available for the agricultural research and extension system because otherwise agricultural extension systems will not be sustainable in the long run. Public expenditure on agriculture research and education (R&E) is funded to the tune of 55.4% by the central government and 44.6% by states. At 2004–05 prices, total R&E Expenditure (including only extension education) increased from Rs. 31.1 billion (or USD0.47 billion) to Rs. 61.6 billion (or USD0.94 billion) between 2000–01 and 2014–15. The compound annual growth rate was about 5%. However, the 2014–15 budget represented a mere 0.54% of GDPA (Gulati et al. 2018). The amount spent on agricultural extension was only 0.16% of GDPA, up from 0.12% in 2000–01 (Gulati et al. 2018). Thus, there is a need to ensure significant additional investment in the agricultural extension system as well as in making the extension and advisory services farmer-led and demand-driven (Babu et al. 2013).

Furthermore, according to some empirics, to ensure that the extension system is financially sustainable, it is necessary to develop and communicate a long-term financing strategy.

7.5.3 Innovations in Agricultural Extension Institutions

Despite all these challenges, extension displays some interesting innovations. An example is the *Hobli*, block-level extension in Karnataka. Introduced under the state's *Raita Mitra Yojna* extension scheme in 2000–01, it takes a decentralised approach to technology dissemination via local *Raita Sampark Kendras* (RSKs). There are now over 745 *Hobli* RSKs, under the administrative control of the *zilla panchayat/* district councils. Personal links with farmers enable them to give up-to-date information on crop production, protection and marketing, facilitate immediate provision and testing of agricultural inputs.

Karnataka has also introduced some innovative sustainable agricultural practices such as *Krishi Bhagya* and *Krishi Honda*. These polythene-lined farm ponds and accompanying micro-irrigation technology encourage efficient use of rainwater. The state's Solar Policy 2014–2021 includes the *Surya Raita* scheme, which covers 90% of the installation costs for solar-powered pumps. After irrigation, farmers can sell any excess power to the government. The public–private partnership *krishi yantra dhare* promotes mechanisation for small and marginal farmers. It provides access to high-tech farm machinery and equipment through custom hiring service centres in each *Hobli*. Machinery matches local cropping patterns.

Increasing use of the Internet and mobile phones creates new extension options. Suddenly, messages can reach many farmers in areas too remote for frequent staff visits. At the simplest level, providers can disseminate advice via SMS. Unlike such text messages, audio-visual material and call centres avoid issues with illiteracy. Government introduced several digital initiatives between 2000 and 2010 including *hariyali kisan bazar*, AGMARKNET, e-*krishi vipnan*, e-*mandi* and e-*choupal*. However, these individual elements remain disjointed. The portals are not linked, and there is lack of co-ordination between the many organisations involved. An important step forward would be to create an integrated platform that delivers real-time localised information in a user-friendly format.

Emerging innovations in "e-agriculture" offer some exciting prospects for extension as well as other aspects of farming. The combination of informatics and entrepreneurship could hugely improve agricultural services and technology dissemination. One frequent limitation, however, is a lack of good Internet connectivity, PCs and reliable electricity supply. "M-Agriculture", using mobile applications, offers an excellent alternative. Numerous customised services can be delivered via phones. Examples include local weather forecasts, prices, crop-specific disease warnings, soil fertility tips, mobile banking and insurance services. Extension will be one of many activities to benefit.

Go Green (2011) is one such initiative. Funded by the Bill & Melinda Gates Foundation, it provides agricultural information to about 42,000 small and marginal farmers via video. Another is eAqua, an Internet-based discussion portal. Despite its name, eAqua provides guidance on much more than just water management: farmers can access a wide range of farm and veterinary advisory services via phone or Internet. The portal is the result of work at the Indian Institute of Technology, Bombay, and is licenced to a software company incubated there. More such innovations are needed, suitably scaled-up to reach the maximum number of farmers in a cost-effective manner.

It is also interesting to see academic interest in non-agricultural areas of farmer education. Extension tends to focus heavily on agronomy, technology and business advice. But many farmers worldwide suffer from mental stress. India is internationally notorious in this respect. Fortunately, researchers at agricultural universities in Punjab, Telangana and Maharashtra are now working on a stress index and a training module to help village volunteers' counsel vulnerable farmers.

Agri-business companies are another source of innovative extension services. Pepsico, for instance, has been working with Punjab farmers since 1989. The company set up contract farming to source tomatoes for its local processing plant. Farmers grew the fruit with inputs, technology and extension from Pepsico. The company developed regional, crop-specific R&D and extension services with Punjab Agricultural University and the state's Agro Industries Corporation and thus ensured the transfer of new technology to the fields. Another example is that of Adani Agrifresh and its "Farm-Pik" initiative in Himachal Pradesh. This has enabled some 15,000 apple growers to access modern technology and improve their profitability, while the company can now supply good apples all over the country. The horticulture company FieldFresh Food goes a step further, enabling farmers to succeed in international markets. In 2004, FieldFresh leased 300 acres from the Punjab government and opened a model farm. The company invested in all aspects of supplying baby corn. Extension covered input delivery, credit, irrigation, scientific advice, production to European specifications, careful harvesting and handling, clean and fast transportation, cold chain management and safety certification as well as grading, packaging and labelling to meet international standards. Importantly, FieldFresh first created demand ("forward linkages") and then ensured an excellent supply chain ("backward linkage").

7.5.4 Concluding Remarks

Smallholders face numerous and widely varying challenges due to lack of access to modern inputs, finance and extension services. This requires an efficient agricultural extension system that goes beyond technology transfer and focusses on implemention of new technology on farmers' fields. There is also a need to support research that specifically addresses smallholders' needs and to ensure adequate incentives for providing them with innovations. A predictable and balanced policy environment is required that encourages public and private investments in both R&D and extension. Public expenditure ratios for extension should reflect the proportionate share of various farming types, such as field cropping, horticulture or animal husbandry. Public extension for high-value products is currently weak and disorganised in India. The government needs to shift from "one-size-fits-all" extension to locally customised services. Private companies have considerable motivation to provide excellent extension but should be further incentivised through appropriate regulations and well-administered institutions. Government should set the "rules of the game" that allow the forces of demand and supply to function as freely for extension as in other markets.

7.6 Concluding Remarks

This section brings out inferences derived from the analysis and suggests how to make agricultural institutions more efficient, inclusive and sustainable.

Indian agriculture is characterised by the predominance of small—often very small—holdings that have shrunk considerably in recent decades. Meanwhile, India's huge population continues to grow, as does the demand for food, feed and fibre. There are many ways to solving this challenge. Among them is the need for optimum use of inputs such as land and water, and for mechanisation and extension. All four must be efficient, transparent, inclusive and sustainable. Among other factors, this optimisation requires a conducive institutional environment.

After independence in 1947, agricultural policy focused on land reforms and better irrigation. Both were crucial to achieve self-sufficiency in food grains. However, the implementation of land reforms was only partially successful. Even today, states restrict land leasing to varying degrees. The results include insecure tenants, lack of investment in land and continued fragmentation of holdings. Land leasing should be fully legalised and freed across India. Land records need to be digitised and geo-tagged. These improvements will help smallholders access vital business inputs such as institutional credit and insurance.

Irrigation is another critical issue. Agriculture uses about 78% of India's fresh water for irrigation, yet production on almost half the cropped area still depends on erratic rainfall. India is now a water-stressed country, as per capita availability of water has fallen from about 5200 m^3 in 1951 to 1544 m^3 in 2011. Production of food, feed and fibre for 1.37 billion people will exacerbate this problem unless the country quickly takes corrective measures. One essential step is to make the price of water and its extraction reflects the true cost of this scarce resource. Bold policy moves such as the complete reshaping of power and water subsidies are also required. Farmers need encouragement to shift from flood irrigation to water-saving practices such as micro-irrigation and to use solar energy instead of electricity or diesel. Innovative incentive policies to save water and power, such as *Paani Bachao, Paise Kamao,* should be scaled up. Investment is also imperative for rapid completion of planned irrigation projects that help ensure equitable distribution of water.

Rising labour costs increase the need for mechanisation, but smallholders cannot afford to buy expensive machinery. Institutional innovations such as custom hiring and "Uberisation" help put the necessary equipment within their reach. Drudgery then decreases and productivity rises. Such innovations need scaling up nationwide, but without the current high subsidies that may cause other problems.

Agricultural extension shares several characteristics with irrigation. Both have a long tradition, are widespread, controversial and difficult to price. Done well, both can greatly increase productivity, but in India, both need improvement. Public sector extension typically does not meet smallholders' needs. Non-profit extension is often unsustainably dependent on donors or pursues a particular agenda, such as organic farming. For-profit extension is often excellent as far as it goes, but tends understandably to be limited to the immediate needs of the company providing it. All three could benefit from greater use of "e-agriculture" and "m-agriculture" to reach more farmers more often, covering more issues in agriculture. All three could also do more to work with groups of farmers, whether aggregated through the private sector's contract farming or self-organised in FPOs and co-operatives. Such aggregation and collaboration in extension can also benefit from supportive government policies. To increase the efficiency, inclusiveness and sustainability of extension, public and private sector activities need to complement each other. China provides a valuable example of how well a hybrid public–private system can provide technology and extension that promote innovative sustainable farming practices (Gulati et al. 2018). As with land, irrigation and mechanisation, wise and well-implemented policies can make a huge difference in extension.

Annexure

See Tables 7.5 and 7.6.

Table 7.5 Financial assistance for establishing custom hiring centre

S. no.	Items	Maximum permissible project cost	Financial assistance by the Govt (%)
1	Procurement subsidy for establishment of custom hiring centre up to Rs. 1,000,000	Rs. 400,000	40
2	Procurement subsidy for establishment of custom hiring centre up to Rs. 2,500,000	Rs. 1,000,000	40
3	Procurement subsidy for establishment of custom hiring centre up to Rs. 4,000,000	Rs. 1,600,000	40
4	Procurement subsidy for establishment of custom hiring centre up to Rs. 6,000,000	Rs. 2,400,000	40

Source DoAC&FW (2017).

Table 7.6 Financial assistance for establishing hi-tech equipment hub

S. no.	Items	Maximum permissible project cost	Financial assistance by the Govt (%)
1	Procurement subsidy for establishing a hi-tech equipment hub up to Rs. 10,000,000	Rs. 4,000,000	40
2	Procurement subsidy for establishing a hi-tech equipment hub up to Rs. 15,000,000	Rs. 6,000,000	40
3	Procurement subsidy for establishing a hi-tech equipment hub up to Rs. 20,000,000	Rs. 8,000,000	40
4	Procurement subsidy for establishing a hi-tech equipment hub up to Rs. 25,000,000	Rs. 10,000,000	40

Source DoAC&FW (2017)

References

Ahluwalia, I. J. (2019, June 27). Saving India's water: Centre and states must jointly address the crisis. *The Financial Express.*

Anupama, G. V., & Thomas, F. (2009). *Effect of farm size on farm productivity: Emperical evidences from India.* Telangana: Innovation Systems for the Drylands Program, International Crops Research Institute for Semi-Arid Tropics (ICRISAT).

Appu, P. S. (1996). *Land reforms in India.* New Delhi: Vikas Publishing House.

Babu, S. C., Joshi, P. K., Glendenning, C. J., Asenso-Okyere, K., & Sulaiman, R. (2013). The state of agricultural extension reforms in India: Strategic priorities and policy options. *Agricultural Economics Research Review, 26*(2), 159–172.

Central Statistics Office. (2018). *National accounts statistics.* Delhi: Ministry of Statistics & Programme Implementation.

CGWB. (2017). *Dynamic groundwater resources of India (As on March 31st, 2013).* Faridabad: Central Ground Water Board, Ministry of Water Resources, River Development & Ganga Rejuvenation, Government of India.

Chaudhuri, S. (2018, March 30). Why China has taken a lead over India in farm production. *The Hindustan Times.*

Cullet, P. (2017, August 08). A gathering crisis: the need for groundwater regulation. *The Hindu* .

CWC. (2014). *Guidelines for improving water use efficiency in irrigation, domestic and industrial sectors.* New Delhi: Ministry of Water Resources.

Dabadge, A., Sreekumar, N., Dharmadhikary, S., & Bhalerao, R. (2018). *Understanding the electricity, water, agriculture linkages (Vol 2: Electricity supply challenges).* New Delhi: Prayas Energy Group.

Deininger, Klaus, Jin, S., & Nagarajan, H. K. (2008). Equity and efficiency impacts of rural land rental restrictions: Evidence from India. In T. Haque, (Ed.) *European Economic Review Vol. 52 (5)*, pp. 892–918.

DES (2018). *Land use statistics at a glance.* New Delhi: Directorate of Economics and Statistics, Department of Agriculture, Cooperation and Farmers' Welfare.

Deshpande, R. S. (2003). Current land policy issues in India. In P. Groppo, *Land reform, land settlement and co-operatives.* Rome, Italy: FAO.

DFI. (2017). *Report of the committee on doubling farmers' income: New Delhi: Department of Agriculture.* Government of India: Co-operation and Farmers' Welfare.

Directorate of Economics & Statistics (2017). *State of Indian agriculture 2017.* New Delhi: Ministry of Agriculture, Co-operation & Farmers' Welfare, Government of India.

DoAC&FW. (2017). *National mission on sustainable agriculture—Operational guidelines.* New Delhi: Department of Agriculture Co-operation & Farmers' Welfare (DoAC&FW), Ministry of Agriculture & Farmers' Welfare, Government of India.

Fernandes, V. (2019, March 06). Govt policies have shrunk Mahyco's ag-biotech research spending by 70%. *The Financial Express.*

Ferroni, M., & Zhou, Y. (2018). Private agricultural R&D in India, farm productivity and the agricultural transformation. In A. Gulati, M. Ferroni, & Y. Zhou (Eds.), *Supporting Indian farms the smart way* (pp. 367–390). New Delhi: Academic Foundation.

Gandhi, V. P., & Namboodiri, N. V. (2011). *Participatory irrigation management in India: An evaluation of the performance in Andhra Pradesh.* Gujarat and Maharashtra. Ahmedabad: Centre for Management in Agriculture, IIM (CMA Publication no.237).

Government of India. (1976). *Report of the National Commission on Agriculture (Part XV).* New Delhi: Government of India.

Government of India. (2015). *Request for proposal for selection of Farm/Institute/NGOs for mid-term evaluation of NLRMP*. New Delhi: Department of Land Resources, Ministry of Rural Development, Government of India.

Government of India. (2017a). *5th census of minor irrigation schemes.* New Delhi: Ministry of Water Resources, River Development and Ganga Rejuvenation.

Government of India. (2017b). *Report of the Committee on doubling farmers' income—Volume I: March of Agriculture since independence and growth trends.* New Delhi: Ministry of Agriculture & Farmers' Welfare, Government of India.

Government of India. (2017c). *Agricultural statistics at a glance 2017.* New Delhi: Directorate of Economics and Statistics, Ministry of Agriculture & Farmers' Welfare, Government of India.

Government of India. (2018a). *Doubling farmers' income, Volume VII: Input management for resource use efficiency.* New Delhi: Committee on Doubling Farmers' Income, Ministry of Agriculture & Farmers' Welfare.

Government of India. (2018b). *Report of the committee on doubling farmers' income, Volume XIII—Structural reforms and governance framework.* New Delhi: Ministry of Agriculture & Farmers' Welfare, Government of India.

Government of India. (2018c). *Review of physical progress in respect of Digital India land records modernization programme (DILRMP).* New Delhi: Department of Land Resources, Ministry of Rural Development, Government of India.

Gulati, A. (2019, July 06). With little allocation for agriculture, budget sends a worrying signal. *The Indian Express.*

Gulati, A., & Banerjee, P. (2016). Emerging water crisis in India: Key issues and way forward. *Indian Journal of Economics, Special Centennial Issue, XCVI*(383), 681–704.

Gulati, A., & Banerjee, P. (2018). Irrigation and power subsidy in India. In A. Gulati, M. Ferroni, & Y. Zhou (Eds.), *Supporting Indian farms the smart way* (pp. 149–214). New Delhi: Academic Foundation.

Gulati, A., & Jain, S. (2012, December 20). Credit inclusion, farm lease and forming clusters can help small farmers overcome poverty much faster. *The Economic Times.*

Gulati, A., & Mohan, G. (2018). *Towards sustainable, productive and profitable agriculture: Case of Rice and Sugarcane.* New Delhi: Working Paper No. 358, Indian Council for Research on International Economic Relations.

Gulati, A., Sharma, P., Samantara, A., & Terway, P. (2018). *Agriculture extension system in India: Review of current status, trends and the way forward.* New Delhi: Indian Council for Research on International Economic Relations (ICRIER).

Gulati, A., Sharma, B. R., & Mohan, G. (2019). *Addressing groundwater challenges in Indian agriculture.* Mumbai: NABARD.

Haque, T. (2001). *NCAP Policy Paper No.- 13: Impact of Tenancy Reforms on Productivity Improvement and Social Economic Status of Poor Tenants.* New Delhi: ICAR.

Hassan, N. (2016). *Agricultural law in India: Overview*. India: Thomson Reuters, Practical Law.

Houdret, A., & Bonnet, S. (2013). Public-private partnerships in irrigation management: socioeconomic, political and environmental concerns. *ECPR General Conference*, (p. 19). Bordeaux.

Maitreesh, G., & Roy, S. (2007). Land reform and agricultural productivity in India: A review of the evidence. *Oxford Review of Economic Policy, 23*(2), 251–269.

MANAGE Report. (2018). *Feed the Future India triangular training program on "entrepreneurship development among rural women" for extension practitioners from African and Asian countries.* Thiruvananthapuram: MANAGE, Government of India.

Mani, G. (2016). Model agricultural land leasing act, 2016: Some observations. *Economic and Political Weekly, Vol. 51*(42).

Mearns, R. (1999). *Policy research working paper 2123: Access to land in rural India.* Washington: The World Bank.

Mehta, C. R., Chandel, N. S., & Senthilkumar, T. (2014). Status, challenges and strategies for farm mechanization in India. *Agricultural Mechanization in Asia, Africa and Latin America, 45*(4), 43–50.

Ministry of Agriculture and Farmers' & Welfare. (2016). *Farm mechanization in India: The custom hiring perspective.* New Delhi: FICCI and Yes Bank.

Ministry of Agriculture and Farmers' Welfare (2017, April 05). Geotagging of assets created under RKVY. *Press Information Bureau.*

Ministry of Agriculture and Farmers' & Welfare. (2018). *Monitoring, concurrent evaluation and impact assessment of submission on agricultural mechanization*. Gurgaon: WAPCOS Limited.

Mohan, G. R. (2019, August 13). New Andhra Pradesh cultivators act unlikely to solve tenant farmers' problems. *The Wire*.

MOSPI. (2018). *EnviStats India 2018 (Supplement on environmental accounts)*. New Delhi: Ministry of Statistics and Programme Implementation, CSO, Government of India.

MOWR. (2018). *Status of participatory irrigation management (PIM) in India—Policy initiatives taken and emerging issues*. New Delhi: Government of India.

NITI Aayog. (2016). *Report of the expert committee on land leasing*. New Delhi: NITI Aayog, Government of India.

Pal, S., Joshi, P. K. M., & Saxena, R. (2003). *Institutional change in Indian agriculture*. New Delhi: National Centre for Agricultural Economics and Policy Research.

Paroda, R. (2018). *Reorienting Indian agriculture: Challenges and opportunities*. Boston: CABI, ISBN: 9781786395177.

Planning Commission (1966). *Implementation of land reforms: A review by the land reforms implementation committee of the National Development Council*. New Delhi: Government of India.

Planning Commission. (2007). *Report of the Sub-group on land related issues*. New Delhi: Government of India.

Rasheed, S. V. (2000). *Agricultural extension in India: Current status and ways forward*. Hyderabad: Centre for Research on Innovation and Science Policy.

Raymond, A., & Jain, A. (2018). *Solar for irrigation: A comparative assessment of deployment strategies*. New Delhi: Council on Energy, Environment and Water.

Reddy, V. R., & Reddy, P. P. (2006). How participatory is participatory irrigation management?: Water users' associations in Andhra Pradesh. *Economic and Political Weekly, 40*(53), 5587–5595.

Saxena, N. C. (2013). *Discussion paper on tenancy reforms vs open market leasing—What would serve the poor better?* New Delhi: Planning Commission, Government of India.

Shah, T. (2010). *India's ground water irrigation economy: The challenge of balancing livelihoods and environment*. Gujarat: International Water Management Institute, C/o INREM Foundation.

Sirhindi, M. (2018, April 24). Punjab issues notification to delay paddy sowing by five days. *The Times of India*.

Srivastava, R., Saxena, N. C., & Thorat, S. K. (2007). Institutions, policy, and reforms in India. In A. Gulati & F. Shenggen (Eds.), *The Dragon and the Elephant: Agricultural and rural reforms in China and India* (pp. 71–96). Baltimore, Maryland: International Food Policy Research Institute, the Johns Hopkins University Press.

Svendsen, M., Gulati, A., & Raju, K. V. (2006). *Financial and institutional reforms in Indian canal irrigation*. Bangalore: Books for Change.

Syngenta Foundation (2018a). *Unemployment of young people in rural areas: Strategic approaches of the Centers for Mechanized Services (CEMA)*. Retrieved April 21, 2020, from Syngenta Foundation for Sustainable Agriculture. https://www.syngentafoundation.org/sites/g/files/zhg576/f/cema_west_africa_en_06.2018_2.pdf.

Syngenta Foundation (2018b). *Agricultural Extension*. Retrieved August 01, 2019, from Syngenta Foundation for Sustainable Agriculture. https://www.syngentafoundation.org/agricultural-extension.

Venkatasubramanian, K. (2008). *Land reforms remain an unfinished business*. New Delhi: The Planning Commission, Government of India.

Zainulbhai, A., Roy, A. N. (2018, April 14). How technology can get insurance money into the hands of farmers in 24 hours. *The Economic Times*.

Chapter 8
Institutional Innovations in Accessing Land, Water, Machinery and Extension Services in China's Agriculture

8.1 Introduction

Institutional improvements have been among the most important reforms pursued by China over the past 40 years. The introduction of household responsibility system (HRS) of 1978–1984 dismantled the People's Communes and contracted cultivated land to individual households. Further reforms to raise agricultural productivity have followed. They include efforts to stabilise HRS, develop rental market institutions and the *San-quan-fen-zhi*. This latter reform lays out three categories of land rights: "village collective landowner", "individual household land contract" and "land operational".

In many rural areas, institutional reforms have also addressed the efficiency of resource use. Among them are reforms related to water, machinery, extension and co-operatives. Irrigation is now a significant feature of the Chinese agricultural landscape. A series of reforms over the past four decades have focused on water supply and demand in agriculture. Major institutional changes include transfer of property rights on irrigation facilities from village collectives to individual farmers, development of water use associations to better manage surface irrigation and the creation of institutions aiming to save water by regulating access rights and markets.

Agricultural mechanisation and extension also play a major role in raising productivity. Both normally face considerable challenges in a production system dominated by small farms. However, despite an average Chinese farm size of less than one hectare, mechanisation has developed rapidly over recent decades. Most activities in grain production are now mechanised. The mechanisation of small-scale farms has benefited from innovative services provided by individual farms or specialised entities, as well as from policy support.

Rapid adoption of new technology by millions of smallholders requires a strong national agricultural extension system. Institutions governing extension must

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constantly adapt to farmers' changing needs. In the last four decades, China has implemented several important initiatives to improve its extension system. This is now the largest such system in the world. Getting to today's strong position has not been easy, however. China has gone through several rounds of personnel, budget and asset reform.

This chapter focuses on the major institutional reforms that have helped raise China's agricultural production. Section 8.2 discusses institutional changes related to farmland and their impact on equity and productivity. Section 8.3 evaluates institutions governing development and use of water resources, with a strong focus on irrigation. Section 8.4 presents the evolution of agricultural mechanisation and the role of innovative custom services. Section 8.5 examines the evolution of agricultural extension, its reform over time and the impact of agricultural extension service to farmers.

8.2 Evolution and Impact of Agricultural Land Reforms

Getting land institutions right is fundamental for rural development. These institutions are crucial in determining if and how people, communities and organisations can acquire rights and associated duties related to land (FAO 2012). In many developing countries, the poorest rural people tend to be landless farmers. Ample literature documents the influence of land institutions on investment and on efficient and sustainable use. China's experience underlines the fundamental role of land institutional arrangements in facilitating inclusive rural development.

8.2.1 Overview of Land Institutional Reform

In the past 60 years, China has implemented four major rounds of land reforms. After a long feudal history, land moved into household ownership in the early years of the People's Republic (PRC). This was followed by land co-operatives from 1953–57, then 20 years of collective land ownership and production, and finally the household responsibility system from 1978 onwards.

The first round of land reform was radical. Before the PRC was established in 1949, most agricultural land belonged to one or a few landlords in each village. Unequal distribution of land was the main barrier to rural development. During 1950–1952, China started a nationwide revolution to give "land to the tiller". This reform confiscated landlords' holdings and distributed them to villagers. For the first time in many centuries, every rural household had access to land. This revolutionary reform quickly helped to revitalise agricultural production after several decades of war.

The second round of land reform, called Mutual Assistance and Co-operation, followed between 1953 and 1957. The first stage, from 1953 to 1955, set up farmers' mutual aid groups and small-scale land co-operatives; the second established community/village collective economic organisations between 1955 and 1957. With these changes, land was collectively owned and operated in a unified way.

The third round of reform arranged collective/village land ownership and unified management under a commune system. The system had three levels: people's commune, production brigade and the basic unit of a production team. Land, labour, draught animals, agricultural equipment, accounting and income allocation were all managed by production teams.

As in other countries, Chinese agriculture performed poorly under the collective system. A fourth round of reform, the 1978 household responsibility system (HRS), aimed to improve the situation. HRS contracted the use of village-owned land back to individual families. More recently, to facilitate land transfer and consolidation and to stabilise tenure, operational rights have been separated from contract rights.

8.2.2 Evolution of Land Institutions Since 1978

Many commentators view HRS as the heart of China's rural economic reforms (Lardy 1983). Between 1978 and 1984, HRS dismantled collective production and distributed the land to households according to the number of family members. The average farm size was about 0.7 ha but varied between regions. Land *ownership* remained with the collective, but the "contract rights" of control and income passed to individual households for 15 years (Lin 1992; Brandt et al. 2002).

That, at least, was the theory. However, land tenure stability became a problem from the early 1980s to the late 1990s. Although village committees were supposed to have given farmers land for 15 years, ownership was insecure in many areas (Liu et al. 1998; Yao 2000; Kung 2000; Brandt et al. 2002). Village leaders often re-allocated land among households for a variety of local reasons. This was primarily a question of small adjustments. A national representative survey showed that before 1996, major re-allocations (e.g. across whole villages or large groups of households) accounted for less than 4% of such changes. This number rose to 11.5% during 1997–1999, but small adjustments between a few households were about three times more frequent over both periods (Ji et al. 2014).

Reallocations took place for several reasons. These included a desire for efficiency, or for equity in line with changes in household numbers. There were also cases of motivation closer to corruption (Kung 2000; Zhang et al. 2011; Huang and Rozelle 2015). Whatever the individual reasons, however, observers and policy-makers worried about the consequences. Insecure tenure for households or producers, they feared, would have negative effects on investment and agricultural production.

China has made several legal and policy efforts to ensure the security of farmers' land contract rights. The second contract period beginning in the late 1990s was extended to 30 years. China also issued the Land Management Law in 1998 and the Rural Land Contracting Law in 2003 to protect farmers' land contract rights. The latter sought to increase tenure security and explicitly prohibited reallocation. The legislation also allowed family members to inherit land during the contract period.

In recent years, China has frequently announced that land contract rights will not change in the long run, implying that inheritance rules will remain in place. The 2017 National Congress of the Communist Party announced that the current farmland contract will be extended by a further 30 years and thus continue until the late 2050s. With this new extension, the current total contract period is 75 years. Although the fourth term of land contract will be made only in the 2050s, a much longer contract period is expected in the next round of contract extension.

8.2.3 Innovations in Land Institutions

8.2.3.1 Land Registration and Certification

To improve the security of contract rights, the authorities have made efforts to register and certify farmland for each rural household. With about 260 million such households to serve, this is a major challenge. It requires precise data on land inventories, contracting records, farmers' transfers of contracting and operating rights, a land registration system to facilitate issuing of certificates and a system for managing disputes. China started with a small pilot in a few counties in the late 2000s. The programme then expanded to more counties and provinces.

Using the experience thus gained, a comprehensive programme of confirmation, registration and certification of ownership and contract rights started in 2013. At the end of 2019, the government announced that the process was essentially complete.

8.2.3.2 Land Rental

Farmland is owned by villages; sales are prohibited. Increasing the size of farms and consolidating holdings, therefore, requires a well-functioning land rental market. The development of this market and related institutions provides an interesting study of how reform can facilitate small-farm transformation and of the important role of land institutions.

China has nearly 40% of the world's small farms, with an average size of less than 1 ha. Up until 2004, farm sizes were in decline (Fig. 8.1). Since then, the transfer of cultivated land has sharply accelerated. By the end of 2013, nearly 53 million rural households (23% of the total) had rented out their land. This area accounted for 26% of all cultivated land under the household responsibility system (MOA 2014). Expansion of the rental market has completely reversed the downward trend in farm size. By 2016, an average farm covered 0.88 ha, a rise of 54% over 2003 (Fig. 8.1). In north and north-eastern China, the average size has doubled over the past decade. Huang and Ding (2016) note the strikingly rapid emergence of medium and large-size farms in many regions.

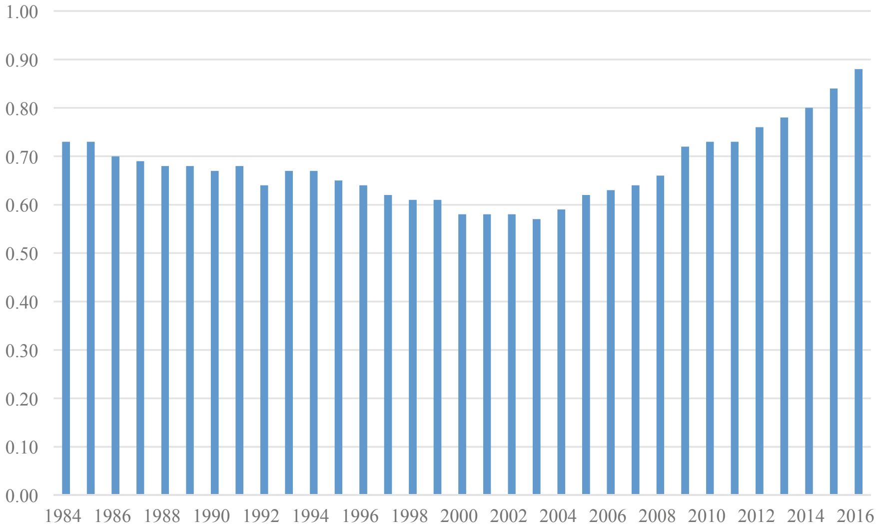

Fig. 8.1 Average operational size (ha) of Chinese farms, 1984–2016. *Source* Huang and Dang (2016) and author's estimate based on CCAP household surveys

There are many reasons behind these changes in the size and composition of farms. Mechanisation services, policy support for consolidation, and the rapid rise in wages and off-farm employment since the mid-2000s have all played a role. Huang and Ding (2016) show that land transfer service centres (LTSCs) have been a further important driver. LTSCs reduce the transaction cost of land transfer for farmers. This finding confirms earlier observations that high transfer costs form a significant barrier to expanding the rental market and farm sizes (Brandt et al. 2002; Carter and Yao 2002; Deininger and Jin 2009).

The LTSCs are a land transfer platform created by local governments since the late 2000s, mostly at the township level. Some larger ones pool rental information at the county or provincial level.[1] The LTSCs have four main mandates. They conduct land rental market surveys, collecting information on people willing to rent out their land. They then facilitate transfers by providing information on location, area and major characteristics and suggested prices for each piece of land for rent. Their third task is to prepare formal land contracts when transactions are completed and to keep the records. Fourthly, LTSCs are responsible for mediating disputes (Huang and Ding 2016).

Table 8.1 presents the growth in LTSC numbers, based on a survey by CCAP. An LTSC at the township level normally provides transaction services for the farmland

[1]There are two reasons for establishing LTSCs at the township rather than the village level. Each centre requires office space, facilities, and a certain scale of service, staff and operational budget. Townships are the lowest government hierarchy level and, unlike most villages, can meet these conditions. Farmers also prefer a formal land contract made in the township offices and witnessed by officials who are also responsible for dispute mediation.

Table 8.1 Percentage of sample counties and townships with LTSCs

Year	LTSCs at county seat				LTSCs at township level			
	All	Eastern	Central	Western	All	Eastern	Central	Western
2008	7	8	13	0	3	0	13	0
2009	7	8	13	0	8	12	13	0
2010	10	15	13	0	11	15	13	5
2011	16	31	13	0	11	15	13	5
2012	19	39	13	0	11	15	13	5
2013	19	39	13	0	11	15	13	5
2014	32	39	50	10	18	19	19	15
2015	48	54	50	40	23	19	25	25
2016	61	77	63	40	32	35	25	35

Source Huang (2017)

within its boundaries. An LTSC at a county seat can provide such services both in the township where county government is located and other townships within the county. About 7% of county seats had established LTSCs by 2008, but this proportion rose to 61% by 2016 (left-hand "All" column). The eastern and central regions developed LTSCs earlier than western China. By 2016, 77% of eastern county seats had such a service centre, with 63% in central China but only 40% in western areas. The difference among regions largely reflects the extent of demand for rental market services. At the township level, percentages were lower and the differences less marked.

8.2.3.3 "Separation of Three Rights of Farmland" (*San-Quan-Fen-Zhi*)

China has long been searching for mechanisms to improve land access for those who stay in farming and have a comparative production advantage. The 2003 Rural Land Contracting Law clarified the rights of transfer and exchange of contracted land. To further facilitate land transfer and consolidation, and improve productivity, China has tried to separate operational rights from the current contract rights. Farmers have been transferring land since the late 1980s with government encouragement. Yet there is still no legal document that defines the rights of farmers with a land contract or those who operate the rented-in land after transfer. The plan to legally separate operational rights from contract rights was first announced in Central Document No. 1 of 2015.

In 2019, China formally announced the *San-quan-fen-zhi* policy for the "separation of three rights of farmland". This new institution separates village collective landowner rights, individual household contract rights and those of land operation. The separation allows operation rights to be transferred through the rental market while the originally contracted farmers continue to hold the contract rights.

8.2.4 Impact of Land Reforms

The positive effects of HRS on agricultural productivity, equitable distribution of land and alleviation of rural poverty in the early reform period were clearly apparent and have been well documented. Most studies show that HRS accounted for about 40 to 50% of the total rise in output between 1978 and 1984 (Fan 1991; Lin 1992; Huang and Rozelle 1996). Researchers have also documented effects that went beyond output. McMillan et al. (1989) showed that the early reforms raised total factor productivity (TFP), accounting for 90% of the overall rise in TFP. According to Jin et al. (2002), the reform contributed greatly to an annual rise in TFP of more than 7%. The significant positive impact of HRS on agricultural production, together with the equitable distribution of land, was a major reason for the massive reduction in rural poverty in the early reform period.

Legal and policy efforts to secure tenure were also successful and have facilitated farm investment and land transfer. Frequent reallocation dampened farmers' incentive to invest in the land (Li et al. 1998; Jacoby et al. 2002). However, as Ji et al. (2014) point out, the proportion of villages experiencing large re-allocation fell from more than 10% in the late 1990s to only about 1% in the early 2000s. Stabilising tenure by prohibiting land adjustment is expected to encourage farmers to invest in land. Several other studies have found that more and more land in China is being rented in and out (Deininger and Jin 2005; Gao et al. 2012; Huang and Ding 2016).

San-quan-fen-zhi does more than just facilitate land transfer. It is expected that this institution can achieve both equity in land distribution, creating some 260 million "small-scale landlords", and better use of land by transferring operation rights to more productive farmers.

However, despite increasing land transfers and gradually rising farm sizes, consolidation still has a long way to go. The good news is that several local pilot reforms are tackling land fragmentation and the small scale of many farms. These include the recent development of land co-operatives and shareholding as well as reallocation for consolidation. However, the full impact, scalability and transferability of these reforms to other regions remain to be seen.

8.2.5 Discussion and Concluding Remarks

China's overall land reform is unique in comparison with those elsewhere. In other countries, the diversity and dimensions of land institutions have meant widely differing political pressure for reform, as well as fluctuations over time. In contrast to more than 60 years of slow agrarian reforms in India (Banerjee and Iyer 2005) and the Philippines (Elvinia 2011), or radical privatisation in the former Soviet Union (Lerman et al. 2004), China's distinctive land reform has been gradually and decisively implemented over the past four decades. At its heart lies the combination of collective ownership overseen by village committees with contract rights vested in households. Since HRS, reform has focused on ensuring tenure security, facilitating land transfer and expanding farm size.

Chinese farmland tenure is complicated. After four decades of reform, the system consists of village collective ownership rights, individual household contract rights and land operational rights. Looking at more than 2000 years of feudal society, the country's leaders believe that private land ownership does not necessarily enrich farmers. China's current institutions have ensured that village households own contract rights, which convey almost all the benefits of land ownership. The rental market enables farmland expansion and consolidation.

Even without ownership of the cultivated land, holders of contract rights can readily expand their farms by renting land from other households. If taking up other employment, they can also easily move out of farming by renting out the operational rights on their contracted land. In recent years, the institutional changes have supported both these inter-linked processes.

Experiences from China's land reforms have policy implications for many developing countries. There are three main lessons. First, get land institutions right. China did so by initially allocating land to all village households equally and then securing and stabilising the contract rights. That has been critically important for improving farmers' incentives and productivity growth. It is also fundamental for inclusive rural development. In developing countries, the poorest in rural areas tend to be landless farmers, indicating a link between land access and poverty alleviation.

Secondly, avoid market failures in farmland transfer. This requires institutional and policy interventions. With rising rural populations in many developing countries, average farm size is expected to continue to decline. China's experience shows that land rental markets can play an important role in consolidating farm operational units. Transfer services may also contribute in other countries, by helping landless farmers to access land, assisting some small-scale farmers to shift to off-farm employment and enlarging the operations of those who stay in agriculture.

The third lesson relates to the separation of rights. In countries that restrict farmland sales, separating operational, ownership and/or contract rights can help achieve the goals of both equity and efficiency. China now has about 260 million rural households with contract rights. They are "landlords" in the sense that their rights will continue long-term and family members will be allowed to inherit them in the next contract round. At the same time, land is consolidated for use by villagers who decide to stay in farming and have the confidence to earn a profit after paying a market price for land rental.

8.3 Evolution and Impact of Irrigation Reform

Irrigation has played a significant role in raising agricultural productivity. However, increasing water scarcity makes the sustainability of irrigation doubtful. China's per capita water availability is only one quarter of the global average, and crop production

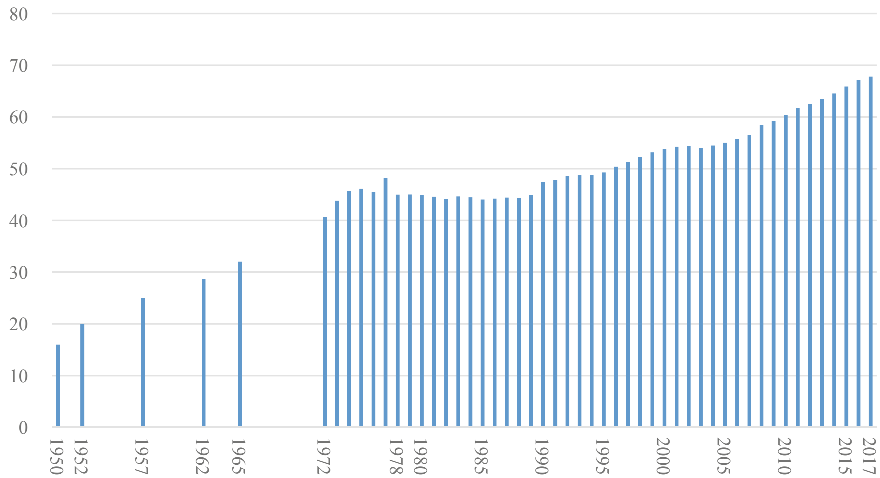

Fig. 8.2 Effective irrigated land area (million ha) in China, 1950–2017. *Sources* NSBC, China Statistical Yearbooks, various years

depends heavily on irrigated land. By 2017, the irrigated area reached 67.8 million ha (Fig. 8.2), about half of all cultivated land.

Irrigation can double crop production by raising yield and enabling more harvests per year (Wang et al. 2010). However, there is increasing concern about water scarcity in many parts of China. From 1961 to 2011, river runoff has declined in 60% of large river basins, primarily in Northern China (Wang et al. 2019). As surface water resources decrease, water users (particularly farmers) have turned to groundwater. This shift has resulted in overdraft and adverse environmental effects. Furthermore, water users in other sectors are increasingly competing with farmers. From 1978 to 2017, water use in agriculture grew markedly, but the share of agriculture in withdrawals fell from 88 to 62% due to increasing industrial and domestic consumption. Climate change is expected to widen the gap between supply and demand, and to increase the variability of supply (Wang et al. 2013; IPCC 2014).

With irrigation so important and water scarcity so threatening, China has implemented several policies to tackle the challenges. These include investment in irrigation, institutional reform of facilities and water rights, and the development and promotion of water-saving technologies. This section focuses on the evolution of institutions governing irrigation and their impact on the efficiency and sustainability of water use.

8.3.1 Overview of Irrigation Expansion and Institutional Changes

8.3.1.1 Overview of Irrigation Expansion

China has a long history of water capture and control, particularly for flood control and irrigation. From 1950 to 1978, investment in water infrastructure accounted for about 7% of the nation's total infrastructure investment (Wang et al. 2019). Rural households contributed a vast amount of labour to construction and maintenance. The result was a tripling of the irrigated area from 16 million ha in 1950 to 48 million in 1978 (Fig. 8.2). The share of irrigated land increased from 16% to almost half.

By the time rural reforms started in 1978, irrigation had tapped into most available surface water. In the early 1980s, the increase in irrigated area flattened off, and in the mid-1980s even declined slightly due to the deterioration of the irrigation system (Fig. 8.2). There were two main reasons for this. The advanced level of irrigation meant high marginal costs for any further expansion, and the shift of production from collectives to households made it difficult to mobilise farmers to work on construction and maintenance.

By the late 1980s, stagnation in irrigation and slower growth of grain production attracted considerable political attention. Investment in irrigation increased, and community-based irrigation work (where farmers were paid for their share of work) was initiated. As a result, the irrigated area has gradually expanded since the early 1990s (Fig. 8.2). China has also introduced a series of institutional and management reforms to improve the efficiency of water use in agriculture.

8.3.1.2 Irrigation Institutions

China has developed comprehensive institutions to manage its water resources. These include a system of unified management at the national and local levels. The Ministry of Water Resources (MWR) administers water resources throughout the country. It is also in charge of managing the major rivers and lakes designated by central government. The MWR's counterparts at the provincial, prefectural and county levels are responsible for water management within their jurisdictions.

At the local level, management of irrigation depends largely on whether farmers use surface water or groundwater. Where surface water is used, an irrigation district (ID) is managed by the local water resource bureaus. Their major tasks include transferring water from major rivers or reservoirs to the upper ID, channelling it down and managing the ID's main and branch canals. More local irrigation (tertiary or lower canals) is administered by county and township governments. Village committees run the village canal networks. In areas that use groundwater, local water resource bureaus and village committees managed the wells and irrigation before rural reform. Since the early 1980s, responsibility has moved to individual households.

Higher institutions governing irrigation have not changed much over time. Within villages, however, groundwater and surface water institutions and management have experienced significant changes. The following sub-section describes these changes and their impact.

8.3.2 Institutional Changes and Their Impact

8.3.2.1 Groundwater Irrigation

Since the early 1950s, China's irrigation investment has mainly focused on surface water. However, from the late 1960s, groundwater irrigation has also developed in northern China. Its share in total irrigation area rose from 30% in 1970 to 55% in 1980 (Wang et al. 2006).

The HRS also had effects on groundwater irrigation, hitherto managed by the village. After HRS, individual farmers made their own decisions on agricultural production. Ownership of tube wells on contracted land shifted from villages to households. This resulted in a profound transformation. To raise productivity, farmers started to invest in tube wells in their own fields. The China Centre for Agricultural Policy tracked the changes in its China Water Institutions and Management Panel Survey in the northern provinces of Ningxia, Henan and Hebei. The survey showed that private tube wells rapidly replaced collective ownership. The share of private tube wells increased from only 7% in 1983 to 83% in 2004 (Wang et al. 2019).

This privatisation helped farmers to access local water based on their own demand, affecting both production and groundwater use. Farmers sowed a larger area of high-value crops (Wang et al. 2010). Their agricultural incomes increased accordingly. A growing groundwater market also gave non-owners access to tube well supply (Zhang et al. 2008). The percentage of villages on the North China Plain with an active groundwater market increased from 5% in 1990 to 80% in 2016. Farmers who bought groundwater on the local market used less than those who had their own tube wells or used collective ones (Zhang et al. 2010).

Despite the positive income effects of tube well privatisation, concerns remain about the sustainability of groundwater use. Wang et al. (2009) found that privatisation had accelerated the fall in the groundwater table in northern China. Institutional innovation is required.

To address the problem, the government has tried to regulate withdrawals via quotas and fees. In 2014, a pilot project for comprehensive control began in Hebei, one of the provinces worst affected by falling groundwater levels. The main goal was to control the total amount of groundwater withdrawn in the region. The project also supported adoption of water-saving technologies, as well as cropping changes and land set aside to reduce groundwater use. In 2018, this initiative was extended to other provinces in Northern China. Although it is too early for a conclusive assessment of the effects, groundwater management has clearly become an important part of water policy.

8.3.2.2 Surface Water Irrigation

Institutional changes in surface water irrigation began in the early 1990s. They followed a period in 1980s when budget constraints reduced local governments' ability to invest in and maintain irrigation districts. To keep IDs functioning, the central government allowed them to commercialise irrigation services. However, the commercialisation was not successful (Lohmar et al. 2003). Managing IDs locally became a problem in many areas. Knowing the importance of irrigation for production, China significantly increased its investment from the mid-1990s. At the same time, government also tried to reform local irrigation management.

The reform was introduced by the World Bank in the mid-1990s and then quickly expanded to many parts of the country. Its major component was the creation of water users associations (WUAs), which took over irrigation management from the village collectives. The first pilot for IDs ran in the southern provinces of Hubei and Hunan. It successfully improved the efficiency of irrigation water use. The government then began to promote similar reforms in other IDs from the early 2000s onwards. Over the past two decades, reform of surface irrigation management has rapidly expanded to most IDs. From 2001 to 2016, the number of WUAs increased from 1000 to more than 80,000. Currently, WUAs provide services for 30% of the irrigated land across all provinces (Li 2002; MWR 2016).

The development of WUAs was accompanied by another innovation. In many provinces, individual farmers contracted to manage surface water irrigation. Because this reform was initiated by local leaders and farmers, the contract terms varied. However, they usually included responsibility and payments for irrigation management and services benefiting all the village's farmers. CCAP surveys in Ningxia and Henan Provinces in the Yellow River Basin show that before 2004, the percentage of villages contracting management in this way was higher than those with WUAs (Table 8.2). Thereafter, however, the percentage rapidly declined. By 2008, WUAs were already the dominant model, serving 71% of villages. In 2016, this figure reached 81%, while the share of villages with contracting or collective management declined to 16% and 3%, respectively.

Several studies have analysed how WUAs and contracting management can reduce water use (Wang et al. 2005, 2014). The major factors include investing in irrigation

Table 8.2 Institutional reform of surface irrigation management in Ningxia and Henan Provinces in the Yellow River Basin

	Share of villages (%)						
	1990	1995	2001	2004	2008	2012	2016
Collective	91	87	64	48	19	15	3
Water users association	3	6	14	22	71	75	81
Contracting	6	7	22	30	10	10	16

Data sources China Water Institutions and Management Survey, organised by China Centre for Agricultural Policy, Peking University. Cited from Wang et al. (2019).

facilities, improving water management skills, strictly regulating irrigation operations, incentivising WUA managers and contractors to save water, creating mechanisms for farmer participation and ensuring sustainable financing of operation and maintenance.

8.3.3 Innovative Market-Based Mechanisms for Water Allocation

As with many other areas of the economy, irrigation water use has moved from supply-side to demand-side management and from planned to market-based mechanisms. This sub-section describes innovative programmes using water price and rights to manage irrigation water, which has rarely been used in most developing countries.

8.3.3.1 Evolution of Innovative Regulations to Raise Irrigation Fees

China has tried to raise fees to improve the efficiency of water use and reduce the financial deficit on irrigation. Farmers were first required to pay a fee in 1985, when the aim was to reduce the irrigation system's burden on the state. In 1992, price bureaus took over fee administration from the water resources bureaus. This institutional change partially shifted the irrigation service from a public good to a commodity. Payment changed from a single sum to two components: a basic fee charged by area and a volumetric fee based on use. Over the past decade, a certain amount of water's scarcity value has been priced into the basic fee. Since 2016, government has also begun changing from fees to water resource taxes in several provinces. These reforms have mainly been implemented in regions with surface water irrigation.

In the case of groundwater, the main owners of irrigation facilities are farmers or village collectives. No resource fee, therefore, is imposed. Farmers only pay for electricity, diesel and other operational costs of pumping water. There have been government plans to charge groundwater resource fees, but the high collection costs have so far discouraged implementation.

The impact of these reforms is significant, though there is still considerable room to improve the water pricing system. Irrigation fees have increased significantly over time, but they still neither fully cover the supply cost nor reflect water's scarcity value. The data in Fig. 8.3 come from a survey in the Zhangye Prefecture of Gansu Province, but are largely indicative of the trend in surface water irrigation prices across rural China. The price rose from 0.006 yuan/m^3 in 1981 to 0.216 yuan/m^3 in 2015, a 35-fold increase. The inflation rate in that period was some 5% annually. In real terms, the 2015 irrigation price, therefore, was about 6.56 times that in 1981. It

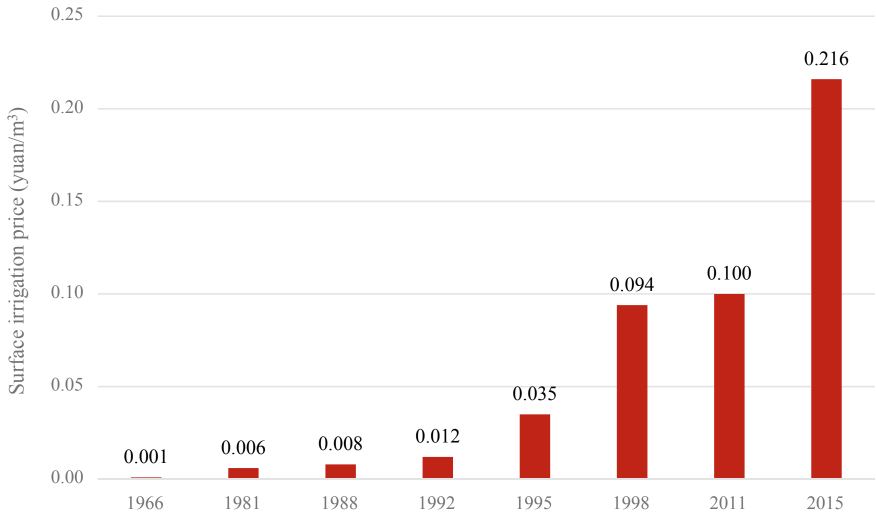

Fig. 8.3 Surface irrigation price (yuan/m^3) in Zhangye, Gansu Province, 1966–2015. *Source* Wang et al. (2019)

nonetheless still only covered about 70% of the irrigation supply cost (Wang et al. 2019).

Irrigation payment has gradually moved from a fee per unit of area to a closer reflection of consumption. A study in Northern China shows that in 2001, charges for 83% of plots were based on area; over the following 14 years, this share fell to 65% (Table 8.3). In 2015, surface water charges for about 27% of plots were based on the time and duration of irrigation application, which is closer to a volume usage fee. This compared with 36% of plots for groundwater in which fees were charged by

Table 8.3 Share of wheat plots with irrigation fees calculated by different methods in North China (in %), 2001–2015

Year	Surface water			Groundwater			
	Area	Time	Elec or diesel	Area	Time	Elec	Diesel
2001	83	6	11	9	27	33	31
2004	80	12	8	9	34	32	25
2007	75	22	4	3	28	37	32
2011	77	16	8	4	30	52	15
2015	65	27	8	1	36	59	33

Data sources China Water Institutions and Management Survey, organised by China Centre for Agricultural Policy, Peking University. Cited from Wang et al. (2019)

Note Area, Time, Elec and Diesel refer to charging water price by plot area, irrigation time, electricity consumption and diesel consumption, respectively the time a pump was run for a day or month. In 59% of cases that year, groundwater irrigation fees were based on electricity use. Most tube wells include an electricity meter.

In the past two decades, other innovative water charging methods have been tried out in various regions. For example, pilot projects in Northern China have used integrated circuit cards to regulate individual farmers' pumping rates. But implementing such projects requires significant initial investment and then a budget for maintenance and monitoring. Another innovative project is the "increase price and provide subsidy" reform for groundwater irrigation in Hebei Province, already discussed in the chapter on Chinese incentive policies. This reform raises the price of groundwater for irrigation in the pilot villages. They can therefore generally collect a higher volume of irrigation fees. The additional income for the whole village is re-allocated to all farmers based on the size of their irrigated land rather than the amount of groundwater used. Since groundwater is volumetrically priced, higher prices should encourage farmers to withdraw less groundwater. The fees returned to farmers largely balance out higher payments for irrigation. The saved water in irrigation could be transferred to industrial uses with higher prices than irrigation water price, and farmers could earn an income if their initial irrigation water use rights are set and fixed.

8.3.3.2 Water Rights System and Water Markets

China's government has been trying to set up a water rights system and allocate water through market mechanisms since the early 2000s (Calow et al. 2009). The first set of important institutions to establish water rights and a transfer system were established in 2005. Local governments initiated a number of transfer systems for industrial and domestic water. In 2014, formal pilot projects to gain experience with setting water rights and transfers started in Ningxia, Jiangxi, Hubei, Inner Mongolia, Henan, Gansu and Guangdong. To support the pilot projects and encourage transactions between regions, sectors and individual users, the MWR issued the Temporary Management Regulation on Water Rights' Transfer in 2016. In the same year, the first national Water Rights Transaction Institute opened in Beijing.

So far, transferring water rights for irrigation has been more challenging than for industrial and domestic uses. Realising the difficulty, China has recently started a policy experiment in the ID system in several places (Sun et al. 2016). Individual farmers receive water rights certificates. These state the maximum withdrawal allowed per household, depending on the water rights area and crop irrigation quota. However, a fully functioning water rights market requires further innovations that lower transaction and monitoring costs.

8.3.4 Future Challenges and Opportunities

Despite numerous achievements, irrigated agriculture still faces challenges. Innovations in groundwater irrigation institutions have increased farmers' access to water. Overdraft of groundwater is common in many regions, which threatens the sustainability of irrigated agriculture. Changes in institutional arrangements for surface irrigation have also improved efficiency, but often require significant investment. Pilot reforms of irrigation pricing may be successful in some locations, but scale-up to whole regions and across China is not easy. Irrigation conditions and farmers' motivation to participate vary between areas. Similar concerns apply to setting up water rights and a transfer market.

However, China is giving itself some important opportunities to cope with the challenges. The country's leaders already put considerable emphasis on sustainable water use. The government's Rural Revitalisation Strategy of 2017 particularly focuses on using less water, including the establishment of water-saving associations. Reform is clearly directed towards this goal, with corresponding investment and policies.

8.4 Evolution and Impact of Agricultural Mechanisation Institutions

China has nearly 40% of the world's small farms, with an average size of less than one hectare (Huang and Ding 2016; Sheng et al. 2019). Mechanising such farms has proved a challenge in many countries. China has found its own solution.

Increases in real wages raise the cost of labour-intensive farming, thereby decreasing its comparative advantage. To restore that advantage, at least partially, requires mechanisation, typically ushered in by farm expansion. Mechanisation is usually difficult if holdings stay small. In China, however, mechanisation of small farms has dramatically accelerated over the last two decades.

This section explores the forces driving this rapid development, with a focus on the governing institutions. Among the most innovative are the mechanisation custom services that separate ownership and servicing. They have enabled establishment of a market for machinery services for hundreds of millions of widely dispersed farms. The rest of this section first documents the overall development path and trend of Chinese farm mechanisation over recent decades. It then presents changes across different cultivating activities, crops and regions, and analyses the development of mechanisation custom services using statistical and household survey data.

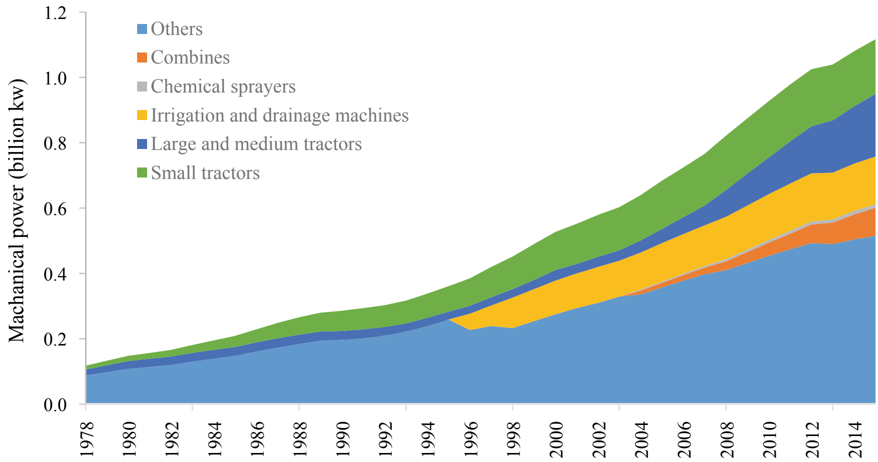

Fig. 8.4 Agricultural machinery power in China: 1978–2015. *Source* Ministry of Agriculture (1980–2016; 2009)

8.4.1 Trends in Mechanisation Development

Significant growth in agricultural mechanisation started in the 1980s and has accelerated in the present century (Fig. 8.4). The rapidly growing number of machines in all categories has significantly increased total agricultural machinery power (tAMP). In 1978, tAMP was only about 1.2 billion kW. This gradually increased in the 1980s and 1990s, with rapid growth in the following decade. By 2015, tAMP had reached 16.7 billion kW, nearly 14 times the 1978 level. Figure 8.4 shows the growth trends for each type of agricultural machinery over the past four decades.

The overall machinery operating rate has grown particularly fast in labour-intensive activities such as ploughing, sowing, crop protection and harvest (see Chap. 4 on innovations in technologies in China). Although the mechanisation rate has accelerated rapidly nationwide, it varies substantially between crops and activities.

8.4.2 Institutional Innovation on Machinery Custom Services

The rise in mechanised operations is a result of rapidly expanding mechanisation custom services (MCS). The paid custom services include ploughing, sowing, irrigation, crop protection, spraying and harvesting. Suppliers of these services include individual farmers and farmers' machinery co-operatives/companies inside or outside the village. Machinery co-operatives/companies sell their services across large geographical areas throughout the year (Yang et al. 2013).

Table 8.4 Farmers with agricultural machinery and professional custom providers, 2001–2015

Year	Farmers with agri. machinery	Professional providers
	Million households	%
2001	28.5	11.2
2002	29.4	11.2
2003	30.5	11.8
2004	32.0	11.3
2005	33.6	11.4
2006	34.8	11.1
2007	36.3	11.0
2008	38.3	11.0
2009	39.4	11.3
2010	40.6	11.9
2011	41.1	12.4
2012	42.0	12.4
2013	42.4	12.4
2014	43.0	12.2
2015	43.4	12.1

Source Ministry of Agriculture of China (1980–2016)

The number of farmers with agricultural machinery rose from 28.5 million in 2001 to 43.4 million in 2015, an increase of 52% (Table 8.4). Professional providers of MCS account for a slightly increasing share of farmers with agricultural machinery. This means that professional providers have grown significantly in numbers. MCS revenue more than doubled between 2004 and 2013, from 210 billion yuan to 447 billion. Service organisations have also greatly expanded, reaching 182,000 by the end of 2015.

A notable feature of MCS history has been the evolution of inter-regional providers. These expanded steadily from 1996 onwards, except in 2003, when China restricted regional movement because of the SARS virus. The inter-regional MCS share of total sown area peaked in 2013 at 22% (36.7 million ha). It then declined as local MCS replaced the wider-ranging type (Table 8.5, column 1). This replacement is further evidence of agricultural mechanisation. As more and more farmers buy agricultural machines and serve their neighbourhoods, so MCS become increasingly local.

Looking into the detailed data, one finds that inter-regional MCS mainly concentrated on harvesting (Table 8.5). An even closer look will reveal that wheat was their dominant crop (Fig. 8.5). Wheat harvesting follows a geographical pattern that is particularly suitable for inter-regional services: it starts in the south and gradually moves north. The inverse U-shape of inter-regional MCS over time is due to the rapid development of village MCS since the mid-2000s.

Table 8.5 Percentage of inter-regional mechanisation services by sown and "mechanised" area, 2008–2015

Year	Share of sown area (%)	Share of area with mechanised operation (%)		
		Ploughing	Sowing	Harvesting
2008	15.4	4.4	2.9	38.2
2009	17.3	4.7	2.7	38.6
2010	18.0	4.9	2.7	35.9
2011	20.3	4.7	3.1	37.9
2012	21.0	5.2	3.4	35.1
2013	22.3	5.9	3.8	33.6
2014	18.9	5.1	3.4	25.5
2015	15.5	4.4	3.0	18.9

Source China Machinery Industry Federation (2009–2016)

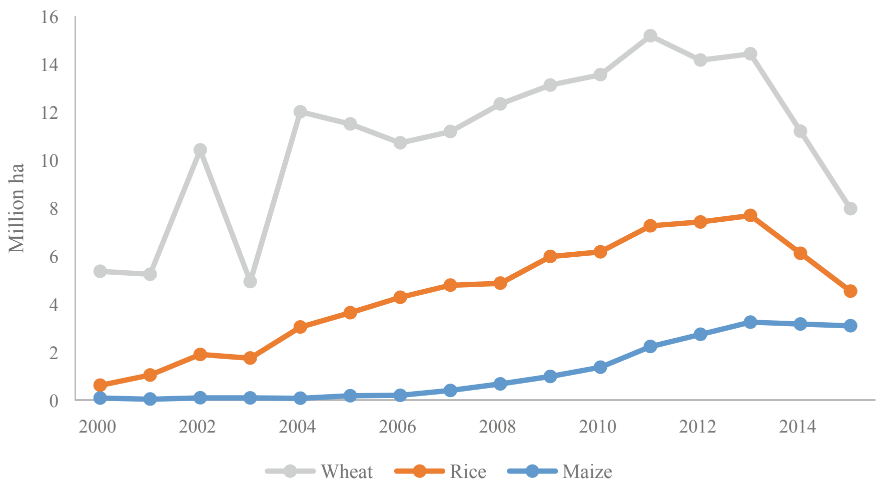

Fig. 8.5 Coverage of major crops by inter-regional mechanisation services, 2000–2015. *Source* China Machinery Industry Federation (2001–2016)

A national survey of rural households by CCAP (Huang and Ding 2016; Sheng et al. 2019; Yi 2019) shows similar trends. Before 2000, the share of villages with MCS increased from 2 to 20% in nearly 20 years. Since 2000, this share has increased dramatically to 84%, more than tripling in 15 years (Fig. 8.6). Local farmers with agricultural machinery are the major providers of MCS. On average, there are 4.8 farmers with agricultural machinery per village, while the number of professional service organisations is 0.5 per village (Yi 2019).

Wheat in Northern China provides a useful illustration of MCS activities. Ploughing, sowing, input application and harvesting can each be done by manpower,

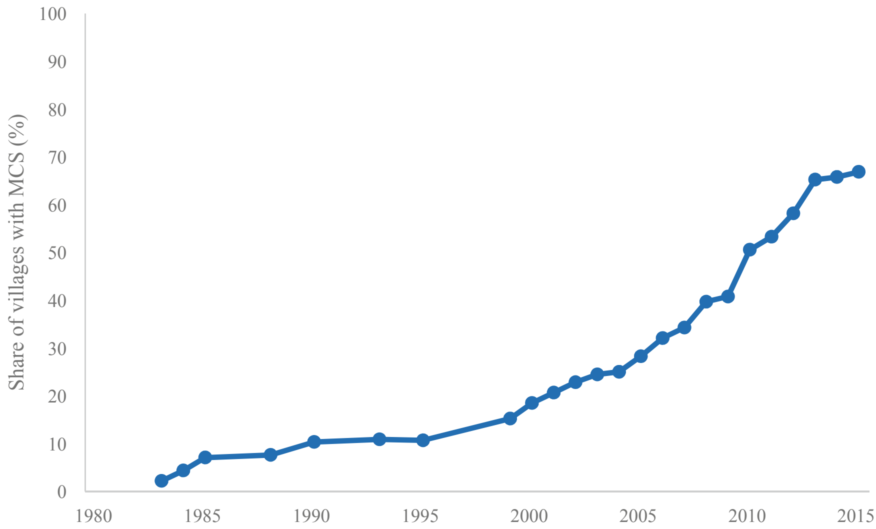

Fig. 8.6 Share of villages with MCS. *Source* Yi (2019)

farmers' own machines or MCS. As shown in Fig. 8.7, MCS dominates in all operations except input application, i.e. use of fertiliser and crop protection products. The MCS share of the ploughed area increased from 78% in 2003 to 90% in 2015.

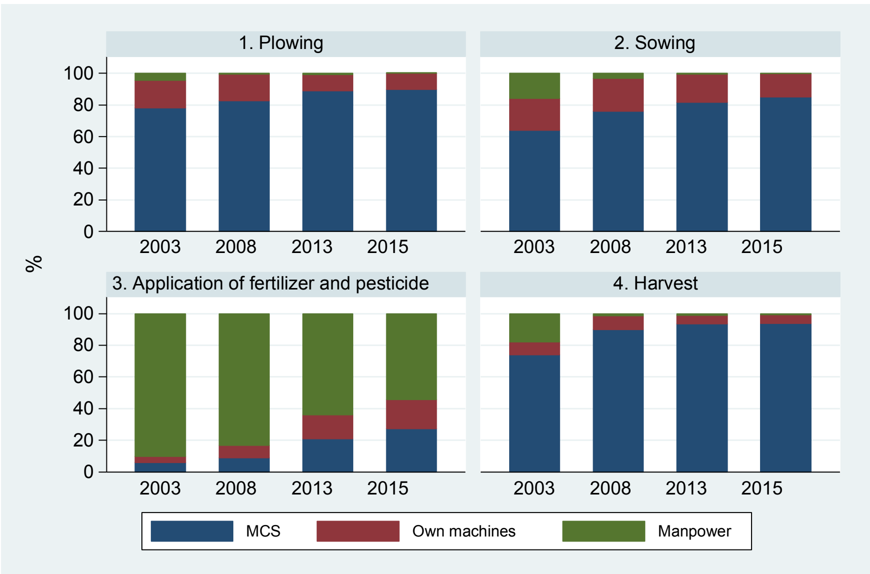

Fig. 8.7 Percentage of mechanisation in wheat farming, North China, 2003–2015. *Source* Yi (2019)

Farmers did most of the remainder with their own machines; ploughing for wheat in Northern China was thus nearly 100% mechanised. The area share of MCS in harvesting is even higher and increased faster, from 74% in 2003 to 94% in 2015. The sowing share is a little lower, but MCS still dominate, covering 64% of the area in 2003 and 85% in 2015. Farmers' own machines thus account for roughly 15% of sowing. In contrast to the overwhelming dominance and fast expansion in these three operations, the area share of MCS in fertiliser and crop protection application has remained low. By 2015, it had reached only 27%, up from 6% in 2003. The use of chemicals requires a lot of human judgement, deciding whether, when, how much and how to apply them. The emphasis in ploughing, sowing and harvesting is more on machine power.

8.4.3 Concluding Remarks

National statistics and household surveys point to several conclusions. First, agricultural mechanisation has rapidly expanded over the last 40 years, especially since the late 1990s. The number of smallholders using machinery and the area farmed mechanically have both increased dramatically. Secondly, institutional innovation such as the establishment of MCS outlets has considerably boosted mechanisation. MCS are involved in all major crops and operations. Thirdly, MCS are largely engaged in power-intensive operations such as ploughing, sowing and harvesting. In operations that require more human judgement, such as input application, manpower currently prevails. There is still much space for mechanisation. Fourthly, MCS benefit small-scale farms by providing machinery services at competitive prices. As more and more farmers purchase their own machines, more of them also decide to provide MCS. The resulting closer connection between providers and users encourages local innovations that match specific conditions. Lastly, the significant growth of MCS institutions is not only a response to rising wages. Government incentives also play a role. Farmers who set up an MCS business and buy machinery benefit from a subsidy of one-third of the purchase price. (For details, see the chapter on Chinese incentives.)

The institutional innovation of MCS in China has important implications for many developing countries aiming to raise agricultural labour productivity and farmers' income. Many smallholders elsewhere are not able to intensify their production, expand their farms or allocate more time to off-farm income generation. This is often simply because they lack agricultural mechanisation. China's experience with MCS, including policy support and subsidies, is an example that can be transferred abroad.

8.5 Agricultural Extension Institutions and Innovations

Over the past 40 years, China has also developed and reformed its agricultural extension system. Before the reform, public extension worked "top-down" and fluctuated in scale. Staff numbers went up and down. Since 2010, they have stabilised at about 700,000, having earlier peaked at more than one million employees.

Public agricultural extension has always been dominant, but other organisations have become increasingly active. They include universities, agricultural companies and professional technical associations.

8.5.1 Evolution of Agricultural Extension System

Five stages of evolution and reform have shaped public extension over the past four decades.

8.5.1.1 Establishing Extension for Individual Households, 1978–1988

After the implementation of the HRS, agricultural extension institutions faced great challenges. Under the previous collective system, the government had planned and/or guided all extension and technology adoption. Crop or livestock farming within production teams or villages was run by local leaders. Technology and information services came mainly from higher layers of government. Households participated in production but did not make production or marketing decisions. This changed with the move from collective to individual household production. Farmer demand for diversified technologies rose significantly, as did the resulting cost of extension. The government responded by increasing the numbers of extension stations and staff close to farmers and villages. By the end of the 1980s, all townships had extension stations, operated by some 450,000 employees.

8.5.1.2 Commercialising and Decentralising, 1989–1992

The expansion of agricultural extension increased the financial burden on local governments. The central government, therefore, allowed county and township extension stations to conduct commercial activities to help fund staff salaries. County governments passed on their responsibility for extension stations, delegating the personnel, finance and asset rights to townships. Township budget constraints led to a large cut in agricultural extension. Overall employee numbers fell to around 300,000.

8.5.1.3 Re-Establishing a Strong System, 1993–2000

The 1989–92 reduction in extension was accompanied by a short period of stagnating grain production in the early 1990s. This stagnation drew the attention of political leaders. From 1993, the accent was once more on expanding extension capacity. County governments took back station management from the townships and invested heavily in extension. By 1999, more than one million Chinese worked in this sector.

8.5.1.4 Further Commercialisation and Curtailing, 2001–2003

The build-up of extension faltered in the late 1990s. Many regions lacked the budget for such a large staff. Extension agents sought to support themselves with commercial activities, particularly by selling fertiliser, crop protection products, machinery and seeds. Such activities distracted their attention from extension and tempted them to provide biased advice. Huang et al. (2009) showed that, on average, staff at township stations spent only 24% of their time on actual extension. Three-quarters of their working hours were devoted to administration or commercial business.

Another set of reforms sought to solve the financial problems. Staff were divided into those working full-time in extension and those engaged in commercial activities. The results were mixed, due to lack of funding and accountability. The government once again pushed the county system down to township level. Fiscal constraints led the townships to reduce staff numbers to about 849,000.

8.5.1.5 Construction of a Strong, Well-Funded System After 2003

In response to the poor results so far, new reforms began from 2003 onwards. These aimed at serving farmers better by separating commercial activities from public extension, increasing staff incentives and responsibilities, shifting personnel management from townships to counties and increasing the budget. An empirical study shows evidence of more engaged and effective extension in the pilot reform areas (Hu et al. 2012). Today's public extension system employs more than 700,000 personnel. Funding comes from counties, with additional support from higher government levels.

8.5.2 Current Institutional Framework of Agricultural Extension

China's extension system shares goals with those in many other developing countries. The focus is on improving productivity, food security and farmers' income through access to new technologies, marketing information and other offers. To achieve these goals, China has set up a comprehensive, top-down, decentralised system (Fig. 8.8). Extension covers nearly all agricultural commodities, provides technology, information and training, and is present at all administrative levels. The system is highly localised and the world's largest. Extension institutions range from national centres/stations at the Ministry of Agricultural and Rural Affairs (called the Ministry of Agriculture before 2018) to local centres/stations at township or sub-county levels.

Over the past four decades, while the institutional framework has adjusted, the top-down approach with a clear division of extension functions at different levels has remained similar (Fig. 8.8). There are currently five levels: national, provincial, prefectural, county and sub-county/township. (The sub-county level combines several townships.) Extension centres/stations at the top level are in charge of national strategic planning, key extension and training programmes, business guidance to lower-level organisations, monitoring and evaluating major programmes, and providing technology and marketing information. Provincial and prefectural centres/stations are the agricultural bureaus of their respective governments. Their functions are similar to those at the national level but limited to their own jurisdictions.

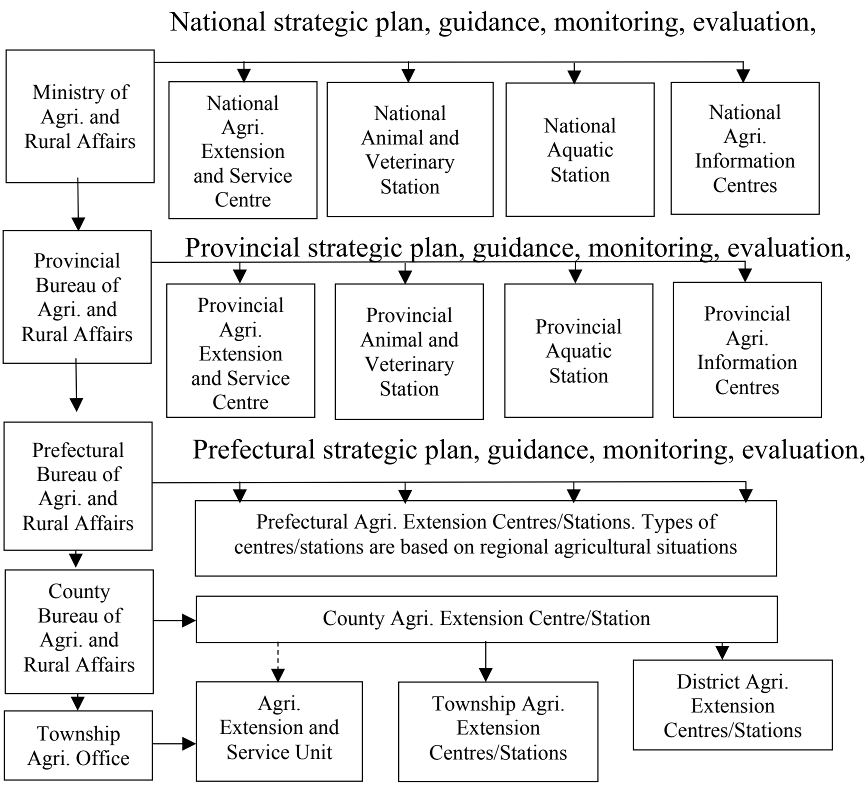

Fig. 8.8 Structure of the agricultural extension system in China

Extension services are delivered through the centres/stations at county and township level. In some counties where townships are not too far apart, district centres/stations cover extension for more than one township; they are the outposts of the county centres/stations. These district organisations account for about 15% of extension stations below county level. Eighteen per cent of extension stations are in townships. Together, these two layers provide "grassroots" coverage and employ more than 75% of public extension staff (Zhong 2014). Governments currently cover the full costs at their respective levels.

Over time, the system has become more pluralistic. An increasing number of other organisations now also provide extension services. The main sources are universities and research institutes, agriculture-related companies, professional technical associations and farmers' co-operatives. Extension services from universities and research institutes are often arranged and guided by the government or driven by market demand. To encourage universities and research institutes to engage more in agricultural extension, the extension service for farmers has become one of the important indicators for their performance and evaluation. Private companies' extension focuses mainly on agricultural inputs such as seed, fertiliser and agricultural mechanisation. Professional technical associations typically concentrate, under government auspices, on specific commodities or special technology training.

8.5.3 Recent Innovations and Reforms

In the past decade, China has implemented several new institutional arrangements and programmes on agricultural extension. This section introduces some innovations with implications for future reform in China and other developing countries.

8.5.3.1 The Institutional Arrangement for Financial Assurance

This reform aimed to reduce extension staff time spent on commercial activities by providing financial assurance. In 2006, national document No. 30 proposed the separation of commercial activities from extension services, thereby reaffirming the public welfare mandate of agricultural extension. As well as separating the commercial activities, institutional arrangements were made to fully fund extension. This enabled the replacement of the system in which some staff funded their extension work through commercial activities such as selling inputs and some combined these activities with partial state funding.

8.5.3.2 The Institutional Arrangement for "Three Rights" Management

Before the reform, township governments managed their extension stations' "three rights" (personnel, finance and assets). This led to the problem of staff spending too much time on non-extension activities when there was a lack of budget (Hu et al. 2009). National document No. 30 proposed that while township extension is located at a township and also supervised by the township government, the “three rights” should be managed at the county level. Provinces adopted different management models in response. Today, some township stations are still managed locally, but most run at county level. In the former case, townships are obliged to present assurances on financing and responsibility.

8.5.4 Concluding Remarks

In their search for a better system, government officials have continuously experimented with different ways to reform public extension. Despite this twisting path, China has developed a robust system. It is the world’s largest by staff numbers and covers nearly every corner of the country. This, together with the strong public research system, has contributed to rapid growth in agricultural productivity. In the long run, technological change is a primary source of agricultural productivity growth for every system, including China’s. Total factor productivity (TFP) has risen strongly in the grain sector, but even faster in cash crops and livestock. In 1995–2005, annual TFP growth in these two sectors exceeded 3.5% (Jin et al. 2010). Using provincial data, Wang et al. (2019) concluded that China’s overall agricultural TFP increased by 2.8% per annum between 2000 and 2013.

China’s experiences underline the importance of maintaining a strong public agricultural extension system if the private sector is weak in the system. Success relies both on allocation of adequate funds and the existence of suitable institutions. Alongside future reforms of the public system, however, China needs to create a better environment for private sector extension. Public–private partnerships may also provide valuable improvements. At the same time, there is a need to attract more young professionals into extension, enhancing current capabilities and ensuring continuing success in the future (Hu et al. 2009, 2012).

References

Banerjee, A., & Lakshmi, I. (2005). History, institutions, and economic performance: The legacy of colonial land tenure systems in India. *The American Economic Review, 95*(4), 1190–1213.

Brandt, L., Jikun, H., Guo, Li., & Scott, R. (2002). Land rights in rural China: Facts, fictions and issue. *The China Journal, 47*(1), 67–97.

Calow, R. C., Simon, E. H., & Wang, J. (2009). Irrigation development and water rights reform in China. *International Journal of Water Resources Development, 25,* 227–248.

Carter, M. R., & Yang, Y. (2002). Local versus global separability in agricultural household models: The factor price equalization effect on land transfer rights. *American Journal of Agricultural Economics, 84*(3), 702–715.

China Machinery Industry Federation (1986–2016). *China agricultural machinery industry yearbook* (in Chinese). Machinery Industry Press, Beijing.

Debaere, P., Richter, B., Davis, K., Duvall, M., Gephart, J., O'Bannon, et al. (2014). Water markets as a response to scarcity. *Water Policy, 16*(4), 625–649.

Deininger, K., & Jin, S. (2009). Securing property rights in transition: Lessons from implementation of China's rural land contracting law. *Journal of Economic Behavior & Organization*, *70*, 22–38.

Elvinia, Jose, (2011). Is land reform a failure in the Philippines? An assessment on CARP' In: Limits of good governance in developing countries, 333–362.

Etchells, T., Malano, H., & McMahon, T. (2006). Overcoming third party effects from water trading in the Murray-Darling Basin. *Water Policy, 8,* 69–80.

Fan, S. (1991). Effects of technological change and institutional reform on production growth in Chinese agriculture. *American Journal of Agricultural Economics, 73,* 266–275.

FAO (Food and Agricultural Organization of the United Nations), (2012). Voluntary guidelines on the responsible governance of tenure of land, fisheries and forests in the context of National Food Security. FAO, Rome.

Gao, L., Jikun, H., & Scott, R. (2012). Cultivated land rental market and investment in China. *Agricultural Economics, 43*(4), 391–403.

Hu, R., Cai, Y., Chen, K. Z., & Huang, J. (2012). Effects of inclusive public agricultural extension service: Results from a policy reform experiment in Western China. *China Economic Review, 23*(2012), 962–974.

Hu, R., Yang, Z., Kelly, P., & Huang, J. (2009). Agricultural extension system reform and agent time allocation in China. *China Economic Review, 20,* 303–315.

Huang, J. (2017). Land transaction service centers in China: An institutional innovation to facilitate land consolidation. *A project report submitted to Food and Agriculture Organization of the United Nations (FAO).* Bangkok: Regional Office for Asia and the Pacific.

Huang, J., & Rozelle, S. (1996). Technological change: The Re-discovery of the engine of productivity growth in China's rural economy. *Journal of Development Economics*, *49*, 337–369.

Huang, J., & Rozelle, S. (2015). The role of agriculture in china's development: Performance, determinants of successes and future challenges. In: P. Shome, P. Sharma (Eds.), *Emerging economies: Food and energy security, and technology and innovation*, Springer Press.

Huang, J., & Ding, J. (2016). Institutional innovation and policy support to facilitate small-scale farming transformation in China. *Agricultural Economics, 47*(S1), 227–237.

Huang, J., Hu, R., & Zhi, H. (2009). Development and reform of local agricultural extension system in the past 30 years: Policy evaluation and recommendation. *Journal of Agrotechnology Economics, 1,* 4–10.

IPCC. (2014). Climate change 2014: Synthesis report. Contribution of working groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on climate change. In R. K. Pachauri & L. A. Meyer (Eds.), *Core writing team* (p. 151). IPCC: Geneva, Switzerland.

Jacoby, H. G., Guo, Li., & Scott, R. (2002). Hazards of expropriation: Tenure insecurity and investment in rural China. *American Economic Review, 92*(5), 1420–1447.

Ji, X., Huang, J., & Gao, L. (2014). Can the current chinese farmland policy effectively restrain the land adjust: An empirical analysis based on the village level date. *Journal of Agrotechnical Economics, 10,* 4–11.

Jia, L., & Martin, P. (2014). How does land fragmentation affect off-farm labor supply: Panel data evidence from China. *Agricultural Economics, 45*(3), 369–380.

Jin, S., Huang, J., Hu, R., & Rozelle, S. (2002). The creation and spread of technology and total factor productivity in China's agriculture. *American Journal of Agricultural Economics*, *84*(4), 916–930.

Klaus, D., & Jin, S. (2005). The potential of land rental markets in the process of economic development: Evidence from China. *Journal of Development Economics, 78,* 241–270.

Kung, J.-S. (2000). Common property rights and land reallocations in rural china: Evidence from a village survey. *World Development, 28*(4), 701–709.

Lardy, N. R. (1983). *Agriculture in China's modern economic development*. Cambridge: Cambridge University Press.

Lerman, Z., Csaba, C., & Gershon, F. (2004). *Agriculture in transition: Land policies and evolving farm structures in post-Soviet countries.* Oxford: Lexington Books.

Lewis, D., & Zheng, H. (2018). How could water markets like Australia's work in China? *International Journal of Water Resources Management, 34*(3), 1–21.

Li, D. (2002). China's irrigation management and farmers' participation in irrigation management. *China Rural Water and Hydropower, 5,* 1–3.

Li, G., Scott, R., & Loren, B. (1998). Tenure, land rights, and farmer investment incentives in China. *Agricultural Economics, 19*(1–2), 63–71.

Lin, J. Y. (1992). Rural reforms and agricultural growth in China. *American Economic Review, 82,* 34–51.

Liu, S., Carter, M. R., & Yao, Y. (1998). Dimensions and diversity of property rights in rural china: Dilemma on the road to further reform. *World Development, 26*(10), 1789–1806.

Lohmar, B., Wang, J., Rozelle, S., Huang, J. & Dawe, D. (2003). China's agricultural water policy reforms: Increasing investment, resolving conflicts, and revising incentives. *Agricultural information bulletin, 782,* Market and Trade Economic Division, Econ. Res. Serv., U.S. Dep. of Agric., Washington DC.

McMillan, J., Whalley, J., & Zhu, L. (1989). The impact of China's economic reforms on agricultural productivity growth. *Journal of Political Economy, 97*(4), 781–807.

Ministry of Agriculture, China (1980–2016). *China agriculture yearbook* (in Chinese). China Agriculture Press, Beijing

Ministry of Agriculture of China. (2009). *Sixty Year's statistical materials of China (in Chinese).* Beijing: China Agriculture Press.

MOA (the Ministry of Agriculture of China). (2014). The status of transferring rural household responsibility land in 2013. *Rural Business and Management, 5,* 42.

MWR (Ministry of Water Resources). (2016). *Monthly groundwater dynamics.* Beijing: Ministry of Water Resources.

MWR (Ministry of Water Resources) (2016). *Statistical bulletin of National water conservancy development*.

Sheng, Y., Ding, J., & Huang, J. (2019). The relationship between farm size and productivity in agriculture: Evidence from Maize production in northern China. *American Journal of Agricultural Economics, 101*(3), 790–806.

Sun, T., Wang, J., Huang, Q., & Li, Y. (2016). Assessment of water rights and irrigation pricing reforms in Heihe River Basin in China. *Water, 8*(333), 1–16.

Wang, J., Huang, J., & Yan, T. (2013). Impacts of climate change on water and agricultural production in ten large river basins in China. *Journal of Integrated Agriculture, 12*(7), 1267–1278.

Wang, J., Huang, J., Huang, Q., & Rozelle, S. (2009). The evolution of China's groundwater governance: Productivity, equity and the environment. *Quarterly Journal of Engineering Geology and Hydrogeology, 42,* 267–280.

Wang, J., Huang, J., Zhang, L., & Huang, Q. (2014). Do incentives still matter for the reform of surface irrigation management in the Yellow River Basin in China? *Journal of Hydrology, 51,* 584–594.

Wang, J., Jiang, Y., Wang, H., Huang, Q., & Deng, H. (2019). Groundwater irrigation and management in northern China: Status, trends, and challenges. *International Journal of Water Resources Development*. https://doi.org/10.1080/07900627.2019.1584094.

Wang, J., Xu, Z., Huang, J., & Rozelle, S. (2005). Incentives in water management reform: Assessing the effect on water use, productivity and poverty in the Yellow River Basin. *Environment and Development Economics, 10,* 769–799.

Wang, J., Xu, Z., Huang, J., & Rozelle, S. (2006). Incentives to managers and participation of farmers: Which matters for water management reform in China? *Agricultural Economics, 34,* 315–330.

Wang, J., Huang, J., Zhang, L., Huang, Q., & Rozelle, S. (2010). Water governance and water use efficiency: The five principles of WUA management and performance in China. *Journal of the American Water Resources Association, 46,* 665–685.

Yang, J., Huang, Z., Zhang, X., & Reardon, T. (2013). The rapid rise of cross regional agricultural mechanization services in China. *American Journal of Agricultural Economics, 95*(5), 1245–1251.

Yao, Y. (2000). The Development of the land lease market in rural China. *Land Economics, 76*(2), 252–266.

Yi, Qing (2019). Agricultural mechanization custom service supply, demand and agricultural productivity. Dissertation. Chinese Academy of Sciences.

Zhang, L., Wang, J., Huang, J., & Rozelle, S. (2008). Development of groundwater markets in China: A glimpse into progress. *World Development, 36,* 706–726.

Zhang, L., Wang, J., Huang, J., Huang, Q., & Rozelle, S. (2010). Access to groundwater and agricultural production in China. *Agricultural Water Management, 97,* 1609–1616.

Zhang, Y., Xiaobing, W., Thomas, G., & Bernhard, B. (2011). The impact of land reallocation on technical efficiency: Evidence from China. *Agricultural Economics, 42*(4), 495–507.

Zhong, Z. (2014), China agricultural extension: History, current status, and supply-demand characteristics. *Asia-Pacific information platform for agricultural policy*, available at: https://ap.fftc.agnet.org/ap_db.php?id=194 (accessed March, 30, 2014).

Chapter 9
Israeli Agriculture—Innovation and Advancement

9.1 Background

Israel's agricultural experience is unique. Despite pervasive water shortages, historic soil erosion and dry land conditions, Israel has become a leader in agricultural innovation, showing the world what can be done to improve agricultural yields with limited water if a country is ready to invest in knowledge-intensive and innovation-driven systems. This chapter offers a brief description of Israel's agricultural technologies, policies and institutions, depicting the "ecosystem" that has produced a steady stream of innovations throughout the agricultural value chain along with its favourable impact on agriculture. In particular, it presents the role of government support in providing adequate incentives as well as in establishing institutions that govern access to critical inputs such as land, water, farm machinery and agricultural extension—inputs which strongly influence agricultural output and farmers' incomes. This has important lessons for many developing countries, especially in Asia and Africa.

Against the backdrop of the Zionist movement and Jewish immigration to Palestine at the start of the twentieth century, Socialists sought to re-establish the Jewish nation in Israel and reclaim the status of the Jewish farmer by holding agriculture as a national mission (Tal 2008). Inspired by the Zionist vision and a passion to achieve self-sufficiency in feeding a growing nation, they established farming co-operatives—the kibbutzim (1910)[1] and the less collective moshavim (1921).[2] This led to a strong, centralised planning system where each farmer was instructed which crop to grow and in what quantity (Tal 2007a, b).

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[1]The kibbutzim were based on egalitarian and communal principles, and their aspiration was to be self-sufficient. All revenue generated by kibbutz members went into a common pool to be managed by a central committee, and all members received an equal budget regardless of their job (Tal 2016).

[2]A moshav is a service co-operative in which the membership comprises individual farmers who reside within the settlement.

A. Gulati et al., *From Food Scarcity to Surplus*,
https://doi.org/10.1007/978-981-15-9484-7_9

Nevertheless, despite the massive investment by international Jewish philanthropy during the first half of the twentieth century and the extraordinary dedication of Israel's pioneers, when Israel attained independence in 1948, the country could only be sustained through international aid. The population was increasing exponentially and its per capita GDP was hardly USD1000 (Tal 2016a). In order to absorb the burgeoning number of people and address the problems of rampant unemployment and housing shortages, new agricultural communities were created. Most of these new farmers, however, had minimal experience in raising crops and livestock in dry land conditions. To address the dynamics, Israel's incipient agricultural bureaucracy quickly established a support system for local farmers that continue until today. This three-tiered system has been jocularly referred to as the "Holy Trinity" and is frequently cited as the key to Israel's agricultural success. The three institutional tiers include:

1. Basic and applied agricultural research at universities and the Ministry of Agriculture's vaunted Volcani Institute;
2. A network of eight regional research and development centres serving farmers across the country; and
3. An extension service (Sha'ham—based on the Hebrew acronym for Technical Advisory Services) of 150 agricultural field workers, in addition to a small but highly trained army of advisors who assist farmers in meeting the challenge of plant protection (Tal 1998).

During this time, Israel's government also supported existing agricultural co-operatives and farmers through tax reductions, protection from competitive imports, large subsidies and financial investments in the development of agricultural infrastructure (roads, water, electricity and logistics). Moreover, to inhibit competition between co-operatives, production quotas were established for every co-operative branch. Besides this, the government invested in establishing an R&D and extension ecosystem, reservoirs and roads connecting the farmers (Rosenthal and Eiges 2014). These continue to play a key role in developing a successful agriculture sector in Israel.

In the mid-1980s, the country's macroeconomic efforts to control inflation rates also affected the agricultural sector. Although the initial retreat from many paternalistic interventions was not without casualties, the new orientation further stimulated the policy innovation of liberalising the agricultural sector. This marked the beginning of the reform era in the history of Israeli agriculture. The government reduced its interference in agricultural markets and significantly cut back on financial support for agricultural co-operatives, while initiating steps that facilitate increased competition (Ben-Bassat 2002).

The farming sector faced budgetary cuts, reductions in subsidies and the discontinuation of the production quota system for a few crops (OECD 2010). A majority of the agricultural co-operatives did not adapt well initially to the new market conditions and began accumulating huge debts. Thus, by the end of the 1980s, it was clear that rehabilitation plans would be necessary to save the co-operatives as well as the banks that funded them in order to effectively stabilise the economy and the farming sector (Sofer and Applebaum 2006).

The situation became even grimmer during the 1990s when a massive wave of over a million new immigrant moved to Israel from the former Soviet Union, increasing the total number of mouths to feed by more than 20% almost overnight. The government, however, stayed the course and continued to let the market lead. At the same time, it invested heavily in public research and development, focused on improving crop varieties to allow Israeli farmers to compete in target markets and facilitated crop switching and expansion. This market-led/government-steered approach contributed to local agricultural innovation by finding commercial opportunities for almost every part of a crop or animal (Schnell et al. 2017).

As a result of dedicated R&D and training—as well as a consistently close relationship and mutual accessibility between researchers, extension agents and farmers—Israel witnessed a remarkable transformation, especially in its arid southlands. Many farmers living in dry lands and deserts expanded their agricultural lands, establishing a thriving export industry for several crops/commodities, based on the country's competitive advantage (Tsaban 2017).

In 2018, Israel recorded the highest productivity of cow milk in the world at 13,000 L per cow per year (Faostat 2019). Further, Israel's tomato yield was 300 tonnes per hectare, compared to an average of 50 tonnes per hectare worldwide (Ben-Zoor and Priampoisky 2015).

The country remains a world leader in the production of fruit such as pomelit, pomegranates, nectarines, plums, dates, strawberries and avocados. Israel also leads in post-harvest handling: it records 0.5% of grain storage loss, compared to a 20% average worldwide (Israel, Ministry of Agriculture 2019).

There are numerous possible explanations for Israel's exceptional success in agricultural innovation and development of new technologies. The most obvious one is a pervasive national sentiment which has long since recognised: *"If we don't continuously produce something with added value, we'll be out of business"*. In addition, farmers in Israel are extremely nimble and frequently change crops or adopt advanced technology based on market conditions, price incentives and the ever-available coaching from government extension personnel. Thus, not only is there always an incentive to do better, but local scientists have developed compelling alternatives (Mualem 2018). Motivation alone, however, is not sufficient for success. There is also a need to correctly set the rules of the game that govern those resources critical for agriculture's lasting economic and environmental sustainability.

9.2 The Israeli Economy

Israel occupies a total land area of merely 2.16 million ha (Mha). Of this, the total area zoned for agricultural production is 0.62 Mha, accounting for about 28.7% of the country's land mass. At the same time, the actual arable area in Israel accounts for a mere 20% of the total land area (Table 9.1). Correspondingly, two-thirds of the

Table 9.1 Basic statistics and population, Israel

Physical Areas			
Land area	2017	2.16	Million Hectares
Arable land/cultivated area	2017	0.39	Million Hectares
Agricultural area	2017	0.62	Million Hectares
Population			
Total population	2019	9.1	Million
As a share of world population	2019	0.1	%
Rural population	2019	8	%
Population density	2019	393.7	Persons per sq. km
Economy and development			
Gross domestic product (GDP) current	2018	394	Billion USD
GDP per capita current	2018	43,400	USD per person
Share of agriculture in total GDP	2018	1	%
Employment			
Percentage of workforce employed in agriculture	2019	1	%

Source World Development Indicators (2019) and Bank of Israel (2020)

land area is arid or semi-arid. These challenging baselines climatic conditions make the Israeli agricultural story even more extraordinary.

As of early 2020, Israel's population was about 9.1 million, only about 0.1% of the global total (Israel Central Bureau of Statistics 2020). Over the past two decades, its population growth has been roughly 2% per annum, reflecting fertility rates about twice the average in OECD countries. At the same time, the share of the rural population in the country's total population continues to dwindle and today is only 8.6%.

In terms of GDP, the size of Israel's economy at the end of 2019 was about USD394 billion (World Bank 2020). Over the last decade, the economy grew steadily at around 3.5% per year—but this figure needs to be understood within the context of the country's rapid population growth: per capita GDP during this period, therefore, only increased by 1.6%. Nonetheless, Israel's per capita GDP today is more than USD42,000 per annum, considerably higher than that of China and India. The contribution of agriculture to total GDP and employment, however, has long been in decline and at present is roughly 1% (Table 9.1).

9.3 Israel's Framework for Agricultural Research and Innovation

For much of Israel's history, its agricultural production technologies benefited from effective government incentives and competent supportive institutions, resulting in a steady string of impressive agronomic achievements. Scientifically, Israel's academic institutions enjoy international recognition as centres of excellence. One indicator of the country's scientific achievement is the 12 Israeli Nobel Prize laureates, among the highest, per capita in the world.

Israeli universities hold the twin advantages of extremely low-cost, high-quality graduate students, along with world-class professors, whose wages are automatically covered by the government. The country's two leading research institutions in agriculture are the government sponsored Volcani Institute[3] and its affiliated facilities and the Faculty of Agriculture of the Hebrew University at its Rehovot campus. In addition, valuable research is conducted at the Faculty of Life Sciences at Tel Aviv University as well as the Department of Dry Land Agriculture at Ben Gurion University's Sede Boqer campus and the Agricultural Engineering Department at the Technion, Israel Institute of Technology.

9.3.1 The Volcani Institute and the Ministry of Agriculture and Rural Development

The Volcani Institute's 100 million-dollar annual budget supports some 200 Ph.D. level researchers and their teams of technicians and graduate students. Roughly 60% of the institute's funding comes from the government and another 40% from competitive research grants received by its scientific staff. The institute is held in high regard throughout Israel and beyond. In recent years, the institute's scientific staff has placed a far greater emphasis on applied research that can produce a commercial project rather than on theory. In a 2018 review, summarised in Table 9.2, Rotem Zelingher, reports an impressive and steady increase in the number of patents for agriculture-related inventions developed at the Volcani Institute. Dozens of new crop types and technologies are manifested in dramatically enhanced productivity, as detailed throughout this chapter.

One of the key political shifts that have taken place in Israel, in this context, is the change in the perceived role and status of the Ministry of Agriculture. The overall ministerial budget is still substantial by Israeli standards: In the 2017–2018 budget, the ministry received 340 million dollars for agricultural activities and 571 million dollars for rural development, which includes a substantial budget for supporting Israel's underprivileged, Bedouin population. Relative to its past dimensions as a percentage of government expenditures, the ministry has declined. Nonetheless, its role as a catalyst of new technological ventures to support agriculture has become central to its institutional identity in recent years. Ironically, during the 1990s,

[3]Since its inception, the Volcani Institute has had more agricultural researchers than all the other Israeli institutions combined. The institute is divided into three different facilities: Volcani Institute headquarter, located near Tel Aviv at the Beit Dagan campus which is also home to the Ministry of Agriculture's central offices; a southern research instillation at Gilad; and a northern research centre at Neveh Ya'ar. The professional staff at the three centres is in constant communication and take advantage of the enormous professional and climatic contrasts between their locations.

Table 9.2 Number of patents attained in Israeli agriculture

Years	Israeli	Internationally
1970/74	4	0
1975/79	6	3
1980/84	17	6
1985/89	27	33
1990/94	13	21
1995/99	32	12
2000/04	35	56
2005/09	25	38
2010/14	30	71
2015/17	29	61

Source Zelingher (2019), Milken Center

when Israel was far less of a "start-up nation", there were more aggressive support programmes for the agro-tech sector by the government.

9.3.2 The Israel Innovation Authority

Agro-tech in Israel benefits from the country's generally hyperactive technology sector. Delighted with its successes and global reputation as the "start-up nation", the Israeli government moved to create a formal government framework for nourishing this local entrepreneurial culture. Established in 2016, the Israel Innovation Authority (Reshut HaChadshanut) is a relatively new agency that operates under the auspices of the Ministry of Economics. Its start-up division is described on its website as offering "unique tools to support the early development stages of technological initiatives". These tools assist entrepreneurs and start-up companies to develop the technological concepts at the preseed or initial R&D stages, transform their ideas into reality and reach significant fundable milestones (Israel Innovation Authority 2020). While the authority has two modest programmes in academic research, their funds are prioritised for young Israeli companies or to help foreign ventures break into Israel.

In a relatively short time, the authority has emerged as a significant government player in Israel's, entrepreneurial culture, supporting Israel's technology programme in general. With an annual budget of grants close to 500 million dollars, its staff of 150 government workers and 180 external technical reviewers process hundreds of requests for assistance. By design, it does not seek out potentially profitable ventures but receives grant requests through tenders which are meticulously reviewed. The Innovation Authority provides a critical "safety net", allowing new companies to take chances without the same kind of risks that a bank loan might entail or the dilution that a venture capital (VC) firm might expect. The authority also has a series of "bi-lateral" programmes, run by its international division, which are designed to allow for expanded economic involvement and opportunity for investment by companies or venture capitalists from other countries. Agriculture per se is not prioritised by the authority. Their two basic criteria are the same across all programme areas—the level of innovation and the potential profitability (Niriah 2018).

9.3.3 Regional Agricultural R&D Centres

Supplementing the scientific capacity at Israel's universities and the Volcani Institute, the second tier of assistance is provided by a network of eight regional R&D centres. The centres' budgets come from government budgeting, funding from the Jewish National Fund (a public Zionist corporation) and grants received by affiliated researchers. These mid-sized field stations serve as a bridge between farmers' on-site needs and ever-evolving scientific knowledge and technological innovation. Some of these applied R&D centres are credited with making substantial technological breakthroughs (Robins 2018). For instance, the researchers at the Arava R&D Centre played an important role in developing the "family drip" systems, which rely on the low surface tension in smooth plastics. In addition, the Medjool date, which originated in Morocco, was significantly improved as a commercial commodity at the southern research stations in Israel, with quantum leaps in yields, based on systematic evaluations and adjustment. The work at R&D centres creates technical advancements that are more iterative and incremental than transformational. For example, their experiments might involve extending the shelf life of a fruit or developing optimal irrigation protocols.

9.3.4 Israeli Agriculture Extension

Recognition of extension services as a critical input in agriculture began before Israel's independence, when such services were provided by the Jewish Agency. Israel's extension service officially started as a professional service in 1955. It was clear that to achieve the incipient nation's dream of agricultural restoration and food sufficiency, the frequently agriculturally illiterate pioneers needed to be trained and supported. Otherwise, they were likely to leave the new settlements due to the harsh conditions and a key component in the Israeli economic strategy would fail. As a result, many of the country's best performing farmers were employed as extension workers to teach others. The government made extension a national priority and committed the funding (Tal 2007a).

From its early days, central planning has been a feature of Israel's extension service. It was believed that "extension has to be public, provided by the government. If it is private, the advice would not be objective and impartial. In the private sector, there is always a vested interest and farmers cannot survive by paying for extension services. It must be provided by the government. Agriculture must be seen as a natural resource, and land was worth money" (Abraham 2019).

While its numbers have dropped significantly over the years, Israel's Ministry of Agriculture and Rural Development still fields a formidable team of highly professional extension agents. All have formal academic training in agriculture and they maintain a steady communication with the top academic centres as well as the regional R&D centres. During the 1950s and 1960s, Israel had one extension worker for every 50–80 farmers. Today, the ratio is far lower: Israel's extension service comprises 136 people, with two to five consultant specialists per crop, serving approximately 15,000 farmers, a ratio of around one worker for every 110 farmers (Yancovich 2020). Farmers in some remote areas of the country report that in recent years, extension support has been largely unavailable. Since the early days, extension workers operated under the Ministry of Agriculture's crop planning framework. The government continues to plan the number of extension workers around actual production needs.

Israeli farmers, almost without exception, see the agricultural extension system as critical for maintaining existing operations. Additionally, more specialised assistance is provided by the staffers of the "plant protection service" who not only regulate pesticide registration but help farmers identify pests in the field and appropriate chemical or biological responses. This expertise is considered essential for addressing pest problems in real time, with "24/7" access to experts, ready to respond with an informed response to any infestation of insects or mites before they get out of hand.

The historical effectiveness of Israel's agricultural extension service's work can be attributed to several factors. It starts with the level of Israeli farmers themselves, who often have advanced training and for all intents and purposes have been self-selected for being innovative and meticulous. Also, the farming community is fairly tight-knit and happily shares its experiences with neighbors and colleagues. Finally, Israeli extension agents are highly motivated. (By way of contrast, not only is the quality of local extension personnel in developing countries considered problematic, but so is their enthusiasm.) In many cases, this is not their fault. If they are lucky enough to have a motorcycle, they probably do not have funding for petrol or money to fix it (Pearl 2018). In Israel, by contrast, the extension bureacracy is based on reliable, reasonably paid civil servants who enjoy strong academic backing. It is also a decidedly friendly and informal system. There is nothing unusual about a farmer making direct contact with a university professor or other experts to elicit help in solving a problem.

There are a few private Israeli companies that also provide technical assistance and advice. Companies like Com*Cultivu; Agriculture Knowledge on-line (AKOL);* and *AgriTask* provide valuable agronomic information, insights about market conditions and weather reports in real time to farmers over calls, messages and the Internet. Indeed, many farmers report that the practical help they regularly get from well-informed representatives of feed or equipment companies may be the most valuable counsel they receive.

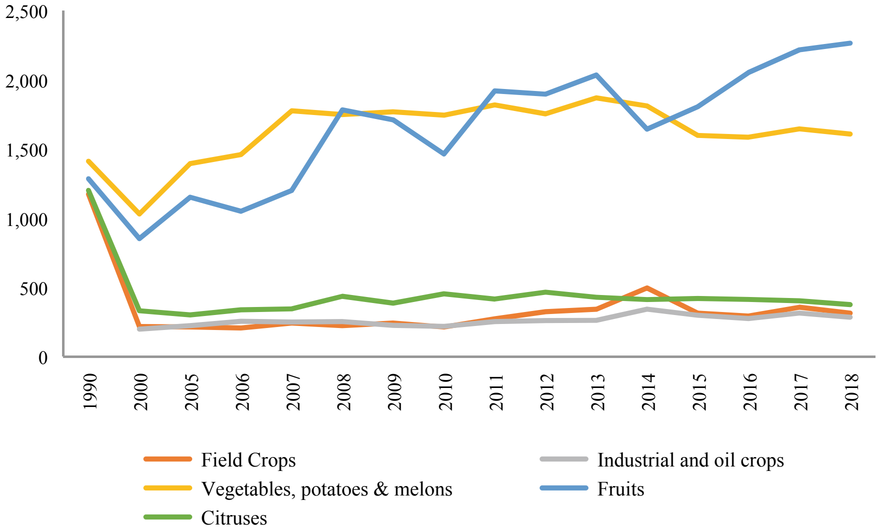

Fig. 9.1 Value of production (in millions of USD) deflated by output prices in Israel. *Source* Annual Census, CBS of Israel (2020)

9.4 Israeli Agricultural Innovations in Production Technologies

Maintaining a flourishing agricultural sector in desert conditions and reversing trends of desertification constitute one of Israel's greatest successes in terms of global agricultural innovation. More than 40% of the country's vegetables and field crops are grown in the desert (Abraham 2019). In addition, the desert is home to fish farms, olive groves, vineyards, date palms and crops for alternative industries. One such example is jojoba.[4] Even though the plant is native to western North America, Israel's Negev desert is now the world's largest commercial producer and distributor of jojoba worldwide, accounting for nearly 50% of overall global production. Another crop Israel revolutionised is melons, especially Galia melons—named after the daughter of Zvi Karchi, the Volcani Institute plant scientist who developed the hybrid in the 1970s. Some 90% of Israeli melons are grown in the hyperarid Arava and Jordan Valleys.

This steady growth in yields is manifested in the increased production of vegetables and especially the 700 thousand tons of fruit crops, grown annually by some 4,000 farmers. Figure 9.1 presents total aggregate Israeli agricultural production from 1990 to 2017. The increase in fruit production is particularly conspicuous.

[4]Jojoba (*Simmondsia chinensis)* is a shrub native to the arid southwest of the USA, whose nuts can be made into oil. In recent years, jojoba oil has found commercial applications in personal care products (e.g. for combating acne and wrinkles) as well as for medicinal purposes, offering an effective cure for herpes. The plant is also considered to have bio-diesel potential.

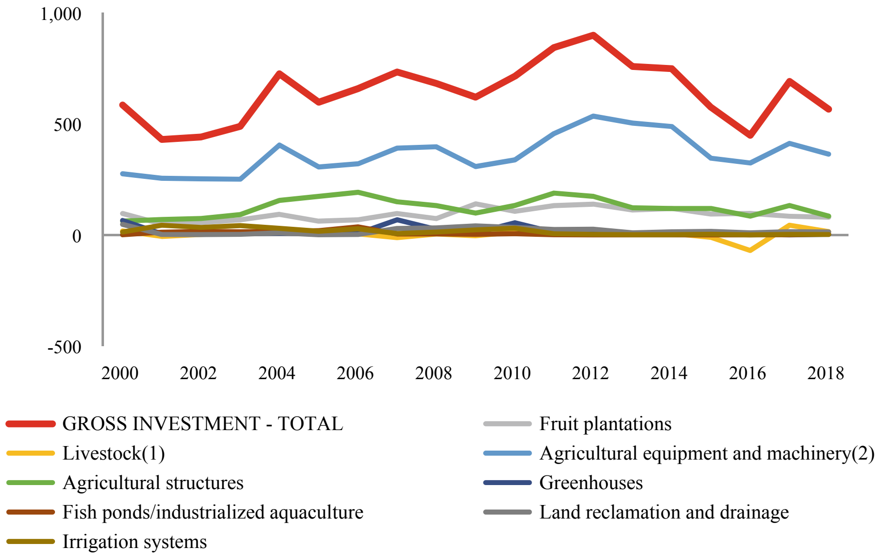

Fig. 9.2 Israeli government investment in agriculture by asset type (in millions of USD), deflated by agricultural output prices. *Notes* (1) *Livestock—changes in livestock inventory, not in investment.* (2) *Agricultural equipment and machinery—includes commercial vehicles over 4 tonnes. Source* Israel Central Bureau of Statistics (2020)

Primary fruit exports include citrus, avocados, dates persimmons and mangoes. As Israel became a wealthier society—with average household incomes inching towards USD50,000—local consumers today are able to purchase top level produce at prices comparable to Europe.

The dramatic increase in fruit values as well as that of vegetables, potatoes and melons is particularly impressive, because investment in fruit plantations has remained fairly steady while total investment in agricultural production has actually decreased over the past several years. Figure 9.2 offers an indication of the relative level of investments in different categories of assets, made by Israeli farmers since the year 2000. Equipment and machinery, as expected, continue to constitute the most significant inputs. But in general, after peaking in 2012, agricultural investment has actually dropped while production value for fruits and vegetables reached new heights. This offers a strong validation for the contribution of science and technological innovation to agricultural profitability.

An important change in Israel's agronomic equation involves the steady drop in exports and increase in domestic consumption of fruits and vegetables. Israel's total agricultural output for 2018 was estimated at around USD8.3 billion dollars. Of this, only 13% (or 1.15 billion dollars) of agricultural exports were recorded—6% lower than in 2017. Vegetable exports were once extremely diverse, but today are totally dominated by three vegetable crops—potatoes, carrots and peppers—as reflected in Fig. 9.3. Together, they constitute 88% of total vegetable exports for 2018.

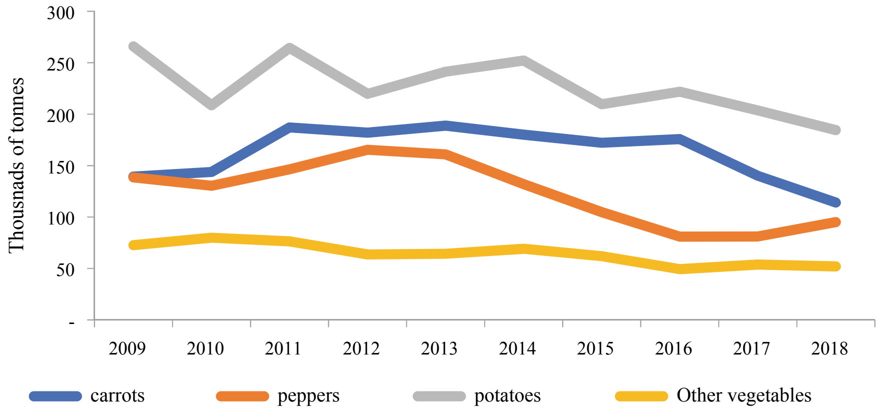

Fig. 9.3 Value of vegetable exports, Israel (2009–2018). *Source* Israeli Ministry of Agriculture and Rural Development, Research, Economics and Strategy Division (2019)

As can be seen in Fig. 9.4, fruit exports are somewhat different. They reflect both a greater diversity of crops along with a general increase in the export of avocadoes and dates.

The OECD records export quantities differently (by weight). Accordingly, Fig. 9.5 appears different. But the overall picture is largely the same: the export of agricultural products used to be a far more dominant part of the Israeli agricultural picture than it is today.

The seemingly steady increase in agriculture production can be misleading in terms of Israel's present food security. As mentioned, the population of Israel has

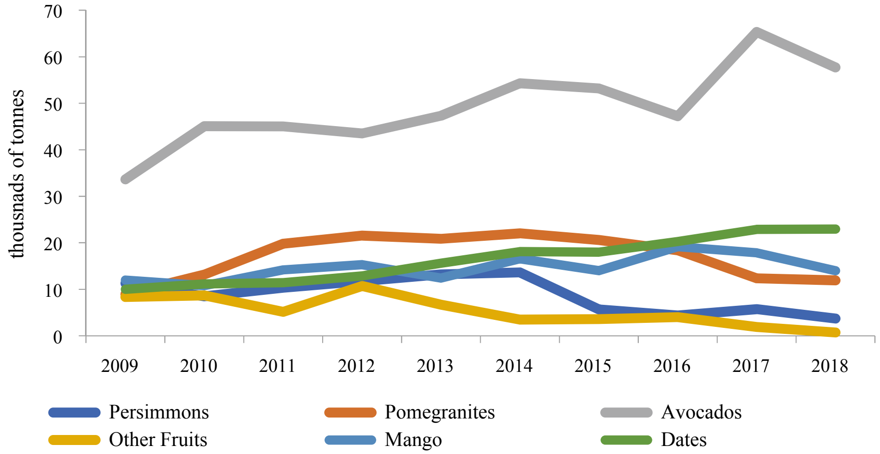

Fig. 9.4 Value of fruit exports, Israel (2009–2018). *Source* Israeli Ministry of Agriculture and Rural Development, Research, Economics and Strategy Division (2019)

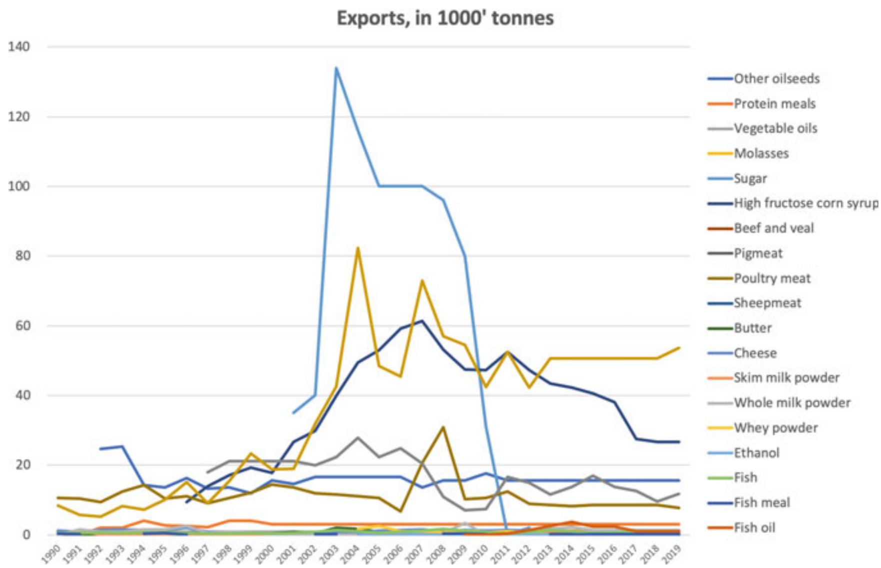

Fig. 9.5 Overall agricultural exports, Israel. *Source* OECD (2020)

expanded more than tenfold during the past 72 years and continues to grow at an annual rate of 2%. Notwithstanding the many impressive breakthroughs in technology and obsession for innovation, for many years now, Israelis total agricultural production has been unable to meet the rising demand for food. A significant part of local calories consumed by the Israeli public, even including produce, must be imported. As presented in Fig. 9.6, the total value of imported food remains

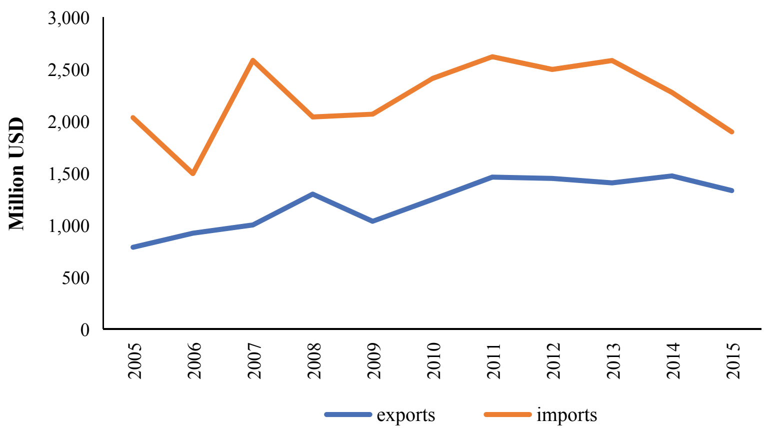

Fig. 9.6 Value of international trade in agricultural produce, Israel (in million USD at current prices). *Source* Israel, Central Bureau of Statistics (2020)

about 50% higher than the agricultural produce being exported, making Israel a net importer of agricultural produce—and a significant importer of feeds and meat/fish. This worrying trend will be explored further in this chapter (Fridman and Kissinger 2019).

9.4.1 Innovations in Seeds, Planting Material and Farming Practices

As described earlier, Israel's approach to innovation is rooted in its agricultural research and extension system. This section offers a review of several promising innovations in agricultural technologies developed in Israel that can offer important lessons for other countries. In preparing this research, dozens of researchers and entrepreneurs were interviewed to present the agricultural and economic benefits of adopting their particular innovations. Almost all emphasise two points that are crucial for a new crop or practice to be implemented on the ground by farmers, especially in developing countries:

1. It is important to provide an entire package of assistance to farmers. Three critical inputs—*irrigation, productive seeds and plant protection*—are essential. If introduced as stand-alone initiatives, new crops are unlikely to produce the desired improvement in yields and higher incomes.
2. Economic feasibility requires minimal economies of scale for companies interested in introducing modern agricultural techniques into any country.

According to senior officials at Israel's Agriculture Ministry, agriculture is a symbol of Israeli innovation and a major contributor to the economic development of the country. It also envisions local agro-tech companies making a meaningful contribution to food security internationally. In other words, at the global level, Israeli agriculture's primary impact is felt through science and technology. Attributing present achievements to past breakthroughs in agricultural R&D, a 2013 Masterplan prepared at the agricultural ministry states that "only entrance into biotechnological and genetic engineering will bring about a meaningful change and a quantum leap to the next phase (in food production)" (Israel Ministry of Agriculture and Rural Development 2013).

In the following section, we look at several selected crop-wise innovations in seeds, breeding technologies and farming practices originating in Israel. All have made major contributions to increased production, improved productivity, better nutritional value as well as higher returns to farmers.

9.4.1.1 Olives

The expansion of Israel's olive industry offers a case in point. Olive trees have been part of the local, Israeli landscape from time immemorial. But for most of Israel's history, it was considered a traditional crop of the indigenous Arab community. Once the world became enamoured of the many health benefits associated with olive oil, the Israeli agro-tech sector began to take notice. It took roughly fifteen years for dramatic results to be seen. Olive yields increased several fold and tree density increased dramatically after the start of the new millennium. This reduced the expenses associated with maintaining an olive grove. And now scientists are moving ahead improving olive crops by *breeding asymmetric particles into olives*. This allows one side of a particle to be hydrophobic and the other hydrophilic, expanding the possible qualities of olives as well as their antioxidant potential.

In the past few years, however, a drop in world prices and expanded global production has slowed the Israeli olive industry. The country divides olive growing into four categories:

- Traditional Arab farms (20,000 ha of lands, but starting to decline);
- Intensive olive plantations, harvested with mechanical trunk shaking (6000 ha, also in decline);
- "Super-intensive" groves—using mechanical picking in the canopy (600 ha, mostly in the Galilee—expanding); and
- Manzanilla table olives (1500 ha—also in decline due to high costs of hand-picking) (Dag 2020).

To a great extent, Israeli olive growers have responded to the world market where prices have been low of late (roughly €2 per litre) not withstanding existing price support. Competing with low-price Spanish and Palestinian olives has pushed some Israeli operations out of the local and international market. Nonetheless, it remains a relatively promising new branch of Israeli agriculture.

9.4.1.2 Animal Husbandry and Dairy Sciences

The Volcani Institute runs an *Institute of Animal Science* which is headquartered on the campus of Hebrew University's Faculty of Agriculture. The institute is home to 22 researchers, divided into three departments—the Department of Poultry, the Department of Aquaculture Sciences and the Department of Ruminant Sciences.

The institute plays a critical role in developing and implementing valuable innovations in animal husbandry. It runs its own farm, located in nearby Beit Dagan on the main Volcani campus for field trials. For instance, Volcani researchers have contributed to significant progress in providing low-cost food for dairy herds without harming their health (Meeri 2019). This involved developing more nutritious seeds and producing food from other farm residuals, such as pomegranate peels or olive oil production residues which would otherwise be thrown away.

The new feeds exhibit tremendous advantages in terms of reduced oxidative stress and strengthening herd immune systems. The new strains of high-yield, rapid growth sorghum and cephalaria being developed have also improved foraging conditions for small dairy farms.

Volcani research has also made a valuable contribution to animal husbandry by reducing thermal or climatic stress for livestock in dry lands, especially for dairy cattle. Study results show a range of optimal feeding regimes that have positively affected milk production over time. Another line of research involves the precise monitoring of cows, whose every step is measured and a range of physiological parameters (heartbeat, temperature, etc.) are constantly monitored. Further, to reduce the carbon footprint of cows and sheep, with a particular emphasis on studying the molecular/genetic level, researchers have evaluated the bacterial communities involved in digestion directly rather than focusing on adjusting diets. An additional area of study involves the development of rumen bacteria population from the birth of the cow until its maturity to reduce methane production by developing transgenic bacteria, with increased hemi-cellulolytic qualities for improving ruminant nutrition (Volcani Institute of Animal Science 2018).

One longstanding, important innovation in dairy management involves the "Herd Book"—a national genetic record which covers 85% of Israel's cow population. The "Book" allows scientists to provide critical information to farmers at the "cow level", enabling them to make optimal management decisions in real time, especially in the area of health regulation. The book also allows the Volcani dairy team to optimise genetic makeup to maximise economic benefits from local herds. Figure 9.7 provides year-wise production quantities of milk that grew from 1179 thousand tonnes to 1635 thousand tonnes between 2000 and 2018. Individual cow productivity has steadily increased, increasing by 4.5% in 2018 alone. Today, Israeli cows annually produce an average of 11,970 kg of milk—significantly higher than the USA and Canada—and more than twice that of countries like Croatia, New Zealand and Turkey (Lavie 2018).

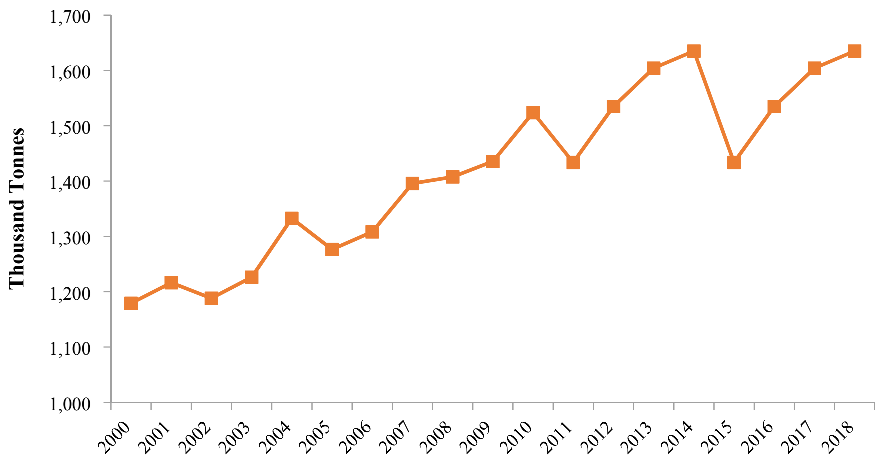

Fig. 9.7 Milk production, Israel. *Source* Annual Census, CBS of Israel (2019)

9.4.1.3 Poultry

Volcani's poultry unit has dramatically increased the growth rate of chicken production and reduced the time required for a chicken to reach 2.5 kg from 75 days—some 30 years ago—to about 38 days at present (Zuidhof et al. 2014). Besides contributing to expanded productivity, innovation in genetic improvement (Fig. 9.8) has resulted in a better feed conversion ratio, down from 1.05 in 1990 to 1 in 2018 (Fig. 9.9). It

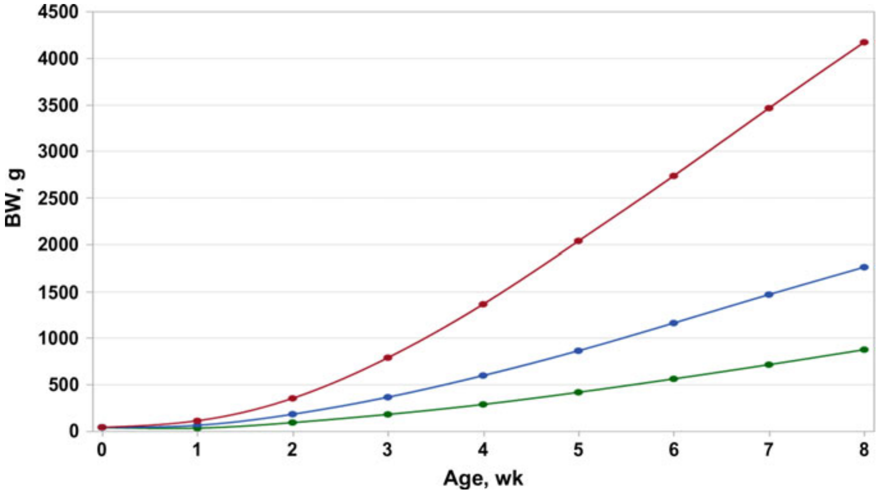

Fig. 9.8 Israel's genetic improvement in livestock 1957–2005 with three strains of chickens. *Source* Zuidhof et al. (2014)

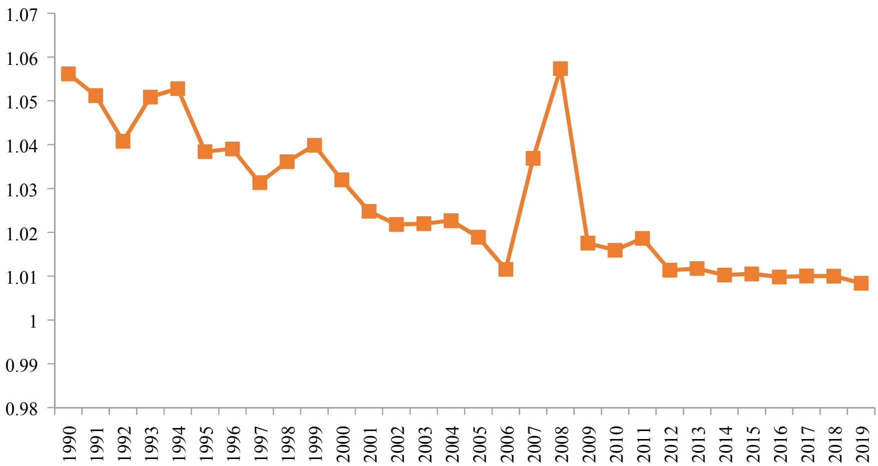

Fig. 9.9 Feed to poultry meat conversion ratio, Israel. *Source* OECD (2019)

is worth noting that Israel's feed to poultry conversion ratio of 1:1 is far lower than in India, which stands at 1.6:1.

One of the fascinating areas of present research at Volcani's Institute of Animal Science involves the manipulation of embryos at developmentally sensitive times to make chicks more resilient. The goal is to influence the gene expression and phenotypes of poultry embryos and new borns (including chickens, turkeys and laying hens) to induce long lasting physiological memory by using epigenetic adaptation. This can enhance resistance to environmental changes in temperature, oxygen partial pressure, etc. Research suggests that such robustness can be achieved through heat treatments or exposure of pregnant hens to carbon dioxide, creating a more resilient cardiovascular system, able to withstand tougher environmental conditions.

Future research challenges in animal husbandry that are currently being tackled by Volcani scientists include adding special qualities into livestock produce. For example, there has already been significant progress in increasing the level of protein in milk or creating a hypoallergenic egg. Animal welfare advocates are justifiably critical about the cruel conditions and suffering of livestock on Israel's increasingly factory-like farms. While formal research rarely focuses on making animals more comfortable, one important area of work involves influencing livestock gender. Among the central challenges in poultry research is the problem of male chicks, who are essentially superfluous in the egg industry and typically are killed immediately after birth. Israeli researchers are now able to hatch almost entirely female chickens through genomic editing. This breakthrough was achieved using the science of epigenetics, where the environment (for example freezing) affects the breakdown and distribution of the proteins. The fundamental research question is: how does the environment affect genetic inheritance. The research methods used are certainly "hi-tech", but Volcani researchers are quick to emphasise that they do not involve genetic modification due to marketing concerns. This cautious inclination also informs the development of grain and other seed varieties.

9.4.1.4 Fisheries

The *Animal Science* Institute also studies fish, although the number of active researchers in this area is relatively small. Nonetheless, there are two areas of work which might be valuable for fish farmers, especially in developing countries. The objective of much of the Volcani unit's research involves raising fish that are a single size and a single sex. Controlling the gender of fish prior to hatching is important because unisexual ponds contain fish that do not waste energy on matters involving courtship and mating. It also reduces the need for hormonal treatments and contributes to a more homogeneous size of fish in the fishpond and later in the market (Budd et al. 2015). There has been excellent progress in Israeli laboratories in controlling the sex of tilapia fish in commercial breeding.

The second area of fish research in Israel involves creating optimal ecological conditions in ponds for growing fish and absorbing their wastes. Researchers create closed systems, where fish wastes and soiled waters can then be utilised for fertiliser and irrigation. These land-based recirculating agriculture systems (RARs) reduce risks of disease and weather. In these systems, some 20–30% of the nitrogen and half of the feed carbon are assimilated by the fish, reducing the organic loadings associated with commercial fish growing (Yogev et al. 2017). Research has also been conducted to improve fish survival in extremely brackish water. This will allow fish farmers to utilise the brine water released from desalination plants and other high salinity groundwater sources, which are typically deemed unsuitable for drinking or irrigation.

9.4.1.5 Chickpeas

The Department of Nutrition of the Hebrew University/Agrinnovation has designed a revolutionary chickpea protein distillation process. The outcome of the process has a product name: *Chick P*. The brainchild of Professors Ram Reifen and Shimrit Bar El, the chickpea distillation process has already been patented, gone through the first round of investment, and is ready for market implementation. The process takes 100 kg of humus and extracts up to 90% pure protein out of the chickpea seed. The product has exceptionally beneficial characteristics beyond its low fertilizer demand: it claims a rich variety of advantages including lower cholesterol, increased protein digestibility as well as freedom from gluten/lactose/egg and GMOs. The new product could be critical to solving a basic nutritional conundrum in developing countries where carbohydrates are often available but there is a chronic scarcity of proteins (ChickP 2020).

Typically, non-animal protein comes from soy beans, an additive found in innumerable processed foods in Western diets. But there are complaints that soy brings with it a range of problems: some claim that it is allergenic for many people and can cause chronic inflammation and an itchy throat; it can block digestion of protein by the body; many soy products contain endocrine disrupting (oestrogen-like) chemicals that have a range of potentially adverse effects. Soy is also known to exacerbate gas; and when it is grown, many farms automatically spray the crop with round up (glyphosate), a possible carcinogen.[5] Chick peas pose none of those problems. In India, there is a chronic scarcity of protein, even though ironically, Indian farmers contribute about 60% of the world's chickpea production. Therefore, the new Israeli product could be extremely valuable in solving a basic nutritional conundrum.

[5]For a recent review of the pros and cons of soy diets, with a thorough literature listing, see: Harvard School of Public Health, *Straight Talk about Soy* (2018), https://www.hsph.harvard.edu/nutritionsource/soy/.

9.4.2 Precision Agricultural Technologies

The dynamics of Israeli agricultural research and innovation tend to be in a response to the specific local needs of the farming sector. In addition, there are at least three key, additional cultural elements at the heart of the country's agro-tech ecosystem:

- The historic commitment to agricultural research and the solid academic infrastructure supporting agricultural science and innovation;
- The general societal veneration of innovation and start-ups which motivates young people (and often not so young people) to brainstorm and constantly think in terms of creating a new product or company; and
- The wide access to, and familiarity with, a range of technologies developed for and utilised by the Israeli security apparatus that facilitates their application in improving agricultural performance.

Regarding the role of Israeli military experience in local agricultural innovation, the same drones that provide critical intelligence for the Israeli military can also help support better decision making by farmers. Most Israeli farms may not be large enough to benefit financially from the insights and efficiencies that this kind of agricultural technology provides. The potential savings are greatest for farmers cultivating vast plots in places like Iowa or Australia. Large farm operations stand to gain far more from adding drones to their inventory of agricultural machinery. Nonetheless, the expertise that their professional staff acquired during compulsory army service unquestionably helps Israeli agro-tech companies continue to produce a range of sophisticated products for export.

This military-agricultural technology connection often emerges unexpectedly, as in the unlikely development of a strategy for controlling the palm weevil (*Rhynchophorus ferrugineus*). The weevils are responsible for the devastation of entire date groves. For farmers, it feels like a phantom invasion, where one fine day, an entire, seemingly healthy date grove will simply collapse. As pests eat out the trees from the inside of the trunk, it is often practically impossible to identify their presence until the infestation is too extensive and the damage too great to reverse.

In recent years, Israel has faced an acute security threat from the many tunnels being dug from the Gaza Strip into Israeli territory by hostile Hamas operatives, who seek to launch terrorist attacks via the subterranean passageways and kidnap or kill Israeli citizens. A deep barrier is being established around Israel's entire southwestern border to physically truncate the burrowing. Sensors were developed that are embedded, below ground, into this new infrastructure that can detect the vibrations of subsurface digging within the adjacent solid soil mass (Levy 2018). Israelis who served in Israel's elite intelligence unit helped develop this technology. Although, they understood practically nothing about entomology and biology, they immediately realised the potential of such sensors to detect the movement of the weevils as they began to attack date trees. When farmers receive these signals, they know that they need to intervene and start spraying. Results have been exceptional.

Recently, two innovative, defence-associated research projects have made it into the news—a robotic sonar for yield assessments developed at the Volcani Research Institute (Udassin 2016a) and a tiny, wireless solar-powered tag, developed by Sol Chip, which enables the autonomous operation of a variety of agricultural sensors (Udassin 2016b). These are clever and highly sophisticated gadgets that can surely improve the efficiency of advanced agricultural operations. At the same time, there seems to be a perennial problem of "scale" in facilitating such high tech-transfers to small farm operations across a developing country: a commercial company simply cannot justify the energy and investment required to introduce such unfamiliar technologies, along with the transfer of new protocols and practices, to dispersed individual operators.

9.5 Innovations in Water Management

In Israel, there has always been an acute shortage of natural water resources. Yet, in its short history, the country has emerged as a global leader in water management for domestic, agricultural and industrial purposes. Israel has 90 m^3 of internal renewable water per capita annually, compared to 1300 m^3 in Germany, 2200 m^3 in the United Kingdom and 8700 m^3 in the USA (Aquastat, FAO 2018). Most importantly, for the present context, 52% of total water produced in Israel still goes to agriculture for irrigating arable land (Tal 2016b).

The integrated National Water Carrier System (NWC)[6] began operations in 1964 and for half a century was the country's most notable investment in natural resource management. At the time, Israel was a relatively poor country with an annual per capita GNP of only USD1400. Beyond the technological achievement, it was also a bold policy decision, involving a disproportionately large investment in water infrastructure for an indigent young nation. The national water grid it created was consistent with the Socialist economic orientation of the government at the time, offering water to all Israeli farmers in the country at the same prices, regardless of their geographical location and the actual cost of water delivery (Teschner and Negev 2013). In recent years, however, climate-changed induced reduction in precipitation has depleted water levels in Lake Kinneret (which had hitherto served as a national reservoir in the Galilee) largely leading to the discontinuation of this elaborate water delivery infrastructure (Tal 2019).

Recycling wastewater is another unique example of Israel's innovative approach to water management (Tal 2016c). Israel was the first country to make effluent recycling a central component of its water management strategy. Israel treats 93% of its wastewater "(sewage and industrial waste) with 86% of sewage water reused for

[6] A north to south water conveyance system that transfers water from Lake Kinneret and the relatively humid northern region to the semi-arid and arid southern region.

agricultural purposes. This level is exceptional when compared to just 34% in Singapore, 18% in Australia and 9% in the USA.[7] For instance, 80% of the orchards in the Negev Desert in the south are irrigated using this recycled wastewater (Tal 2016b).

Additionally, followed by back to back droughts and over-exploitation of water during the 1990s, the government decided to construct a network of large-scale, seawater desalination plants and integrate them into the NWC system. Mekorot, Israel's national water utility, uses the 660 million cubic metres of desalinated sea water produced each year to provide 60% and 85% of water for domestic and industrial uses respectively. Indeed, more than 50% of Israel's drinking water comes from desalinated water from the Mediterranean Sea (Avgar 2018). This development has freed up conventional freshwater for agricultural irrigation and for stream restoration. Furthermore, Mekorot registers a world record, miniscule 3% water loss across its water distribution system, compared to an average of 15% in developed countries and 35% in developing countries.

9.5.1 The Sociological Origins of Israel's Drip Irrigation Industry

Since only 20% of the land in Israel is arable and more than half of that is arid or semi-arid requiring irrigation, it was necessity that led Israel to develop innovative, efficient methods of irrigation. Chief among these is *drip irrigation,* the brain child of Simcha Blass, the brilliant and irascible first Director of Water Resources for the nascent State of Israel. In his autobiography, *Water in Strife and Action,* Blass describes his "Eureka moment" while visiting a friend at the rural town of Karkur in the 1930s. Blass noticed the exceptional growth of a tree that was watered by a leaky pipe that left droplets of water on the seemingly dry soil surrounding the tree. He writes: "*water droplets raising a giant tree hit me like a mosquito in the mind of Titus the evil"* (Blass 1973).

In Blass's revolutionary system, water is delivered to trees and plants through a narrow, black plastic piping system and released, "drop-by-drop", above the root zones through cleverly designed drippers. Tests showed that the slow release of water produced yields far higher than comparable sites using flood or furrow irrigation. The amount of water required was a fraction of that utilised for the conventionally irrigated crops. Blass subsequently sold the rights to Netafim, a multinational company founded at Kibbutz Hatzerim in 1965[8] that today continues to control a major share of the global drip irrigation market. It is worth highlighting that the *Netafim* Corporation is just the "jewel in a very rich crown" of exceptional agricultural innovations that emerged from Israel's "kibbutzim" (Siegel 2017). Drip irrigation systems have solved a range of technical problems, allowing for irrigation on steep terrains on

[7]Mekorot (Israeli Water Company), which serves as a national utility.

[8]https://www.israel21c.org/whats-next-for-drip-irrigation/.

shallow soils, both sandy and with clay, (Hillel 1982). The technology is utilised in more than 100 countries around the world and used on 75% of Israeli farms.

There are several other kibbutzim that created industries involving water management and irrigation accessories. By the 1970s, Kibbutz Na'an was producing a range of irrigation equipment, beginning with sprinklers, and eventually adding drip and micro-irrigation systems. The company operated independently for over thirty years until it was sold in two phases to *Jain* Irrigation, India's largest irrigation company, for 60 million dollars in 2012 (Globes 2012). Although *Jain* has some 10,000 employees in installations worldwide, pursuant to the sales agreement, the Na'an plant has actually expanded. Kibbutz Amiad manufactures water filtration systems; Kibbutz Evron established Bermad, which specialises in manufacturing hydraulic control valves for irrigation and other non-agricultural applications. Kibbutz Ma'agan Michael's Plason factory makes plastic fittings and spigots for water systems. Kibbutz Hevtzibah specialises in the production and repairs of water metres.

It is worth noting that in retrospect, all of these farming communities were responding to insights gained by members who were dealing with real world agricultural challenges. For example, rural legend has it that farmers at Israel's northern border settlement were concerned about their personal security and the risk of going into the fields in the dark, early morning hours to open the valves for the irrigation, due to exposure to potential snipers or terrorists just over the border. This led to their invention of the automatic water valve. The associated water savings turned out to be a bonus. For over sixty years, the focus among many kibbutz industries has been on developing innovations to upgrade irrigation infrastructure, to optimise agricultural inputs (e.g. fertilisers and of course water itself) as well as to design new technologies that can deliver water even more efficiently and less expensively to plants and trees.

9.5.2 Family Drip Systems

There seems to be evidence that a few companies played with the idea of creating a drip irrigation system that would not require electricity and pumps and that could be adopted widely by smallholders. But it was *Netafim* that created a product it hoped would sell throughout the developing world—the *family drip system (FDS).* The primary advantage of FDS is that it requires no centrally pressured water system. Rather it runs on a gravity-based flow which allows farmers to farm in remote areas, without the benefit of pumps and electricity and still have access to low-volume drip irrigation technology. Typically, a tank is raised to a height of at least 1.5 m, filled with water and then released into heavy-duty, polyethylene pipes, with drip outlets spaced at 30 cm. intervals. Kits come in a variety of sizes, accommodating plots ranging from 100 to 2000 m^2. A 250 square metre kit can cost as little as 150 dollars. Figure 9.10 offers a photograph of an operational family drip system in India.

Further, Netafim introduced irrigation NetKits that contain small to medium-sized irrigation systems. NetKit systems can deliver water to parcels as large as a hectare, a cultivated area which often is beyond the scale of a typical subsistence smallholder.

Fig. 9.10 Family Drip System in Indian Community Irrigation Project. *Photograph* Courtesy Netafim, Inc

Regardless of the actual size in the series, all Netkits share similar specifications: The same dripper wall thickness; the same size pipes, drippers, platforms, etc. (Netafim 2014). Yet their capacities can be entirely different.

To make a water management innovation successful and scalable, it is critical that farmers intuitively understand that the innovation will be cost-effective and truly help their business. One such innovation in this context is the *Community Micro-Irrigation* model, recently applied by *Netafim* in Karnataka India—that serves as a proof of concept of sorts (Netafim 2015). Karnataka, the seventh largest Indian state (191,000 square kilometres) with over 60 million people, provides an example of how a community irrigation project in a poor region might work and how drip irrigation can be disseminated among smallholders.

Netafim launched its largest project in Asia at Ramthal, Karnataka. The project involves 11,700 ha of farmland and some 6700 small farmers, with average land holdings of only 1.74 ha (with farms ranging from 0.4 to 10 ha). Technically, the project succeeded because it both enjoyed political stability and a significant infrastructure: a network of pressurised pipelines, rather than canals or other distribution channels. Figure 9.11 offers a schematic demonstration of the project's design. From *Netafim's* internal publications, agronomically the results were dramatic. On average, yields for tomato, chilly, cabbage, capsicum, potatoes, ginger, *karela* (bitter gourd) and *kheera* (cucumber) either doubled or more than doubled during the first harvest after installation. These figures have not yet been confirmed, however, by independent research. Table 9.3 shows the associated economic calculus for individual farmers.

The purported success of the Karnataka project was due to institutional innovation along with the engineering breakthrough. It was essentially a public–private partnership, proving that in drip irrigation dissemination, public policy matters. In Karnataka, the government set the rules of the game wisely: it engaged some twenty-three water user's associations that took on the task of initial publicity and farmer training. The associations went on to form an additional 230 water user groups, which

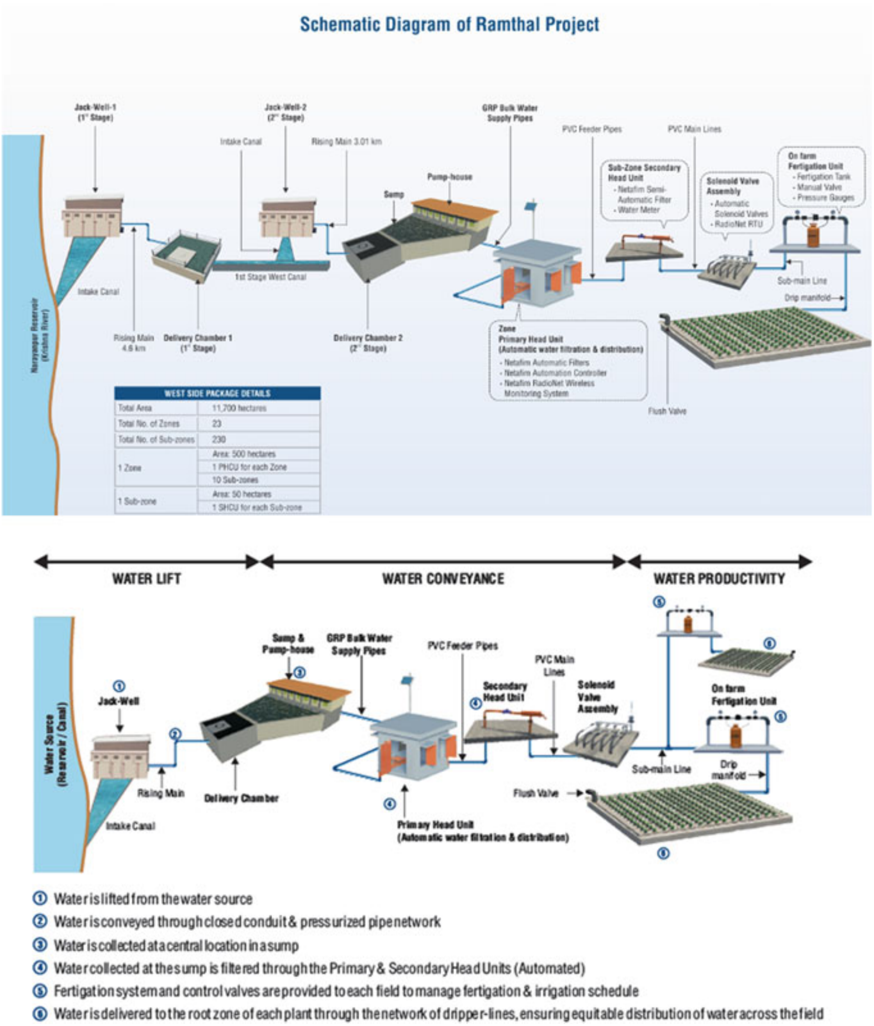

Fig. 9.11 Design of the Community Drip Program in Karnataka, India. *Source* Netafim (2015)

were a critical organisational framework for implementing the five-year maintenance guarantee. It also found the money to make a significant investment in the new irrigation infrastructure. A fund was created, based on local government financing, bank loans and support from *Netafim* itself. The experience confirms that Israeli irrigation technology is not only beneficial for farmers in developed economies with access to capital and infrastructure, but can also be a game changer in rural areas of the developing world.

Table 9.3 Summary of Netafim Smallholder Initiative in Karnataka, India

Annual crop plan cost	Tomato Crop 1 July–November	Cabbage Crop 2 November–January	Bitter gourd February–June
Drip costs	USD400	0	0
Pump	475	0	0
Inputs	USD100	USD100	USD100
Plant costs	USD45	USD45	USD80
Labour	USD50	USD50	USD50
Total costs	USD670	USD195	USD230
Yields/production	2320 kg @ USD0.42	9000 kg@ USD0.8	2500 kg@ USD0.30
Sales	USD970	USD720	USD750
Gross profit	USD300	USD525	USD520
Bank payments	USD250	USD525	USD520
Net profit	USD50		
Pay back period	5 Months		
Benefit/cost ratio	2.23		
Net benefit	USD1095		

Source Netafim (2015)

9.5.3 Sciroot—New Generation of Israeli Irrigation

One promising innovation in this field is based on the concept of "irrigation on demand". The product involves a sensor that is embedded into a drip system, designed to address fundamental inefficiencies facing even the most sophisticated conventional drip irrigation systems. That is because the precise amount of water required by crops to maximise yields can vary dramatically in a single field due to the spatial variability in field conditions as well as vicissitudes in diurnal weather and seasonal climates. Traditional drip systems are able to deliver a high percentage of water to root zones of plants. But they cannot tell farmers the actual amount of water plants need at a given time. As a result, farmers frequently overcompensate and excessively water crops, as a precautionary or "better safe than sorry" agricultural strategy. Crops may end up receiving the required amounts of water, fertilisers and chemicals—but by definition, substantial quantities of inputs are wasted.

Cumulatively, the runoff of nitrates and other chemicals can exacerbate water quality problems; farmers incur significant and unnecessary costs. So, the idea behind "irrigation on demand" was to build a sensor into the dripper that could tell farmers the actual conditions at the roots with regards to moisture and water availability. Emitters are covered in a geo-textile cloth that allows for roots to grow inside of a tensiometer, which then signals the actual soil moisture at the specific site. This offers a highly accurate measure of conditions between the root zone and the soil, allowing for a far more precise irrigation regime (Dabach 2015). Initial field trials showed that the system works well and saves significant quantities of water. Table 9.4 shows

Table 9.4 Yield and water use efficiency in Sciroot active, Israel (2010–16)

Crop	Irrigation method	Irr	Yield (Ton/Dun)	WUE (kg/mm)
Onion	Sciroot	460	3.6	7.83
	Farmer	572	2.8	4.90
Sunflower	Sciroot	395	4.52	11.44
	Farmer	455	4.16	9.14
Lettuce	Sciroot	84	4.08	48.6
	Farmer	86	3.95	45.9
Radish	Sciroot	60	1.97	32.8
	Farmer	106	1.85	17.5
Corn	Sciroot	384	1.51	3.93
	Farmer	487	1.47	3.06
Potato	Sciroot	245	3.5	14.3
	Farmer	565	3.58	6.34
Tomato	Sciroot	526	12.21	19.6
	Farmer	568	11.7	20.6
Pomegranetes	Sciroot	211	22	104
	Farmer	309	22	71

Source Innovative Unique Sensor System, Sciroot (2019)

comparative results from the company's recent field trials. At the same time, the sensors and associated information management system are relatively costly, raising the expense of drip irrigation systems to a level that may be beyond the economic capacity of many farmers in other countries. Yet, as water scarcity increases, or as farmers begin to rely on desalinated water, water prices will rise and the cost-effectiveness of such systems will become more compelling.

The product was developed under the auspices of the, Adama Company (formerly Machteshim Chemicals), an agrichemical conglomerate and the name of the product was changed to "Sciroot". The focus of the new product was also modified, with the present emphasis placed on providing critical information, in real time, to farmers about plants' water availability in order to make for better informed management decisions. Figure 9.12 provides a schematic depiction of the system. Pilot efforts suggested that many farmers were loath to concede managerial control over key decisions about how to best use their irrigation and fertigation systems, even though empirical experience showed that yields would probably improve. The product is now marketed as a state-of-the-art system for "accurate and reliable field and crop information analysed, using 'big data' technologies that serve farm and market decisions for effective management". By contrast, the Sciroot product purportedly provides a "smart, accurate, inexpensive system for sampling soil volume and active roots for a variety of vegetables, field crops, orchards and soils, under a range of climate conditions, allowing for reduced consumption of water usage and greater yields…".

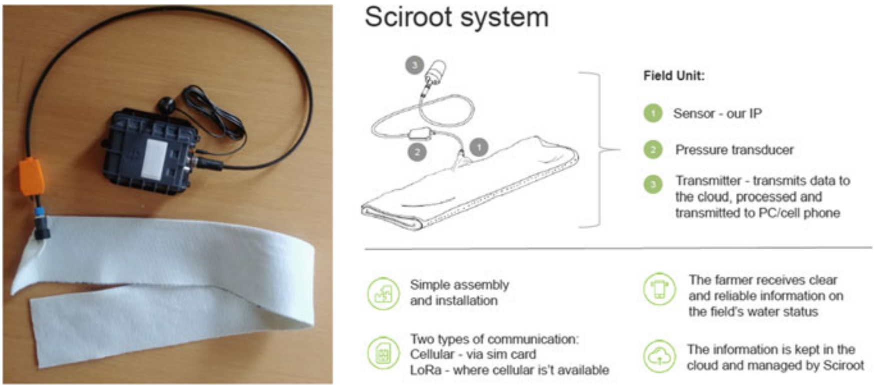

Fig. 9.12 Components of a basic Sciroot unit, Israel. *Source* Sciroot (2019)

9.5.4 NDrip

Flood irrigation is an 8000-year old, highly wasteful practice that started around the same time in ancient Egypt and Mesopotamia. And yet, it remains the predominant irrigation technology, still used by 85% of the world's farmers. With some 75% of the planet's freshwater consumed by agriculture for irrigation, much of the water used by humans is utilised at efficiency levels as low as 30% (Jägermeyr et al. 2015).

This means that new ideas and new approaches need to be adopted to move the world away from flood irrigation's enormous inefficiencies and towards a more sustainable water management strategy. To do so, one of the new Israeli technological innovations introduces an entirely different approach to drip irrigation. The resulting product was patented as the "*NDrip*". It constitutes a fundamental break from the prevailing Netafim drip paradigm:

A black polyethylene pipe of modest quality is embedded with drippers that release water to plants, powered solely by gravitation pull: No pumps or associated infrastructure are required nor are filters. On the one hand, the low-quality system lasts for only one year (but then can be fully recycled). The system then needs to be replaced on an annual basis. But relative to existing family drip systems, it is very inexpensive. While it appears as if the dripper is a "low tech" product, in fact there is tremendous engineering creativity and substantial, empirical field trials behind the design. An *NDrip* production facility has been established in the Israeli development town of Beit Shean and the first system is already operational in a large farm in Swaziland. Demonstration sites are soon to be established in Texas and in Arizona along with Australia. There is talk with the European Investment Bank to make a major grant so that the technology can be introduced to agricultural operations in Central Asia. The company's ultimate vision is to make these systems widely available in Africa.

9.6 Integrated Pest Management (IPM)

In dryland agriculture, notwithstanding any number of precautions—from double doors in greenhouses to the full array of biological controls—Israeli experience suggests that when warm weather arrives, pest infestation is ineluctable. Ultimately, farmers will need to resort to using some array of chemicals to control the outbreaks—even though there is little disagreement that this should constitute a last resort. Integrated pest management (IPM) is pragmatic in this regard: any chemicals used should be prioritised by their low toxicity and persistence, while applications should be as parsimonious as possible. Even farmers who are the most enthusiastic advocates of biological controls in Israel prefer to speak about pest suppression rather than pest eradication. Eternal vigilance is perhaps the most critical component in any effective pest control strategy—more than reliance on any chemical or natural predator per se.

9.6.1 Bio-pesticides

With toxic chemical pesticide applications affecting public health negatively and contributing to pest resistance, bio-pesticides emerged as a critical component of plant protection strategies in Israel. Bio-pesticides comprise active agents such as bacteria, fungi and viruses, which are completely natural and do not harm the environment. It is estimated that the growth of the bio-pesticide market is expected to be significant in most regions.[9] Nonetheless, effective, environment-friendly control solutions have not yet been found for many pernicious, local agricultural pests. Among the leading Israeli companies developing bio-pesticides, singled out for their potential contribution to reducing pest damage worldwide, are:

- *Bio-Bee*
- *Timorex Gold*
- *Botanocap*
- *BioFeed*
- *Agro-Shelef and*
- *Tamar Tech.*

Bio-Bee constitutes a particularly interesting case.

9.6.2 Bio-bee's Biological Solutions

In a relatively remote corner of Israel, near the border with Jordan and the ancient town of Beit Shean lies Kibbutz Sdeh Eliyahu, home to *Bio-Bee*. For 35 years, this company has been steadily expanding the "tool kit" available locally and internationally to

[9] https://www.marketsandmarkets.com/PressReleases/biopesticide.asp.

support integrated pest management strategies and the biological control of pests. The company's success is generally attributed to the creative genius of its long-time, chief scientist, Shimon Steinberg. In addition to producing and disseminating beneficial insects and mites, in 1991, *Bio-Bee* started raising bumblebees (*Bombus Terrestris*), for pollination services. Soon thereafter, in response to concern about an outbreak of the Mediterranean fruit fly in the central Arava Valley, it became the first place in Israel to offer sterile insects technique on a regional scale. This allows for the release of flies who can mate, but are infertile due to radiation treatment. Populations plummet as a result. In retrospect, the initiative is credited with saving the area's red pepper crop. During the 1990s, given the high export prices, as much as 2000 ha of Israeli farmlands went over to pepper production. Most of the peppers were grown in the arid central Arava region. Even after a collapse in prices in the year 2010 reduced the cultivated lands from peak levels, the biological pest control remains standard procedure (Roth-Avnermi 2017).

In 2013, the company added bio-pesticides to its lists of products. The use of essentially organic entomopathogenic fungi and nematodes can protect plants from pest infestation. To this, they added distribution of botanicals such as natural pesticides from *neem* trees that are purchased in India as well as pheromones (imported from the American company, ISCA) and other techniques for disruption of pests' natural mating processes. Then, the company began to use mycorrhizal fungi as an inoculant for soils and crops and other bio-stimulants to strengthen plants against pests. Finally, some three years ago, Bio-bee developed an entirely new product for farmers: the raising of insects as feed and food. The company established a "proof of concept" about the advantages of producing "feed" by breeding the "black soldier fly" (BSF). While all of Bio-Bee's products might be helpful to smallholders that face pest problems, Steinberg believes that the black soldier flies offer a product which could be revolutionary for them economically (Blumer 2018).

These remarkable flies eat anything that resembles decaying organic waste. This could be agricultural residues, manure, industrial or human wastes. After they are ground up, the BSF maggots make first rate insect meal. Their oil is rich in anti-oxidants. Anything that the flies leave behind in terms of waste makes excellent fertiliser. Thus far, Bio-Bee has managed to develop fifteen separate commercial products and uses for BSF production. At the same time, the flies can solve some of the acute sanitation problems that are so vexing in rural settings. Recently, Bio-Bee's board of directors decided to put the black soldier fly expansion on hold until they had funds to scale up the initiative significantly. The capital shortages at one of Israel's most successful, kibbutz-based, agro-business companies suggest that there is still considerable room for investors in the field (Fig. 9.13).

Successful biological pest control requires more than an effective product. There is constant technical assistance that pest control companies need to provide to farmers who typically do not know: "What is the balance between beneficial insects and pests?" "Is there a need for chemically corrective measures?" "Is the dosage precise enough to prevent a non-target effect?" The disengagement, so common, between pest

Fig. 9.13 Minute pirate bugs, ready to take on Western flower thrips: Bio-Bee packing house, Kibbutz Sdeh Eliyahu, Israel *Source* Bio-Bee (2019)

control suppliers and smallholder consumers in developing countries is particularly unfortunate because the *poorest* farmers tend to purchase the *cheapest* pesticides (e.g. DDT) which are frequently the most ecologically destructive or harmful to human health.

Global marketing for biological pest control products is not without its challenges. Many countries require risk assessments that will detail non-target effects, impacts on biodiversity and the likelihood of competitive displacement. In the case of pollinators, these concerns may have some strong empirical support. For instance, *Bombus Terrestris*, the large earth bumble bee that is *Bio-Bee's* main pollinator, has been singled out in Chile and Japan as supplanting local, endemic, bee species. Similar concerns were raised in Israel after a major forest fire in the Carmel Forest decimated the diverse local bee populations. As regeneration began, it was the *Bombus Terrestris* that initially repopulated the forest, rather than local honey bees, raising the possibility of an interference in natural succession processes. Most empirical studies, however, have not been able to associate any meaningful biodiversity loss with biological pest control efforts.

9.6.3 Weed Control and Cultivators

Weeds present an entirely different challenge to farmers. In many cases, if they are not destroyed in time, weeds compete for scarce resources, supplanting nutrients and water from the crop. There are a range of approaches to address the perennial challenge of weed control, including the age-old chore of human weeding. For the better part of a century, herbicides have been applied with great alacrity around the world. But, this input adds to the costs of production, exposes farmers and consumers to chemicals, which by definition are poisonous, and also can lead to the development of resistance among plants. Cultivators offer an alternative “mechanical” approach that remove weeds directly via tillage.

Israeli researchers have begun to develop a range of new cultivators that are both more precise and can be utilised by smallholders with the benefit of tractors or plough-pulling farm animals. Early weeding operations, subsequent to cultivation and prior to planting, can be especially valuable because as weeds develop roots and gain access to greater food reserves, they can increasingly resist and recover from mechanical damage. Early treatment with cultivators can prevent germination of weeds altogether. After planting, the challenge is even greater, given the importance of controlling weeds when they are not yet well established.

Dr. Ron Lati, from the Volcani Institute’s northern research station, Neveh Ya’ar in Ramat Yishai, has developed one such new model with several unique accessories. His “Finger Wither” cultivator contains specially designed discs that can remove almost all vegetation outside the thin line of crop rows, where seeding takes hold. Here precise seeding also turns out to be critical: the more systematically the seeds are placed, the more complete the removal of weed vegetation can be and the closer to the crop plant cultivators can operate. Flaming systems are an acceptable pest control system for organic farms as well and have been used with great success in the cultivation of organic onions in Israel. Lati claims that for agriculture to be sustainable, it is critical to look at weed control (and pest control in general) with a long time horizon—rather than as a yearly cycle (Lati 2018).

9.7 Innovations in Post-harvest Loss Management

With an alarming 1.3 billion tonnes of food on the planet defined as “lost” every year, reducing wastage and maximising the amount of produce that is actually consumed is a critical global challenge, beyond increasing yields (Food and Agriculture Organisation 2018). Providing *safe* food from “farm to table” is becoming an increasingly important policy objective all over the world. It is important to meet safety and export standards. Israeli scientists have developed numerous innovations to address the issue. The *Volcani Institute* is probably among the top three research centres in the world developing post-harvest practices and pursuing related plant biotechnology research. The fact that 99.5% of the seeds imported into Israel reach their destination and are consumed reflects the very sophisticated, post-harvest technologies and practices adopted in the country.

One of the promising innovative technologies involves “high-end fruit and vegetable coatings” that extend the shelf life of vegetables. A research team led by Professor Amos Nussinovitch faced the challenge of finding a healthy generic coating that could extend the shelf life of vegetables. Marketing specifications required that it be comprised of organic materials without any synthetic chemicals. Prof. Nussinovitch eventually settled on bee’s wax as the primary component of the coating, calling the product “Sufresca”. Bee’s wax has the advantage of being an effective seal, but with sufficient permeability to allow for fruit respiration. Peppers were a

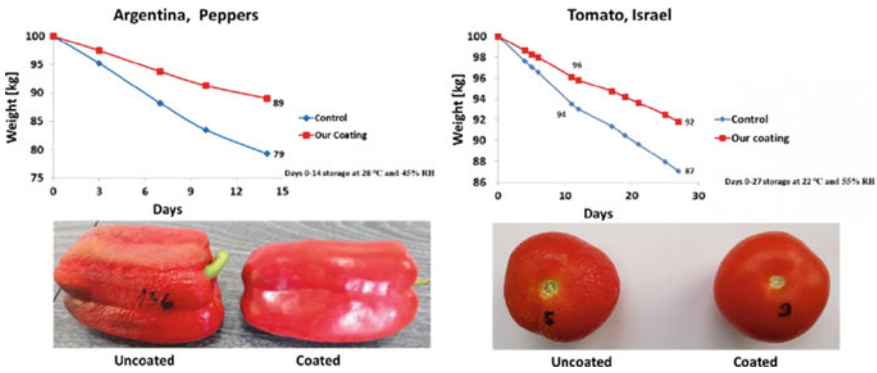

Fig. 9.14 Impact of Sufresca coating on Tomato, Israel. *Source* Agrinnovation Brochure (2020)

natural place to start for assessing the coating's efficacy. Because they are filled with air, the decomposition process begins quickly. Trials showed that when peppers were dipped in Sufresca, it extended their shelf life by twenty-one to twenty-four days. Tomatoes, garlic and avocadoes all responded well—with two weeks of additional viability after being coated. Figure 9.14, taken from an Agrinnovation promotional brochure, shows the advantage of coating with the new product, both visually and quantitatively.

In developing countries where smallholding farmers have practically no access to refrigeration and half of the crops never make it to consumers or even the market, this additional window of time becomes crucial. Israeli agriculturists have further developed cost-effective technologies to reduce post-harvest losses such as special storage bags, ethylene removable packaging and edible coating, along with mobile cooling units for short transport and modified atmosphere packaging. Among the Israeli companies offering products which address the problem of food damage or spoilage are the following.

- *Amaizz* and *Pimi Agro*, for storage products
- *BT9* that has "cold chain management"
- *Aclartech* that analyses fruit ripeness
- *Yarok*, and its food safety testing system
- *Stepac* and *ROP* that provide modified atmosphere and humidity packaging.

Israeli farmers also follow post-harvest protocols, where produce is typically divided into two groups: preclimacteric fruits and climacteric fruits. Once climacteric fruits begin ripening and ethylene begins to trigger cellular respiration, the process is largely irreversible and it is prudent to expedite marketing for immediate consumption. Preclimacteric fruit can usually be stored for extended periods, given appropriate cooling and chemical treatments. Applying Methylcyclopropene (MCP) increases the potential storage duration dramatically, with apples and persimmons effectively stored for as long as 14 months. If no refrigeration is available, utilising packaging that contains 1-MCP can also extend the life of fresh produce.

Understanding these dynamics and adjusting practices accordingly is often the difference between a prosperous farm and one that goes bankrupt. There are many commercial projects spawned by the Volcani Institute in this context. The post-harvest research team has helped develop a series of plastic bags and wrappings that prevent condensation of water in packaged fruits and vegetables. The Gates Foundation found that storage of produce in airtight bags—triple layered—cuts crop loss by 25%. While these bags can cost as much as two dollars, they can hold 100 kg of produce. The extended lifespan of fruits and vegetables usually can increase farm income by up to 50%. The packaging essentially creates an optimal range of oxygen and carbon dioxide concentrations for each fruit and vegetables, which slows the ripening process suppresses pathogens or decay while preserving taste. In addition, when the relative humidity is kept at 90–95%, shrivelling, dehydration and loss of weight can be prevented (Stepac 2018).

Some twenty Israeli companies at present are developing technologies for storage, production and contamination tracking in addition to post-harvest sterilisation. The most important is probably StePac. Their packing is called Xtend and it is "tailor made for each specific vegetable, fruit or herb, ensuring extended shelf life while maintaining produce freshness, taste and nutritional value". There are other commercial outcomes from the Volcani Institute's post-harvest research unit. Researchers there discovered that a brief rinsing of fruit in hot water increases its shelf life significantly. Biologists and the mechanical engineers at the institute developed a relatively low-cost cleaning machine that rinses and brushes some twelve different types of fruits and vegetables with impressive results (Fallik 2004).

The process is important for extending storage capacity, as the treatment eliminates pathogens that cause surface decay, while maintaining fruit quality during prolonged storage and marketing. The rinsing machine recycles a third of the water it uses in the cleaning process. The machine also received Israel's vaunted Kaplan prize for innovative invention.

Today, there are 150 machines operating in Israel that utilise the hot water immersion treatment and brushing for vegetables for a range of crops including peppers, mangos, avocados, citrus fruit, tomatoes, melons and pitayas (where it even takes out the thorns). Best estimates suggest that the extended lifespan of produce creates revenues that allow a return on the entire investment within two years.

As mentioned, contamination of food by pathogens constitutes a significant public health threat globally, contributing to an estimated 420,000 annual deaths (WHO 2020). About twenty Israeli companies are now developing post-harvest technologies to improve food safety, in areas involving contaminant detection, sterilisation and food tracking/quality monitoring. For example, *Yarok*, a Jerusalem-based start-up, won a 2017 international agribusiness award (UNIDO ITPO) for its high-resolution, 45-min, microbiological testing for freshness of foods. Yarok offers a critical service, especially for developing countries where in the absence of refrigeration, food safety constitutes a paramount challenge: Within 45 min, its system can indicate the presence of food contamination (such as *E. coli*, Listeria, Salmonella) to ensure that fresh produce is safe for consumption. Pilot units are successfully operating in Italy and Israel (Sierra 2018). Another start-up produces a pocket micro-spectrometer that can measure material composition in fruits and vegetables and help reduce produce ripeness, spillage and contamination. The instrument can also conduct nutrient analysis of animal feed. Another company utilises breast cancer screening technology to assess dairy contamination at the farm level.

Food safety is an area where the Israeli market share in the agro-tech business appears to be unusually high. Israeli companies attracted some 23% of the investment in post-harvest innovations worldwide in 2015. The supply chain sector reportedly raised 8.3 million dollars in 2016.

9.8 Farm Mechanisation

While Israel does not enjoy "powerhouse" status in the area of farm machinery as it does in other areas, (such as irrigation systems), there are a few, promising Israeli start-up companies who focus on different aspects of agricultural mechanisation. They include the following.

- ***Etgar and Yung-Etgar***—which produce customised harvester heads that fit onto existing combines for a range of specialty crops. The product has specific harvest capabilities for tomatoes, peas, corn, beans, paprika, parsley, herbs, broccoli, cauliflower, sweet potatoes and onions
- **Virentes**—a company which makes high-throughput robots that apply multirootstock grating technologies
- ***Syx*** along with several other companies that outfit drones with autonomous spraying and monitoring capabilities.

9.8.1 The Agritech Exhibition

An important institutional contribution to the Israeli agro-tech ecosystem is made by the Israel *Agritech* exhibition, which is held every three years in Tel Aviv. The first exhibition was held in 1970 as an outreach initiative by the now defunct mechanisation department at the Ministry of Agriculture. As Israel's agro-tech ecosystem prospered, international interest grew. In response, *Agritech* expanded and became more successful, with the project eventually spun off as an NGO, whose board comprises a range of institutional partners. Technically, the exhibition is sponsored by a non-profit organisation that hires a commercial company (*Kenes*) to run the three-day extravaganza. The first exhibition, forty years ago, was held at the Mikveh Yisrael agricultural school on the southern outskirts of Tel Aviv. But the event soon outgrew this venue and for some time has been held at the Israel Trade Fairs and Convention Centre in Tel Aviv.

The May 2018 event was the twentieth *Agritech* exhibition. The 15,000 attending international guests were almost double the number that came for the previous 2015 fair. The considerable investment by local companies in their exhibition stands suggests that the event constitutes an important opportunity to reach thousands of potential buyers from around the world and that the meeting place indeed catalyses many important deals. The *Agritech Association* has recently decided to establish a permanent exhibition, returning to the original Mikveh Yisrael site, which will serve as a year-round "gateway" for visitors interested in agricultural technologies, as well as an educational centre for Israelis (Libstein 2018). Agritech in Israel hosts a series of scientific/policy conferences that offer lectures from experts, local and international, on a range of relevant topics. One of the sessions in the 2018 conference focused on technology to assist smallholders in developing countries.

9.9 Innovations in Incentives Policies in Israeli Agriculture

Until the 1980s, Israel's agricultural sector remained highly regulated through provision of subsidies, price controls, import restrictions, production quotas and other government programmes. In 1977, however, this began to change when the Capitalist Likud party replaced the Labour government that held power since the country's inception, forming a new, right-wing coalition. The new regime adopted a range of policies that supported a free market and reduced the heavy government involvement in numerous economic sectors, including agriculture. By the 1980s, the deregulation of the farming sector was well advanced, with an eye to opening up the Israeli economy to outside competition.

Not all Israeli agricultural operations were able to make the transition successfully into the more turbulent, unprotected waters of open markets. The economic reform period (1985–2009) included the collapse of regional co-operatives (1989); debt restructuring and write-off agreements (1989–90); along with the removal of fruit and vegetable production quotas (late 1980s), followed by the cancellation of most price controls (except for milk, eggs and flour). The 1990s subsequently brought reforms in the poultry and dairy sectors (OECD 2010).

This section reviews the structure of the policies introduced by the government that sought to support farmers through incentivising competitive prices and reduced input costs, policies that ultimately led to higher incomes and improved markets. In addition, the government continued to underwrite extensive infrastructure. For instance, government support remains substantial in the area of water infrastructure development, in addition to maintaining its long-standing commitment to research and development as well as extension services. The chapter also evaluates where overall support for Israeli agriculture stands at present, as measured by the producer support estimates (PSEs) developed by the OECD for most agriculturally important countries.

9.9.1 Price Support Measures

Price support measures in Israeli agriculture still include production quotas, guaranteed minimum prices and surplus absorption schemes (later removed in 2004) that directly support farming operations. During the economic reforms, the government removed quotas from vegetable production in the 1980s, followed by their complete removal in 2007 except for egg production. Milk producers are incentivised through production quotas and are further supported through a guaranteed price system that enables farmers to cover the average cost of production, in addition to an agreed return on labour and invested capital. Figure 9.15 presents the year-wise milk production quotas applied since 2000. The overall quota allotments, reflecting the expected consumption volume in the local market. Through the quota system, the annual volume is divided into monthly quotas so that dairy producers are rewarded for meeting production requirements throughout the year. This ensures that the national supply of milk is uniform during all months.

In the case of excess milk production during "winter" months (November–April), a reduced price is paid to the producers for every litre of milk provided beyond the monthly quota, but this disincentive is often dispensed with during the hot "summer" season. Therefore, a base milk price for the producers is agreed upon between the government, farmers and dairy industries. In the case of eggs, producers are guaranteed a price that only reflects production costs. In addition, the Israel Ministry of Agriculture and Rural Development (MARD) manages wheat reserves as state security stocks through minimum prices that are fixed every year and are based on the Kansas market prices, adjusted for quality as well as for transportation costs (OECD 2010). The Israel Dairy Board and the national Poultry Board occasionally intervene in local markets to prevent producers' price from falling. Thus, the dairy and egg industry in Israel is strongly supported and protected through production quotas and fixed producer prices.

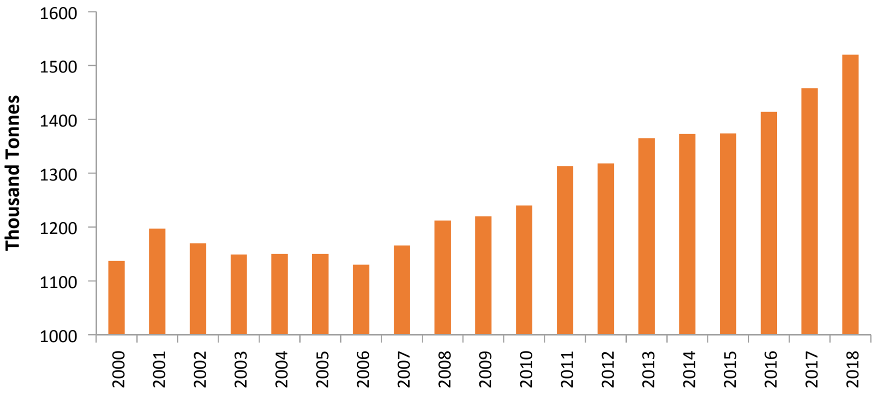

Fig. 9.15 Milk production quotas in Israel. *Source* Israel Dairy Board (2018) (https://www.israeldairy.com/milk-quality-copy/)

9.9.1.1 Reduction of Input Costs

To help the farming sector, whose economic margins often are minimal meet expenses, MARD employs two primary policy measures to make farming more profitable: investment support and reduced water prices.

9.9.1.2 Investment Grants

The “Investment Centre” at Israel’s agricultural ministry provides grants for a range of traditional and innovative products. For instance, if a kibbutz needs to purchase new “cherry pickers”, it can receive a grant of up to 20–40% of the purchase price. If it wants to expand its fields, the Jewish National Fund, a public corporation, will join the government in covering the cost of preparing land for cultivation. In Israel’s southern deserts, where agriculture is still expanding, this can be a highly expensive proposition, involving land levelling along with the purchase and transport of prodigious quantities of sand. Grants can be received for planting new orchards, especially when they contain emerging crops that the ministry believes will be profitable. For example, when they were not yet well accepted by Israeli farmers, subsidies for planting avocado and papaya orchards were made available and were effective in introducing the new crops into the country, eventually contributing to the establishment of these lucrative markets.

The ministry not only espouses support for farmers and farming, but also implicitly includes support for agro-tech into its mission statement: “To develop agriculture and establish settlements in Israel; to ensure the supply of fresh, high-quality food for residents of the state; *and to leverage the relative advantage of Israeli agriculture”* (Tzuk-Bar 2015). In this context, the previously described contribution of its research arm—the Volcani Institute—is recognised as a critical engine for progress in agro-tech.

The ministry not only plays a key role supporting Israeli farmers through grants, but also by protecting them from potential on-farm damages, such as by facilitating pest control measures. For instance, it uses quarantine regulations effectively for pest protection. The case of the red palm weevil (*Rhynchophorus ferrugineus)* is instructive. These pests had begun devastating palm trees throughout Israel, leading to the disconcerting phenomenon of collapsing palms in the middle of city centres. By preventing the importation of palms into the Arava region of Israel, the agricultural ministry intervened and spared the country’s largest cohort of date growers the trauma of infestation from this most persistent pest.

In addition to innovation in monitoring and chemical control, in cases like the weevil scourge, the ministry has taken a preventative approach relying on the discipline of local farmers. It serves as a national “choreographer” of sorts, directing the genetic quality of life stock, orchestrating the quotas for milk and other subsidised products, promoting more productive seeds and helping farmers to stay on top of the latest innovations. In retrospect, Israel’s Ministry of Agriculture’s agricultural policies appear to have been largely effective in these areas. Israeli farmers still provide

Israelis with most of their fruits and vegetables, taking advantage of the generally favourable year-round climate, technological sophistication and economic opportunities. One of the central explanations for the extraordinarily successful collective performance of Israeli farmers lies in the country's agricultural incentive support system.

Even during the transitional period away from highly subsidised agriculture, during the years 1995–2008, the annual support for investment grants in agriculture ranged from ILS 90 to ILS 170 million (~USD25–45 million) (OECD 2010) where the supported projects involved greenhouses, heavy machinery for open-field crops and drip irrigation (OECD 2010). More recently, the ministry's budget has grown modestly, and with it, funds available for agricultural investment. That said, a significant percentage of available support is allocated for rural development which typically does not involve agricultural activities. According to the ministry's 2019 activities report, ILS 55 million of the ministry's budget was defined as direct investment but this vastly understates the actual support granted in a range of programmes. Assistance programs are devoted to a diverse range of project areas: from USD114 million to support farmers in the economically depressed Galilee, and ILS 117 million designated for Jewish settlement (Israel Ministry of Agriculture 2019b), to ILS 45 million shekels in grants to encourage young people to take up farming to (Israel Ministry of Agriculture 2018a) and ILS 20 million shekels to encourage promising agro-tech start-ups (Yablonko 2019).

Moreover, to improve the efficiency, inclusiveness and sustainability of the dairy sector, a substantial share of investment was directed to increasing milk production capacity, as well as to ensuring that Israeli farmers are incentivised to bring their production facilities into compliance with environmental requirements. Similar reforms were undertaken in the egg sector in 2009 by licensing table egg production units that conform to the country's strict health and cleanliness standards.

Farmers remain extremely sensitive to the level of import taxes. For example, the profitability of the local production of sea bass is largely dependent on the high import taxes imposed on European competitors. And dairy farmers remain suspicious of the new openness to butter, yoghurts and dairy products that increasingly crowd supermarket shelves. But zooming out to see the big picture, Israeli farmers are becoming increasingly competitive in their specialty crops without being excessively overindulged by a protective agricultural ministry.

9.9.1.3 Water Support

There are some traditional areas where Israeli farmers continue to enjoy considerable support from the Ministry of Agriculture. One of these is water infrastructure.

For its first four decades, Israel's agricultural sector benefitted from prodigious government subsidies for water, leading to chronic inefficiencies and the growing of water-intensive crops (e.g. cotton) that made little economic sense. Indeed, farmers were often criticised for "exporting virtual water", which was in short supply. A scathing report in 1990, by Israel's State Comptroller, documented massive mismanagement of the country's water system. The report documented the over-pumping of groundwater to provide farmers with prodigious quantities of water at rock bottom prices, leading to the salinisation of Israel's aquifers (Tal 2002). The "agricultural lobby" was demonised as responsible for its unsustainable and selfish orientation. The surrounding controversy highlighted the potential consequences of ill-advised water subsidies. Subsequent reforms reduced this government support for water to a fraction of its previous levels.

Today, around 18.5% of the government's water budget support is spent on subsidising water prices, where fresh water (frequently brackish or recycled effluents) is supplied to farms at lower rates than the cost of fresh water.[4] On the other hand, the government invests another 15.8% of its budgetary support on-farm irrigation facilities and infrastructure, such as drip irrigation systems. Another dominant expenditure is on natural disaster support for premium payments. The insurance scheme accounted for an average of 15% of budgetary spending in 2018–19, covering part of the premium (around 80%) against natural disasters affecting fruit crops—in particular, droughts and flooding.[4] In the same context of nudging farmers towards environmental sustainability, operations have to pay an extraction levy for using surface and groundwater for irrigation.

This support is extremely meaningful at the farm level. For instance, when water prices were raised (due to the integration of desalinated water into many farms' irrigation supply) in 2018, the ministry compensated farmers by offering grants of up to 80% for the price of water conservation infrastructure and hyperefficient irrigation equipment. These grants were even made retroactively for expenses incurred in 2017. The ministry continually subsidises the capital expenses of farm equipment. So, for examples, 25% off the cost of new "hydraulic lifts" is offered—even as the ministry

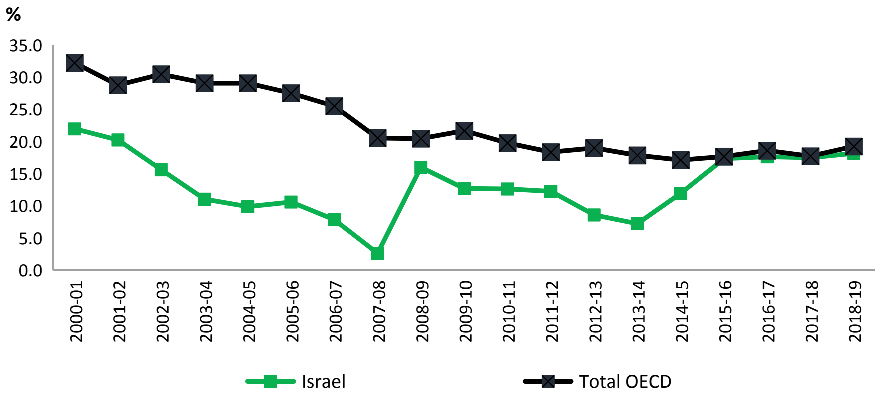

Fig. 9.16 Producer Support Estimate in Israel and OECD countries. *Source* Producer and Consumer Support Database, OECD: Israeli agriculture remains highly subsidised, on par with OECD countries, with support reaching almost 18% of farm receipts

determines what they believe to be the fair price of the equipment. Typically, farmers feel that at the district level, ministry bureaucrats are actually quite committed to helping them and making the paperwork manageable so that government funding can be accessed and utilised expeditiously (Fig. 9.16).

9.9.2 Income Support Measures

The Israeli government continues to provide support for Israeli farmers, especially when a need arises, to help them overcome geo-political circumstances. For example, the MARD has traditionally provided income supplements to poultry, egg and wheat producers in Israel's northern region under the Galilee Law. In addition, the producers are compensated in every seventh year for the income losses caused by the foregone sales associated with the Jewish sabbatical year, where according to religious tradition, tilling the soil is prohibited (OECD 2010). According to a 1988 regulation, a special subsidy is paid to poultry producers along the Lebanese and Syrian borders so as to support stable production in the unique periphery. The subsidy is calculated as a percentage of the production costs.

In the past, to support table egg production, a subsidy of 17% of production costs were offered to chicken farmers—up to a maximum amount of 500,000 eggs/grower. Aggregated, this support came to roughly ILS 40 million during 1996–2008 (OECD 2010) while the support to poultry meat producers amounted to 13% of production costs, up to 50 tonnes/grower for moshav farmers and 500 tonnes/grower for kibbutz operations (OECD 2010). In 2009, the Government of Israel replaced income support for rain fed grain growers (wheat and barley) with an income insurance policy where MARD subsidises premiums at rates varying from 40 to 80% according to the differences in yields in each region (OECD 2010). This is estimated to cost around ILS 9 million per year. More recently, support for the egg industry has taken different forms. For instance, in 2018, an ILS 50-million initiative was designed to consolidate small family egg production units to larger ones that could be located at the edge of agricultural communities to reduce nuisance and sanitation concerns (Ministry of Agriculture 2018c). Yet, this sustained support was not enough to provide the country with all the eggs required by its growing population. During the Corona epidemic crisis in March 2020, a national shortage of eggs emerged, leading the agricultural minister to order emergency imports to meet the Passover holiday demands (Times of Israel 2020).

9.9.3 General Service Support

The collective support to producers through policies that invest in research, infrastructure and education is represented by a general service support estimate (GSSE). GSSE has six components:

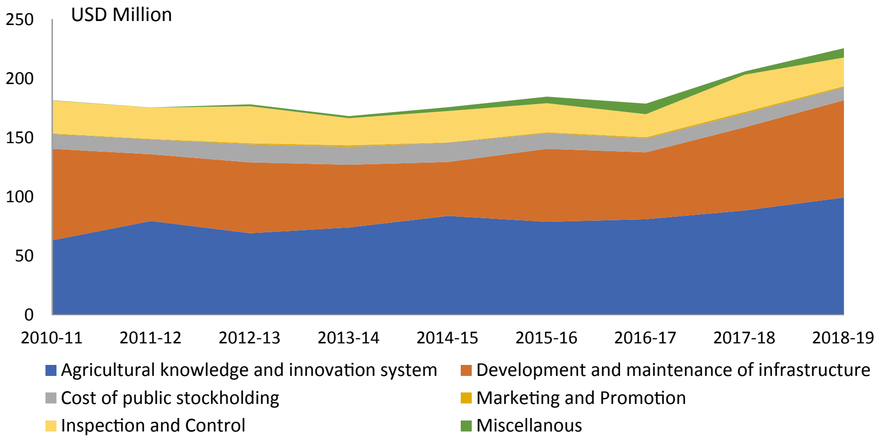

Fig. 9.17 Level and components of GSSE in Israel. *Source* Producer and Consumer Support Database, OECD

(a) Agricultural knowledge and innovation system;
(b) Inspection and control;
(c) Development and maintenance of infrastructure;
(d) Marketing and promotion;
(e) Cost of public stockholding; and
(f) Miscellaneous.

Investment in major four components of GSSE for TE 2018–19 accounted for USD90 million, USD70 million, USD10 million and USD30 million, respectively. All told, Israel invested USD203 million towards General Services Supports in 2018–19 (Fig. 9.17).

Most of the investment is provided to agriculture knowledge generation, specifically through research institutes or in cases of infrastructure development, irrigation-related projects. The investment under these two categories has been continuously increasing, consistent with the trend in OECD. The year 2018–19 witnessed a 10% increase in GSSE expenditure, mainly due to additional expenditures for agricultural knowledge and innovation systems as well as the development and maintenance of water infrastructure.

Israel is generally investing in the right direction but should increase the quantum of investment. Overall, close to 70% of all transfers to and from agricultural producers continue to involve measures that contribute to distorted farm decisions rather than strengthening their long-term competitiveness. A large part of support to producers still includes measures that perpetuate the gap between domestic and world market prices.

Concerns about preserving the integrity of Israeli agriculture in light of growing challenges to local food security are legitimate. The Corona crisis and the associated retreat of some assumptions associated with globalisation have revived local anxiety about Israel's agricultural self-sufficiency. There have been mounting calls in the country's popular press to ensure reliable food supply. Supporting Israel's agricultural community is increasingly considered to not only be a legitimate public policy intervention, but an essential one (Zomar 2020).

The question is the form that this support should take. Significant price supports for some products—with depressed prices for others—exacerbate prior distortions in the domestic market. These policies surely contribute to the extremely high price of food for consumers in Israel, relative to other developed countries. Some of these policies can be justified in the name of ensuring agricultural productivity growth, sustainable use of resources and prevention of environmental degradation. But whenever possible, governments concerned about future competitiveness in every economy should roll back distortive, inefficient and environmentally harmful support and focus on investment in research and development.

9.9.4 Total Support to Israeli Agriculture

Regardless of political and economic ideology, Israelis justifiably take pride in local agriculture. But there is a growing consensus, as part of Israel's generally neo-liberal economic perspective, that farmers need to strive to be economically self-sufficient. Markets play an important role in this process, as theoretically, they offer a guarantee to farmers that their produce will find a profitable outlet. This allows farm operators to simply focus on growing produce as best they can. This section focuses on Israel's evolving incentive policies that seeks to aggregate farmers output efficiently and connect them to the consumers:

A significant change in the historically paternalistic, government orientation towards the sector can be seen in the steady phase out of subsidies and price supports for Israeli farmers and tariffs on food products. Agricultural assistance can be better understood through producer support estimates (PSE) and general service support estimates (GSSE). PSE relates to transfers to producers individually through public measures and has two components—market price support and budgetary transfers. The rationale for price supports can be linked to a policy-driven price gap between the domestic price of an output commodity and its reference price (which can be negative or positive). Budgetary spending involves government payments to producers as well as revenue foregone.

Support for producers is unequal among countries and commodities. According to OECD statistics, price supports are the most common form of agricultural subsidy in Israel, "Market Price Supports" (MPS) on average accounts for 84% of producer support estimates in TE 2018–19 in Israel. It is worth noting that Israel's price support is higher than the OECD average. Over time, agricultural policymakers have continuously increased the MPS, enacting relatively high price controls and border protection that target specific commodities.

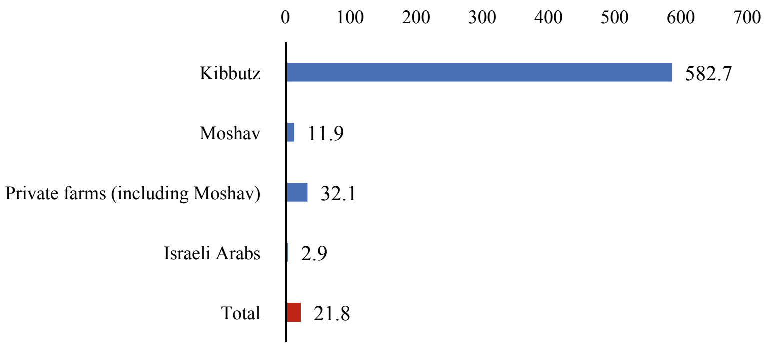

Fig. 9.18 Average landholding size in Israel, by type (in ha, 2017). *Source* CBS, Agricultural Statistics Quarterly (2020)

In 2018–19, MPS was on an average 14.85% of gross farm receipts (OECD 2019).[10] During that year, domestic prices received by Israel farmers were on an average 14% higher than world prices. Present price policies are highly favourable for poultry, milk and some selected fruits and vegetables. At the same time, in 2018–19 alone, the PSE was as high as 18.1% of gross farm receipts and very close to the OECD average of 19.2%. The focus on substantial price support may stabilise the agricultural sector and help it prosper in the short term. But it also exacerbates distortions in the domestic market and may create a complacency that stifles the kind of innovation that Israeli farmers need in order to maintain their relative advantage in the future. Free market advocates see this as important for fostering competitition while avoiding distortions in trade and resource allocation. Nonetheless, the government remains highly involved in regulating numerous aspects of agricultural production, including water resources and foreign workers. This kind of engagement has helped countless farm operations make it through challenging times.

In its evaluation of Israeli agriculture, the OECD further attributed the country's steady progress to increased sophistication and efficiency—surely something that is not strengthened by automatic commodity subsidies: "Growing labour productivity was a key contributor to the almost twofold increase in total factor productivity in agriculture in 1990–2008, much stronger than in any other sector of the Israeli economy". In short, the country's steady commitment to agricultural research and development appears to be the most sustainable strategy for the future, consistently manifested in higher yields and profits for farmers. Indeed, for much of the past two decades, government expenditures in research and development averaged 17% of the government's agricultural budget or USD58 million a year. This amounts to less than 1% of Israel's overall agricultural output. It seems like a very good return.

In recent years during the controversial tenure of right-wing politician, Uri Ariel, as agricultural minister, government R&D investment was cut to as little as ILS 90 million (USD25 million) (Israel Ministry of Agriculture 2019c), invoking the ire of

[10]Monitoring and Evaluation report 2019, OECD.

scientists and farmers alike (Tal 2018). Ironically, several government documents issued during this period emphasised that the future of Israeli agriculture lies in cutting-edge agricultural science and technology.

In general, while Israel has reduced its subsidies for local farm operations, it has hardly eliminated them. A 2017, OECD review summarises: *"Despite efforts to implement market-oriented reforms, the persistence of some regulations, price controls and border protection continue to isolate domestic farm gate prices for some commodities from changes on international markets… Producers of some commodities benefit from market price support, with the largest support for milk and bananas in 2014–16"*. (OECD 2017).

This view, however, is not universally held, especially among environmental advocates. For instance, a recent report issued by the Israel Association for Ecology and Environmental Science argued that more subsidies are actually needed to encourage consumption of healthier foods and produce with a smaller ecological footprint (Israel Association for Ecology and Environmental Sciences 2016). More recently, as part of the EAT-Lancet study, a new Israeli report was released that laid down ambitious recommendations for making local agricultural production prioritise healthier foods while reducing its carbon footprint (Gavrielli 2020).

9.10 General Trends in Imports and Exports

One trend is clear: Israeli farmers are exporting less produce—and receiving higher prices locally. Clearly, Israel's general prosperity is one of the reasons for this shift. Another reason involves the ability of different produce sectors to organise and successfully negotiate better terms with local retailers. Israel's grape industry offers an interesting example of this phenomenon. Over the past several years, grape sales in Israel have been transformed by the *Tali* Grapes co-operative. This company, formally founded in 1966, is slowly cornering the market in Israel. With some 66 farms representing 150 families, today the co-operative has close to a 50% domestic market share (Tali Grapes 2018).

With some thirty grape types, *Tali Grapes* now has sufficient product volume to negotiate prices effectively with supermarket chains in Israel and beyond. Today, other Israeli grape growers have come to recognise the benefits and are trying to sell their grapes to the co-operative even when they are not members. In the field of citrus fruits, *Mehadrin* offers a similar story, where aggregation served to empower farmers who, without organising, would be unable to hold their own in negotiations with retailers. Starting by representing Israeli citrus farms of varying sizes, the company now has access to a range of produce grown on 5000 ha. Today, it boasts USD300 million in sales, with 70% of Israeli citrus exports and deliveries to every continent (Mehadrin 2020). These aggregation and converging processes are critical in a country like Israel, where most farm operations are small by international standards. (Recently, a single Mexican grape grower came to Israel to look at new technologies for his 3000 ha of grape vineyards. Such land holdings are equivalent in size to the entire grape crop in Israel.)

Because of their high-quality produce and reasonable dimensions, *Tali Grapes* can now enjoy access to the latest in genetic innovations coming out of California. Suppliers would otherwise not consider individual farmers worth the trouble. The same is true for packaging—with *Tali Grapes* buying the only model of the latest rinsing and packaging machine in Israel.

While market forces contribute to greater efficiency, there may be other considerations that are important for Israeli decision makers, especially given the country's relatively isolated status. Because of geopolitical dynamics, Israel functionally is an island state. With the advent of the Corona virus crisis, increasing concerns are heard about Israel's growing dependence on agricultural imports and the associated food security risk. As many of the assumptions spawned by globalisation become less certain, Israeli farmers might need to be supported to expand the amount of protein they produce. Given present uncertainty, this might be reasonable public policy even if agricultural costs in the local arid environment run slightly higher than production of the same protein source in the international market.

9.10.1 Agro-Tech Companies in Israel

There are at present close to 500 active Israeli companies working in the agro-tech field. Twelve of them were established before the country gained independence in 1948 (Start-up Nation Central 2018). But over a quarter of these are less than five years old; half were founded within the past decade. In 2017, some USD160 million was raised by private investors, an increase of 65% relative to USD97 million raised in 2016.

On average, roughly USD500 million has been invested annually in Israeli agro-tech industries over the past several years. This represents a significant share of related international investment. In recent years, the percentage of global investment in Israeli agro-tech increased from 4 to 7% of total global funding. This may seem like a modest share. But then Israel is home to only 0.1% of the world's population. On a per capita basis, this is 2.4 times greater than US investment in the agro-tech sector (Start-up Nation Central 2018). At present, the Israeli agro-tech sector is expanding, providing jobs for 18,000 workers by taking advantage of the skilled and educated elite.

9.11 Private Sector Investment and Entrepreneurial Involvement in Agricultural Innovation

The private sector is the heart of the Israeli agricultural innovation ecosystem. Given the numerous robust tech mutual funds operating in Israel, there are relatively few venture capital operations that target agro-tech and prioritise investment in agricultural technologies. Among the leaders is Green Soil Investments. This Ra'ananah-based venture capital firm already has six major investments and is in the process of raising an additional USD30–50 million. It seeks to provide funding to promising start-ups that have passed beyond a proof of concept stage and need to move into a more mature phase of development. Generally, the company seeks "Round A" or "Round B", rather than seed or preseed investments. As a rule of thumb, Green Soil Investments direct 80% of its funds to Israeli inventions and start-ups, diverting only 20% to ventures in other countries.

Another player is Herzliyah-based Copia Ag. and Food, which specialises in working with researchers in academia and bringing their ideas to the market. The company is essentially a "technology transfer" company that generates resources to support ideas that emerge from scientific research, until they ripen sufficiently for industrial application. The company initially raised 25 million dollars to help launch twelve agro-tech projects, which it believes have significant potential impact. Its largest single investor is Altshuler-Shacham, an Israeli pension fund manager. Several individual investors from Japan, the USA and Europe also "bought in", providing additional capital.

9.11.1 Agro-Tech's Incubators Role in Promoting Innovation

In Israel, technological incubators offer a relatively small, but important organised framework that supports local agro-tech start-ups. The incubators are operated through the licensing of the chief scientists of the Ministry of Industry and Trade, as well as the new Innovation Agency created by Israel's government. The government incentivises these agro-tech companies by providing funding to the new ventures: 85% of the funding is provided by the state—with corporate participation set at 15% by the licensed incubators. Pursuant to the business model, in practice, the state takes responsibility for most of the financial risk associated with the new companies.

Once a new venture begins to make revenues, it begins to pay back the money that it received from the state, under extremely comfortable conditions and interest rates—far lower than those offered by commercial banks. The new start-ups are not expected to pay back sums in excess of 3% of their total revenues, so that the payments can take many years to complete. Moreover, the new start-ups enjoy the benefit of advisors, professionals and support-staff that assist them on an ongoing basis. The time spent in the incubators by start-ups is characterised by relative emotional and economic stability, allowing entrepreneurs to focus on developing products rather than chasing funds to pay back loans.

Start-ups are automatically allowed to stay in the technological incubators for a two-year duration, enjoying direct financial aid of up to USD850,000. Certain kinds of initiatives are entitled to an additional USD125,000. In return for their initial investment, investors who back the product early, receive from 30 to 50% ownership in the company with the government receiving 3–5% of the earnings that are eventually generated until the initial loan is repaid. Today, there are some 20 technology incubators working in Israel. Of these, two incubators focus exclusively on agro-tech: "*Mofet in Judah Ltd.—the Periphery Incubator*, in South Hebron, which is funded by *Trendlines* and other companies, along with *Yahin Impact*, which focuses on products that prevent food loss. Other Israeli incubators focus on biotech and other products related to agriculture.

A recent evaluation of financing by *Start-up Nation Central* shows that funding for Israeli agro-tech is provided primarily by venture capital firms (46%), "angel funds" (23%); corporate investments (18%) with only 5% coming from incubators. Moreover, some 3% of the agro-tech start-ups receive their first capital through Internet crowd-funding platforms (Start-up Nation Central 2018).

9.11.2 Trendlines—The Original Israeli Agro-Tech VC and Incubator

One of the most important private sector players in Israel's agro-tech ecosystem is Trendlines Group. Dividing its efforts between medical and agricultural technologies, Trendlines, on its website, describes itself as an innovation commercialisation company: "Trendlines invents, discovers, invests in, and incubates innovation-based agricultural technologies" (Trendlines 2020). The company was founded by two American businessmen, Steve Rhodes and Todd Dollinger, who brought their considerable business experience with them to Israel. With its headquarters in the Galilean village of Misgav, Treadlines has some 40 employees with significant operations recently established in Singapore.

Given the rapid ascent of the local hi-tech sector, Israel's incubators hold enormous economic potential by bringing different types of innovative technological solutions to agricultural practices. The incubator supports companies in the R and D stages, helping them in the transition to becoming independent companies.

9.12 Innovations in Agricultural Institutions in Israel

Beyond the significance of government support, finding an appropriate institutional setup has played an important role in developing Israel's agricultural sector.

Stable, professional and well-funded institutions that are capable of evolving can be seen as the backbone of the Israeli agricultural economy. They remain critical to the optimal allocation of scarce natural resources among farmers and for the facilitation of effective agricultural production. In retrospect, governmental and non-governmental institutions have set the rules of the game and created an enabling infrastructure for farmers—with a long-term view and a generally clear economic strategy in mind. Israel's farmers enjoy reasonable ministerial synchronisation that co-ordinates priorities through a systematic planning process that still gives fundamental autonomy to agricultural operations. Israel's story also shows that policymaking and implementation need to evolve in parallel.

9.12.1 Land Institutions

Israel is unique among developed countries in that 93% of the agricultural land is publicly owned and only 7% is in private hands (OECD 2010). Land is administered by the Israel Land Administration (ILA), overseen by government representatives and the Jewish National Fund (a public corporation) which leases user rights to farmers for varying time periods. Another distinctive institutional feature is the continued domination of co-operative communities, principally the kibbutz and moshav. Together, these communities account for about 80% of the country's agricultural production. With very rare exceptions, these co-operative communes and collaborative agricultural villages have remained socially harmonious and economically dynamic. The staying power of Israel's moshavim and kibbutzim can generally be attributed to competent local management along with a nimble agronomic orientation, accompanied by close government supervision. These communities have essentially empowered farmers through economies of scale, a strong link to the market and relatively strong bargaining power in both farm input and produce markets. Moreover, issues of trust and corruption have typically been limited because of the inherent transparency of kibbutzim (Abraham 2019).

Israeli farmers also tend to be relatively educated, talented and motivated. The general mindset of community members can be characterised as a powerful commitment to their society, economic co-operation and openness to change—rather than free-riding. Many of the founding members of these agricultural co-operatives grew up in youth movements where from a young age they focused on problem solving, collaboration and developing an ideological mindset. Children from kibbutzim and moshavim generally share their parents' core values, frequently taking leadership roles during compulsory military service. It was perfectly natural that the mindset and principles that informed Israel's agricultural settlers began to find expression as entrepreneurship and "learning-by-doing". Given their disproportionate influence, a brief description of the two types of communal lifestyles is in order.

Broadly, the kibbutz is the more extreme form of a co-operative, even though the actual level of community ownership of property and means of production varies dramatically. At present, there are some 284 kibbutzim in Israel. At their inception, they were all heavily funded and supported by the government, which provided land, water and basic infrastructure. An equal proportion of land plots of around 3–6 ha were allocated according to the number of families, and each kibbutz was expected to average around 150 families. Land was never owned by individual families, but by the community. In the early stages, total agricultural production was aggregated for the kibbutz members to sell. Any income generated belonged to the kibbutz, as did all the assets and possessions of the families living on the co-operative. Today, families own their possessions and typically enjoy considerable economic freedom. But the land, at least formally, remains communal (Abramitzky 2018).

Moshavim are fundamentally different from kibbutzim. The unit of production in the moshav is the family, not the co-operative as in the case of the kibbutz. In moshavim, plots of land were always privately owned by each family. Each family decides what to grow and how much to plant. For the most part, land plots are equal, and aggregation, processing, packaging, marketing and distribution are centralised. Over the years, settlements develop their own individual dynamics so that not all moshavim share marketing and distribution. And many moshavim, which are located near urban centres, have converted farm land into new neighbourhoods, increasingly coming to resemble rural suburbia.

On traditional moshavim, the farming is independent but post-harvest marketing is collective. Farming equipment is owned by the co-operative and members can lease it. Land can only be sold to other farmers who are members of the moshav. Again, with considerable local variation, typically each moshav has a board, a general assembly and a chief executive officer, who is elected. For the most part, this is the only paid position on the board. Marketing and distribution are often outsourced, executed by a separate not-for-profit entity with its own staff, which may or may not be owned by the moshav.

At present, there are 440 moshavim in Israel. Over the years, there has been considerable land consolidation through a mix of land market dynamics and policy incentives, leading to the present average farm size of 22 ha. There are two nation-wide farmer associations in Israel. The Israel Farmers Federation Association is the umbrella organisation, primarily for farmers that includes kibbutzim and moshavim, while the Farmer's Federation of Israel represents non-co-operative private farmers. The co-operatives are also part of farmer associations for key crops, such as dairy, dates and apples—and these report to the umbrella organisation (Abraham 2019).

Historically, land use contracts allocated to farmers involved long-term leases of state-owned lands for a maximum for 49 years—with the option for renewal. In theory, a leaseholder who does not cultivate the land for ten years bears the risk of losing the land user rights (OECD 2010), although this provision is rarely enforced. Legally, leaseholders are not to trade their land leases outside their settlement unless they sell the whole farm including their residence. When an OECD team evaluated the existing land allocation system in Israel, its authors argued that it would be more efficient, inclusive and sustainable to privatise agricultural land compared to the current approach. They observed that this would allow the establishment of active and transparent land market transactions. They also noted the need for formal partnerships for any cross-settlement land lease transactions to take place.

Like many international consultants, the agronomists who prepared the study may not have been fully aware of the deep cultural identity that these two agricultural lifestyles have in Israel's national consciousness. Moreover, vested interests—both economic and cultural—suggest that this sort of radical reform is unlikely. Nonetheless, it would surely be a valuable undertaking for the Israeli government to conduct a new agricultural census that more accurately captures existing farm structures and actual land usage in order to better understand the outcome of land policies implemented over the last two decades.

9.12.2 Water Institution

It took Israel over a decade after receiving independence to enact a water law, presumably because the British government's unpopular water policies left residual suspicion about centrally controlled water regulation (Blass 1973). Under the law, water resources in Israel (including wastewater and drainage) are publicly owned with oversight for their regulation entrusted to the Water Commission—which re-emerged in 2007—as the Israel Water Authority. For over sixty years, Israel's water system has been characterised by top-down, centralised management, led by a single independent agency that reports to a minister. For Israel's first forty years, the Water Commission reported to the Minister of Agriculture. But in 1996, in order to resolve a political crisis with Ariel Sharon (later to become Prime Minister), a Ministry of Energy and Water was created that continues to oversee Israel's Water Authority. Sharon was a farmer himself and strongly supported agricultural interests. Nonetheless, symbolically, the institutional transition reflected the dwindling influence of Israel's agricultural community. (In 2020, as part of a political compromise to form a government coalition, a Ministry of Water and Higher Education was created, and decoupled from the Israeli energy bueracracy. But it is unlikely to remain a permanent institution.)

The Water Commission (and, as of late, the Water Authority) was designed so that one government agency with consolidated authorities would be able to see the "big hydrological picture" and implement a holistic development strategy for Israel's agricultural water sector (Tal 2006). In retrospect, there is a consensus that this goal was only partially achieved. Israel's Ministry of Environmental Protection retains considerable authority on issues relating to quality and pollution prevention; the Ministry of Health sets standards for wastewater reuse for irrigation; the Ministry of Interior oversees municipal supply along with the water and sewage corporations who deliver water to homes and collect sewage. Regional drainage and stream restoration authorities are important players as well.

While there is generally a reasonable effort to co-ordinate efforts, it is impossible that this many institutional actors—whose underlying missions are so different—will agree about everything. Within this network of agencies, Israel's Water Authority is unquestionably the first among equals. This is certainly true in the area of irrigation water for farmers. Not only does it decide on the size of water allocations to farmers, but its respected professional staff plan for the development of water supply, oversee sewage infrastructure and wastewater use, set water prices, run water conservation campaigns and are ultimately responsible that potable water be delivered to every Israeli household, 24/7. Notwithstanding the somewhat labyrinthic division of authorities between different government agencies and despite the imperfect statutory framework, Israel has managed to develop one of the most advanced water management sectors in the world (Tal 2007b).

In addition, given the public ownership of Israeli water resources, since the 1950s, any water drawn from a well under a farmers' property is also regulated via a water production licence. Once water is allocated, it is brought to the farm through public corporate providers—either Mekorot, the national water utility or through agricultural water associations (Tal 2017). The Water Authority issues annual licences for extraction of water by suppliers, with decisions generally driven by the hydrogeological condition of aquifers and past allocations. Despite a long litany of declarations, ensuring the natural flow of streams remains a low priority (Tal and Katz 2012). The Water Authority seeks to reach a balance between the overall economic welfare of farmers and the hydrological health of the country's aquifers and surface waters. The emergence of recycled effluents and even desalinated water has allowed the Authority to be more consistent and reliable in its water allocations, notwithstanding intermittent periods of drought. This helped Israeli farmers make agronomic plans into the future with a reasonable level of certainty.

The two central policy instruments used by the Water Authority to ensure optimal allocation and utilisation of water are water quotas and water pricing. Implementation has been expedited by all Israeli farm operations being connected to water metres. In the 1950s, the "Uzani Committee" established criteria for allocation of water quotas that remain largely unchanged until the present. These include farms' location, land area, total land suitable for irrigation, cropping patterns and soil types (OECD 2010). Quotas historically were reallocated every year, with the authority providing 75% of agricultural water quotas up front among users. Then, depending on the actual rainfall and hydrological reserves, the remaining reserves would be parcelled out. This staggered release has been discontinued after desalination made Israeli water supply increasingly reliable.

From the inception of the country, water officials espoused a commitment to ensuring inclusiveness and equitable distribution of water among farmers across the country. But in fact in recent years, the pricing system for agriculture strayed from this egalitarian ideal. In 2009, facing drought conditions, the government signed an agreement with agricultural representatives, which linked the price of agricultural water delivered by Mekorot in the national grid to the real costs of supplying this water. In practice, this price was driven by the relative percentage of desalinised water in the total supply. As desalination expanded, farmers in the south of Israel, whose water was not supplied by a local or private water association, found that their irrigation costs for fresh water had risen precipitously. And so it was ironic that in 2017, Israel's Capitalist government returned to the "Socialist" orientation of the country's founding water managers. This came in the form of "Amendment 27" to Israel's Water Law. By then, farmers living in the north of Israel who received water extracted by their local water associations from nearby sources were paying prices that ranged between a mere 15 and 40 cents for a cubic metre of water. Israel's other farmers, located, largely in the south, were paying 73 cents per cubic metre to Mekorot for water delivery. Moreover, there were differential extraction fees charged to users, based on actual costs, which often made the price variations even greater.

The new reform cancelled the demand for extraction fees, integrating the expense into a single price of water. Over a five-year period, water prices for all Israeli farmers were ratcheted down—or up—to a single national rate of 52 cents/cubic metre. This final price will be reached within two years. A small number of farmers, who are unable to use recycled effluents because of environmental concerns about runoff to adjacent surface waters are, however, entitled to pay a lower 42 cent/cubic metre rate (Yefet 2017). Ultimately, Israel's water pricing policy can be considered as a "cross-subsidy", where higher prices are charged to one type of farmers to artificially lower prices for another group of consumers.

Freshwater prices themselves are determined, with parliamentary approval, by the Authority based on its multi-tier block pricing structure (introduced originally in 1991). This means that the actual price that farmers pay for water depends on the quality of the water used. Water is divided into two general categories—fresh water and marginal water. Marginal water is further divided into four categories: saline water (from brackish aquifers); tertiary-treated effluents; secondary-treated effluents and water from the Tel Aviv region wastewater treatment plant—the "Shafdan". The Shafdan price is extremely low (roughly 25 cents/cubic metre) based on an old agreement made with the farm community designed to encourage them to purchase effluents from Israel's largest wastewater treatment plant. As the Shefdan sewage is treated to a very high level, today there is tremendous demand for this ostensibly underpriced water source, as it constitutes something of an irrigation "bonanza"! Table 9.5 presents the relative quantities of each category of water allocated to agriculture for the year 2020. It should be noted that if an operation uses water beyond its quota, it is expected to pay fines. Should a farmer use more than 30% of the allocated quota, she will be expected to pay the full municipal water rate, which is roughly twice the agricultural price.

Ever since Simcha Blass was selected to head the first water management agency in Israel in 1949, the water sector generally has not been politicised. With a few

Table 9.5 Allocation of water to agriculture in Israel, in thousands of cubic metres (2020)

Goal	Fresh Mekorot	Fresh Private	Saline Mekorot	Saline	Effluents Tertiary	Shafdan	Rain Harvest	Total
Agriculture	293,088	229,499	88,161	123,866	381,510	149,411	61,268	1,326, 839

Source Israel Water Authority

temporary exceptions, Israel's water institutions have a history of being run by professional scientists or engineers. The government ensures that the water sector does not excessively drain public funds by setting unrealistically low prices. This has proved essential in distributing water resources efficiently across sectors and stopping the deterioration in ground and surface water resources.

Economic logic has also been one of the keys to success in Israel's water sector, allowing for long-term strategic decisions to be taken over the years. In addition, the careful pricing of this most limited natural resource to recover the opportunity cost of water use in agriculture, constitutes an implicit environmental tax which internalises a scarcity value to prevent over exploitation of aquifers by farmers and to avoid market failures. Today, any government subsidies on water for domestic and industrial uses are extremely modest when compared to past levels. This allows efficient, inclusive and sustainable allocation as well as an optimal utilisation of water resources.

In terms of overall quantity, Israeli farmers today use roughly the same amount of water that they used 25 years ago (~1195 million m^3). "Getting more crop for the drop", it seems, is not just an empty slogan. Given the higher level of yields for crops across the board, this stability in water demand is a testimony to the agricultural community's commitment to water efficiency and openness to the ongoing improvements in drip irrigation technologies (as well as crop genetics). It is also worth noting that the sources of water for Israeli farmers have changed from ground and surface water to recycled effluents and, in some locations, even desalinated water sources.

Figure 9.19 shows the rise of recycled effluents as a source of irrigation water for Israeli agriculture operations. In 1993, only a third of Israeli irrigation water came from recycled sewage; by 2018, the rate had almost reached two-thirds. Questions remain about the long-term sustainability of farming (and in particular soils) based on wastewater reuse, especially due to salination and concerns about

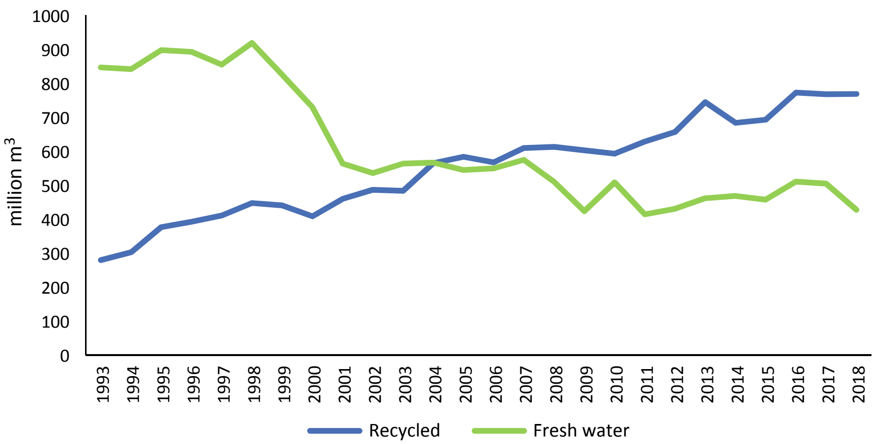

Fig. 9.19 Agricultural water consumption (by source) in Israel. *Source* Israel's Water Authority, Water Consumption Report (2018)

endocrine disrupting chemicals (Dotan 2016). Recent studies offer grounds for cautious optimism, confirming that Israel's *desalinated* municipal water supply has in fact contributed to reduced level of salts in the country's sewage. This means that the recycled effluents today are of far better quality than even a decade ago, causing far less soil salination. It also suggests that this transition may be one which can sustain Israeli farming for generations (Tal 2018).

9.13 Conclusions and Recommendations

Without massive investments in research and development along with a well-developed education and extension system, Israeli agriculture would never have flourished and become a world leader in agricultural technology, particularly technology associated with farming under arid conditions. Israel's experience with agriculture in desert conditions suggests that a country's agricultural success need not rely on "natural" comparative advantages in farming. Rather, it can enjoy an "induced" comparative advantage, built on creativity and technological progress. Indeed, countries can transform climatic and topographic disadvantages into blessings. This requires ongoing ingenuity and entrepreneurial initiative. The future success of Israeli agriculture and further productivity gains rely heavily on preserving and expanding its historically effective system of research, development and technology transfer as well as maintaining its well-established extension services (OECD 2010).

Israel's exceptional achievements in agriculture are also a function of cultural factors that cannot be easily exported or transmitted in training courses. It is not a coincidence that the "kibbutz", historically perhaps the single greatest source of Israel's agricultural innovation, is an idiosyncratic, intentional community. It emerged as an expression of the country's highly idealistic, Socialist founders' values and has not really been duplicated in other milieus. Another unique, societal characteristic that forms Israeli agriculture is the centrality of compulsory military service for most Israelis. In recent years, many of the agro-tech initiatives to come out of Israel can be linked to applying technologies developed for the military to agricultural challenges.

Ultimately, however, it is Israel's ongoing commitment to basic and applied research which has provided the greatest boost to local agricultural innovation. This was also the conclusion of OECD researchers when the organisation made its first, formal external evaluation of Israel's agricultural sector a decade ago:

"The agricultural sector has benefited from high levels of investment in research and development, well developed education systems and high-performing extension services. Israel is a world leader in many aspects of agricultural technology, particularly those associated with farming in arid conditions. Thus, agriculture relies not so much on a "natural" comparative advantage in farming, but on an "induced" comparative advantage built on technological progress. The future success of Israeli agriculture and further productivity gains will rely heavily on ensuring an effective system of research, development and technology transfer, and on maintaining well established extension services" (OECD 2010, 12).

Without detracting from the acumen of Israeli farmers and the resourcefulness of agricultural researchers, it is difficult, however, to characterise present dynamics as fully sustainable. While Israeli agriculture enjoys technological prowess and its knowledge and extension services are cutting-edge, ironically, the country cannot feed itself today. In practice, the country has long been a net importer of calories. Israel's rapidly growing population distances the country ever further from self-sufficiency and raises serious anxiety about food security (Hadas 2014). A recent study by Ben Gurion University researchers quantifies the full magnitude of Israeli dependence on imports. Some 60% of Israel's food supply (8.7 million tonnes of crops) is imported. But because it grows little of its own cereal and oil crops; more than 85% of its calorie supply is embedded in imported produce (Fridman and Kissinger 2019).

For the foreseeable future, a considerable portion Israel's calories will increasingly be imported. Yet, the local incentive structure is still not aligned with an open-economy free trade scenario, and supports for producers remains relatively high—almost as high as the OECD average. Israeli leadership needs to come to terms with these dynamics and consider what a long-term sustainable food security strategy might be. This should begin by revitalising its commitment to upgrading local farming. Undoubtedly, it will choose to maximise new, sophisticated production technologies in efforts to overcome the country's diminutive dimensions and limited space for agricultural production.

The country's institutional structure governing land ownership and water are also somewhat unique. China had similar structures for land ownership before 1978, but ultimately chose to dismantle its commune system and institute a household responsibility system; more recently, it started leasing land to large corporate entities. By contrast, Israel has managed to preserve the vibrancy and productivity of its agricultural sector within a similar communal (kibbutz and moshav) system. There is nothing in present dynamics that suggests that these farm units, which remain paragons of water efficiency and agronomic innovation, should be phased out. Indeed, their resilience over time is remarkable and a matter for further study by international researchers.

In the interim, Israeli innovation continues and there are numerous products available in a range of areas—from drip irrigation to greenhouses to marketing assistance via simple cellphone chat bots as well as mini-grids of electricity, with banks of batteries charged by solar panels that power water pumping. Such technological breakthroughs can be implemented in other regions of the world, including developing countries. In other words, the new modular infrastructures that are now available, given the dramatic drop in solar energy and storage prices can create a completely new reality for smallholders, in which large irrigation projects, refrigeration and Internet associated technologies are accessible, for the first time making many sophisticated Israeli innovations useful. Furthermore, Israel's training programmes are inexpensive and effective in transferring knowledge and inspiring young farmers from developing countries to be entrepreneurial in their agricultural activities back home. They could easily be expanded.

Interviews with university researchers, agro-tech entrepreneurs, government officials, and investors reveal a consensus that Israel can—and should—do more to assist the world's small and indigent farmers. With the right incentives, assistance and partners in the developing world, the impact of Israel's agro-tech ecosystem and culture of innovation could be magnified far beyond present levels. As world food security emerges as an increasingly acute global challenge, this is an opportunity which should not be missed.

Israel's agricultural experience is unlike any other on earth. Its ability to consistently produce new technologies, new crops and new forms of irrigation justifiably make it a source of interest to investors, researchers and farmers alike from around the world. For over seventy years, the country's academic institutions, policies, R&D stations and extension services have produced one of the most sophisticated agricultural sectors in the world. In parallel, in recent years, a start-up culture and entrepreneurial ecosystem that develops agricultural technologies has emerged, making the country a global leader in agro-tech. The steady stream of exciting ideas and ventures has been nurtured by private investment—both local and international. Israel's scientific acumen and technical creativity holds considerable potential for improving the yields of farmers around the planet, including the wellbeing of smallholders in developing countries.

References

Abraham, D., Ngoga, T., Said, J., Yachin, M. (2019). *How Israel became a world leader in agriculture and water*. London: Tony Blair Institute for Global Change, October 9, 2019. https://institute.global/advisory/how-israel-became-world-leader-agriculture-and-water.

Abramitzky, R. (2018). *The Mystery of the Kibbutz: Egalitarian principles in a capitalist world*. Princeton: Princeton University Press.

Agrinnovation, Where Future is Present, last visited November 5, 2020. http://www.agri-nnovation.com/.

Avgar, I. (2018). *Israel water sector—Key issue*s. Jerusalem: Knesset Research and Information Center. https://m.knesset.gov.il/EN/activity/mmm/mmmeng250218.pdf.

Ben-Bassat, A. (2002). *The Israeli Economy, 1985–1998: From government intervention to market economics.* Cambridge, Massachusetts: MIT Press.

Ben Niriah, Talia, (2018). Israel innovations authority, Interview, August 6, 2018.

Ben-Zoor, D., Priampolsky, M. (2015). *The Israeli agritech sector*, Report for Bank Leumi, Tel Aviv. https://english.leumi.co.il/static-files/10/LeumiEnglish/Leumi_Review/The_Israeli_Agritech_Sector_082015.pdf.

Bio-Bee. (2019). Biological Systems Limited. Israel.

Blass, S. (1973). *Water in strife and action.* Givataim: Masada.

Blumer, U. (2018). Kibbutz start-up turns fly larvae into protein-rich animal feed. *Ctech*, January 7, 2018. https://www.calcalistech.com/ctech/articles/0,7340,L-3729038,00.html.

Budd, A., Quen, Q., Domingos, J., & Jerry, D. (2015). Sex control in fish: Approaches, challenges and opportunities for aquaculture. *Journal of Marine Science and Engineering, 3*(2), 329–355.

ChickP (2020). The next big thing in protein. https://www.chickpea-protein.com/. Last visited April 8, 2020.

Dabach, S., Shani, U., & Lazarovitch, N. (2015). Optimal tensiometer placement for high frequency subsurface drip irrigation management in heterogeneous soils. *Agricultural Water Management, 152,* 91–98.

Dag, A. (2020). Volcani Institute, Personal communication, February 23, 2020.

Dotan, P., Arnon, S., Godinger, T., Odeh, W., Groisman, L., Al-, N., et al. (2016). Occurrence and fate of endocrine disrupting compounds in wastewater treatment plants in Israel and the Palestinian West Bank. *Chemosphere, 155,* 86–93.

Fallik, E. (2004). Prestorage hot water treatments (immersion, rinsing and brushing). *Postharvest Biology and Technology, 32,* 125–134.

FAO (2018). SAVE FOOD: Global initiative on food loss and waste reduction. Rome: FAO. https://www.fao.org/save-food/resources/keyfindings/en/.

FAO (2019). Israel**,** FAOSTAT. https://www.fao.org/faostat/en/#data/QC/.

Fridman, D., & Kissinger, M. (2019). A multi-scale analysis of interregional sustainability: Applied to Israel's food supply. *Science of the Total Environment, 676*(1), 524–534.

Gavrielli, Y., Adler, D., Teffer, S. (2020). Food, health, our planet. *Israel sustainable food forum* (in Hebrew).

Globes (2012, May 14). Naan sells Naan-Dan-Jain irrigation. https://www.globes.co.il/en/article-1000748674.

Hadas, E., & Gal, Y. (2014). Barriers preventing food security in Israel, 2050. *Managing Global Transitions, 12*(1), 3–22.

Hillel, D. (1982). Irrigated agriculture. *The Negev, land, water and life in a desert environment*. New York: Praeger.

Israel Association for Ecology and Environmental Sciences. (2016). *Integrating objectives and indicators for sustainable agriculture in the framework of director support for agriculture.* Tel Aviv: IAEES.

Israel Central Bureau of Statistics (CBS). (2019). Agricultural Annual Census of Israel, https://www.cbs.gov.il/he/publications/doclib/2019/21.shnatonagriculture/diagrams21.pdf.

Israel Central Bureau of Statistics, Agricultural Statistics Quarterly, January-March 2020, (Ed. Rinat Dweck-Siksak) August, 2020. https://old.cbs.gov.il/publications20/agriculture_q202001/pdf/e_print.pdf.

Israel Central Bureau of Statistics (2020). *Population*, site last visited, April 6, 2020. https://www.cbs.gov.il/en/subjects/Pages/Population.aspx.

Israel Dairy Board, Quota and Milk Supply in Israel, last visited November 5, 2020, https://www.israeldairy.com/milk-quality-copy/.

Israel Innovation Authority (2020). Start-up Division, last visited, April 8, 2020. https://innovationisrael.org.il/en/.

Israel Ministry of Agriculture and Rural Development (2013). *National plan for agriculture and rural regions in israel: policy and planning document*. Beit Dagan: Ministry of Agriculture, June 2013, p. 10. https://www.moag.gov.il/Files/tochnit_leumit_lahaklaut.pdf.

Israel Ministry of Agriculture and Rural Development (2018a). The Ministry of Agriculture continues to encourage farming's young generation, July 18, 2018. https://www.moag.gov.il/en/Ministrys%20Units/Spokesmanship%20and%20Publicity%20Department/publications/Publications_18/Pages/farmings_young_generation-.aspx.

Israel Ministry of Agriculture and Rural Development (2018b). Tender for Developing Egg Farms, January 11, 2018. https://www.moag.gov.il/yhidotmisrad/reshut_technun/technun_kafri/publication/2018/Documents/Noal_Tmicha_Lulim.pdf.

Israel Ministry of Agriculture and Rural Development. (2018c). Tender for Developing Egg Farms, January 11, 2018. https://www.moag.gov.il/yhidotmisrad/reshut_technun/technun_kafri/publication/2018/Documents/Noal_Tmicha_Lulim.pdf.

Israel Ministry of Agriculture and Rural Development (2019a). Food security and grain storage—Technologies and management, Beit Dagan, Israel, Cinadco. https://www.agri.gov.il/download/files/FoodSec019.pdf.

Israel Ministry of Agriculture and Rural Development. (2019b). *Activities of the Ministry of Agriculture, 2018*. https://www.moag.gov.il/hofesh_meyda/Documents/Activities_Report_2018.pdf.

Israeli Ministry of Agriculture and Rural Development—Research, Economics and Strategy Division (2019). *The agricultural sector in Israel—The economic situation for the year 2018* [Hebrew]. https://www.moag.gov.il/yhidotmisrad/research_economy_strategy/publication/2019/Documents/Annual_Report_2018.pdf.

Israel Water Authority, Water Consumption for the Year 2018, Final Report, September 2018, (In Hebrew). http://www.water.gov.il/Hebrew/ProfessionalInfoAndData/Allocation-Consumption-and-production/20183/Intro.pdf.

Jägermeyr, J., Gerten, D., Heinke, J., Schaphoff, S., Kummu, M., & Lucht, W. (2015). Water savings potentials of irrigation systems: Global simulation of processes and linkages. *Hydrology and Earth Systems Science, 19*, 3073–3091.

Lati, A. (2018). Researcher, Neveh Ya'ar Research Center, Volcani Institute, April 9, 2018.

Lavie, D. (2018). Rising white: Increase in milk production in Israel. *Israel Today,* May 16, 2018. https://www.israelhayom.co.il/article/556601.

Levy, Michal (2018). Deputy Director, Ministry of Agriculture, Personal Interview, August 2, 2018.

Libstein, O. (2018). Chair, Agritech Israel Association, Personal Interview, August 7, 2018.

Meeri, Noam (2019). Director of Institute of Animal Science, Volcani Institute, Personal Interview, April 10, 2019.

Mehadrin, (2020). Growers at heart website. Last visited April 12, 2020. https://www.mehadrin.co.il/.

Ministry of Agriculture. (2019). *The Agricultural Branch in Israel, An Economic Picture from the Year 2018*, (Ed. Ziv Bar-Nahum), (In Hebrew) Beit Dagan, Israel.

Mualem, J. (2018). Marom, Director, "Kidum" R&D Applications, Personal Interview, August 1, 2018.

Netafim. (2014). *Netakit catalogue*. https://mida.com.ar/files/Catalogo-Kits-2014.pdf.

Netafim. (2015). *Community micro irrigation* (p. 2015). Tel Aviv: Israel.

OECD. (2010). *OECD review of agricultural policies: Israel 2010*. Paris: OECD.

OECD. (2017). *Israel, agricultural policy monitoring and evaluation 2017* (pp. 114–121). Paris: OECD.

OECD. (2019). *Agricultural policy, monitoring and evaluation report* 2019. Paris: OECD. https://www.oecd.org/agriculture/oecd-ag-policy-monitoring-2019/.

OECD. (2020). *Country statistical profile, Israel*, last visited, November 5, 2020. https://data.oecd.org/israel.htm.

Pearl, Avi (2018). Chief Scientist, Israel Ministry of Agriculture, Personal Interview, August 20, 2018.

Robins, Ezra (2018). Director, Southern Arava, Research and Development Center, Personal Interview, April 2, 2018.

Rosenthal, G., & Eiges, H. (2014). Agricultural co-operatives in Israel. *Journal of Rural Cooperation, 42*(1), 1–29.

Roth-Avnermi, D. (2017). Red rising, a message for the Arava: The pepper crisis is over. *Israel Today*, August 10, 2017. https://www.israelhayom.co.il/article/496371.

Schnell, I., Greenberg, Z., Arnon, S., & Shamai, S. (2017). Entrepreneurship in the periphery and local growth: The case of northern Israel. *GeoJournal, 82,* 217–229. https://doi.org/10.1007/s10708-015-9676-9.

Sciroot. (2019). Smart Irrigation Management System. Israel.

Siegel, S. (2017). *Let there be water, Israel's solution for a water starved world,* New York: Saint Martin's Press 2017.

Sierra, J. (2018). CEO, Yarok, personal interview, July 26, 2018.

Sofer, M., & Applebaum, L. (2006). The rural space in Israel in search of renewed identity: The case of the moshav. *Journal of Rural Studies, 22*, 323–336.

Startup Nation Central (2018). *Agro-tech Report 2017,* Tel Aviv, October, 2017.

Stepac (2018). About Stepac, *Corporate Website* 2018. https://www.stepac.com/about-stepac.
Tal, A. (1998). Enforceable standards to abate agricultural pollution: The potential of regulatory policies in the Israeli context. *Tel Aviv University Studies in Law, 14,* 223–286.
Tal, A. (2002). *Pollution in a promised land—An environmental history of Israel*. Berkeley, California: University of California Press.
Tal, A. (2006). *The environment in Israel: Natural resources, crises, campaigns and policy from the advent of zionism until Twenty-first century* (in Hebrew). B'nei Brak: HaKibbutz HaMeuhad Press.
Tal, A. (2007a). To make a desert bloom—the Israeli agriculture adventure and the quest for sustainability. *Agricultural History, 81*(2), 228–258.
Tal, A. (2007b). Natural flow: questions and answers regarding the suitability of Israel's water law to a new environmental reality. *Legal Research (Bar Ilan University Law Review), 23*(2), 317–370.
Tal, A. (2008). Enduring technological optimism: Zionism's environmental ethic and its influence on Israel's environmental history. *The Journal of Environmental History, 13,* 275–305.
Tal, A. (2016a). *The land is full: Addressing overpopulation in Israel*. New Haven: Yale University Press.
Tal, A. (2016b). Has technology trumped adaptive management? A review of Israel's idiosyncratic hydrological history. *Global Environment, 9,* 484–515.
Tal, A. (2016c). Rethinking the sustainability of Israel's irrigation practices in the drylands. *Water Research, 90,* 387–394.
Tal, A. (2017). The evolution of Israeli water management: the elusive search for environmental security. In: Cahan, J. (Ed.), *Water security in the Middle East essays in scientific and social cooperation*. London: Anthem Press, 119–143.
Tal, A. (2018). Israel's shrinking commitment to agricultural research. *Times of Israel,* May 6, 2018. https://blogs.timesofisrael.com/israels-shrinking-commitment-to-agricultural-research/.
Tal, A. (2019). The implications of climate change driven depletion of Lake Kinneret water levels: The compelling case for climate change-triggered precipitation impact on Lake Kinneret's low water levels. *The Science of the Total Environment, 664,* 1045–1061.
Tal, A., & Katz, D. (2012). Rehabilitating Israel's streams and rivers. *Journal of River Basin Management, 10*(4), 317–330.
Tali Grapes (2018).Website, Last visited, April 12, 2020. https://www.taligrapes.co.il/.
Teschner, N. & Negev, M. (2013). The development of water infrastructures in Israel: Past, present and future. In S.B. Megdal, R.G. Varady & S. Eden (eds), *Shared borders, shared waters*. Leiden: CRC Press.
Times of Israel (2020). Israel Agriculture Minister orders egg imports as panicked buyers spark shortage. *Times of Israel,* March 28, 2020. https://www.timesofisrael.com/agriculture-minister-orders-egg-imports-as-panicked-buyers-spark-shortage/.
Trendlines (2020). *Website,* last visited, April 12, 2020, https://trendlines.com/.
Tsaban, S. (2017). *Statistical Atlas for Israeli agricultural*, *2017*. Beit Dagan: Israel Ministry of Agriculture and Rural Development. https://www.moag.gov.il/shaham/publication/Documents/atalas_haklaut.pdf.
Tzuk, U., Hershkovitz, R., & Kahal, Y. (2015). *Tools for supporting agriculture in Israel*. Beit Dagan: Israel Ministry of Agriculture.
Udassin, S. (2016a). Israeli agricultural robot aims to help farmers assess fruit yields. *Jerusalem Post*, December 4, 2016.
Udassin, S. (2016b). Israeli firm launches solar powered device to monitor farm fields. *Jerusalem Post*, December 6, 2016.
Volcani Institute of Animal Science (2018). PowerPoint presentation, April 2020, copy with author.
WHO—World Health Organization (2020). *Food safety: Fact sheet*. Last last visited April 12, 2020. https://www.who.int/topics/food_safety/factsheets/en/site.
World Bank (2020), Israel, last visited, April 6, 2020. https://data.worldbank.org/country/israel.
Yablonko, Y. (2019) Israeli gov't to invest NIS 20 m in agritech this year. *Globes*. https://en.globes.co.il/en/article-israeli-govt-to-invest-nis-20m-in-agritech-this-year-1001271906.

Yancovich, S. (2020) Senior Manager, Budgets Branch, Israel Ministry of Agriculture, personal communication, March 12, 2020.

Yefet, N. (2017). The Northern Farmers Lost, Amendment 27 Passes the Knesset. *Globes* (January 5, 2017). https://www.globes.co.il/news/article.aspx?did=1001170401.

Yogev, U., Sowers, K., Mozes, B., & Gross, A. (2017). Nitrogen and carbon balance in a novel near-zero water exchange saline recirculating aquaculture system. *Aquaculture, 467*(20), 118–126.

Zelingher, R. (2019). *Leveraging ARO's R&D through agricultural sector development in Africa*, Jerusalem: Milken Center. https://milkeninnovationcenter.org/publications/leveraging-aros-rd-through-agricultural-sector-development-in-africa/.

Zomar, Z. (2020). Now we see that without local agriculture, we do not have food security, *Ynet,* March 9, 2020. https://www.ynet.co.il/economy/article/B12Vc8mHI.

Zuidhof, M. J., Schneider, B. L., Korver, D. R., & Robinson, F. E. (2014). Growth, efficiency, and yield of commercial broilers from 1957, 1978, and 2005. *Poultry Science, 93*(12), 2970–2983.

Chapter 10
Comparative Analysis of Agricultural Innovations in India, China and Israel

10.1 Introduction

In the past, China, India and Israel were all confronted with the formidable challenge of feeding their populations amidst natural calamities, and they assigned the highest priority to agriculture and food security. It is, therefore, interesting to see how the countries came up with technological innovations and agricultural reforms to transform from food-deficient countries into major exporters of staples (India), processed food (China) and agricultural technology (Israel).

This chapter presents a comparative summary of all the major innovations in production technologies, incentives and institutions in Indian, Chinese and Israeli agriculture. The objective is to see how these innovations have significantly influenced agricultural productivity and production over the past decades in these countries and helped them feed their large and growing populations. The chapter also aims to draw key lessons and provide policy insights for the continuing reform processes in the three countries as well as for other developing and transitioning economies, where it is a challenge to produce enough food, feed and fibre for their populations. The chapter will summarise the insights on both what happened and how it happened across major food products. It also attempts to evaluate what aspects have been particularly effective and the relative weaknesses of the agricultural innovation system across the three countries. The following conceptual framework is applied for the comparative analysis.

10.2 Conceptual Framework

In recent years, the approach adopted towards agricultural innovation systems (AIS) advocates a shift from interventions focusing on single elements of innovations towards a system-approach aimed at strengthening institutions and stakeholders'

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network that better respond to the needs of farmers (Pound and Conroy 2017; FAO 2018). The World Bank defines an "innovation system" as a network of organisations, enterprises and individuals focused on bringing new products, new processes and new forms of organisation into economic use, together with the institutions and policies that affect their behaviour and performance (World Bank 2006).

Agricultural innovation typically happens through a multistakeholder process involving not only researchers, extension workers and farmers, but many other food value chain actors like processors, distributors and consumers. Different stakeholders hold different kinds of knowledge and expertise. Dynamic interactions and collaborations among these stakeholders are critical as innovation is an ongoing, evolutionary process. Apart from strong R&D capabilities, the ability to innovate is often related to collective action, coordination, the exchange of knowledge among diverse actors, the incentives and resources available to form partnerships and develop businesses and conditions that make it possible for farmers or entrepreneurs to use the innovations (World Bank 2012).

A simplified conceptual framework for an AIS approach has been developed and used for the comparative assessment in this chapter. Figure 10.1 shows the three major components of the innovation system (technology, institutions and incentives), the interactions with farmers and the policy and regulatory environment in which the farming sector operates.

Innovation in agricultural technologies contributes significantly to improving the efficiency and output of the agricultural sector. Technologies can be provided by the public sector and private companies. Government finances most of the public agricultural research and extension, which is a key component of an AIS. It provides the knowledge, research and development infrastructure such as labs, academic and

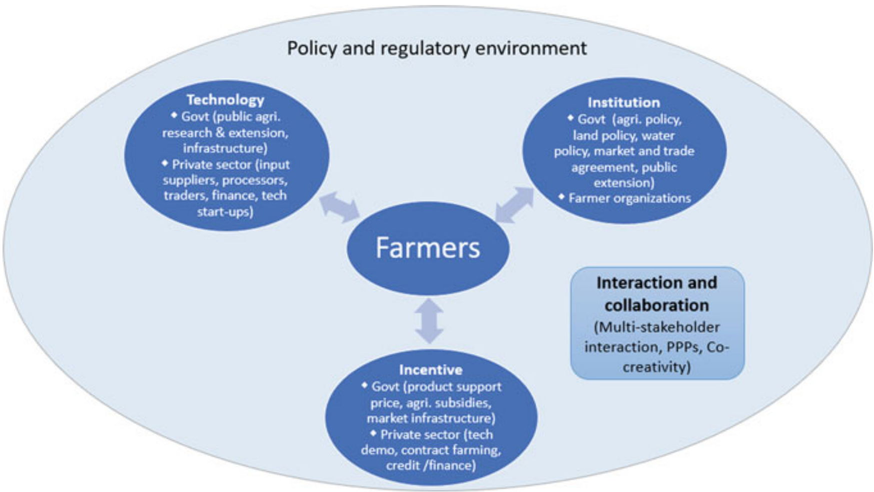

Fig. 10.1 Agricultural innovation system for sustainable and resilient agriculture. *Source* Authors' compilation

extension institutions. It also sponsors physical infrastructure including roads, irrigation schemes and power, which enables technology adoption. The private sector comprises input suppliers, processors, traders, financial service providers, tech start-ups and rural entrepreneurs, which are at the forefront in terms of provision of modern technologies and related services to farmers. There is increasing involvement of private agricultural businesses in extension and rural advisory services, especially on cash crops (Zhou and Babu 2015).

The technological innovation process will be effective only if there is a supportive enabling environment and institutions are properly established and governed. Government plays an important role in setting up formal institutions including agriculture related laws and regulations, international trade agreements, food quality standards and land and water property rights. Innovation in institutions is required to support farmers to better access and manage agricultural land, water, extension services and mechanisation at different stages of crop development. Farmers' organisations, particularly those which are innovation oriented, form an integral part of the AIS. In addition, informal institutions, practices, behaviours and attitudes also either support or hinder the process of innovation (World Bank 2012).

The third major component of the innovation system is incentives. Right incentives facilitate and expedite the innovation process and adoption. Governments play a dominant role in providing incentives to farmers, often in the form of agricultural subsidies. On the output side, there are product support prices such as minimum purchase price for staple crops in China and India, and a guaranteed price for milk in Israel. On the input side, there are considerable subsidies going to essential inputs like fertilisers, seeds, machinery and credit schemes. In addition, investment in and development of the agricultural marketing infrastructure (e.g. wholesale markets, storage, transport facilities) make markets efficient and remunerative, encouraging farmers and other actors in the value chain to create and adopt innovation. Private firms can also incentivise growers by providing appropriate solutions and products and facilitating their adoption through the credit system, contract farming or other innovative business and financial models.

Finally, interaction and collaboration across all the actors including farmers, government, private companies and non-profits are critical for the success of an AIS. Multistakeholder interaction for learning and problem solving is important, as is the facilitation of networks and linkages between actors to share knowledge and information. Public–private partnerships can play a significant role in creating the right conditions for innovations to be taken up widely. In addition, there is a need to balance power relations between the supply push of the R&D community and the demand pull of the farmers, especially in situations where smallholders lack the purchasing power and ability to influence the R&D agenda (Pyburn and Woodhill 2014).

It is worth noting that the agricultural innovation system is not static, but rather a dynamic, evolving structure, which takes shape in the political, social and economic context of a country.

10.3 Comparative Assessment of Agricultural Innovations Across the Three Countries

Based on the conceptual framework, Table 10.1 provides a high-level comparative assessment of what has happened with respect to the main agricultural commodities in each country, how it happened (including the role of innovations in production technology, incentives and institutions) and how good the overall system was.

10.3.1 Staple Crops

For staple crops, the development and commercialisation of high-yielding rice and wheat varieties was instrumental in increasing grain productivity and gaining self-sufficiency, particularly in India and China. For staple crops, the development and commercialisation of high-yielding varieties of seeds, together with increased irrigation, fertiliser and agrochemical use and farm mechanisation, were instrumental in increasing productivity and gaining self-sufficiency, particularly in India and China. Government incentives including minimum support prices and input subsidies also encouraged farmers to expand the acreage under major grains. In addition, institutions like the setting up of the Food Corporation of India and Agricultural Prices Commission in India and the establishment of the household responsibility system in China played an important role in boosting national grain production. Today, India and China are the two largest producers of rice in the world, together accounting for roughly half the global rice production. China has a higher yield, but India gained value with a breakthrough in basmati rice, making it the largest cultivator and exporter of basmati rice in the world. Figure 10.2 gives a comparative picture of rice yields in India and China, depicting an increasing gap over time. Figure 10.3 illustrates the trends of wheat yields across the three countries.

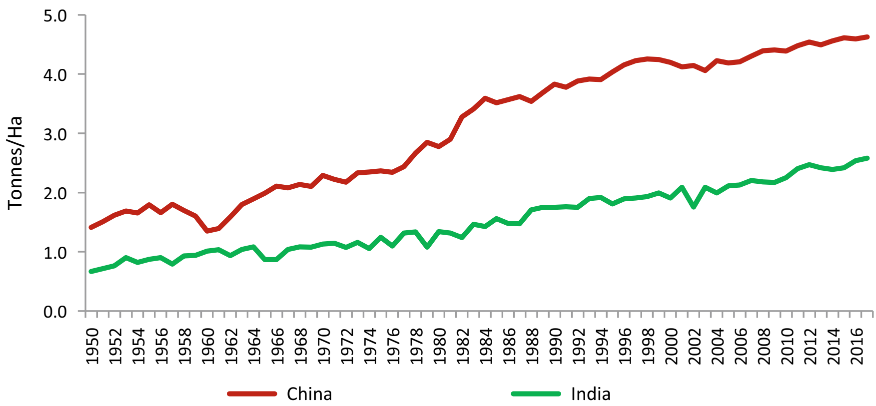

Fig. 10.2 Rice yields (milled) in India and China. *Source* FAOSTAT (2019)

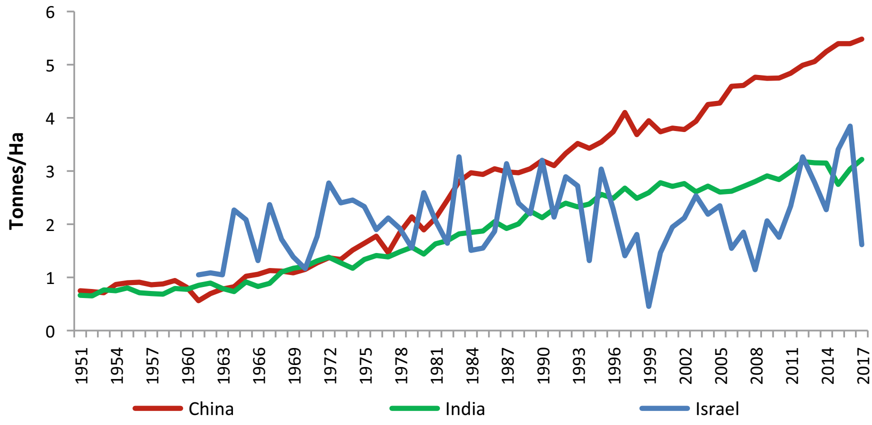

Fig. 10.3 Wheat yields in India, China and Israel. *Source* FAOSTAT

What was particularly strong in India's agricultural innovation system was first, the effective collaboration between international institutions (particularly CIMMYT and IRRI) and the national network of agricultural R&D and extension (ICAR), which led to the development and diffusion of HYV of wheat and rice, and second, the resolve and support of political leaders, agricultural scientists, extension functionaries, and above all, of Indian farmers to embrace the new technology to usher in the Green Revolution. This made India not only self-sufficient in basic staples, but also the largest exporter of rice. In China, what was particularly effective is high government support in infrastructure development (roads, irrigation, electricity, wholesale markets) and investment in agricultural R&D and extension; the latter resulted in the development of indigenous high yielding hybrid rice and semi-dwarf wheat varieties, among others. The household responsibility system and secured land contract rights unleashed the individual farmer's drive for higher productivity and better income. The coordinated sequencing of agricultural policy, market and institutional reforms, including the gradual liberalisation of domestic and international market for strategically important food commodities (from horticulture to livestock to staple crops) has had a positive impact on the agricultural sector. The shift from taxing to subsidising since 2004 provided further stimulus to the agricultural economy.

What was less effective in both China and India was the failed containment of the unintended and negative effects of intensified grain production, supported by minimum support prices and various farmer subsidies. For example, the incentives for grain production discouraged crop diversification and resulted in the depletion and contamination of water resources and land degradation. The situation is particularly severe in the Punjab–Haryana belt in India and the North China Plain in China. Increased food production has been at the expense of the environment and sustainable development. In addition, there are considerable challenges to reform the subsidy schemes and minimum purchase price policies for grains in both China and India. The MSP regime not only led to environmental degradation, but also bulging stocks with the government. In India, as on 1 June 2020, grains stocks with the government were 97 MMT against a buffer stock norm of 41.1 MMT (FCI). This level of stock (97 MMT) is about 43% of India's annual production of rice and wheat. In China, grain stocks with the government reached as high as 465 MMT in 2018/19, about 87% of the total national production in the same year. Both these have to be seen against a global average stock to use ratio of cereals that hovers around 23–24% (excluding China). So, the very high levels of stocks in China and India speak of the massive inefficiency in the grain management system. This happens typically when MSP goes above world prices, which is the case typically in China for rice, wheat and corn. Stocks keep accumulating as governments continue to procure with support prices and taxpayers pay for this inefficiency. Exports of grains are no longer viable. In India, the restrictive land leasing laws and concealed tenancy discouraged farmers from making long-term investments in land or cultivating it more efficiently. This led to low capital formation and low farm productivity. In China, there has been falling comparative advantage of many land-intensive commodities due to the rising costs of labour and land.

10.3.2 Cash Crops

In Israel, 85% of the total value of agricultural production came from fruits and vegetables (2018). Roughly 90% of the country's produce is raised locally with over half of vegetables, and a significant percentage of fresh fruits grown in Israel's dry lands. The kinds of fruits and vegetables grown by Israeli farmers are constantly in flux in response to market conditions and the development of new crops. India and China also made great strides in improving the production of fruits and vegetables, resulting from both area expansion and productivity enhancement.

Israel's technological innovations in agriculture are rooted in its research and development and extension systems. Increasingly efficient irrigation and nutrient management (via fertigation) have been critical to agricultural progress. Strict adherence to post-harvest protocols and innovation in post-harvest management including fruit coating and packaging served to reduce food waste and extend shelf life, offering Israel a competitive edge. In India, ultra high-density plantations for mango, micropropagation for banana, improved varieties for potato and an increasing number of modern fruit and vegetable cultivars contributed to the huge increase in total production. In China, the development and spread of simple, cost-effective greenhouses for vegetables led to significant growth in production. In terms of incentives, the opening up of agricultural trade and removal of production quotas on fruits and vegetable by Israel in the 1980s stimulated farmers' production. In China, the government established a multichannel distribution system (1978–84) and developed wholesale markets (late 1980–1990s), which made the vegetable and fruit markets efficient and competitive. Institutions, such as the National Horticulture Mission (2005) in India for promoting production and marketing, and China's market reform that liberalised vegetables and fruits before the mid—1980s and that took place prior to the liberalisation of any other food product, also played a key role. In Israel, the institutional arrangement related to land ownership (93% of the agricultural land is publicly owned), considerable land consolidation, as well as the domination of co-operative communities (kibbutz and moshav) contributed to the productivity and export market gains.

For fruits and vegetables, what was particularly strong in Israel was government support including investment support, adjusted water prices and research and extension support. During 1995–2008, annual support for investment grants in agriculture was between USD25 million to USD45 million. Almost 17% of the government's agricultural budget is allocated for R&D. Government invests in grants to encourage young people to take up farming as well as to support promising agro-tech start-ups. Besides government, private companies also contribute to the extensive agricultural extension system. In India, the revolution in the horticulture sector is driven largely by the private sector. What is relatively weak in both India and China is excessive pesticide use that has led to food safety issues and water and soil contamination. For Israel, the obstacles for export competitiveness that need to be addressed include the cost of water and delivery, uncertainty regarding the availability of labour and relatively high labour costs, problems of appropriate scale and demographic and economic pressures to shift land from agriculture to other uses.

In the case of cotton, both India and China have benefited hugely from the commercialisation of Bt cotton. It now covers over 85 and 90% of the total area under cotton in China and India, respectively. Cotton yields have increased three-fold in the past 40 years in China as a result of Bt varieties and a high mechanisation rate. In India, the cotton revolution is largely led by the private sector; it led to higher incomes for farmers and a 50% reduction in pesticide use. What was perceived less positive was the recent development of court cases regarding disputes on the licensing fees between the foreign company, which holds the patents for Bt cotton, and local seed companies, which are the licensees. Many state governments put a cap on licensing fees and, later on, even the central government issued similar orders. This may discourage other companies from bringing the latest technology into India in the future.

The private sector has played decisive roles in driving innovation in cash crops and gets it adopted in the value chain and in the fields. This is evidenced by the cases of greenhouse expansion in China, drip irrigation in Israel, cotton growth in India and improved seed varieties of fruits and vegetables across the board. The private sector has fostered productivity improvements and created jobs and value in supply chains "from farm to fork" in India, including for many smallholders (Ferroni and Zhou, 2017). Compared with staple crops, the kind of public policy and support for cash crops seem different due partly to the perishable nature of such crops and the resulting logistics and distribution needs. The multichannel distribution system and wholesale markets in China and the National Horticulture Mission of India were key enablers of adoption of innovation in cash crop production, marketing and distribution. Favourable export markets also spurred cash crop sectoral growth. To further develop the sector, there is a strong need for appropriate regulation and well-administered enabling policies that encourage private investment.

10.3.3 Livestock and Dairy

In India, the growth of milk production has been driven by both institutional engineering as well as an expansion in herd numbers, along with unfolding technological changes (e.g. cattle breeding through sexed semen technology). It was often referred to as the "white revolution". Institutions such as the National Dairy Development Board (1965) and Operation Flood (during 1970s) helped India emerge as the largest milk producer in the world. The delicensing of the dairy sector in 1991 encouraged private participants to enter the sector and contract farming schemes enabled further growth in milk production. In Israel, the growth in the dairy and livestock sector has been driven by both an expansion in herd numbers and technological changes (e.g. animal breeding, nutritious feed and management). Dairy management has benefited from the "Herd Book"—a national genetic record that covers 85% of Israel's cow population. In addition, the dairy and egg industry in Israel are strongly supported and protected through production quotas and fixed producer prices.

What was particularly impressive in the Indian dairy sector was that the co-operative sector became a model of inclusiveness of smallholders: farmers got 70–80% of the consumer's rupee, employment of women in the dairy sector was about 70%, and daily income meant that its impact on reducing poverty was very strong. What needs further improvement in India is to close the productivity gap between its current level and global standards.

One of the strengths of Israel's dairy system is that dairy products remain of extremely high quality and production units adhere to strict environmental standards. The opening of Israeli markets to imported dairy products has led to a reduction in their price and increased the public's accessibility to a full range of dairy products. However, in recent years, Israeli consumers have faced shortages of certain dairy and animal products (e.g. butter and eggs) due to protective agricultural policies.

In China, total meat production, including pork, beef, mutton, poultry and other meat, has expanded substantially over the past decades and reached 85.4 MMT in 2016. Red meat production increased at an annual growth rate of 5% in the past three decades. The growth was driven by technological changes and expansion of animal production. In India, poultry meat production expanded substantially from 0.06 MMT in 1960 to 3.4 MMT in 2016 at an annual growth rate of 7.5%. Fish production also increased significantly, enabled by fish breeding, polyculture, cage culture and commercial shrimp cultivation. This made both China and India the top exporters of aquatic products. In terms of farmer incentives, the market for animal products (e.g. fish and meats) was liberalised in the late 1980s in China, followed by trade reform and further liberalisation after joining the WTO. The government's "shopping basket programme" also contributed to the increase in production.

In India's poultry sector, indigenous pure-line breeding using germplasm of foreign strains led to genetic improvement, faster growth and a better feed conversion rate. The sector has been transformed from backyard poultry farming to an organised commercial poultry industry, largely driven by the private sector. What was particularly successful was the spread of vertical integration practices in poultry and contract farming, whereby large integrators tied up with small players, with contract to give chicks and take them back after 33–36 days or so, covering the market risk of small players. This was a great model of how large and small players worked together. In Israel, there has been development of climate-resilient poultry birds by influencing gene expression and phenotypes of embryos, and the use of gene editing and the science of epigenetics to produce only female chickens. On the downside, the rise in milk, beef and poultry productivity has come at the expense of animal welfare with Israeli livestock growers adopting high density, factory farm techniques and norms. In India, a large number of cattle with low productivity also led to high emission of methane (GHG). The environmental footprint from livestock production has to be mapped and reduced.

10.3.4 Environmental Sustainability

While agricultural production intensified, there have been negative consequences on the environment. In India, wrong price signals provided through the MSP policy for water-intensive crops in water-stressed regions have increased demand, leading to overdraft of groundwater, especially in the northern and north-western parts. Similarly, most of northern China is experiencing a falling groundwater table due to rising demand for underground irrigation water. In addition, excessive use of modern inputs (e.g. fertilisers and pesticides) has caused serious non-point pollution and soil degradation. More than half the cultivated land has reportedly experienced some levels of degradation. Similarly, roughly 37% of total land area in India is affected by various types of degradation. The situation in Israel is more uplifting, despite two-thirds of the agricultural land being arid or semi-arid, creating acute shortages of water and ongoing demand for irrigation. Centralised water ownership, strategic management of allocations and effective pricing have facilitated local technological advances to grant Israel remarkable water security. At present, 52% of total water produced in Israel goes to agriculture for irrigating arable land. In recent years, policies have begun to address the historic excessive use of pesticides, which spawns pest resistance and threatens biodiversity.

Intensified agriculture with high input and high output has resulted in huge stresses on limited natural resources and the rural environment. In India, technologies to address this issue include micro-irrigation, solar pumps, *neem* coating of urea, soil health cards and protected agriculture. Some of these are yet to be scaled up to the national level. *Neem* coating of urea has reduced the quantity of urea required by crops. It reportedly increases nutrient use efficiency by 10%. Besides, the central and state governments have come up with different incentives for farmers to save water and use solar technology. A positive development has been the great application efficiency gains from micro-irrigation (85–90% of water saved), which now covers around 10 million ha. Institutional support, such as command area development projects, participatory irrigation management (PIM) and introduction of water users associations (WUAs) also emerged.

Similarly, in northern China, the government tried to regulate groundwater use through water quota management and charging water fees. Irrigation water pricing and WUAs were introduced across the country to improve water management. Since the 2000s, the government started providing incentives and supporting policies to foster sustainable agriculture. Positive developments include a national commitment to more sustainable and green development of agriculture since the mid-2010s, including new programmes on soil improvement, guidelines for efficient use of resources and land and water conservation. A lot of effort has been made to tackle environmental issues, such as non-point pollution control and livestock waste management. These include setting a target of zero growth in total fertiliser and pesticide use in agriculture by 2020 and a zero discharge of agricultural waste by 2030, pilot crop rotation programmes to improve soil quality and ecological construction programmes aimed at protecting grasslands. In 2018, China initiated the Rural Revitalisation Strategy aimed at largely modernising agriculture and the rural economy by 2035 and fully modernising them by 2050.

In Israel, the integrated National Water Carrier System was started in 1964, ensuring that all farmers in the country had access to water at an identical price. Development of innovative drip irrigation systems continues to ensure "more crop per drop". About 75% of Israeli farms utilise drip irrigation, while the remainder use sprinklers. Israel treats 93% of its wastewater (sewage and industrial waste), with over 86% of sewage water reused for agriculture purposes. In addition, desalination of seawater has increased domestic supply, released fresh water for the agricultural sector and reduced the salinity of recycled effluents. The quality of wastewater used for irrigation has improved significantly over the years. The massive supply of clean water from new desalination facilities allows for restoration of depleted aquifers and reservoirs, providing water in the future. Finally, optimal allocation and utilisation of water is facilitated through water quotas and water pricing. Moreover, Israel has the highest rate of vegans and vegetarians in the Western world, reducing its overall water footprint. Israel has also adopted integrated pest management widely. Farmers are increasingly committed to reducing the extent of their pesticide use. The use of bio-pesticides for some crops such as peppers remains standard procedure. Mycorrhizal fungi as an inoculant for soils and crops and other bio-stimulants have been used to improve the resilience of plants to pests.

However, there is still a long way to go to achieve environmental sustainability, particularly in India and China. In India, technological innovations in irrigation and fertiliser application and the development of climate-resilient crops need more investment in agricultural R&D and a conducive policy environment for scaling up, which is missing at present. Likewise, huge investment is also required to mitigate land degradation and improve soil quality in China. Some negative effects on the environment such as water and soil pollution are unfortunately irreversible. There is also rising concern over falling groundwater table in northern China. In many regions of Israel, particularly in the arid Arava region, groundwater quality is rapidly deteriorating due to over-pumping for irrigation. Use of plastic as a conventional farming method to cover crops and suppress weeds creates massive solid waste challenge. Regulation of farmer's pesticide application and pesticide residue monitoring remain extremely lax.

Table 10.1 Comparative assessment of agricultural innovations by main commodities in India, China and Israel

	What happened	How it happened	How well—strengths	How well—weaknesses
INDIA				
Staple crops	India transformed from a "ship-to-mouth" country in the mid-1960s to not only a self-sufficient one but also a significant net exporter of cereals (e.g. largest exporter of rice). **Rice** All-India rice yields improved from 0.86 t/ha in 1965 to 2.6 t/ha in 2017, with an annual growth rate of 2%. **Wheat** Wheat yields increased sharply in the wake of the Green revolution from 0.8 t/ha in 1965 to 3.4 t/ha in 2017, with an average annual growth rate of 3%.	India's green revolution is a success story of innovations in production technologies (seeds, irrigation, fertilisers), and in marketing institutions. **Technology** – Development and commercialisation of high-yielding and semi-dwarf rice and wheat varieties using foreign cultivars; subsequent introduction of hybrid rice. – Development of high-value Basmati rice varieties. – Bio-fortified wheat and rice varieties developed, yet to be scaled up. – Access to groundwater, fertilisers and machinery catalysed the change. **Incentives** – Minimum support prices (MSP) and effective procurement of wheat and rice through the food corporation of India or state agencies in key grain surplus states. – Input subsidies on fertilisers, power, irrigation, credit, etc. – Direct income transfer (2018-19): *PM-Kisan*. – Electronic national agriculture market. – Negotiable warehouse receipts system. **Institutions** – Agricultural prices commission (APC, now CACP) set up in 1965 to ensure remunerative prices to farmers. – Food corporation of India set up in 1965 to ensure effective procurement, storage, marketing and distribution channels for basic staples.	– Effective collaboration between international institutions (particularly CIMMYT and IRRI), and the national network of agricultural R&D and extension (ICAR) led to the development and diffusion of HYV of wheat and rice. – Resolve and support of political leaders, agricultural scientists, extension functionaries, and above all, of Indian farmers to embrace new technology ushering in the Green revolution. – This stimulated farmers to take up grain production extensively and make India not only self-sufficient in basic staples, but also the largest exporter of rice.	– While the policy of MSP and guaranteed procurement for wheat and rice in certain states incentivised farmers' towards cultivating these crops, it discouraged crop diversification. It also resulted in depleting water tables in the Punjab–Haryana belt, the seat of the Green revolution. – High subsidies on modern inputs, especially power for irrigation, and fertilisers (especially urea) led to excessive depletion and contamination of groundwater and soil degradation. – Large-scale paddy cultivation in the Punjab–Haryana belt with flood irrigation created GHG emissions and groundwater contamination. Stubble burning of rice and wheat further led to pollution at harvest time. – Restrictive land leasing laws and concealed tenancy discouraged farmers from making long-term investments in land or cultivating it more efficiently. This led to low capital formation and low farm productivity. – Low investment in R&D and extension in relation to agricultural GDP. – Excessive focus on wheat and rice led to lack of diet diversification, and thus, less nutritious food.

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Table 10.1 (continued)

	What happened	How it happened	How well—strengths	How well—weaknesses
Cash crops	**Cotton** – Bt cotton commercialised (2002), now covers over 90% of the total area under cotton. – Cotton yields increased from 295 kg/ha in 2002–03 to 482 kg/ha in 2019–20. – The total production in 2017–18 stood at 37.2 million bales, making India the largest producer of cotton in the world. – India's net cotton exports increased from minus (-) USD0.4 billion in 2001–02 to plus USD4.0 billion in 2011–12. But since then, net exports of cotton have been falling. **Fruits and vegetables** – The area under fruits and vegetables increased from 10.1 million ha in 2000–01 to 16.6 million ha in 2017–18. – Total production increased by 109% from 131.6 MMT in 2000–01 to 276 MMT in 2017–18, exceeding food grain production at 249 MMT in 2017–18.	Growth driven by technology changes and diversification. **Technology** – Bt cotton varieties driven primarily by foreign technology (Monsanto) in collaboration with domestic seed companies (like Mahyco). – Ultra high-density plantation (Mango). – Micro-propagation (Banana). – Development of high-yielding varieties (potato). – Raised bed plantation with micro-irrigation (onion). – Increasing number of modern fruit and vegetable cultivars. **Institutions** – National Horticulture Mission (2005) promoting production and marketing.	**Cotton**: – Led by private sector, Bt technology spread fast; – Farmers gained in terms of augmented incomes. – Pesticide consumption dropped by more than 50%. – Within 15 years covered more than 90% of the area under cotton. **Fruits and vegetables** – Revolution in the horticulture sector is also driven largely by the private sector. – It is normally more income augmenting for farmers.	**Cotton**: – A problem arose with some domestic companies over the licence fee to be paid to the foreign company (Monsanto); many state government put a cap on trait fees and, later on, even the central government issued similar orders. – Discourages any company now from bringing in the latest technology. Herbicide tolerant (HT) Bt now being grown by many farmers (almost 15% of the area under cotton in Maharashtra) illegally. This does not argue well for the import of best technologies. Future uncertain and cotton revolution may fizzle out as pests become immune to Bollguard-II and technology is not upgraded. **Fruits and vegetables** At places, use of excessive pesticides for crop protection. Need for better extension and regulation to ensure food safety.

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Table 10.1 (continued)

	What happened	How it happened	How well—strengths	How well—weaknesses
Livestock and fisheries	**Milk** From 1960 to 2017, milk production increased from 20 MMT to 176.4 MMT, with an annual growth rate of 4%. Yields improved from 900.8 kg/animal in 1960 to 1997.4 kg/animal in 2016 (in the case of cows) and from 423.5 kg/animal to 1642 kg/animal (in the case of buffaloes). **Poultry** Poultry meat production expanded substantially from 0.06 MMT in 1960 to 3.4 MMT in 2016 with an annual growth rate of 7.5%. Egg production also increased significantly from 2.8 billion in 1960 to 88.14 billion in 2016. **Fisheries** Fish production increased significantly from 1.16 MMT in 1960 to 11.41 MMT in 2016. Marine products accounted for the second highest share in the total value of exports from India, valued at USD5.78 in 2016–17.	The growth of milk production has been driven by both institutional engineering as well as expansion of herd numbers, along with unfolding technological changes (e.g. cattle breeding through selective sex semen technology). **Technology** – (Cow) Expansion of herd through improvement in the success rate of artificial insemination. – (Poultry) Indigenous pure-line breeding using germplasm of foreign strains led to genetic improvement, faster growth and better feed conversion rate. – (Fishery) Induced breeding of Indian carps (catla, rohu and mrigal), and carp polyculture. – Specific pathogen free, commercial shrimp cultivation. – Cage Culture. **Incentives** – Delicensing of the dairy sector (1991). – Spread of vertical integration practices in poultry. – Contract farming. **Institutions** – National dairy development board (1965). – Operation flood (during 1970s)–Establishment of dairy co-operatives. – Development of organised logistics network. – Transformation from backyard poultry farming to organised commercial poultry industry, largely driven by the private sector. – Liberalisation of grandparent poultry breeding stock. – National egg co-ordination committee (1981). – Broiler Marketing co-operative society (1994). – Marine products export development authority.	(Dairy) Co-operative sector became a model of inclusiveness of smallholders; farmers got 70–80% of the consumer's rupee; employment of women in the dairy sector is about 70%; daily income meant that impact on reducing poverty very strong. (Poultry) primarily led by the private sector. Large integrators tied up with small players, with contract to give chicks and take them back after 33–36 days or so, covering the market risk of small players. Model of how large and small players can work together. (Fishery) Private sector driven. Large and small players both entered inland fisheries production.	(Dairy) Still overall low productivity per animal compared to global standards; with farm mechanisation, bulls becoming redundant, and with a ban on cow slaughter in many states, they are left roaming around. Large number of cattle with low productivity also meant high emission of methane (GHG). The challenge is to have reduction in the number of animals but ensure high productivity. Environmental footprint has to be mapped and reduced. (Fishery) In certain areas, especially the Godavari belt, intrusion of sea water for inland fishery created salinity in neighbouring paddy farms.

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	What happened	How it happened	How well—strengths	How well—weaknesses
Environmental sustainability	Currently, India's gross cropped area is 198 million hectares, and about 48% of the cultivated area is under irrigation. Wrong price signals provided through MSP policy for water-intensive crops in water-stressed regions have increased the demand for irrigation water leading to overdraft of groundwater. Mostly, northern and north-western parts of India are observed to be over-exploited. Excessive use of fertilisers and pesticides (imbalanced ratio of N, P, K) has caused soil/land degradation and water contamination. Roughly, 37% of total land area in India is affected by various types of degradation.	Intensified agriculture with high input and output subsidies has resulted in huge stress on limited natural resources and on environmental sustainability. **Technology** – Micro-irrigation—drip and sprinkler. – Solar pump sets with micro-irrigation. – Solar boat; solar tree. – *Neem* coating of urea—to reduce quantity of urea required by crops. – Soil health card. – Protected agriculture: poly-house farming, soilless farming. (These innovations need further scaling up). **Incentives** – Per Drop, More Crop: '*Pradhan Mantri Krishi Sinchayee Yojana*' (Introduced by the Government of India). – Solar as a third crop: '*Mukhyamantri Aay Badhotari Yojana*' (by the Government of Delhi). – Save Water, Earn Money *('Pani Bachao, Paise Kamao'*) (by the Government of Punjab). **Institutions** – Command Area Development Projects. – Introduction of WUAs. – Introduction of participatory irrigation management (PIM).	So far, overall area under micro-irrigation in India is around 10 Mha. There are great application efficiency gains (85–90% of water saved) compared with flood irrigation. *Neem* coating of urea has reduced the quantity of urea required by crops. It is reported to increase nutrient use efficiency by 10%. It also prevents leaching of nitrates into groundwater aquifers; hence, slowly addressing the problem of groundwater pollution.	There is a long way to go to achieve environmental sustainability. Technological innovations in irrigation and fertiliser application as well as development of climate-resilient crops need more investments in agricultural R&D and a conducive policy environment for scaling up, which is missing at present.

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	What happened	How it happened	How well—strengths	How well—weaknesses
CHINA				
Staple crops	**Rice**: Rice yields (milled) increased from 1.4 t/ha in 1961 to 4.8 t/ha in 2018, with an annual growth rate of 2.15%. **Wheat**: Wheat yields increased sharply after the 1978 reforms from 1.85 t/ha to 5.4 t/ha in 2018, with an annual growth rate of 2.7%. **Maize**: From 1978 to 2017, maize yields increased from 2.8t/ha to 6.1 t/ha, with an annual growth rate of 2%. Area increased by 77%, and total maize production increased nearly three-fold.	China's revolution in grains was largely driven by the country's own technologies and investments in R&D. **Technology** **High-yielding varieties**: – Development and commercialisation of high-yielding and semi-dwarf rice and wheat varieties and hybrid rice and maize seeds. – GM rice and maize varieties available, pending approval for commercialisation. **Access to irrigation, inputs and mechanisation:** – increasing availability of irrigation, inorganic fertilisers and agrochemicals. – Increasing number and range of machinery and access to custom machinery services. **Incentives:** – Minimum purchase price for rice and wheat. – Temporary purchase and storage policy for maize (phased out in 2015). – Abolition of agricultural taxes in 2004 and introduction of agricultural subsidies thereafter – Direct income transfer (2016). **Institutions:** – Household responsibility system (1978–1984) led to acceleration in agricultural growth. – Stabilising land contract rights. – Development of land rental market and land transfer service centres. – Continuous reform of public extension system. – Introduction of irrigation water pricing and Water Use Associations (WUA).	(These apply to all three main product categories of staples, cash crops and livestock). – High government support in infrastructure development (roads, irrigation, electricity, wholesale markets) and investment in agricultural R&D and extension. – Household responsibility system unleashed individuals' drive for productivity. – Land contract: initially 15 years, later extended to additional 30 years twice. – Gradually liberalising domestic and international markets. – Sequencing of agricultural policy, market and institutional reforms. – Shifting from taxing to subsidising agriculture since 2004. Diversification: – From 1978 to 2016, within crops, the proportion of area under non-grain cash crops increased from 20 to 32%. – The share of the non-crop sector (mainly livestock and fishery) in the total value of agricultural output increased from 20 to 47%.	(These apply to all three main product categories of staples, cash crops and livestock). – Increased food production has been at the expense of environment and sustainable development. – Strong public R&D system but weak private engagement. – Falling comparative advantage of many land-intensive commodities due to rising costs of labour and land. – Challenges of reforming rice and wheat minimum purchase price policy and moving towards income support. – Concerns on how to modernise its agriculture with hundreds of millions of small-scale farms. – Food safety issues.

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	What happened	How it happened	How well—strengths	How well—weaknesses
Cash crops	**Cotton**: – Bt cotton commercialised (1997), now covering over 85% of total area under cotton. – Cotton yields increased from 0.45 t/ha in 1978 to 1.7 t/ha in 2017. The total production in 2017 stood at 5.5 MMT. **Vegetables and Fruits**: – The area under vegetables increased rapidly from 2.06 million ha in 1978 to 22.3 million ha in 2016. – Total vegetable production increased from 257 MMT in 1995 to 798 MMT in 2016. – Vegetable and fruit markets are competitive and efficient.	**Technology** – Bt cotton varieties and high mechanisation rate. – Development of simple and cost-effective greenhouses (1980s) for vegetables. Area under vegetables increased to 981,000 ha in 2016. – Increasing number of new vegetable and fruit varieties adopted by farmers. **Incentives** – Government established a multichannel distribution system (1978–84) and developed wholesale markets (late 1980–1990s). **Institutions** China's **market reforms**: – Vegetables and fruits were the first products liberalised before the mid-1980s. – Cotton liberalised in mid-1990s. "**Shopping Basket Programme**" aimed at developing vegetable, meat (and other fresh produce) production base in suburban areas. – Improving the traceability of all agricultural products (mid-2000s).		

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	What happened	How it happened	How well—strengths	How well—weaknesses
Livestock	Total meat production, including pork, beef, mutton, poultry and other meat, has expanded substantially over the past decades and reached 85.4 MMT in 2016. Red meat production rose from 10.6 MMT in 1979 to 64.7 MMT in 2016, at an annual growth of 5%. China became the largest exporter of aquatic products, exporting 4.34 MMT valued at USD21.15 billion in 2017.	The growth of meat production has been driven by both the expansion of herd numbers and technological changes (e.g. animal breeding, nutritious feed and management). **Technology** – Pig stock breeding led to faster growth, improved feed conversion rate. Precise and nutritious feeding as well as improvement in the success rate of artificial insemination. – Poultry breeding equipment and environmental control technologies. **Institutions and Incentives** – The market for animal products (e.g. fish and meats) was liberalised in the late 1980s. – Rapid trade reform and liberalisation after joining the WTO. – Government's "shopping basket programme" also contributed.		

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	What happened	How it happened	How well—strengths	How well—weaknesses
Environmental sustainability	Currently about half the cultivated land is irrigated. Rising demand for irrigation water has resulted in an overdraft of groundwater; most of northern China is experiencing a falling groundwater table and land degradation. Excessive use of modern inputs (e.g. fertilisers and pesticides) has caused serious non-point pollution and soil degradation. Reportedly, more than half of the cultivated area has experienced different levels of degradation. Nitrate and phosphorous pollution occurred in nearly all major lakes, rivers and groundwater in most areas.	<u>**Stage 1**</u>: Intensified agriculture with high input and high output has resulted in huge stress on limited natural resources and the rural environment. Countermeasures: – In northern China, the government tried to regulate groundwater use through water quota management and by charging a water fee. – Introduction of irrigation water pricing and WUAs. <u>**Stage 2**</u>: Incentives and supporting policies for fostering sustainable agriculture (since 2000s). Mainstreaming sustainable agriculture into the national development goal: "*Cang-liang-yu-di*" ("storing food in land,") and "*Cang-liang-yu-ji*" ("storing food in technology"). **Reducing chemical use**: In 2015, setting a target of zero growth in total fertiliser and pesticide use in agriculture by 2020. **Pilot programme to improve soil quality**: land rotation through direct subsidy to farmers. Ecological construction programmes aimed at protecting grasslands. **Rural revitalisation strategy (2018)**	National commitment for more sustainable and green development of agriculture since mid-2010s. New programmes on soil improvement, regulation on the use of land and water resources for crops and water conservation. A lot of effort has been made to tackle environmental issues (e.g. non-point pollution control, livestock waste management, etc.).	Need huge investment to mitigate land degradation and improve soil quality. Rising concern over falling groundwater table in northern China Some negative impact on environment is irreversible.

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	What happened	How it happened	How well—strengths	How well—weaknesses
ISRAEL				
Cash crops	**Vegetable and fruits**: – Roughly 90% of the country's produce is raised locally with over half of vegetables, and a significant percentage of fresh fruits grown in Israel's dry lands. – Israel supplies 220 kg/person of fresh fruits and vegetables annually. – Vegetable exports are dominated by three crops: potatoes, carrots and peppers, together constituting 88% of total vegetable exports (2018) while in fruit exports, avocados and dates constitute the dominant share. – While agricultural production rose consistently for decades, recently production is starting to level out. The kinds of fruits and vegetables grown by Israeli farmers are constantly in flux in response to market conditions and development of new crops. In recent years, Israelis pay a higher price for produce, which has contributed to the drop and even discontinuation of the export of many locally grown crops.	**Technology** – Israel's technological innovations in agriculture are rooted in its research and development and extension systems. – Increasingly efficient irrigation and nutrient management (via fertigation) have been critical to Israel's agricultural progress. – Strict adherence to post-harvest protocols and innovation in post-harvest management including fruit coating and packaging have been critical to reducing food wastage and extending shelf life. **Incentives** The relaxation of Israeli agricultural markets from government regulations, price controls, import restrictions, subsidies, production quotas, etc. (1977). – Opening up of agricultural trade (1980s). – Removal of production quotas on fruits and vegetables (late 1980s). **Institutions** **land ownership:** – 93% of the agricultural land is publicly owned, and 7% is in private hands. Typically, government lands are leased to farmers for extended periods (e.g. 49 years). – Considerable land consolidation through a mix of land market dynamics and policy incentives, resulting in an average farm size of 22 hectares. **Domination of co-operative communities**: kibbutz and moshav, together account for 80% of the country's agricultural production.	Government support makes the agricultural sector remunerative through three main policy measures: • investment support • adjusted water prices and • research and extension support. During 1995–2008, annual support for investment grants in agriculture was between USD25 million to USD45 million. 17% of government budget on agriculture is allocated for R&D. Government invests in grants to encourage young people to take up farming as well as to support promising agro-tech start-ups. The percentage of private investment in Israeli agro-tech increased from 4 to 7% of total global funding. Government supports an extensive agriculture extension system. Private companies also contribute. Massive investments continue in water infrastructure development. Heavy investments in fruit and vegetable production.	Israel is increasingly a net importer of agricultural produce: Some 60% of Israel's food supply is imported. In terms of calories, more than 85% of its calorie supply is through imported produce. Obstacles to export competitiveness include: – the cost of water and delivery – labour uncertainty – relatively high labour expenses – decrease in government support for R&D and extension – problems of scale that affect competitiveness in export markets and – demographic and economic pressures to shift land from agriculture to other uses.

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	What happened	How it happened	How well—strengths	How well—weaknesses
Livestock	**Milk**: Milk production has increased from 1179 thousand tonnes in 2000–01 to 1635 thousand tonnes in 2018–19. Aggregate milk productivity of cows has steadily increased at the rate of 4.5% (average productivity has reached 11,970 kg/cow/year). **Poultry**: In Israel, the feed conversion ratio has improved from 1.05:1 in 1990 to 1:1 in 2018. The average time it takes for a chicken to reach 2.5 kilograms went from 75 to 38 days.	The growth in animal husbandry and dairy sciences has been driven by both by an expansion in herd numbers and technological changes (e.g. animal breeding, nutritious feed and management). **Technology** – Feed and Nutrition Management: Production of animal feed from farm residues, such as pomegranate peels or olive oil production residues. – Development of climate-resilient poultry birds by influencing gene expression and phenotypes of embryos. Use of gene editing and the science of epigenetics to produce only female chickens. **Incentives** – The dairy and egg industry in Israel are strongly supported and protected through production quotas and fixed producer prices. – Guaranteed price system for milk producers. **Institution** – Adherence of milk and egg production units to environmental standards that conform to the country's strict health, water and cleanliness standards. – Dairy management has benefited from the "Herd Book"—a national genetic record that covers 85% of Israel's cow population.	The opening of Israeli markets to imported dairy products has led to a reduction in their prices and increased accessibility for the public to a full range of dairy products. Israeli dairy products remain of extremely high quality.	The rise in milk, beef and poultry productivity has come at the expense of animal welfare with Israeli livestock growers adopting high density, factory farm techniques and norms. In recent years, Israeli consumers have faced shortages of certain dairy and animal products (e.g. butter and eggs) due to protective agricultural policies.

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Table 10.1 (continued)

	What happened	How it happened	How well—strengths	How well—weaknesses
Environmental sustainability	– Currently, the area in Israel zoned for agriculture accounts for 28.7% of the total land area (2.16 Mha); two-thirds of this land is arid or semi-arid, creating acute shortages of water and ongoing demand for irrigation. – Centralised water ownership, strategic management allocation and effective pricing have facilitated local technological advances to grant Israel remarkable water security. – At present, 52 per cent of total water produced in Israel goes to agriculture for irrigating arable land. – In recent years, policies have begun to address the historic excessive use of pesticides, which spawns pest resistance, destroys ecology and is harmful to human health.	**Water resource management for agriculture**: – Israel's integrated National Water Carrier System began operation in 1964, ensuring that all farmers in the country had access to water at an identical price. – Development of innovative drip irrigation systems continue to ensure "more crop per drop": About 75 per cent of Israeli farms utilise drip irrigation. The remainder use sprinklers. – Recycling wastewater: Israel treats 93 per cent of its wastewater (sewage and industrial waste) with more than 86 per cent of sewage water reused for agriculture purposes. – Desalination of seawater has increased domestic supply, released fresh water for the agricultural sector and reduced the salinity of recycled effluents. – Optimal allocation and utilisation of water is facilitated through water quotas and water pricing. **Integrated pest management (IPM):** – **Use of bio-pesticides** for some crops such as peppers; biological pest control remains standard procedure. – **Use of mycorrhizal fungi,** an inoculant for soils and crops and other bio-stimulants to increase the resilience of plants to pests.	– The quality of wastewater used for irrigation has improved significantly over the years. – The steady salinization of soil and water resources due to wastewater reuse is starting to be reversed as recycled effluent quality improves. – Massive supply of clean water from new desalination facilities allows for restoration of depleted aquifers and reservoirs, providing water for the future. – Farmers are increasingly committed to reducing the extent of pesticide use. In using biological controls, they prefer to speak about "pest suppression" rather than "pest eradication". – As of 2019, 89% of produce sampled showed that pesticide residue standards were met; 36% showed no pesticide presence at all. – Israel has the highest rate of vegans and vegetarians in the Western world, reducing its overall water footprint. Demand for organic produce is rising steadily.	– In many regions of Israel, particularly in the arid Arava region, groundwater quality is rapidly degrading due to over-pumping for irrigation. – Use of plastic as a conventional farming method to cover crops and suppress weeds creates a massive solid waste challenge. – Livestock feedlots continue to create odour nuisance. – Regulation of farmer's pesticide application and pesticide residue monitoring remains extremely lax. – The Ministry of Environmental Protection and Ministry of Health remain largely irrelevant to the pesticide registration process, with several pesticides banned in Europe but still in use in Israel. – Organic produce prices significantly higher than conventionally grown vegetables and fruits.

Source: Authors' compilation

10.4 Conclusion and Lessons Learned

The comparative assessment of innovations in production technologies, incentives and institutions and the outcomes in each country makes clear that there has been significant progress in improving food security in all three countries. This shows that right incentives, institutions and appropriate technologies can transform agricultural production and can change the lives of hundreds of millions of the world's poorest people. Among many innovations, breeding technologies including genetic engineering and biotechnology are considered major innovations by national leaders to boost crop and livestock productivity and ensure national food security in the near future.

A few key lessons can be drawn from the experiences of the three countries:

First, strong political commitment is critical to transform countries from food scarce to food surplus ones. All three countries had faced food shortages and crises in the past and the government assigned top priority to increasing agricultural production. They took different paths to develop technological innovations, design incentive structures and set up institutional frameworks to support agricultural growth and ensure food security. The experiences of the three countries show that if a country has its own capacity to develop technologies, such as improved varieties, they should continue to support the national R&D and innovation system. If a country is not well positioned to do so, it should be open to getting technology from outside, either through the public or private sector. An enabling policy environment including an appropriate system of intellectual property rights (IPR) must be in place for this to happen.

Second, technology alone cannot move mountains; it is a necessary but not sufficient condition for success. Incentives for farmers are important and are required to facilitate technology adoption. Farmers must be remunerated for higher production enabled by improved technologies and access. The experiences of all three countries show that a range of incentive policies were put in place to support farmers to do a better job of farming.

Third, depending on the political configurations, one may ask what type of institutional framework for land rights and administration is most conducive. The government owns the major part of arable land in both China and Israel, while land is privately owned in India. China moved away from the commune system (after the failures) to the household responsibility system with secured land contract rights, unleashing the farmers' potential to achieve high productivity gains, while the commune system still dominates Israeli agriculture. Each country has to find its own way of identifying the most suitable system of land rights. What works for one country may not work for another. Besides, for smallholder economies such as China and India, how to further enhance farmers' access to water, good quality and eco-friendly inputs, farm mechanisation and other emerging technologies remains an important issue.

These lessons were drawn largely from experiences aimed at achieving national food security, especially in India and China. These might be relevant for other developing countries. Although the innovations and improvements were developed uniquely and independently in the three countries, there is a need to evaluate the potential of these agricultural innovations across the globe so that they can contribute to the transformation of other developing countries that have been left behind and are still struggling to produce enough food, feed and fibre.

Annexure

See Table 10.2.

Table 10.2 Comparison of general indicators

S. No.	Indicators	Year	India	China	Israel	Source
1	Population	2020	1.38 billion	1.44 billion	8.66 million	United Nations world population prospects[a]
2	Population as a share of World population (%)	2020	17.7	18.4	0.11	
3	Population projections	2030 2050	1.50 billion 1.64 billion	1.46 billion 1.40 billion	9.9 million 12.7 million	
4	Population density (persons per km^2)[b]	2020	464.1	153.3	400	
5	Percentage of rural population	2020	66	40	8	World development indicators (WDI)
6	Percentage of urban population	2020	34	60	92	

(continued)

Table 10.2 (continued)

S. No.	Indicators	Year	India	China	Israel	Source
7.	Geographical area (Mha)	2017	328.7	960	2.2	Food and agriculture organization of the united nations (FAO)
8.	Agricultural land (Mha)[c]	2017	179.7	528.5	0.62	
9.	Arable land (Mha)[d]	2017	156.4	119.4	0.38	
10.	Land under permanent crops (Mha)[e]	2017	13	16.2	0.096	
11.	Cropped area (Mha)		140.1 (Net sown area) and Gross cropped area: 198.3–2014–15	166.4 (Total sown area)—2018	–	Land use statistics, government of india and national bureau of statistics of China (2019)
12.	Irrigated area (Mha)		68.3	69.1 (2018)	0.25[f]	
13.	Irrigation ratio as a percentage of Arable land[g]	2018	43.6	57	68 [h]	Estimated
14.	Irrigation ratio	2018	48.7% of net sown area	41.5% of total sown area	–	Estimated
15	GDP (Trillion, current USD)[i]	2018	2.7	13.6	0.36	World development indicators
16	GDP (Trillion USD in PPPs)	2018	10.5	25.3	0.35	
17	GDP per capita (Current USD)	2018	2015.6	9770.8	41,614	
18	GDP per capita (USD in PPPs)	2018	7761.5	18210	39,822	
19	Per capita income (Current USD)	2018	1990	9516.1	42,987	
20	Share of agriculture in GDP (%)[j]	2019	16.5	8	1	

(continued)

Table 10.2 (continued)

S. No.	Indicators	Year	India	China	Israel	Source
21	Share of crops in GVO (gross value of output) (%)	2018	58	53	59	MOSPI, Government of India and national bureau of statistics of China (2019)
22	Share of livestock in GVO (%)	2018	29	26.8	40	
23	Share of fisheries in GVO (%)	2018	5.1	10.5	1	
24	Share of Forestry in GVO (%)	2018	7.9	4.5	–	
25	Percentage of workforce employed in agriculture	2019	42.3	26	0.9	World development indicators
26	Average land holding size (Ha)		1.08 (2015–16)	0.88 (2016–17)	21.8 (2018)	Agricultural census
27	Poverty headcount ratio at $1.90 a day (% of population), 2011 PPP	–	13.4 (2015)	0.7 (2015)	0.2 (2016)	World development indicators
28	Poverty headcount ratio based on national poverty lines (% of population)	–	3.1 (2017)	0.6 for rural and 0.25 for country (2019)	–	
29	Fertiliser consumption (kilograms per hectare of arable land)	2016	165.8	503.3	280.7	
30	Trade as a % of GDP	2018	43	38	57	

(continued)

Table 10.2 (continued)

S. No.	Indicators	Year	India	China	Israel	Source
31	Agriculture food export (USD billion)	2017	32	55	2	OECD
32	Agriculture food import (USD billion)	2017	28	116	6	

[a](https://population.un.org/wpp/Publications/Files/WPP2019_Highlights.pdf), (https://population.un.org/wpp/DataQuery/), (https://population.un.org/wpp/DataQuery/).
[b]https://population.un.org/wpp/DataQuery/.
[c]According to the FAO, "Agricultural land includes arable land, permanent crops and permanent pastures".
[d]According to the FAO, "Arable land refers to land under temporary crops (double cropped areas are counted only once), temporary meadows for mowing or pasture, land under market and kitchen gardens and land temporarily fallow (less than five years). The abandoned land resulting from shifting cultivation is not included". http://www.fao.org/ag/agn/nutrition/Indicatorsfiles/Agriculture.pdf.
[e]According to the FAO, "Permanent crops are sown or planted once, and then occupy the land for some years and need not be replanted after each annual harvest, such as cocoa, coffee and rubber. This category includes flowering shrubs, fruit trees, nut trees and vines, but excludes trees grown for wood or timber". http://www.fao.org/ag/agn/nutrition/Indicatorsfiles/Agriculture.pdf.
[f]Estimated from irrigation ratio as a % of arable land and arable land figures.
[g]Calculated by dividing net irrigated area by arable land.
[h]https://institute.global/sites/default/files/2019-09/Israel%20World%20Leader%20Agriculture%20Water.pdf.
[i]https://data.worldbank.org/indicator/NY.GDP.MKTP.PP.CD?locations=IN.
[j]Agriculture, forestry, and fishing value added (% of GDP)—World Bank Data (https://data.worldbank.org/indicator/NV.AGR.TOTL.ZS).

References

FAO. (2018). *FAO's work on agricultural innovation: Sowing the seeds of transformation to achieve the SDGs*. http://www.fao.org/3/CA2460EN/ca2460en.pdf.

Ferroni, M. & Zhou, Y. (2017). The private sector and India's agricultural transformation. *Global Journal of Emerging Market Economies, 9*(1), 1–10

Pound, B., & Conroy, C. (2017). The innovation systems approach to agricultural research and development. In B. Pound & S. Snapp (Eds.), *Agricultural systems: agroecology and rural innovation for development*. Burlington, MA: Academic Press.

Pyburn, R., & Woodhill, J. (Eds.). (2014). *Dynamics of rural innovation–a primer for emerging professionals*. Arnhem: LM Publishers.

World Bank. (2006). *Enhancing agricultural innovation: how to go beyond strengthening research systems*. Washington, DC.

World Bank. (2012). *Agricultural innovation systems: an investment sourcebook*. Washington, DC.

Zhou, Y., & Babu, S. C. (2015). *Knowledge-driven development: Private extension and global lessons*. Cambridge, MA: Academic Press and Elsevier.

Chapter 11
Way Forward

We list here at least five major challenges that these countries will face in varying degrees as they move towards 2030 and beyond. Thereafter, we also look at how these challenges can be met with emerging innovations in agriculture. The key challenges likely to be faced by these countries are the following:

1. The challenge of feeding large and growing populations with rising per capita incomes
2. The challenge of tackling hidden hunger (malnutrition), which is specifically critical for India
3. The challenge of climate change and its likely impact on agriculture
4. The challenge arising from increasing urbanisation and the need to move larger quantities of food from the hinterland to urban areas, while ensuring food safety, traceability and freshness
5. The challenge of declining attractiveness of farming to young people, especially in India and China.

This is not a very comprehensive list, but at least these can be predicted with a reasonable degree of certainty. Needless to say, there are likely to be several short-term challenges such as the outbreak of disease (e.g. COVID-19 virus, swine flu, foot and mouth disease, plant diseases, etc.), but they cannot be predicted with certainty. Yet, countries have to remain ready to meet such exigencies to ensure food security and food safety for their people.

These five challenges are discussed in some detail below.

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11.1 The Challenge of Feeding an Increasing Population with Rising Prosperity

A major challenge that the world is going to face in the next two to three decades is how to feed a rapidly growing population with rising incomes. This is particularly true for India, China and Israel, given that their basic resources of cultivable land and water are extremely limited in relation to their populations.

According to the recent United Nations' World Population Prospects, the world population is projected to rise by 26% from 7.7 billion people today to nearly 9.7 billion in 2050 (United Nations 2019). A large part of this growth will come from South Asia, notably India, and Sub-Saharan Africa. It is estimated that by 2030, India will be the most populous country surpassing China. Its population is likely to increase from the current 1.38 billion to 1.5 billion in 2030 and 1.64 billion in 2050, while that of China will stabilise at around 1.4 billion in 2050 (United Nations 2019) (Fig. 11.1). Israel, on the other hand, has a much smaller population compared to India and China, but it is also expected to feed about 12.7 million people in 2050, up from its current level of about 9 million.

Limited agricultural land and water resources, relative to population, pose a critical challenge to ensuring a high degree of self-sufficiency in food at competitive costs and prices for these countries.

Besides population size and its growth, demand for food also depends on the disposable incomes of households. This determines the economic access to food as well as the dietary preferences of individuals. Globally, per capita income (a proxy for disposable income) is expected to grow by 2.5% per annum over the next decade, with India having the highest growth rate of 6.6% per annum and China's growth rate slowing down to 4.1% per annum (OECD/FAO 2019). This implies that not only that there will be more mouths to feed, but as per capita incomes grow, there will

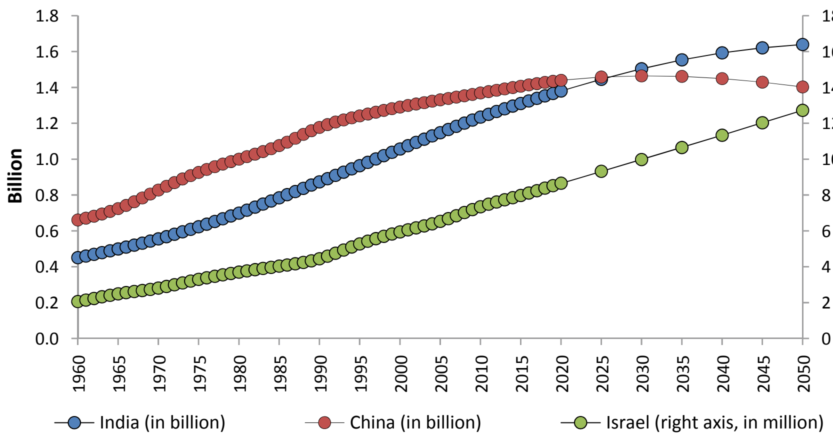


Fig. 11.1 Population size in India, China and Israel. *Source* (United Nations 2019)

also be increasing pressure of demand for high-value agricultural products such as meat, fish, dairy, fruits and vegetables. India and China have already experienced to a certain extent the transition to diversified high-value crops. The trend will continue and intensify in the years to come.

Driven by rising incomes, evolving demographics and changing food preferences, the Indian agricultural sector has already been diversifying slowly from grains towards pulses, fruits and vegetables (F&V), livestock products and fish for better protein intake. According to the NSSO (68th round survey), 62.3% of households in India consumed non-vegetarian food in 2011–12, up from 56.7% in 1993–94 (Gulati and Verma 2016). Notwithstanding the changes in dietary patterns over the years, per capita consumption of meat in India is still one of the lowest at 2.9 kg in 2015 compared to other countries such as China at 50 kg, Brazil at 75 kg and USA at 95 kg, respectively (Gulati and Verma 2016). India's extremely low consumption of meat in per capita terms stems mainly due to the preference for vegetarianism among Indians, influenced partly by religious and cultural factors but also by low income. However, it is projected that with the rise in population growth and per capita income by 2030 and 2050, the demand for higher value products such as livestock products and F&V will grow faster than that for staples. This has already happened in a major way in China, where meat consumption is way above that in India. Higher demand for livestock products implies an increase in demand pressure for grains such as maize and soybeans that are used as feed. The feed demand in China is several times higher than in India. Israel may not feel the same pressure, because sizeable proportions of its population are vegans and vegetarians. The rising trend of vegetarianism in Israel will also help it reduce its GHG emissions.

In addition to population growth, it is important to note that the world's population is growing older, with the age group of 65 and above growing the fastest. According to UN projections, by 2050, "one in six people in the world will be above 65 years of age (United Nations 2019), which implies a fall in the labour force, high economic dependence of the ageing population on the working class, and high fiscal pressure on governments for building and maintaining social systems (e.g. health care, pensions) for older people" (United Nations 2019). However, compared to China, in India the proportion of the dependent population to the working-age population is going to decline from the current 49.7% (2018) to 46.4% in 2050 (Fig. 11.2)—India will have the youngest population in the next two decades. Thus, India is yet to tap its "demographic dividend" fully. In China, on the other hand, the dependency ratio is projected to increase rapidly from 42% now to 67% in 2050; thus, the workforce in China is going to shrink dramatically in relative terms. The dependency ratio in Israel is expected to be on average 65% in the coming two decades, somewhat akin to China. How these changes in demographic profiles are going to affect their capacity to produce ample food, and how it changes consumption patterns in these countries are questions that remain to be answered.

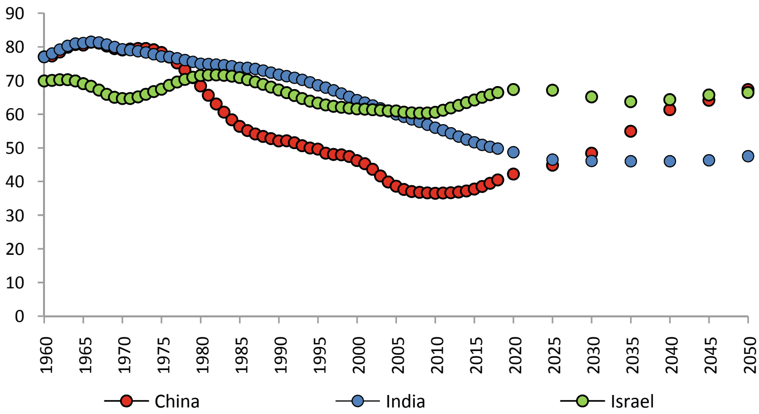
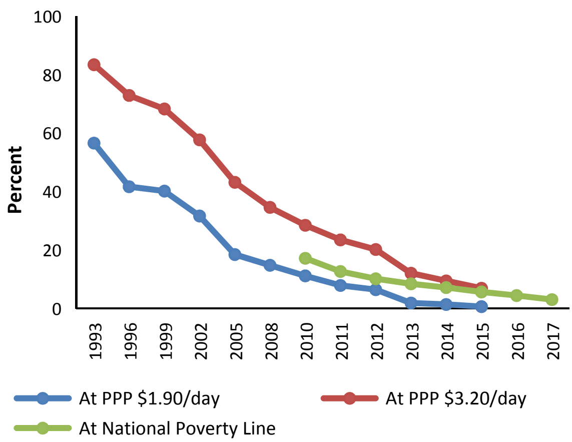


Fig. 11.2 Dependency ratio in India, China and Israel. *Note* Age dependency ratio is the ratio of dependents (people younger than 15 years or older than 64 years) to the working-age population (those aged between 15 and 64 years). Data are shown as the proportion of dependents per 100 working-age population. *Source* World Bank (2019) and United Nations (2019)

11.2 The Challenge of Hidden Hunger and Malnutrition

In 1990, more than a billion of the extremely poor lived in China and India alone (Roser and Ospina 2020). However, since then, these two economies have grown faster than most of the richest countries in the world, and, as a result, the head count ratios of extreme poverty (at PPP prices of USD1.90 per capita, per day) have declined substantially to 0.7% (2015) in China and 13.4% (2015) in India (The World Bank 2019). Thus, China has almost eliminated extreme poverty by 2020, and India is on track to eliminating it by 2030 according to the Sustainable Development Goals (SDGs) of the United Nations (Figs. 11.3 and 11.4). However, merely eliminating

Fig. 11.3 Poverty ratio in China. *Source* The World Bank (2019) and Planning Commission (2011–12)



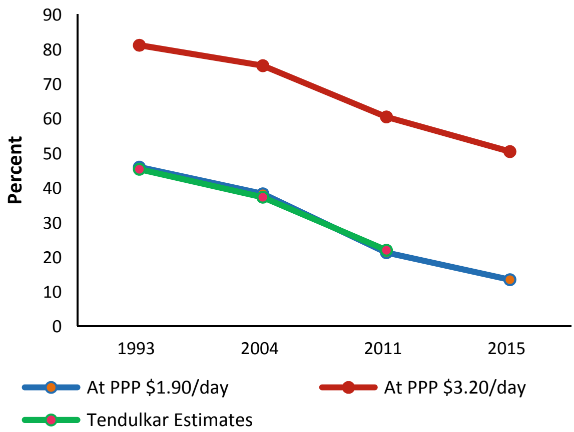


Fig. 11.4 Poverty ratio in India. *Source* The World Bank (2019) and Planning Commission (2011–12)

extreme poverty is not sufficient. The zero-hunger goal by 2030, which calls for not just sufficient food but also eliminating malnutrition would be a daunting task, especially for India. FAO estimates that about "815 million people of the 7.7 billion people in the world or 10.7% are suffering from chronic undernourishment, about 150 million (or 2%) under-five-year age are stunted and 50.5 million are wasted (or low weight for height), due to deficiency of critical micro-nutrients".[1] In India, the challenge of malnutrition among children less than 5 years of age is extremely acute with almost 38% children stunted and underweight (NFHS 2015–16). Therefore, the need is to assign the highest priority to address all forms of malnutrition.

In China, the gradual shift from traditional diets of consuming diverse staple foods and vegetables to a diet containing high fat content has affected peoples' health outcomes. Malnutrition among adults and stunting in children decreased by 2.5 and 3.1% from 2002 to 2012 (NHFPC 2015). However, in the same period, the proportion of overweight Chinese adults increased from 22.8 to 30.1% while the obesity rate rose from 4.5 to 9.6% (NHFPC 2015). Furthermore, chronic diseases, such as diabetes and cardiovascular diseases appear to be on the rise in China—the cause–effect relationship between diets and such diseases has been highlighted in many studies.

11.3 The Challenge of Climate Change

Another daunting challenge is climate change affecting different countries in varying degrees. According to the OECD article, "Three key challenges facing agriculture and how to start solving them",[2] the global food system has an enormous environmental footprint (OECD/FAO 2019). "Agriculture covers nearly 40% of the earth's surface and accounts for 70% of global water use. In addition, it directly contributes to 11%

[1] https://www.worldhunger.org/world-hunger-and-poverty-facts-and-statistics/.

[2] https://www.oecd.org/agriculture/key-challenges-agriculture-how-solve/.

of global greenhouse gas (GHG) emissions (mostly through cattle)", posing a severe threat to overall environmental sustainability. Therefore, it is vital to move beyond the narrow focus on merely increasing production or emphasising GDP growth numbers towards prioritising investment in sustainable agricultural development that promotes the adoption of renewable energy and green technologies and the building of climate-resilient infrastructure.

Indian agriculture, in particular, faces serious production risks due to climate change as the country experiences "prolonged droughts in the Deccan plateau states of the west and southern peninsula and floods in the Himalayan foothills from melting glaciers in the Himalayas (Gulati et al. 2019)". So, farmers always have the fear of crop failure and income volatility. A recent IPCC report predicted that temperature in India will rise in the range of 0.5–1.2 degree Celsius (°C) by 2020, 0.88–3.16 °C by 2050 and 1.56–5.44 °C by the year 2080. This will have a significant negative impact on crops, lowering yields by 4.5–9.0%, depending on the magnitude and distribution of warming (NICRA 2018). Furthermore, according to the IPCC projections on crop yields in India, if temperatures rise by 1 °C, wheat production is expected to drop by at least 5 million metric tons; if temperatures rise beyond 2 °C, the production losses will increase more rapidly (Gulati et al. 2019).

In China too, there are recurrent floods in the southern parts of the country while the northern parts receive less rainfall (OECD 2018). The loss in yield for each degree Celsius increase in global mean temperature was estimated at about 8.0% for maize and 2.6% for wheat (Zhao et al. 2017). As China is a major importer of feed in the global market, how climate change affects China's agriculture can have broad implications for food security in China and on commodity prices worldwide.

In Israel, a recent report from the Ministry of Environmental Protection shows that climate change is expected to have a negative impact on crops (deterioration in quantity, quality and types of agricultural crops) and on livestock farming (increased pest spread and multiplicity, land erosion).[3] It is estimated that in the coming decade, more climatic changes are expected to occur, with serious implications for the agricultural sector, affecting the productivity of certain crops adversely. Therefore, the adoption of climate-smart and resilient agriculture is imperative in the future.

11.4 The Challenge of Urbanisation

Urbanisation is increasing in both developed and developing regions, slowly changing the demand-supply balance of agriculture. According to the OECD-FAO Outlook, it is predicted that by 2050, the percentage of world population residing in urban settings will rise to nearly 60% from the current 55% (OECD/FAO 2019). As the report points out, "change in demographic structure and urbanisation critically impacts the development of long-term strategy for the food and agriculture sector" (OECD/FAO 2019). Broadly, there are two serious challenges arising from urbanisation. First, a change in the dietary pattern towards more diversified and high-value

[3] https://www.jpost.com/israel-news/new-climate-report-spells-disaster-for-israel-609748.

agricultural commodities such as dairy, meat, fish, processed foods and fast food, which in turn may lead to overconsumption of high calorie foods, often resulting in obesity, nutrient deficiencies or disease. Second, as a region develops and urbanises, the share of the agricultural workforce declines. For example, in the USA, less than 1% of the population are farmers.[4] In China, along with rapid urbanisation and city sprawl, grain production is affected by the decline in the quantity and quality of land, water shortages and the departure of agricultural labour (Wang 2019). Hence, it will be necessary to adopt innovations and technologies that can produce more output with limited resources in a cost-effective and sustainable manner. Moreover, dietary guidelines can guide people to adopt a well-balanced diet that contains few animal products.

11.5 The Challenge of Declining Attractiveness of Farming to Rural Youth

Although the ageing demographic among rural farming populations is observed across the globe, the situation in some developing countries is more severe. In China, the average age of farmers is believed to be around 55, although there are no official statistics. For more than two decades, young people flocked to fast-developing cities in search of better income, often as low-skilled migrant workers. Rural youth shun a farming future as earnings and living conditions lag behind those of urban residents considerably. Farming is seen as an unattractive job with little prospects; farmers themselves encourage their children to migrate to the city. Instead of abandoning their farms altogether, a proportion of young migrant workers remains part-time farmers. They return to the countryside during harvest season to help on their family farms while for the rest of the year, they go to cities, leaving older family members or relatives to take care of the fields. This arrangement is viewed positively in the sense that not all the basic knowledge in agriculture is lost. However, as the rural–urban income gap widens, fewer and fewer young people would bother with such arrangements. Recognising the trends, the Chinese government has made commitments to develop "professional and modern farmers", but policy needs to be changed to provide young people real business opportunities to continue or take up farming as a profession (Teng and Foo 2018).

In India, rural youths are increasingly turning to the non-farm sector as the possibility of gainful employment in the farm sector is limited. The proportion of farmers shifting out of farming is high among those below 30 years of age. They were found to be more sensitive to income differentials between farm and non-farm occupations. In both China and India, a majority of students graduating from agricultural universities switch to other professions.

[4]https://blog.startupnationcentral.org/agritech/industrial-age-farming-how-urbanization-is-changing-the-industry/.

An ageing farming population and the shortage of young people interested in farming pose serious challenges to sustaining agricultural production in the future. This will affect agricultural output as there are fewer people who want to fill the roles when the current generation of farmers is no longer fit to work on their land. In addition, young people can revolutionise industries with technology and creativity, which the agriculture sector badly needs for the next stage of development.

11.6 Innovations and Investments as Potential Answers to Emerging Challenges

To meet these emerging challenges as we move forward towards 2030 and beyond, countries need innovative solutions to produce more, diversified and nutritious food economically and in an environmentally and financially sustainable way. Some of the potential innovations are already on the table, ready to be scaled up for higher efficiency, while others are unfolding and could be implemented by India, China and Israel to overcome the challenges that they are likely to face in the years to come.

The lesson learned from Chap. 10 continues to be relevant, including the need for strong political commitment to support the agricultural innovation system, right incentives for technology adoption and appropriate institutions for access to land, water and other resources. However, the emerging challenges require a change in priority from food security to nutrition security and more sustainable, climate-resilient agriculture. This will need different kinds of technologies (e.g. digital, microbes), insights and knowledge for climate-smart and resilient farming and perhaps, a shift in the significance of current actors and their roles in the agricultural innovation system. For example, while continued support to the agricultural innovation system by the public and private sector will remain critical, the private sector is expected to play a greater role in technology innovation, especially in the crop and livestock improvement and digitalisation space. Agricultural start-ups and entrepreneurs will become important actors in revolutionising the food and agriculture sector. Public–private partnerships are needed to deal with environmental sustainability issues such as soil health, water scarcity and climate change. For successful technology adoption, the public, private and NGO sectors should work together to provide relevant advice, training, support and maintenance through extension workers or intermediary organizations, particularly for smallholders. Youth will need to be attracted to agriculture in a remunerative way.

11.6.1 Climate-Resilient Crops

First, to ensure food sufficiency for growing populations, raising agricultural productivity sustainably through new strategic investments in agricultural R&D, knowledge and innovations systems is imperative. There will be increasing pressure to improve yields and produce more with less land and water. This will require higher investments in agricultural R&D and technological start-ups. At present, in India for example, only 0.32% of gross value added in agriculture is spent on agricultural knowledge and innovation, which is quite low compared to China, which spent over 0.9% and Israel, which spent about 2.2% in 2018–19 (OECD database 2020). It may be noted that India faces the critical challenge of low average yields in the case of most key crops compared to other major producing countries; yields, in some cases, are even lower than world averages. For instance, India's wheat and rice yields are approximately one-third of the highest world yields, while yields for major fruit and vegetables such as mango, banana, onion or potato hover between half to one-third of the highest world yields (OECD/FAO 2019). This, in a way, is also a blessing in disguise as India can raise its production frontier with known technologies. It is only a matter of adopting best farm practices, best seeds, optimal doses of fertilisers and introducing better incentives for producers. That sort of opportunity may not be available to China and Israel as yields in the case of several crops are already high, and they need to invest even more in R&D to push further their production frontiers.

In crop production, the story begins with seeds and farming practices. Investments in better quality seeds with higher yields, climate-resilient seeds with tolerance against droughts, floods, etc., and bio-fortified seeds with better nutrition value are the way forward, as these help farmers to grow more and valuable output in a resource-constrained environment. Israel invests heavily in knowledge and innovation systems and has innovated several salt and drought-resistant strains of fruits and vegetables through different combinations of germplasms for higher productivity and better quality (OECD 2010). It is interesting to note that the horticulture sector contributes significantly to agricultural growth in Israel and accounts for a nearly 46% share in the total value of agricultural production. Further, its greenhouse production of tomatoes, peppers, herbs and melons adheres to the highest international standards. As a result, Israel has emerged as a competitive and leading agricultural food exporter of F&V.

In India, the Indian Council of Agricultural Research (ICAR) has recently introduced climate-smart rice varieties—CR Dhan 801 and 802, which have greater tolerance to submergence as well as drought. These varieties are recommended for states like Andhra Pradesh, Telangana, Odisha, Uttar Pradesh and West Bengal. Globally, these varieties are unique and developed for the first time in rice research. These have been notified for official release by the Government of India on 19 February 2019 (ICAR-NRRI 2019). There is lot of ongoing research on drought and submergence-resistant seed varieties. The farmers just need to be incentivised to use such seeds and adopt climate-smart farming practices such as changing sowing and harvesting timings, cropping patterns and inter-cropping.

Chinese scientists have in recent years also demonstrated significant technological advances in wheat transformation and genetic engineering to improve traits such as drought tolerance, resistance to pests and diseases and specific aspects of grain quality. A few projects have already led to field-trial applications. Wheat transformation tests in China mainly utilise micro-particle bombardment, which is relatively genotype-independent and enable the introduction of DNA directly into various tissues for transient gene expression studies. At present, the method is being conducted in a lot of laboratories in China (see Chap. 4 for details). Further, for improved quality and better nutrition, Chinese scientists have developed new lines of GM wheat that are resilient to major diseases, pests, insects, salinity and droughts and are also rich in nutrients. Many lines among these have passed field trials and are under the environmental release trial stage. The field experiment data show that with GM wheat varieties, yields will improve by 10–15%. However, the policy environment regarding commercialisation of GM wheat within a short time period is uncertain, but the technology promises new tools to increase the level of nutrition in China.

The future, however, lies in genomic sequencing and bioinformatics analysis that offer the potential to ramp up the process of developing crop varieties with desired agronomic traits, which can bring about a revolution in crop sciences and open up avenues for economic benefits to farmers. The experiences from the three countries have shown that improved breeding using modern technologies including genetic engineering and biotechnology can result in stress-resistant and high-performing varieties. Going forward, it would require the right policy framework for such new varieties to be released, stewardship mechanisms to ensure proper use, access of farmers to such varieties and right incentives for farmer adoption.

11.6.2 Bio-fortified Crops

Second, bio-fortification of staples is an innovative way to tackle malnutrition, which can go a long way. Globally, the HarvestPlus programme of the Consultative Group on International Agricultural Research (CGIAR) is working in this direction. In India, the collaboration has released iron-rich pearl millet varieties. Furthermore, ICAR has also introduced indigenous zinc and iron-rich wheat (WB 02 and HPWB 01), rice (DRR Dhan 45) and pearl millet (HHB 299 and AHB 1200) in 2016–17. It is believed that this will possibly lead to one of the biggest breakthroughs in staples, making them more nutritious (Gulati and Juneja 2018a, b). The National Agri-Food Biotechnology Institute in Mohali has innovated bio-fortified coloured wheat (black, blue, purple) by cross-breeding Indian cultivars (PBW550, PBW621, HD2967) and coloured wheat varieties from Japan and America to produce new colour wheat varieties rich in anthocyanins (antioxidants such as those found in blueberries) and zinc (40 ppm compared to 5 ppm in white wheat). This seems to be the beginning of a new journey, from food security to nutrition security by 2030. The best is yet to come (Gulati and Juneja 2018a, b).

It needs to be noted that besides technological breakthroughs, the country needs an enabling policy environment and the right market structure to deal with the challenge of malnutrition. For instance, the government needs to assign high priority to women's education through liberal scholarships and better sanitation (toilets and safe drinking water), as these can have significant positive multiplier effects on child care and access to healthcare facilities, which reduce malnutrition among children below the age of 5 years. According to experts, education is critical to increase awareness of nutrient-rich diets and personal hygiene (Gulati and Khurana 2020). Besides, government should promote a shift in dietary patterns away from basic cereals towards the consumption of crops that are rich in micro-nutrients. This will also help farmers to get markets for their produce at reasonable prices. In the case of India, it is believed that diverting a part of the food subsidy from wheat and rice to more nutritious food crops can be a game-changer policy intervention in this direction (Gulati and Khurana 2020).

Overall, the need is to have targeted investments in agricultural R&D, education, knowledge building and social protection programmes to produce and consume more nutritious agricultural products by 2030 and beyond.

11.6.3 Agricultural Diversification and Precision Farming

Third, as per capita incomes rise and the demand for higher value products such as livestock and fruits and vegetables grow faster than that for staples, it is necessary to diversify the basket of agricultural products. It is important to highlight that as compared to other developing countries, China has done pretty well in reshaping its crop economy steadily from a "grain-first" sector to one producing higher value agricultural commodities like fruits and vegetables and livestock products (primarily dairy and meat). Between 2000 and 2018, fruit production registered the highest annual growth rate of 11.2% followed by dairy with an annual growth rate of 8.4%, fisheries with 3.2% and meat (poultry, pork, beef and mutton) with an average 1.5%. Further, within crops, the proportion of arable land area under non-grain cash crops increased from less than 20% before the 1980s to 32% in 2016. Over the same period, the share of the non-crop sector in the total value of agricultural output increased from 20% to 47% (NSBC 2010 and 2017). While many factors have contributed to this agricultural growth, technological innovations have been the most important source that boosted production. Besides technological intervention, innovative incentives and adequate institutions such as liberalising markets first for vegetable and fruits and then gradually for animal products (e.g. fish and meats) and other cash crops (edible oil, cotton, etc.) played a great role in agricultural diversification (see Chap. 3 for more details). The other breakthrough in policymaking came with the merging of all subsidies on grain, seed and aggregate inputs into a general income support programme for owners of cultivated land.

In the case of dairy products, India is at present the largest producer of milk in the world, while China is a net importer, mainly of whole milk powder. According to OECD-FAO projections, "China is expected to continue to be the world's major dairy importer, mainly for whole milk powder and these imports are likely to grow by 2.7% per annum till 2028" (OECD/FAO 2019). So, China's self-sufficiency ratio for dairy products is likely to fall unless it takes some major steps to augment its dairy production faster than the growth in demand. Further, India is the second largest producer of F&V in the world after China. But it faces a serious challenge of high post-harvest losses, ranging from 4 to 16% (2015) of total output (OECD/ICRIER 2018); it also suffers due to a collapse in prices whenever there is a sudden rise in the production. According to experts, this is because the country lacks modern storage facilities and the linkages between processing and organised retailing are very weak. Data suggest that at the all-India level, only 12% of total F&V output is covered by cold storages (OECD/ICRIER 2018). Furthermore, the lengthy supply chain and restrictive marketing policies guided by the ECA and the APMC Act permit the entry of numerous aggregators, market traders and wholesalers, whose margins account for somewhere between 30 and 50% of the retail consumer price (OECD/ICRIER 2018), depriving farmers of more than three-quarters of the price that consumers pay.

In such a situation, what are the innovations in value chains required so that farmers are assured of best prices? India desperately needs to make huge investments in constructing modern cold storages facilities, food processing and, most importantly, linking farmers to organised retailers, bypassing the *mandis*, so that they can get the best market prices on a sustained basis. Keeping the 2030 and 2050 scenario in mind, the government should gradually open up the retail sector for FDI inflows as it will boost investment in building efficient and sustainable supply chains, eliminating middlemen and ensuring better prices for farmers. Further, farmers can be organised in farmer producer organisations (FPOs) to negotiate good deals with organised retailers. At present, there are around 4000 FPOs under NABARD and SFAC (small farmers' agribusiness consortium) together, which could be the starting point for building backend infrastructure for aggregation of commodities, assaying, sorting, grading and even packaging (Gulati and Juneja 2018a, b). The government recently took a positive step in this direction by initiating measures to establish 10,000 additional FPOs by 2023–2024 under a scheme called the "Formation and Promotion of Farmers' Produce Organisations" with a total budgetary provision of Rs. 4496 crore for five years (GOI 2020).

Interestingly, a bold step has been taken by the government on 5 June 2020, by bringing in three ordinances aimed at reforming the whole agricultural marketing system. The Essential Commodities Act (ECA) of 1955 has been amended to ensure that stocking limits of commodities, such as cereals, pulses, oilseeds and edible oils, onions and potatoes, are liberalised and are imposed only under extreme situations of natural calamities, wars, famines or extraordinary price rise. Similarly, the APMC Act has also been liberalised to allow the free flow of agricultural commodities across state borders, and that traders, processors, exporters and organised retailers can go directly to farmers/FPOs to buy their produce, bypassing the *mandi* system. The buyers are also encouraged, via a new ordinance called "The Farmers' Produce Trade and Commerce (Promotion and Facilitation) Ordinance" to enter into a sort of contract farming with farmers, at an agreed price at the time of sowing, thus hedging farmers' marketing and price risks. Some have hailed these changes as historic, akin to the 1991 economic reforms. Like the delicensing of industry in 1991, this could be termed as delicensing of agricultural marketing. The impact of these will be seen in due course in terms of more efficient value chains and improved price realisation by farmers by widening the choices available to farmers to sell their products without demolishing the *mandi* system.

Further, on the technological front, solar-powered cold storages are the way forward to reduce the wastage of perishable agricultural produce and improve storage quality. The government can support the entire value chain from farm to fork by improving farmers' access to the latest innovations and by providing them adequate extension services, resources and markets.

In Israel and China, as the dependence on the working population resulting from an ageing population increases by 2030 through 2050, there will be greater need for farm mechanisation, including the use of smart technologies such as artificial intelligence, drones, sensors and the Internet of things that require less labour but the infusion of more capital and knowledge. India may follow these technologies with a lag unless it decides to leapfrog.

11.6.4 Sustainable Environmental Practices

Fourth, to mitigate the risks of climate change in the near future, it is important that the government, private companies and farmers pay more attention to water availability and its usage in agriculture. Public–private partnerships can play an important role. There will be greater need to invest in expanding the irrigation cover, in building more water storage capacities at the village level and in adopting precision irrigation practices such as micro-irrigation. In India, some positive steps are being taken in this direction. For instance, the Government of Maharashtra recently issued an advisory to cultivate sugarcane mandatorily with drip irrigation to address the issue of groundwater depletion in the state. The Gujarat Government has also introduced an innovative initiative, the "Gujarat Green Revolution Company Limited (GGRC)", for time-bound implementation of micro-irrigation systems in the state. In 2018-19, 142 thousand hectares have been covered and 84.4 thousand farmers have been benefitted.[5] Overall, at the all-India level, about 10 million hectares are under micro-irrigation.

To improve surface irrigation in India, the central government in 2017 assigned high priority to 99 medium and major projects that are to be completed in three phases by the year 2017, 2018 and December 2019. This is expected to create irrigation potential of 7.6 million hectares and benefit 145 districts of the country. However, the progress so far has been sluggish, as only 43 projects had been completed by December 2019 (Gulati and Banerjee 2020).

Further, for better water usage to address climate change, on the demand side, governments need to have rational pricing of water and power to reflect their long-term scarcity value. For this, state governments need to shift from free or highly subsidised water and power as these policies are distortionary and financially as well as environmentally non-sustainable (Gulati et al. 2019).

[5] https://ggrc.co.in/documents/MISwiseTPASummary.pdf.

The future, however, lies in precision irrigation technologies through satellite crop monitoring systems that assess soil moisture, expected rainfall and overall crop conditions to suggest the exact quantity of irrigation required. Use of irrigation sensors can also help save water. India, China and Israel will all have to move in this direction. Israel is known for being for having developed the most innovative ways of harnessing water for agriculture, from drip irrigation to recycling wastewater to desalinising sea water and so on. Israel can be a lighthouse of innovations in water use not only for India and China but also for the world at large.

In addition, healthy soils are a key element of sustainable agricultural systems. However, all three countries face soil health issues, including contamination, salinity, compaction and other sorts of degradation, which affect productivity and harm human health. One of the promising developments is microbial technology to address some of these issues. Microbes can be utilised to deal with all sorts of crop stressors, such as water stress, salinity, nutrient deficiency and pest and disease susceptibility. Advances in DNA sequencing and machine learning have helped the process of analysing microbes and identifying those that are best suited to target key crop stressors. Beneficial microbes can be delivered via seed treatment, where the microbes grow as their plant host grows. Israel has used mycorrhizal fungi as an inoculant for soils and crops and other bio-stimulants to ensure that crops are more pest-resistant. China and India need to move in this direction.

Most importantly, it is critical to derisk low income farmers against climate especially in developing countries like India through appropriate crop insurance schemes, which reduces income volatility during times of crop loss (Gulati et al. 2019). In India, the *Pradhan Mantri Fasal Bima Yojana* is a policy in the right direction but is not free from implementation challenges. Another initiative in this direction by the Indian government is the establishment of climate-resilient villages as a learning platform to design, implement, evaluate and promote various climate-smart agricultural interventions to ensure enabling mechanisms at the community level (Srinivasrao et al. 2016). This could potentially provide stability to farm productivity and household incomes and resilience through livelihood diversification in the face of extreme climatic events like droughts, cyclones, floods, hailstorms, heat wave, frost and seawater inundation.

China is also undertaking policies to address production risks by improving flood control and drought resistance capacity, which includes improvement of river reaches and reservoirs. Simultaneously, the government is strengthening monitoring and early-warning information systems. The government is also encouraging water-saving technologies, improving soil quality and reducing agricultural residues and waste, notably through the rural revitalization strategy. China also has crop insurance for farmers, the coverage of which is more than twice that in India.

Further, to combat climate change and desertification, scientists have innovated a cornerstone technology in the recent past that transforms deserts into high-yielding fertile farmland using liquid NanoClay. The technology helps in retaining water and fertilisers in the soil like a sponge by changing its physical qualities. Thus, there is a huge potential in adopting the technology in Israel and India to fight high temperatures and desertification (Global Opportunity Report 2017).

11.6.5 Protected Agriculture

Lastly, in the wake of rising urbanisation, the need is to overcome the challenges of loss of agricultural production due to diversion of agricultural land for non-agricultural purposes and of producing a diverse basket of high-value food crops to cater to the varied preferences of a more urbanised population in 2030 and beyond. The future lies in fully automated agriculture systems that monitor and analyse crop health and development, providing actionable value points to farmers telling them what to do and when with the crops, thus replacing labour-intensive processes and outdated equipment. Vertical farming, protected agriculture and greenhouse cultivation can also go a long way because indoor farming offers controlled environments for crop growth of improved quality. Soil-less farming systems such as hydroponics, aeroponics and aquaponics can be game-changers as they allow growing fruits and vegetables in nutrient solutions instead of soil. Start-ups in Israel are working in this direction. These improvements are not just limited to growing more food but also contribute to more efficient use of available land and other resources to meet the increased demand for high-value products by urban consumers.

11.6.6 Youth Participation in Agriculture

To address the challenge of young people quitting farming, a holistic approach is required, which includes skills development, strengthening information exchange and career guidance and stimulating investment. Both the public and private sectors have important roles to play. Governments can design favourable policies and regulations for rural youth, provide vital investment and rural infrastructure and offer training and skills development programmes. The private sector, as the engine of innovation, transformation and growth, can create new jobs for youth. Both sectors need to work together to be able to provide labour and job opportunities in the agricultural value chain in rural areas. Opportunities exist not just in value chains in production and selling, but also in processing, finance, information and skill development and agricultural entrepreneurship. Farming must be viewed as a business and offer a remunerative profession for young people who are willing to learn and join the sector. Without an integrated approach, the majority of rural young people will turn away from agriculture permanently and look for opportunities in urban areas or other sectors.

11.7 Conclusion

Greater investment in agricultural R&D and an enabling policy environment are imperative to tackle emerging challenges. The R&D agenda must be reoriented to address the major gaps in a country and integrate nutrition, sustainability and climate resilience needs. It is pivotal to have a consistent and systematic approach to assessing changing farmers needs and challenges as a feed into making sure that innovations are demand driven. Besides, there are other innovations that could help in further developing the agricultural innovation system. For example, collaboration and exchange of information across countries and sectors in the globe can accelerate progress in the pace of technological advancement and dissemination. In India and China, closer and deeper co-operation between public research institutions and the private sector is needed for furthering agricultural transformation. Agricultural technology start-ups should be nurtured and financed to support the growth and development of innovative solutions to tackle evolving challenges. Both China and India have a lot to learn from Israel in this regard. In addition, innovative processes must be established to enable and enhance profitable market access for smallholder farmers. An important aspect of enabling innovation is to promote transparent, efficient and inclusive market systems. The private sector has a key role to play there. The recent development of digital and e-commerce platforms linking farmers and aggregators to the market represents such initiatives. Furthermore, for transitions to more sustainable agriculture, there have been discussions on how an agricultural innovation system can be opened up to better support the creation of innovation niches, which can be identified as spaces (i.e. physical, ecological, technological and virtual) where stakeholders come together to define shared objectives and engage in social learning to support an innovation process (Pigford et al. 2018).

In conclusion, to address the complex challenges of population growth, food security, increasing incomes, changing demand patterns, urbanisation, nutritional security and climate change, there is a need for forward-looking innovations (in technology and the agricultural innovation system), a balanced policy mix of incentives and right institutions related to land, water, agricultural research and extension and farm machinery use. This will enable the production of sufficient food, feed, fibre and a diverse variety of high-value agricultural products for their populations. It will also stimulate economic growth and take the agricultural sector towards greater efficiency, social inclusivity and environmental sustainability.

References

Global Opportunity Report. (2017). *Global opportunity report: your guide to a world of opportunities*. Høvik, Oslo: DNV GL AS.

GOI. (2020). *Establishment of Farmer Producer Organisations, Government of India*. https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1605030, accessed in September 2020.

Gulati, A., & Banerjee, P. (2020). Goal setting for Indian agriculture. *Economic and Political Weekly 55*(9)

Gulati, A., & Juneja, R. (2018, February 19). From plate to plough: a vision coloured green. *The Indian Express*.

Gulati, A., & Juneja, R. (2018, October 15). From food security to nutrition security. *The Indian Express*.

Gulati, A., Kapur, D., & Bouton, M. M. (2019). *Reforming Indian agriculture.* Center for the Advanced Study of India.
Gulati, A., & Khurana, K. (2020, March 02). To ensure good health by 2023, focus on agriculture, sanitation, women education. *The Indian Express.*
Gulati, A., & Verma, S. (2016, October 24). From plate to plough: a clear trend towards non-vegetarianism in India. *The indian express.*
ICAR- NRRI. (2019). *CR Dhan 801 and CR Dhan 802: climate-smart rice varieties of NRRI.* ICAR-National Rice Research Institute.
NFHS. (2015–16). *National family health survey.* Delhi: Ministry of Health and Family Welfare, Government of India.
NHFPC. (2015). *Chinese nutrition and chronic disease report.* Beijing: China Statistics Press, National Health and Family Planning Commission of the People's Republic of China.
NICRA. (2018). *Research highlights (2016-18).* Hyderabad: ICAR-Central Research Institute for Dryland Agriculture.
OECD. (2010). *Review of agricultural policies: Israel*. Paris: OECD Publishing.
OECD. (2018). *Working party on agricultural policies and markets: innovation.* Trade and Agriculture Directorate Committee for Agriculture: Agricultural Productivity and Sustainability in China.
OECD database. (2020). https://data.oecd.org/, accessed in September 2020.
OECD, FAO. (2019). *OECD–FAO agricultural outlook 2019-2028*. Rome: OECD Publishing.
OECD, ICRIER. (2018). *Agricultural policies in India.* Paris: OECD Food and Agricultural Reviews, OECD Publishing.
Pigford, A. A. E., Hickey, G. M., & Klerkx, L. (2018). Beyond agricultural innovation systems? Exploring an agricultural innovation ecosystems approach for niche design and development in sustainability transitions. *Agricultural Systems*, *164*, 116–121.
Planning Commission. (2011–12). *Poverty line.* Government of India.
Roser, M., & Ospina, E. O. (2020). Global extreme poverty. *OurWorldInData.org.*
Srinivasrao, Gopinath, K., Prasad, J., Channalli, P., & Singh, A. K. (2016). Climate resilient villages for sustainable food security in tropical India: concept, process, technologies, institutions, and impacts. *Advances in Agronomy*.
Teng, P., & Foo, M. (2018). *Food Matters: Food Security and the Future of Food*. Write Editions. ISBN-10: 9811153736.
The World Bank. (2019). *Poverty and equity data portal.* Retrieved February 22, 2020, from povertydata. http://povertydata.worldbank.org/poverty/country/CHN.
United Nations. (2019). *World population prospects.* Department of Economics and Social Affairs: Population Dynamics.
Wang, Y. S. (2019), The challenges and strategies of food security under rapid urbanization in China. Sustainability 11(542). https://doi.org/10.3390/su11020542.
Zhao, C., Liu, B., Piao, S., et al. (2017). Temperature increase reduces global yields of major crops in four independent estimates. *Proceedings of the National Academy of Sciences, 114*(35), 9326–9331.