Chapter 14
Adaptation to Climate Change in Agriculture: An Exploration of Technology and Policy Options in India

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14.1 Introduction

Climate change is a global phenomenon impacting everything on planet earth, but it impacts them differently. Agriculture being a highly weather-dependent enterprise is impacted most. There are already significant observed adverse impacts, and the projections are that it may reduce the global agricultural yields up to 30% by 2050 (Global Commission on Adaptation 2019). The irony is that the most affected would be the 500 million small farms across the world. Climate change impacts agriculture, but it also gets impacted by the activities involved in various processes in agriculture and food system, which contribute to about a quarter of the global greenhouse emission (IPCC 2014). Thus, it is a two-way relationship. Greenhouse gas (GHG) emission from agriculture may grow up to 70% of the remaining allowable emissions from all human sources by 2050 (Searchinger et al. 2019), and most of it is likely to come from developing countries in Asia and Africa. Though linked to the general global changes, which are largely the consequences of the development activities pursued in the developed part of the world, the climatic regime in South Asia has significant departures from the global mean in terms of changes and the impact on agriculture (Schellnhuber et al. 2013). The need for adaptation to climate change arises because of the changes, which have been introduced in the natural systems in the process of the development.

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A. Pandey et al. (eds.), *Hydrological Aspects of Climate Change*,
Springer Transactions in Civil and Environmental Engineering,
https://doi.org/10.1007/978-981-16-0394-5_14

14.1.1 Climate Change Impact on Agriculture

Agriculture and water resources (availability and distribution) are highly dependent on specific climate conditions. The climate change will have a universal, but differentiated impact depending upon the location of the countries. Projections for climate impact on agriculture for South Asia are quite alarming, particularly when weighed together with adaptive capacity and the population growth. In India, because of its size, different regions experience differentiated effects. Cline (2007) has projected that by 2080, agricultural output in India may fall between 19 and 39% with benefits of carbon fertilization and 29–44% without benefits of carbon fertilization in different parts of the country. It may be added that irrigation requirements have significant correlation with temperature and for every 1 °C rise in temperature, the irrigation requirements go up by 10% (Cline 2007). The recent projections on impacts on production are much more alarming. The report of Indian Network for Climate Change Assessment (INCCA), which has been established to study the impact of climate change and advise the government (INCCA 2010), projected a fall in yield of rice in the order of 4–20% under irrigated condition and 35–50% under rainfed condition as early as 2030 (Table 14.1). These projections tally with Cline's estimates of 30–40% (Cline 2007). The only difference is that what was expected to happen in 2080 may happen in 2030. How to minimize the adverse outcomes and build on the positive ones remains the issues to be resolved.

Addressing issues introduced by climate change in agriculture, which supports livelihood of about 58% population in India, assumes urgency (GoI-MoSPI 2014). The two major mechanisms to turn down the heat, and to enable it to keep operating within safe space of resource boundaries, are mitigation and adaptation (GCA 2019). The mitigation processes take care of the causes of climate change, while adaptation tries to moderate the adverse impacts and establish resilience in the system. The resilience to agriculture, which is defined as the capacity of an ecosystem to tolerate disturbance without collapsing into a qualitatively different state, is imparted by both, the adaptation and the mitigation. Understanding this inter-relationship would help develop an optimized mix to maximize benefits and minimize cost. The low-carbon technologies employed for mitigation, being patent protected in developed countries, are costly. But technologies in adaptation have no such constraints and are readily available, and this makes technology transfer easier (Irfanullah et al. 2011). Further, investment in adaptation to bring resilience is highly profitable, because as per the report from Global Commission on Adaptation, the rate of return ranges from 2:1 to 10:1, and in dryland agriculture, it was about 5:1 (GCA 2019). But there are limits on adaptation in terms of technology, finance and social and cultural norms. Though adaptations are largely technology-driven, soft interventions like risk transfer and capacity building, to take advantage of the technology development, also play a very important role in adaptation process (Mobarak and Rosenzweig 2013; Tyagi and Joshi 2019a, b).

In developing countries like India, stress due to climate change is only an additional factor, as the farmers face a large number of non-climatic stresses with high

Table 14.1 Impact of climate change in different sectors and regions of India by 2030

Sector	Himalayan region	Northeast	Western Ghats	Coastal region
Crops	Apple-Overall negative impact	Irrigated rice: +5% to −10% Rainfed rice: +5% to −35% Yield reduction Maize: up to −40%	Yield reduction Rice: −4% Maize: −50% Yield increase Coconut: +30%	Yield reduction Irrigated rice: −(10–20)% Rainfed maize: −35% Irrigated maize: −(15–50)% Coconut: up to −40% (West Coast) Yield increase Coconut: + (10–30) % (in parts east coast)
Fishery	–	–	–	Positive impact
Livestock		Negative impact	Negative impact	Negative impact
Water	Increase	Decrease	Variable	General reduction
Biodiversity (in terms of natural plant productivity (NPP)	NPP increase by 57%	NPP increase by 23%	NPP increase by 20%	NPP increase by 31%

Source Indian Network for Climate Change Assessment (INCCA) 2010. Climate Change and India: A 4 × 4 Assessment: A sectoral and regional analysis for 2030s damaging potential. These stresses arise due to limited access to assets, capital, technology infrastructure and markets (Vyas 2007; Hazell et al. 2010; World Bank 2008). Among these stresses, lack of human capital is the most constraining, in so far as adaptation capacity is concerned. For example, in the northern states of Bihar and Uttar Pradesh, where human development in terms of health, education and income is low; the potential to assimilate new knowledge and the capacity to interact with input suppliers, bankers and traders is also low.

Thus, there are multiple issues involved in planning, implementing and assessing the adaptation in agriculture, as it has multiple inter-sectoral implications. The key issues addressed herein are: some intricacies of adaptation concept, mapping of India's vulnerability to climate change, biophysical adaptations which would help ensuring food and nutrition security with minimum tradeoffs between increased production and the environment (health of soil and water resources systems), and risk transfer through agricultural insurance and the policies to promote adoption of climate-smart technologies.

14.2 Understanding the Adaptation

Adaptation to climate change in agriculture means adjusting to the changed set of climatic attributes like increased floods, droughts, heat waves, etc., to take care of the biophysical and socio-economic vulnerabilities of natural and built environments by building capacity and using it to implement desired interventions (IPCC 2014; Tompkins et al. 2010; Smit and Skinner 2002). The resilience to agriculture, which is defined as the capacity of an ecosystem to tolerate disturbance without collapsing into a qualitatively different state, is imparted by both, the adaptation and the mitigation. So, it requires mitigation as well as adaptation to keep the climate change impacts within acceptable limits. Mitigation and adaptation are sometimes considered interchangeable, as many interventions serve both the purposes. Understanding the interrelationship between them would help develop an optimized mix to maximize benefits and minimize cost.

Improved agricultural production and sustainable management of natural resources also have considerable mitigation potential as well (Nin-Pratt et al. 2011; Tyagi et al. 2019). For example, carbon sequestration in agricultural soils reduces GHGs, creates an economic commodity for farmers (sequestered carbon) and improves soil productivity by improving soil health. Similarly, stopping the existing practices of straw burning in Indo-Gangetic plain, shifting cultivation in Northeast India, wetland cultivation of rice and traditional tillage practices offer opportunities for conserving the resource base and reducing emission of greenhouse gasses (GHGs). It may however be noted that mitigation has global benefits with some ancillary benefits which can be realized at local or regional level, whereas adaptation mostly works on the scale of an impacted system (Klein et al. 2007).

14.2.1 Classification of Adaptations

Adaptations have been classified in multiple ways depending upon the purpose, mechanism and time sequence. In agriculture, farmers have been adapting to gradual changes since long, albeit unconsciously, in response to ecological changes in the production system or market forces. These are called autonomous or spontaneous adaptations (IPCC 2001). On the other hand, adaptations resulting from deliberate policy guided action to achieve a desired state are called planned adaptations. Depending upon the time (before or after the impact of climate change), adaptations are classified as anticipatory (e.g. early weather warning system) or reactive (adjustment in date of sowing in response to late monsoon), respectively. Planned adaptions can be both anticipatory and reactive.

The adaptation requirements depend on the vulnerability in terms of loss in production and/or income from agriculture under the given set of biophysical and socio-economic factors (Howden et al. 2010). As the degree of climate change increases, the efficacy of the adaptation measures goes down, and so do the benefits requiring change from incremental adaptations to systemic adaptations and finally to transformational adaptations. Further, there are limits on effectiveness of the measures arising from biophysical factors (the ecological tipping points) which create absolute limits for adaption, social limits (how much is acceptable) and economic limits (how much is affordable) (Schipper and Lisa 2009). A partial list of adaptation measures with varying intensity of climate change is given in Table 14.2.

In agriculture, opportunities for adaptation, which connotes adjustment to moderate the impacts of climate change, are higher than mitigation. Adaptations are required to deal with vulnerabilities associated with climate variability, in human health, coastal settlements, infrastructure and food security. The resilience of most sectors in Asia to climate change is very poor. Expansion of irrigation will be difficult and costly in many countries. For most developing countries in Asia, climate change is only one of the many other problems to deal with, including nearer term

Table 14.2 Adaptations in relation to degree of climate change and benefits from adaptation

Degree of climate change	Nature of adaptation	Benefit/cost tradeoff
Moderate	**Incremental**: Crop varieties, planting dates, spacing, nutrient management, canopy management, irrigation scheduling, etc.	No regret
High	**Systemic**: Climate ready crops, precision agriculture, crop diversification, crop insurance, micro-finance and risk management, early warning systems	Income-environment tradeoff
Extreme	**Transformational**: Land-use changes and distribution, ecosystem services, migration	High

needs such as hunger, water supply, pollution and energy. Resources available for adaptation to climate are limited, and the priority areas for adaptation are land and water resources, food productivity and disaster preparedness.

14.2.2 Strategies for Adaptation Planning

Adaptation responses are closely linked to development activities, which should be considered in evaluating adaptation options. Early signs of climate change are already observed and may become more prominent over 1 or 2 decades. If this time is not used to design and implement adaptations, it may be too late to avoid upheavals. Long-term adaptation requires anticipatory actions. A wide range of precautionary measures are available at the regional and national level to reduce economic and social impacts of disasters. These measures include awareness building and expansion of the insurance industry. Development of effective adaptation strategies requires local involvement, inclusion of community perceptions and recognition of multiple stresses on sustainable management of resources. Adaptive capacities vary between countries, depending on social structure, culture, economic capacity and level of environmental disruptions. Limiting factors include poor resource and infrastructure bases, poverty and disparities in income, weak institutions and limited access to technology. The challenge in India lies in identifying opportunities to facilitate sustainable development with strategies that make climate-sensitive sectors resilient to climate variability. Adaptation strategies would benefit from taking a more system-oriented approach, emphasizing multiple interactive stresses, with less dependence on climate scenarios.

Apart from addressing the climate *risks,* adaptation offers multiple social, economic or environmental co-benefits (Hallegatte 2009). The important dividends of adaptation in agriculture include: reduction in crop yield losses, improved economy and livelihood, and better environment due to avoided deforestation (Tyagi et al. 2019). But there are barriers and limits on effectiveness of adaptation responses. In certain situations, adaptation may become impossible for lack of strategies, high cost and unacceptable consequences. The limit to adaptation may be due to socio-economic, ecological, physical and technological factors.

14.2.3 Adaptations in Agriculture Are Water-Centric

Agriculture, which is the nature's carbon and water-based industry, globally accounts for 70% of all water withdrawals, and its share in consumptive water use is even higher (World Bank 2020; Hoekstra and Mekonnen 2012). In India, agricultural water use is as high as 85% (NITI Aayog 2015). Agriculture being a carbon and water-dependent sector, it is but natural that the impacts of climate change would be largely transmitted in terms of water-related stresses like increased floods and droughts. The observed data over a period of 1951–2015 shows a significant increase in frequency and spatial extent of droughts, particularly in Indo-Gangetic Plains of India (Mujumdar et al. 2020). A similar trend is found in the frequency of heavy rainfall events, which cause floods. Projections for the future indicate a rise in extreme rainfall events of short duration on rise of global temperature between 1.5 and 2.0 °C (Ali and Mishra 2018). Whereas short-lived and localized floods are also an important source of risk in agriculture, it is the widespread river inundation in flood plain areas in low-lying deltaic regions in Eastern India, which is a major concern. The flooding is a widespread phenomenon, and the floods in river basins of Brahmaputra and Barak Basin, Ganges and Mahanadi create serious problem for agriculture. For example, the state of Bihar, which is one of the most flood-vulnerable states to floods, the average annual crop loss from 2004 to 2013 (Fig. 14.1) was assessed at Rs. 1580 million per year with peak value at Rs. 7084 million in 2007 (Government of Bihar 2014). It is a matter of great concern that at the river basin level, the multi-day frequency is also projected to increase significantly under changing climate (Ali et al. 2019).

Apart from floods, a major concern is the trending reduction in summer monsoon rainfall during last 100 years in Central and East India, which is of the order of 10–20%, having very severe potential socio-economic implications (Roxy et al. 2015). By introducing shifts in rainfall pattern, rainfall intensity and thereby more runoff and less groundwater recharge and increasing evaporation, climate change introduces unprecedented changes in water system.

Uncertainties in water cycle shifts have undermined the concept of stationarity which, in the past, has been the concept used in managing water availability variability (Milly et al. 2008). Further, water, because of its systemic nature, is embedded in all sectors of economy and, therefore, an effective tool of adaptation (Smith et al. 2019). Aligning water management practices and policies with changing climate scenarios remain important, but challenging (Smith et al. 2019).

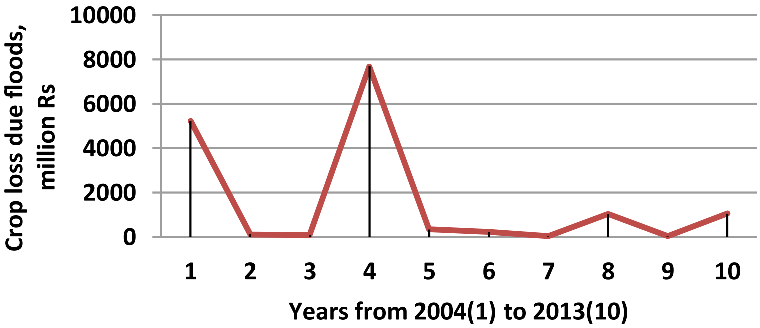

Fig. 14.1 Crop damage due to floods in Bihar-2004–2013 (Source: Based on data from Flood Report-2013 Govt. of Bihar, 2014. https://fmis.bih.nic.in/aboutus.html)

14.3 Vulnerability Mapping of Indian Agriculture

In relation to climate change, the IPCC (2007) defined vulnerability as "the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes." Accordingly, in agriculture, vulnerability to climate in agriculture would mean the loss of production or income, when faced with climate shocks, and is impacted by both biophysical and socio-economic factors. The three components of vulnerability are sensitivity, exposure and adaptive capacity, and there are a number of determinants reflecting these components, which combinedly decide the level of vulnerability. These determinants, which are dynamic in nature, are location and the system-specific and also change with climatic stimuli (Smit and Wandel 2006). The capacity of farming communities to manage the impact of climate change varies with social status, ethnicity and class; and the impact is greater on the poor small farm holders (Adger et al. 2009; Joshi and Tyagi 2019).

Various attempts have been made to map the agricultural vulnerability in India, the important ones being those by Kavi Kumar et al. (2007) and Ravindranath et al. (2011). The other two, more recent and comprehensive assessments, are due to Sehgal et al. (2013) for Indo-Gangetic plain and the other by Rama Rao et al. (2013) for the entire country under the auspices of National Initiative on Climate Resilient Agriculture (NICRA). In a large country like India, vulnerability being location-specific is bound to vary in a wide range. As observed in Joshi and Tyagi (2019), the following is the picture of relative level of vulnerability status for 572 districts in the country, developed by Rama Rao et al. (2013).

1. The highest incidence of districts, in very high and high category of vulnerability, occurs in Rajasthan (31),[1] Uttar Pradesh (30), Madhya Pradesh (30), Bihar (21), Gujarat (20), Karnataka (19) and Maharashtra (17).
2. The major exposure factors in Rajasthan and Uttar Pradesh were the projected rise in minimum temperature and decrease in July rainfall, whereas the increase in drought years was an additional factor in Madhya Pradesh and Karnataka, besides the first two factors. In Bihar, major exposure factor was only the decrease in July rainfall. In Maharashtra, the rise in minimum temperature and the increased number of drought years were the factors of exposure.
3. Low rainfall followed by high net sown area were the two major sensitivity factors across the states with a sprinkling of drought proneness.
4. The low net irrigated area and low groundwater availability were the major constraints to adaptive capacity across the vulnerability classes.
5. In case of Punjab, the vulnerability was compounded by low livestock density, while in Uttar Pradesh and Bihar, the culprit was high level of poverty.

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[1] Values in parenthesis are numbers of districts.

The observed data for India indicates 8–10% decrease in monsoon seasonal rainfall in Eastern Madhya Pradesh, Northeastern India and parts of Gujarat and Kerala over the past century (Lal et al. 2010). The sea level has risen between 1.06 and 1.75 mm per year (IPCC 2007). The projections of climate change for the next 40–80 years are more frightening.

14.3.1 *Quantitative Estimation of Vulnerability*

Indian agriculture is essentially a smallholders' farming; 85% of the farms fall in this category, and a very large number of these farms (54%) lie in Indo-Gangetic Plain (GoI-MoA 2014a, b). As discussed in earlier section, the adaptive capacity of farmers in this region is very much constrained by non-climatic factor. For this region, a quantitative analysis of exposure, sensitivity and adaptive capacity on a scale of 0–5 has been performed by Sehgal et al. (2013). The analysis showed that as one traversed from west to east, the exposure and sensitivity increased, whereas adaptive capacity decreased, resulting in increased vulnerability (on 0–4 scale) (Fig. 14.2). But in Punjab and Haryana, the two states which had high irrigation intensity (more than 90%), the adaptive capacity was high. Higher use of chemical fertilizers, greater degree of electrification and improved rural road network were the other contributory factors for their low vulnerability.

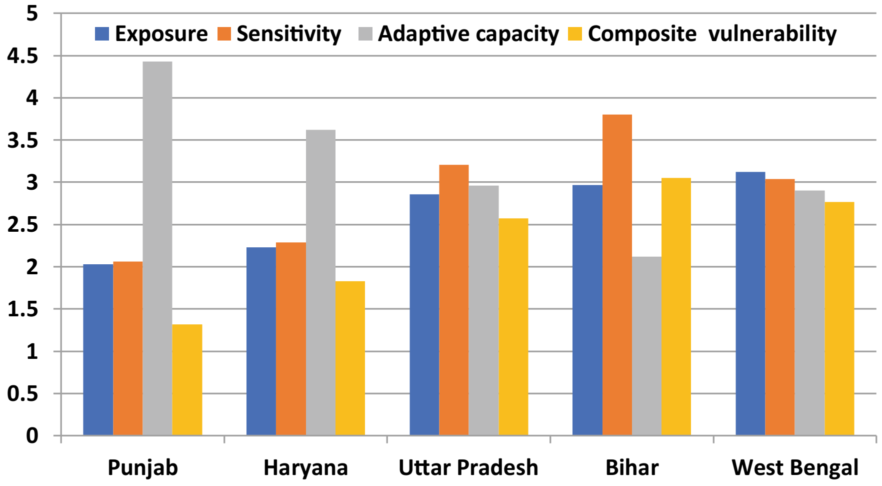

Fig. 14.2 Exposure, sensitivity, adaptive capacity and composite vulnerability of agriculture across Indo-Gangetic Plain (Based on data from Sehgal et al. 2013)

14.4 Adaptation Actions in India

Farmers in India, or for that matter everywhere in the world, have been adapting to climatic and non-climatic factors, since ancient times. But a break from the past occurred in the seventh decade of twentieth century with introduction of seed, fertilizer and water-based productivity enhancing Green Revolution period interventions. These biophysical adaptations were not planned with climate lens, but aimed at increasing food production to feed the teeming millions. Adoption of incremental agro-technologies like improved seeds, higher doses of fertilizers and irrigation helped achieved higher productivity and reduced production cost, resulting in 15–20% higher income (Tyagi et al. 2019).

The dawn of twenty-first century saw adoption of two parallel approaches similar to the ones' mentioned in the 3rd SCAR Foresight Report of European Union (Freibauer et al. 2011). Whereas most farmers continued with the existing Green Revolution period technologies, progressive farmers of upper and middle Indo-Gangetic Plain and parts of Southern India started experimenting with climate-smart low-carbon technologies like zero till, laser levelling and micro-irrigation systems (Tyagi and Joshi 2019a, b). Though a major driver for acceptance of the new technologies was the rapidly declining groundwater, extension activities, like Climate-Smart Village under Climate Change, Agriculture and Food Security (CCAFS), Accelerated Irrigation Benefit Programme (AIBP) and National Horticulture Mission, etc., (GoI-MoA&FW 2019) under which financial support was extended to the farmer, were also quite helpful. According to some estimates, the laser levelling has modified more 20 million ha land surface effecting about 20% increase in water use efficiency, and zero/reduced tillage has gone into 3 million ha, saving both energy and water, while micro-irrigation has changed the way farmers practiced agriculture bringing in more crop per drop, per unit of energy and per unit of GHG emission in about 8 million ha (Tyagi and Joshi 2019a; Global AgriSysrem 2017). But we need to add more technologies and out scale them at country level.

14.4.1 Case-I: Adaptation and Adaptation-Led Mitigation with Green Revolution Technologies

The adoption of Green Revolution technologies (the term was coined in 1968 by former USAID director William Gaud) got initiated in India in late nineteen sixties and reached its peak by 1990. The main ingredients of GRTs in India were improved seeds (mostly rice and wheat crops), large-scale expansion of irrigation and dramatic increase in use of chemical fertilizers. Starting with 1.9 million ha in the initial stage, the coverage of GRTs reached 75 million by 1995 (Swaminathan 2017; Kanolkar ND).

14.4.1.1 Data and Methodology

As reported in Tyagi et al. (2019), a span of two decades from 1990–2010 was selected for analysing the impact of Green Revolution technologies on adaptation, mitigation, resilience and sustainability through the observed reported data on crop area, irrigated area, fertilizer consumption, the resulting production and productivity etc. Simultaneously, using standard procedure on data from FAO for the respective years (FAOSTAT 1990, 2010), the green GHG emissions from each activity were also estimated (Table 14.3).

An empirical framework, explained in detail in Tyagi et al. (2019) to compute adaptation, mitigation and sustainability aspects of out-scaling surface and groundwater irrigation, micro-irrigation technology and fertilizer consumption, was developed. Changes in land productivity, food availability, deforestation, water resources exploitation and emission balance capture impacts of interventions. Indices for mitigation and adaptation were constructed to provide a quantitative basis for assessing the net mitigation or intensification by each technical intervention. The evaluation was performed under "with and without" incremental adaptation situations, to design policy initiatives.

14.4.1.2 Results

The two-decadal change in technology adoption brought an increase of 40% in production, 46% in productivity and 35% in per capita FG availability. The contributions of irrigation and fertilizers to these positive changes were 40 and 20%, and the remaining 40% was attributed to seed and other factors. The most encouraging effect of increased productivity was saving of 56 million ha of forests from being brought under cultivation. Increased land productivity and avoided deforestation achieved through technology implementation had significant impact on potential greenhouse

Table 14.3 Impact of incremental adaptation of Green Revolution period technologies (seed, water and fertilizer) on production, productivity, food grain availability and carbon footprints (Adapted from Tyagi et al. 2019)

Item	1990	2010	Change (%)
Area under food grain production (Mha)	127	122	−3.90
Irrigated area (MHa)	67	85	+ 26.9
Fertilizer consumption (Kg/ha)	68	115	+ 69.1
Food grain production (Mt)	151	212	+ 40.4
Land productivity (T/Ha)	1.19	1.74	+ 46.2
Food grain availability at 1990 population base (kg/cap/year)	203	274	+ 35
Food grain (FG) carbon footprints (TCO_2e/TFG)	1.196	0.907	−24.2

MHa = million-hectare, MT = million-ton, Kg/Ha = kilograms per hectare, CO_2e = carbon dioxide equivalent (Data Sources: GoI-MoC&F 2012; Chand and Pandey 2008; and GoI-DoE&S 2011) gas mitigation and food security. The carbon footprints of food grain (FG) production, in terms tons of carbon dioxide equivalent emission per ton of FG (TCO_2e/TFG), decreased from 1.2 to 0.91 over period of 20 years (Table 14.3). Total emission from food grain production which was 181 million TCO_2e, in 1990, increased to only 193 million TCO_2e, by 2010 (Fig. 14.3). Estimates indicated that in the absence of incremental GRT technologies, greenhouse gas emissions would have increased to 430 million TCO_2e. Thus, an adaptation-led virtual mitigation of 237 million TCO_2e was achieved due to increased productivity (Tyagi et al. 2019).

The increased agricultural intensification, which saved about 56 million ha of forest land from being brought under the plough, was largely dependent of groundwater. The over exploitation of surface and groundwaters has made the management of irrigation systems difficult and has implications for long-term sustainability of irrigated agriculture. As seen from Table 14.4, the degree of development of surface water (DDS), a ratio of water diverted from the river system and average river flows

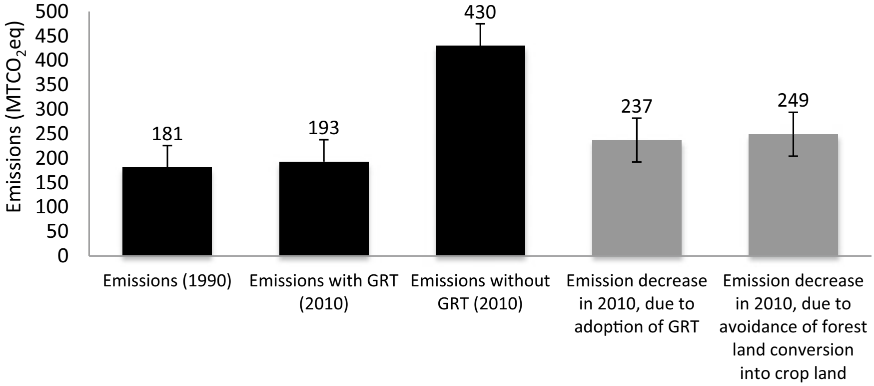

Fig. 14.3 Estimated annual GHG emissions from land under food grains under two scenarios—(i) with adoption of GRTs and (ii) without adoption of GRTs (Source: Tyagi et al. 2019)

Table 14.4 Water resources and sustainability indices of water resource development in India

Item	Level of development (BCM)		
	2000	2010	2050
Surface water	360 (690)[a]	404	647
Groundwater	210 (396)[a]	260	396
	Degree of stress		
DDS	0.522 (high)	0.586 (high)	0.938 (extremely high)
GWAR	0.530 (normal)	0.657 (high)	1.00 (extremely high)

[a] Source—Water resources data are from NCIWRD Report (1999)

during non-monsoon period, stood at about 0.59 in 2010, while the projected value of DDS in 2050 was 0.95, which according to Alcamo et al. (2000) was extremely high value. Similarly, the groundwater abstraction ratio (GWAR), the ratio of groundwater abstracted and the annual recharge, was 0.657 in 2010 and is projected to be >1 in 2050. It may be added that development is considered safe up to a GWAR of 0.65, moderately stressed between 0.65 and 0.85 and unsafe beyond 0.85 (CGWRE 2009).

14.4.1.3 Inferences

1. Out scaling of incremental Green Revolution technologies (GRT) in India not only translated into increased food security by way of increased productivity and more income, but also provided a buffer against climate-induced fluctuations.
2. There was significant adaptation-led virtual mitigation, which saved more 50 million forest land being brought under cultivation, proving Borlaug's hypothesis that increased productivity saved land (Borlaug 2007).
3. The policies promoting GRT out scaling led to evolution of cropping patterns which caused overexploitation of water resources. This calls for urgent action and required corrections in crop area allocation, introduction of water smart technologies and the enabling policies.

14.4.2 Case-II: Adaptation Through Diversification and Climate-Smart Technologies

This case study pertains to the state of Haryana in upper Indo-Gangetic Plain, which has been one of the most significant beneficiary's Green Revolution technologies leading to food grain sufficiency. But the tremendous increase in rice and wheat production, which brought food grain sufficiency, has been traced to the excessive development of groundwater, setting in an ecological crisis (World Bank 2001; Tyagi and Joshi 2019a). Most parts of the state being arid and semi-arid, there was dominance of low water requiring crops like millets, pulses (mostly gram) and oilseeds under rainfed conditions till 1970 (Fig. 14.4). However, 1980 onward, the situation has dramatically changed, and in 2015, rice, wheat and cotton had become the dominant crops, turning into a cropping system which is not ecologically sustainable as the annual groundwater draft was 13.05 billion cubic metre (BCM), against the annual utilizable recharge of 9.79 BCM (CGWB 2017; GoH 2011). Of the total 108 administrative blocks in the state, 55 are overexploited, 11 are critical and 5 are in semi-critical stage (CGWB 2017), as the groundwater table is falling at the rate of 0.65 m/year from 2001–2015.

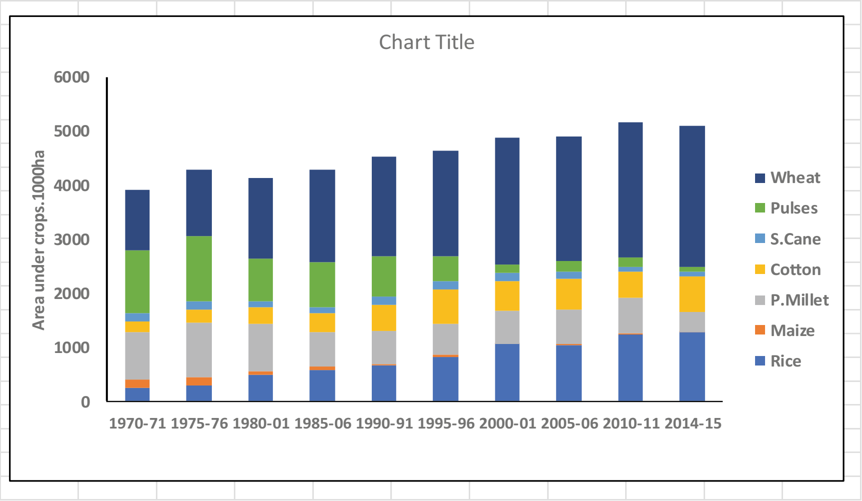

Fig. 14.4 Dramatic changes in cropping pattern during 1970–2015 in Haryana (based on data from GoH 2017)

14.4.2.1 The Emerging Issues

1. Continuous fall in groundwater table requires frequent deepening of tube wells, because of well failures. As a result, the farmers incur heavy cost leading to increased cost of production and decline in farm income.
2. In countryside, the demand for electricity far exceeds the supply, leading to power cuts and putting extra burden on public exchequer, as the electricity charged from farmers is much below the production and distribution cost, rendering the electricity board bankrupt.
3. Coal-based thermal power stations supply 70% of electricity. About 25% of this energy is used to extract groundwater for irrigation, adding significant amount of GHG emissions from agriculture sector.
4. Establishing a balance between food–water–energy security nexus is an urgent issue.

This study investigated the possibilities of achieving the stated objective at farm level through water and energy smart technologies and crop diversification.

14.4.2.2 Methodology and Data

It is important that India transits to new production patterns that keep land, water and other resources within safe limits. The study is based on designing a cropping system based on the combination of ecologically compliant crop mix and experimentally tested technologies, which have out scaled at mesoscale. In India, concerted research

Table 14.5 Average change in important agricultural adaptation parameters over traditional methods and practices (Tyagi and Joshi 2019a)[a]

Attribute	Laser levelling	Zero tillage+	Micro-irrigation
Improvement in irrigation efficiency (%)	15(70)	15(70)	25(85)
Increase in crop yields	15	−5	30
Decrease in energy use (Mj/Ha)	−15	−20	−30
Increase in income (%)	15	15	30

( )Values in parenthesis are the average values under improved methods

[a] Based on data from Naresh et al. (2016), Tyagi and Joshi (2017), Pathak and Aggarwal (2012), IAI and FICCI (2016)

efforts during the last two decades have been made to test and recommend the resource conservation technologies, ranging from micro-irrigation, zero tillage, laser land levelling, salt, drought and heat-tolerant crop varieties for different regions across the country (ICAR 2015). It would be appropriate to mention that zero tillage, laser levelling and micro-irrigation, which were found to increase irrigation efficiencies and crop yields and reduce energy requirements in the range of 15 to 30% (Table 14.5), at research farms (Naresh et al. 2016; Pathak et al. 2011; Tyagi and Joshi 2017), have been adopted by farmers on millions of hectares.

A very important project to reduce energy consumption in groundwater irrigation has been launched by the government under the programme ‘Ag Demand Side Energy Management’. Under this programme, the poorly performing irrigation pump sets are being replaced with Bureau of Energy Efficiency (BEE) labelled pumps (BEE 2009; Vasudevan et al. 2011). The energy audit of more than 20,000 pump sets across eight states was undertaken by Bureau of Energy Efficiency. The energy audit indicated that as a result of this improvement, a saving in energy use in the range of 28–49% with an average value of 40% was achieved (Saini 2011).

14.4.2.3 Results

A diversified cropping pattern along with water and energy smart agro-technologies described in this section showed that it was possible to harmonize the water–energy–food security nexus to keep operating within safe natural resource boundaries. The suggested biophysical interventions would yield a reduction in irrigation requirement in the order of 10 BCM and also save about 2200 million kWh of energy on annual basis (Table 14.6). Along with these monitory benefits, the country would get GHG reduction of 3.38 million-ton CO_2e for meeting national GHG mitigation commitments.

Table 14.6 Water and energy saving through crop diversification and introduction of energy-efficient Bureau of Energy Efficiency (BEE) labelled pump sets (Tyagi and Joshi 2019a)

Interventions	Reduction in groundwater draft (BCM)	Energy (million kWh)	GHG reduction (million-ton CO_2e)
Diversification through reduction in rice, wheat cotton area &increase in pulses, oilseeds and arid horticulture	5.33 (53.4%)	Energy saving: With the existing pump sets = 1434 With BEE labelled pump sets = 2213	With the existing pump sets = 1.5 With BEE labelled pump sets = 3.38
Introduction of zero till and laser levelling in entire area	2.27 (23%)		
Micro-irrigation in sugarcane, wheat, cotton, fruits and vegetables	2.27 (23%)		
Area reduction (%) & reallocation: Rice–30% (Reallocated to Maize: Pearl millet: 80:20); Wheat–15% (Reallocated to Veg: Pulses & Oilseeds: 12.5:87.5); Cotton–23% (Reallocated to Arid zone fruits: Pulses: 67:23)			

14.4.2.4 Inferences

1. Diversification of cropping pattern by relocation of crop areas is necessary to make it ecologically compatible. The proposed reallocation would reduce irrigation demands by about 10 BCM, arrest fall in groundwater table and economize energy consumption by 28%, without compromising on food security.
2. Adoption of the diversified cropping through change in cropping mix in order to promote ecologically compliant cropping would require a level playing field, which at present favours water-intensive crops like rice and wheat. The inclusive pricing policy would have to bring the horticultural crops under the regime of minimum price support.
3. Groundwater management is highly political in nature, and it would require generating strong empirical evidence to indicate resource use efficiency, adoption challenges and economics of adoption for end users.

14.4.3 Risk Transfer as Mechanism for Promoting Adaptation

In the past, weather risk management focused more on engineering responses and the ex-post response like compensation. But in recent years, the importance of "soft measures" such as planning, regulations, early warning systems and the risk transfer through insurance is growing. Efficient risk transferring mechanism like crop insurance can enable them to take substantial risks without much hardship. Insurance itself does not directly reduce any damage and the consequent financial losses. But it provides much-needed financial support and, under certain circumstances, promotes other aspects of flood risk management in the form of risk-reducing interventions (Crichton 2008). A series of agriculture insurance schemes have been implemented in India, and there have been progressive improvements in successive insurance schemes starting from Comprehensive Crop Insurance Scheme (CCIS), through National Agricultural Insurance Scheme (NAIS) and the Modified National Agricultural Insurance Scheme (MNAIS) which were index-based and the one Weather Index-Based Scheme (WBCIS), which were implemented during 1985–2013 (GoI-MoA 2004, 2011, 2013). These improvements were attempts to address the technical, institutional, financial and operational challenges, which cropped up during implementation. The most recent addition to these insurance schemes is Prime Minister Fasal Bima Yojana (PMFBY) and the Revised Weather Index-Based Scheme (RWBCIS) launched in 2016 (GoI-MoA&WF 2019).

Weather index insurance overcomes the defects traditional crop insurance schemes and addresses the problems of moral hazard, adverse selection, high administrative costs, etc., as this financial product is linked to measurable weather parameters, which correlate with crop yield (AFC 2011; Odening et al. 2007). The pilot WIBCIs with varying weather indices, experimented in India, are given in Table 14.7.

A pilot Weather Based Crop Insurance Scheme (WBCIS) was launched in 20 states (as announced in the Union Budget 2007–08) and was implemented as a full-fledged component scheme of National Crop Insurance Programme (NCIP) from Rabi 2013–14 season to Rabi 2015–16. WBCIS intended to provide insurance protection to the farmers against adverse weather incidence, such as deficit and excess rainfall, high or low temperature, humidity, etc., which are deemed to adversely impact crop production. It is planned to set up 5000 automatic weather stations (AWS) in public–private partnership (PPP) mode. The WBCIS component of the above scheme also has a provision for add-on/index plus products for horticultural crops to compensate perils of hailstorm’ cloudburst etc.

Table 14.7 Weather index-based insurance products experimented in India (Tyagi and Joshi 2019b)

Weather index parameter	Promoted by
Weighted rainfall	ICICI Lombard-2003 and AIC-2004 and IFFCO Tokyo-2005
Total seasonal rainfall	AIC during Kharif 2005
Multiple phase weather rainfall	ICICI Lombard 2004
Multiple phase weather rainfall	ICICI Lombard 2004
High temperature/low temperature	AIC-IARI-2007, ICICI Lombard-2010

AIC—Agricultural Insurance Corporation, ICICI—Industrial Credit and Investment

Corporation of India, IARI—Indian Agricultural Research Institute

Recently, the scheme has further been restructured on the basis of premium structure and administrative lines of Prime Minister Fassal Binma Yojana PMFBY and has become operative from Kharif 2016 as restructured WBCIS (GoI-MOA&FW 2019) and has covered. With a view to increase efficiency, speed in getting data and improved communication, this new scheme envisages use of innovative technologies like satellite imagery, vegetation indices, smart phones/handheld devices and digitization of land records.

14.4.3.1 Performance of Weather Index-Based Crop Insurance Scheme

With a small beginning in 2007, the scope of WIBCS was expanded, and by 2013, it was competing with the earlier MNAIS. During 7 years of its operation (2007–2013), the WIBCIS covered 63.2 m ha lands, progressing at an averaging rate of 9.7 m ha/year and insured 46.94 million farmers (7.2 million farmers per year) (Tyagi and Joshi 2019b). Except for one season, the claims were less than the amount of premium, and claim ratios ranged between 0.51 and 1.06 with an average of 0.76 for all the crops insured (Fig. 14.5), whereas the loss cost remained in the range of 6–12% (GoI-MoA 2014a, b; Tyagi and Joshi 2019b). The PMFBY and RWIBCS together covered 51.94 million ha, benefitting 52.08 million farmers in 2017–18, and the payout was Rs 20.16 billion against a premium of Rs 25.49 billion (GoI-MoA 2014a, b).

In spite of several modifications in WIBCS, there still remain some issues to be resolved. The most important is the basis risk as there is not only non-homogeneity in insurance unit area in terms of weather, but in farming techniques. The second issue is of de-trending (removing the effects of accumulating data sets from a trend to show only the absolute changes in values and to allow potential cyclical patterns to be identified) to minimize effect of inadequate historical weather data. Further,

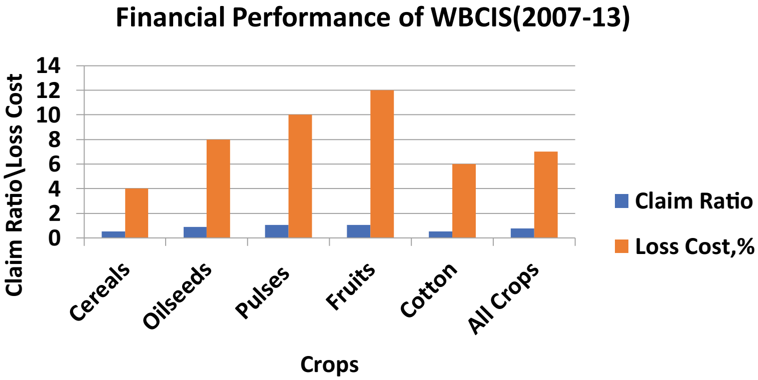

Fig. 14.5 Premium–claim ratio and loss cost (claim/sum insured) for WBCIS during 2007–2013 (Data from GoI 2014)

awareness and appreciation of the beneficial aspects of crop insurance programme hinder its out scaling, and as a result, the degree penetration is still very low. Organized efforts have to be strengthened to educate farming community for expansion of the programme.

14.5 Policies and Institutions

Most adaptation interventions require an enabling environment for action, which is provided by government policies. Unless mainstreamed into development programmes of the governments, large-scale implementation of action programmes is not possible. In India, smallholder farms constitute the backbone of agriculture, and except for some autonomous adaptations, which the poor rural farming communities can take by themselves (or might have already undertaken in response to the gradual changes which have been occurring all the time), large-scale planned adaptations were beyond their capacity. In developing countries, the performance of adaptation process through intensification by adoption of yield increasing technologies has been only 16% (Thornton et al. 2018), even though the technologies were available. The food-insecure regions, as observed by Cline (2007) and Lobell et al. (2008), would require more expensive adaptation measures including the development of new crop varieties and introduction of new irrigation technologies along with related infrastructure. Further, agricultural production takes place under open sky and is subject to damage from weather vagaries like floods, droughts, hail, storms, hurricanes, etc. This requires additional expenses on risk sharing and transfer.

14.5.1 Green Revolution Period Policies

The Indian agricultural policies during Green Revolution period focused on modernization of agriculture sector by focusing on seed–fertilizer–irrigation-based interventions through subsidies and the mechanism of minimum support price (MSP) for selected crops. Though greenhouse gases were not specifically targeted in this effort, modernization had effect on total GHG emissions as well (Climate Policy Initiative 2013; Tyagi et al. 2019). A major advantage of these productivity enhancing policies was the saving of forest land from being brought under the plough, thereby proving Borlaug hypothesis (Borlaug 2007). The MSP and very nominal charges for water and electricity (in some cases free power) policy, weighed as it was in favour of rice and wheat, made them economically remunerative crops. Thus, traditional crops got substituted by water-intensive crops at the cost of diversification (Johal 2002; Sharma et al. 2015).

Box 1: Some Common Features of Climate Policy in India/South Asia

Unlike global climate policy, in India and the South Asian countries, emphasis on adaptation to climate change in agriculture remains in focus. In the absence of legislation, there may not be direct mention of policy, and adaptation strategies are sometimes called action plans. These are currently the most common policy instrument for adaptation (Satpathy et al. 2011).

Climate policy document of all the South Asian countries makes a special mention of attending to concerns of farming community and rural poor as one of the guiding principles of climate policy.

Subsidy has been the main mechanism for mainstreaming adaptation in development programmes.

Policy statement is very elaborate, but the mechanisms to put them into practice are missing. This is particularly true of funding the adaptation programmes.

14.5.2 Post-Green Revolution Policies

The national policies in respect of climate change are reflected in documents on national climate policy, national communications on climate change to United Nations Framework Convention on Climate Change (UNFCCC) and National Action Plan(NCP), which deal with laws, regulations strategies that guide course of action at national and international forums (GoI-PMCCC 2008; GoI-MoEF 2012; GoI-MoWR 2012). The current agricultural development programmes to increase adaptation capacity are: the Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA), Prime Minister Krishi Sinchai Yojana (PMKSY), Rastriya Krishi Vikas Yojana (RKVY) and National Mission on Micro Irrigation (NMMI). These programmes not only help achieve production targets, but also provide livelihood support by generating employment (GoI-MoACFW 2019). The mission on micro-irrigation has made major headway, as micro-irrigation has been implemented in 8.6 million ha by 2017 (NITI Aayog 2015).

As groundwater has become a major source of irrigation, low electricity tariff and price support to water-intensive crops like rice and sugarcane are leading to drying of aquifers. The recent initiative—Atal Bhujal Yojana (GoI-MoJS 2019)—is the corrective action, but it will succeed only if ecologically compliant cropping is introduced. In agriculture, irrigation is a major consumer of energy. Inefficiency in more than 20 million of these agricultural pump sets results in huge wastages of energy, inflates the energy demand and generates additional greenhouse gas emission. The government has initiated a drive for replacement of inefficient agricultural pumps, under Ag. Demand Side Management (AgDSM) programme (BEE 2009).

This is a climate friendly step in right direction. Speeding up and scaling out of this programme would require creation of appropriate business model like the Domestic Efficient Lighting Programme (DELP).

14.6 Concluding Remarks and Way Forward

There are ample opportunities for agricultural systems to adapt to climate change impacts through biophysical and socio-economic interventions. In India, adaptations in agriculture have been largely productivity enhancing biophysical incremental interventions. The effectiveness of incremental adaptations is getting reduced due to the combined effect of climatic and non-climatic stress. It is reported that globally, adaptation to climate change impacts is lagging behind, as against the projected required growth rate of 1.8% in crop yields, to meet the food demands in 2050, it was growing only at the rate of 1.2% (Aggarwal et al. 2019).

It is therefore important that India transits to a new production system that not only targets yield, but also keeps land, water and other resources within safe limits. To achieve this goal, India would have to go for transformative options such as changes in cropping pattern and resource allocation for harmonization of water–energy–food security nexus (Tyagi and Joshi 2019b). But as there are cost and income tradeoffs, carefully crafted policies and institutions (access to technology, finance and markets) have to put in place.

It would require implementation of both biophysical and socio-economic adaptations to take care of the entire set of vulnerabilities. The major non-climatic factors, which constrain adoption, are: credit, risk, information and access to markets. In India, agro-technical adaptation measures dominate the scene. Though a number of socio-economic, safety nets like crop insurance, short-term crop season loans and incentives for organic farming are included in the basket, the coverage is very low.

Transformative adaptation requires higher investment, watersheds and irrigation infrastructure, advanced water technologies and risk transfer instruments. Most adaptations need additional investment, and adoption of technologies lags behind in the absence of investment. This is particularly true of small farms, which have limited capacity for infrastructure development (de Janvry and Sadoulet 2019).

Information and its communication are the basic elements for adaptive actions. Digital technologies have proved their potential in data gathering at fast speed and communicating to the farming community. India has established a good weather advisory service, and there exists a vast network of Krishi Vigyan Kendra, which remain in direct contact with farming community. There is however need to strengthen their capacity through better training and equipment.

Water has now been recognized as a major enabler of adaptation, and this is reflected in the government policies (PMKSY, NMMI, Atal-Bhujal, etc.) in respect of climate change. Adaptation planning under climate change would need information on water resources, and to capture change at micro-scale, monitoring network would have to be intensified. Further, water interconnects agriculture with other sectors, and therefore, it would require better coordination between agriculture, water, energy, industry etc., as adaptation in one sector can impact other sectors. At present, the required level of coordination is missing and needs strengthening for improved governance (Tyagi and Mehta 2018).

Like cross-sector linkages of climate impacts, the impacts of climate policies in one sector affect another sector adversely or positively as water is embedded in most sectors. For example, sectors like biodiversity, forestry, disaster management, etc., are the areas outside agriculture, but the policies in these sectors affect the food security of vulnerable people, both positively and negatively (tradeoffs and conflict situations). Therefore, it is not only the technology, but also the inter-sector risk management and risk reduction that should also be incorporated into adaptation planning in agriculture.

Industry is moving towards fourth-generation technologies, and a similar change may be needed to drive systemic and transformative adaptation in production and production supporting services in agriculture. The new precision agriculture technologies that allow us to maximize yields by controlling different farming variables including soil moisture levels, pest stress, nutrient deficiency, micro-climates etc. Progress in these inputs, energy and cost saving technologies would require steep increase in investment in research.

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