Dryland Agriculture in South Asia: Experiences, Challenges and Opportunities

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1 Introduction

South Asia—comprising eight countries *viz.* Afghanistan, Bangladesh, Bhutan, India, the Maldives, Nepal, Pakistan and Sri Lanka—has a population of about 1.5 billion (22 % of the world's population) is the most populated region in the world but only 4.8 % of the world's total land area (Lal 2006). Among different south Asian countries, India is the largest with about two-thirds of the geographical area and coastline, and nearly three-quarters of the population (Table 1). Its topography includes a variety of mountains, plateaus, dry regions, intervening structural basins and beaches. The elevation varies from the world's highest point, Mount Everest, to the world's lowest, the sea beach. It has about 10,000 km of coastline. The region has a largely tropical monsoon climate with two monsoon systems: the southwest monsoon (June–September) and the northeast monsoon (December–April). The region features large year-to-year variations in rainfall which frequently cause severe floods and droughts over large areas. South Asia has some of the world's largest river systems: the River Indus flows from China to Pakistan, the Ganga stretches for about 2525 km, and the Brahmaputra flows for about 2900 km through Tibet, India and Bangladesh (Sharda 2011). Soil and water are considered the principal natural resources of the South Asian region and the ultimate source of people's livelihood. However, the sustainability of these resources poses a challenge due to land degradation. Soil erosion and landslides are critical environmental hazards in the region.

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Table 1 Profile of South Asia

Particular	Afghanistan	Bangladesh	Bhutan	India	Maldives	Nepal	Pakistan	Sri Lanka
Geographical area (Mha)	65.22	14.85	3.84	328.73	0.03	14.72	79.61	6.56
Land area (Mha)	65.22	13.02	3.84	297.32	0.03	14.34	77.09	6.46
Population (millions)	32.56	168.96	0.74	1251.70	0.39	31.55	199.09	22.05
Coastline (km)	0	580	0	7000	644	0	1046	1340

Source: Central Intelligence Agency (2015)

The region is characterized by diverse climates, and equally-diverse soil and water resources. South Asian economies are agriculture based, so the land constitutes a valuable resource. The region shows extraordinarily diverse landforms due to the diverse climatic regimes, latitudes, altitudes and topography. Afghanistan and Bhutan are mostly rugged with mountains. Bangladesh is mainly flat alluvial plains. India has an upland plain (Deccan Plateau) in the south, a flat to rolling plain along the Ganges, deserts in the west, and the mountainous Himalayas in the north. The topography in Maldives is flat with white sandy beaches. Nepal has the flat river plain of the Ganges in the south, a central hill region and the rugged Himalayas in the north. Pakistan has the flat Indus plain in the east, mountains in the north and northwest, and the Baluchistan plateau in the west. The terrain of Sri Lanka is mostly low, flat to rolling plains with mountains in the south-central interior. Land degradation is one of the biggest problems in South Asia due to water erosion resulting from the steep topography coupled with high-intensity rainfall. Modern methods of agriculture further aggravate the situation, with practices such as overuse of fertilizers and pesticides, excessive irrigation of saline lands, and shifting cultivation. About 50 % of the total land area in South Asia is used for agriculture. Due to the high population pressure on the land, the percentage of agricultural to total land area is much higher in the region than the global average. In South Asia, agricultural land occupies more than 50 % of the land area in Afghanistan, Bangladesh and India and less than 50 % in the other countries (Table 2).

Most of the South Asian region is under rainfed agriculture. Afghanistan, Bhutan and Sri Lanka are predominantly rainfed (≥80 %), as are India and Nepal (60–70 %). Irrigated agriculture predominates in Pakistan (26 %) and Bangladesh (45 %). India, Bangladesh, Pakistan, Nepal and Sri Lanka produce a wide range of agricultural and animal husbandry products. The forest area compared to land area is less than 30 % in all countries except Bhutan where 86 % of the land area is forest. Of the South Asian countries, Pakistan and Afghanistan have the least forest (2.1 %).

The climate in Afghanistan is arid to semiarid. Mountains in Afghanistan cause many variations in climate. More than three-quarters of the annual precipitation (327 mm) is received as snow in the mountain ranges of central Afghanistan. Bangladesh is located in the deltaic plains of river basins and the sea shore. This

Table 2 Natural resources and land use in South Asia

Country	Afghanistan	Bangladesh	Bhutan	India	Maldives	Nepal	Pakistan	Sri Lanka
Agricultural land (% of land area)	58.1	70.1	13.6	60.5	23.3	28.8	35.2	43.5
Rainfed land (% of agricultural land)	94	45	94	63	–	72	26	80
Forest (% of land area)	2.1	11.1	85.5	23.1	3	25.4	2.1	29.4
Average precipitation (mm) per year	327	2666	2200	1083	1972	1500	494	1712
Natural hazards	Earthquakes, floods, droughts	Droughts, cyclones, floods	Violent storms, landslides during rainy season	Droughts, floods, severe thunderstorms, earthquakes	Tsunami, rising sea level	Severe thunderstorms, floods, landslides, drought	Earthquakes, floods	Occasional cyclones and tornadoes
Per capita total renewable water resources (m^3)	2006	7262	105133	1527	–	6662	1240	2394
Electricity production per capita (kWh)	26	251	10176	779	674	109	451	535
Crude oil production bbl/day/million people	60	25	0	607	0	0	299	0

Source: Central Intelligence Agency (2015)
Note: Reference year ranges from 2011–2013 except for rainfed land (2003–2011)
bbl billion barrels, *kWh* kilo watt hour

country has a tropical climate—summer (March to June) is hot and humid while winter (October to March) is mild—the rainy season is (June to October) warm and humid. Annual rainfall is more than 2500 mm. Bhutan has a tropical climate in the southern plains, cool winters and hot summers in the central valleys, and severe winters and cool summers in the Himalayas. Annual precipitation is 2200 mm. The Indian climate varies from tropical in the south to temperate in the north. The annual average precipitation in India is 1083 mm with about 85 % of this rainfall received in 100–120 days (southwest monsoon). The climate in the Maldives is tropical; hot and humid. Annual precipitation is about 2000 mm. The climate in Nepal varies from cool summers and severe winters in the north to subtropical summers and mild winters in the south. Annual precipitation is about 1500 mm. Pakistan's climate is mostly hot, desert with a temperate northwest and arctic north. Annual precipitation is about 500 mm. Sri Lanka is an island nation with a tropical monsoon. Average annual rainfall is around 1700 mm. The northeast monsoon occurs between December and March and the southwest monsoon between June and October.

Most of the South Asian region is under rainfed agriculture, but some regions have been facing challenges regarding drought. Farmers in India, Afghanistan, Bangladesh and Sri Lanka have incurred large losses due to drought. Drought is affecting the economies in general and threatening food security in particular. Floods occur in India, Bangladesh, Pakistan, Nepal and Afghanistan and can cause substantial damage to standing crops. Cyclones and severe thunderstorms cause irrevocable damage to the general life of public as well as to agriculture and livestock. Bangladesh is extremely prone to floods and cyclones. The westernmost and easternmost parts of Bangladesh are prone to drought. About 33 % of India receives less than 750 mm rainfall, and 68 % of the sown area is subject to drought in varying degrees. Floods and cyclones are also frequent in India. The east coast of the country is hit by more cyclones. Sri Lanka has been experiencing drought since the ancient times. An average of 11,000 hectares of paddy land is destroyed every year due to the lack of water in sufficient quantities (Bhaskara Rao 2011). Soil erosion, deforestation, limited freshwater resources, and water pollution are among the major environmental concerns in South Asian countries.

Per capita renewable water resources are highest in Bhutan due to its low population. Bangladesh and Nepal have reasonably good water resources on a per capita basis. Per capita water resources in the remaining five countries range from 1000–2500 m^3 per year. Per capita electricity production (in kWh) is highest in Bhutan on account of the rich water resources, and ranges from 600–800 kWh in India and Maldives, 100–500 kWh in Bangladesh, Nepal, Pakistan and Sri Lanka, and 26 kWh in Afghanistan. Crude oil production per day per million people is highest in India (607 billion barrels (bbl) followed by Pakistan (299 bbl), with the remaining countries at less than 100 bbl.

The South Asian region sustains the world's poorest people; the contribution of this region (by 22 % of world population) to the world's GDP (Gross Domestic Product) is less than 5 %. Agriculture is the main source of livelihood in this region. High agricultural population densities in the south Asia have reduced the amount. The region has a high concentration of poverty and hunger. The Asian Development

Bank estimated that 451 million people in the subcontinent live below their respective national poverty lines (Chand 2010). The region has a 2.62 % share in global income, which is very low. The region is home to 40 % of the world's poor, with 29.5 % of its population living on less than $1 a day (ADB 2009).

The per capita gross national income (GNI) in these countries in 2014 ranged from US$690–5600. The lowest per capita income is in Afghanistan and the highest is in the Maldives. Per capita GNI in India and Pakistan ranged from US$1300–1600. The population density in 2014 was more than 1000 persons per km^2 in the Maldives and Bangladesh, but less than 400 persons per km^2 in the other countries with Bhutan at 19 and Afghanistan at 43. The population growth rate ranged from 0.08 % (Maldives) to 2.32 % (Afghanistan) per annum. The undernourished population was as low as 17 % in Nepal to as high as 30 % in Bangladesh. In 2013, the percentage of the population in poverty ranged from 6.7 % in Sri Lanka to 36.5 % in Afghanistan, with more than 60 % in rural areas in all countries except the Maldives. The infant mortality rate (deaths per 1000 live births) ranged from 20–60 in all countries except Afghanistan (115) and Sri Lanka (8.8). The life expectancy ranged from 67–77 years in all countries except Afghanistan (51 years). The literacy rate is very high in the Maldives (99 %) and Sri Lanka (93 %) but very low in Afghanistan (38 %). The average size of landholding is more than 3 ha in Pakistan but less than 1 ha in Nepal, Sri Lanka and Bangladesh. Unemployment in South Asia ranges from 4 % in Sri Lanka to 46 % in Nepal. The percentage of the labor force engaged in agriculture is highest in Afghanistan (78.6 %) and lowest in the Maldives (15 %). Per capita electricity consumption is less than 100 kWh in Afghanistan and Nepal. Bhutan has the highest per capita consumption of electricity with 2488 kWh. Emissions of carbon dioxide (ton/capita), a greenhouse gas causing climate change and global warming is highest in India (1.7) and lowest in Nepal (0.2).

The dependency on land for livelihoods is rising in South Asian countries (Chand 2010). The study compared agricultural workers per 100 ha of arable land between 1989–90 and 2003–04 and observed a rise in the number of workers per hectare of land in all South Asian countries except Sri Lanka (data not available for Bhutan and the Maldives). Other serious issues in South Asia's agriculture are the heavy dependence on rainfed agriculture and the small size of operational holdings (except Pakistan). The percentage of cropland area under dryland agriculture is 70 % in Afghanistan, 46 % in Bangladesh, 80 % in Bhutan, 66 % in India, 65 % in Nepal, 17 % in Pakistan and 33 % in Sri Lanka. About 60 % of the total arable land in South Asia is under dryland agriculture. About 83 % of the total dryland agricultural area of 129 Mha in South Asia is in India (Lal 2006). Cereals are cultivated in all countries except the Maldives. Rice is a major crop in all countries except the Maldives and Afghanistan.

The area under cereals is about 100 Mha in India, and less than 15 Mha in the other countries. As per the triennium ending (TE) 2013, the cereal yield was highest in Bangladesh (4.38 t/ha) followed by Sri Lanka (3.73 t/ha) and may be explained to a large extent by high fertilizer use. The productivity of cereals was lowest and less than 2 t/ha in Afghanistan. Compared with TE 1993, cereal yield doubled in

Bhutan and the Maldives and increased by 25–70 % in the other countries. In TE 2013, the yield of pulses was more than 1 t/ha in Sri Lanka and Bangladesh and increased from TE 1993 in all countries except Afghanistan by 5–65 %. Access to electricity in rural areas is lowest in Afghanistan (32 %), Bangladesh (49 %) and Bhutan (53 %), but is 100 % in the Maldives. The number of tractors per 100 km^2 of arable land is regarded as an indicator of mechanization in agriculture. India, Pakistan and Nepal have more than 100 tractors per 100 km^2 but Afghanistan, Bangladesh and Bhutan have less than 12. Fertilizer consumption in Afghanistan, Bhutan and Nepal is less than 30 kg/ha of arable land but ranges from 140 to 280 kg/ha in other countries. Livestock plays a key role in agriculture, especially in rainfed agriculture, in minimizing the risk of livelihood and coping with crop failures due to natural hazards. The cattle population per km^2 of land is highest in India (64), Nepal (51) and Pakistan (48) but less than 20 in Afghanistan, Bhutan and Sri Lanka. Similarly, the buffalo population ranges from 35–45 in India, Nepal and Pakistan, but is only 1.4 in Sri Lanka; the goat population is very high in Nepal (315) but very low in Bhutan, Afghanistan and Sri Lanka (<15); and the sheep population is >20 in India and Pakistan and <15 in Bhutan, Afghanistan and Nepal.

The South Asian region has the highest rate of irrigated agriculture (40 % of the cultivated area), but the water resources are becoming stressed due to the increasing population coupled with poor management practices. The mean annual precipitation—1083 mm in India, 2666 mm in Bangladesh, 280 mm in Pakistan, 1500 mm in Nepal, 1712 mm in Sri Lanka, 300 mm in Afghanistan, and 2091 mm in Myanmar—is characterized by high temporal and spatial variability resulting in excess surface water during summer and water shortfalls during winter. Groundwater and surface storage along with efficient utilization of available water resources are of utmost importance for agriculture in South Asian countries (Hasanain et al. 2012). In the last three decades, large irrigation projects have not been viable financially or environmentally, which has led to increased exploitation of groundwater, and increased the share of groundwater in total irrigated area from 50 % two decades ago to 75 %. This has serious consequences for the declining groundwater table.

The eight countries within South Asia are characterized by low volumes of intraregional trade in goods and services. While a quarter of the world's population lives in the region, South Asia accounts for only 3 % of the global gross domestic product (GDP), 1.9 % of world exports, and 1.7 % of the world's foreign direct investment (ADB 2009). Nevertheless, South Asia's economy has grown by an annual average of 6 % in the last ten years. Dominance of small holder (small and marginal farmers) agriculture in South Asia lead to very low marketed surplus ratio (proportion of the produce available with farmer to market after meeting requirements such as family consumption, payment of wages in kind, feed, seed and wastage). Marketed surplus ratio is bound to be negligible with the livelihood options the farmer is left with.. The export performance of the region was credible during the pre- World Trade Organization (WTO) period. Growth rates during the implementation period, 1995–2000, declined sharply (−0.54 %). The entire post-WTO period, 1995–2003, had an average growth of 1.82 % compared with almost 8.00 % pre-WTO export. Imports to South Asia as a whole increased by 11 % in the pre-WTO period. The imports growth rate in WTO implementation period (1995–2000) was 2.38 % whereas entire post-WTO period (1995–2003) recorded a growth rate of 4.73 %. The 'lack of trade balance, therefore, hurt the region due to the unanticipated and extraordinary decline in commodity prices. Consequently, exports declined and imports spiraled, which adversely affected farmer incomes (George 2005).

2 Technological Developments: Experiences

Rural livelihood systems in dryland areas have, by persisting over several decades, demonstrated a resilience which runs counter to some predictions of imminent, irreversible degradation or collapse (Mortimore et al. 2000). The potential for technically-based interventions varies across South Asian countries. For example, in India, a diverse bank of proven technologies for dryland farming and conservation has grown over eight decades due to a massive investment in research. Research in dryland agriculture in India began in the 1930s. During the 1950s, the research focused on soil management and water conservation including bunding, terracing, gully plugging and check dams along with improved agronomic practices such as deep plowing, early sowing, improved varieties and crop rotations, optimum crop stands and weed control. Location-specific technologies—including *in-situ* moisture conservation, rainwater harvesting in farm ponds and its efficient utilization, integrated nutrient management modules, foliar sprays for drought mitigation, resilient crops and cropping systems, seed priming, improved sowing methods and contingency crop plans—have been developed by different research organizations including the Central Research Institute for Dryland Agriculture (CRIDA) to improve the productivity and profitability of dryland systems (Srinivasarao et al. 2014d).

2.1 Natural Resources Management

The management of natural resources in dryland areas is important not only because the livelihoods of millions of rural poor (>500 million) are directly connected to these areas but also because these areas will continue to play a crucial role in determining food security for the growing population and in reducing poverty in the coming decades (Rockstrom et al. 2007). Enhancing the efficiency and sustainability of natural resource management (NRM) projects in these areas is a universal challenge faced by concerned stakeholders.

2.1.1 Water

Rainwater management is a critical component of rainfed farming; the successful production of crops largely depends on how efficiently soil moisture is conserved *in-situ* and how the surplus runoff is harvested, recharged, stored and reused for supplemental irrigation (Rao et al. 2010; Srinivasarao et al. 2013a). Dryland areas receive an annual rainfall of less than 750 mm and experience more frequent water scarcity events during summer, in years with deficient monsoon rainfall, and during drought years. In these regions, agriculture is the prime source of income for local inhabitants and the major constraints to agricultural production is the availability of water during dry spells and a shortage of drinking water due to the declining groundwater table. The seasonal distribution of rainfall and temperature affects crop water requirements and hence the soil and water conservation interventions needed (Murty and Jha 2011). The adoption of *in-situ* and *ex-situ* soil and water conservation techniques is essential for arid, semiarid and rainfed regions due to the erratic nature of monsoon rainfall (Rejani et al. 2015b). These interventions need to be based on the runoff potential and resulting soil loss.

In-situ soil and water conservation techniques based on soil loss (Reddy et al. 2005; Rejani et al. 2016a); soil, rainfall and slope of the land (Reddy et al. 2005; Pathak et al. 2009; Srivastava et al. 2010); slope and soil depth (Kalgapurkar et al. 2012); and precipitation, slope, soil depth, texture, salinity, land use, land cover and geological information (De Pauw et al. 2008) have been reported. The major *in-situ* soil and water conservations interventions planned for dryland regions are agronomic measures such as contour cultivation, strip cropping, proper crop rotations, tillage practices, mulching, planting of grasses for stabilizing bunds, and deep plowing in black soils once every three years to reduce soil losses (Table 3).

An important strategy to enhance the infiltration rate of water into the soil during the 1970s was deep tillage because traditional tillage using the wooden plow (non-inverting plow) was usually less than 10-cm deep (Vittal et al. 1983). In addition to crop yield, deep plowing improved porosity, infiltration and available water capacity, and reduced runoff and erosion. In dryland areas, water harvesting and storage in farm ponds, which is then used for supplementary irrigation of crops using efficient water application methods like drip and sprinkler irrigation, can substantially increase crop productivity (Murty and Jha 2011; Srinivasarao et al. 2014a). In non-arable lands with black soils, graded bunds with waterways, farm ponds, gully stabilization structures like check dams, gabion structures and horticultural crops such as pomegranate (*Punica granatum* L.), amla (*Phyllanthus emblica* L.) and guava (*Psidium guajava* L.) are recommended (Reddy et al. 2005). In non-arable areas, soil conservation measures such as contours or staggered trenching on foothills, plugging of stream courses, gabion structures and check dams are preferred (Reddy et al. 2005). The selection of suitable structures mentioned above for a specific location and its optimal spacing for drainage line treatments are key factors for the effective and economic control of sedimentation and runoff (Kadam et al. 2012; Rejani et al. 2016b). Since the implementation of drainage line treatments is expensive, site selection and construction need precision. The literature on site selection procedures for water harvesting structures considers slope, runoff, watershed area, stream order and socioeconomic aspects (IMSD 1995; Geetha et al. 2007). Researchers have used remote sensing and geographical information systems (GIS) to find suitable locations for rainwater harvesting structures (Chowdary et al. 2009; Ramakrishnan et al. 2008, 2009; Shanwad et al. 2011; Rejani et al. 2016b).

Table 3 Location-specific *in-situ* moisture conservations practices in different countries

Country	*In-situ* moisture conservation practices	References
Afghanistan	Organic and inorganic mulches for three ecoregions of Afghanistan: lowland (900–1300 m), upland (1300–2400 m) and mountains (above 2400 m)	Bhuchar et al. (2016)
	Pit composting suitable for all three ecoregions: pit composting, conservation tillage.	Virgo et al. (2006)
	Low and upland regions: vermicomposting.	
	Lower slopes: water harvesting bunds.	
	Simple contour plowing would reduce erosion and retain moisture.	
Bangladesh	Plantation along contours, mulching, zero tillage with surface mulching	Uddin and Saheed (2016)
Bhutan	*In-situ* management practices include multiple cropping, cover crops, intercropping, strip cropping, mulching using crop residue and organic matter, terracing and planting of fodder trees and grasses, terraced wetland with bunds for rice cultivation, stone bunds along contour lines	Katwal (2010)
India	Arid regions (rainfall <500 mm): contour farming / cultivation, conservation furrows, mulching, deep plowing and inter-row water conservation systems.	NRAA (2009)
	Semiarid regions (500–1000 mm): conservation furrows, contour farming, compartmental bunding, runoff strips, tied ridges, graded ridging, mulching, live hedges, ridge and furrow system, off-season tillage on conserved soil moisture, broad beds and furrows, graded border strips.	
	Subhumid regions (>1000 mm): field bunds, graded bunds, vegetative bunds, level/graded terraces, contour trenches, inter-plot water harvesting, raised bed and sunken system.	
Maldives	Traditional farming systems are based on shifting agriculture, polycultural home gardens, agroforestry and taro pits. Improved agricultural practices include crop rotation, intercropping, composting, irrigation.	FAO (2016)
Nepal	Contour bunding	Tamang (2016)
	Crop rotation using legumes, traditional plowing	Pokhrel and Pokhrel (2013)
	Zero/minimum tillage for rice–wheat system	Hobbs and Giri (1997)
	Application of farmyard manure and rice stubble left in field	
Pakistan	Terracing, contouring, strip cropping, construction of soil and water conservation structures, contour planting, hedgerows, living fences and barriers.	Baig et al. (2013)
	Improved tillage practices include conservation tillage, mulches, addition of crop residues such as wheat straw, cover crops including nitrogen-fixing legumes	
	Zero tillage for rice–wheat and cotton–wheat systems, gully land management for degraded lands, conservation tillage, stubble mulch, trash farming, strip tillage.	Zia et al. (2004)
	On steep sloping lands, stone bench terraces in cultivated areas, and installation of water disposal system with grass waterways and water drop structures.	

(continued)

Table 3 (continued)

Country	*In-situ* moisture conservation practices	References
Sri Lanka	Conservation bunds and drains, vegetative measures such as glyricidia, vetiver or citronella hedges to control soil erosion and restore degraded lands	Dharmasena (2003)
	Orchard or eyebrow terraces and sand pits (modified terrace system) for shallow soils with steep slopes	Wijayaratna and Weerakoon (1996)
	Graded bunds, drains and stabilization of bunds in undulated or rolling dry zones; bund stabilization by vegetative means (Vetiver grass).	Somasiri et al. (1990)
	Application of organic matter increases the waterholding capacity of soil.	
	Shade management using glyricida (hedge row cultivation) and roof water harvesting.	

Under the Technology Demonstration Component (TDC) of the National Innovations on Climate Resilient Agriculture (NICRA), farm ponds are considered a key intervention to cope with climate variability (Fig. 1). Various cropping system modules have been developed using harvested water. Most farmers opted to cultivate vegetables with harvested water in a ratio of 1:10 (command to catchment area) with sustained profits (Prasad et al. 2014).

Watershed management could be a key strategy to unlock rainfed production potential. An integrated watershed management approach shows promise in the sustainable development of land and water resources. Watershed development projects are designed to harmonize the use of water, soil, forest and pasture resources while raising agricultural productivity by conserving moisture in the soil and increasing irrigation through tank- and aquifer-based water harvesting. Of the rainfed cropped area in India, it is estimated that 15 Mha is in arid regions with less than 500 mm of annual rainfall, 15 Mha is in the 500–700 mm rainfall zone, 42 Mha is in the 750–1100 mm rainfall zone and 20 Mha receives more than 1150 mm. A single supplemental irrigation of 100 mm in a rainfed area of 27.5 Mha increased annual production of food grains by about 9.3 Mt (Sharma et al. 2010). Significant production improvements could be realized in cotton (*Gossypium* spp.), sesame (*Sesamum indicum* L.), groundnut (*Arachis hypogaea* L.), soybean (*Glycine max* L. Merrill) and chickpea (*Cicer arietinum* L.) (Sharma 2011). On a regional basis, collecting small amounts of runoff using macro-catchments during the rainy season for supplementary irrigation can improve agricultural production in rainfed areas (Molden 2007) by more than 50 % (Sharma 2010). The theory of water pricing, and improved water use efficiency, are also better technical solutions. In many northern states of India like Uttar Pradesh, Punjab and Haryana, the conjunctive use of surface water and groundwater has been practiced using canal systems and tube or dug wells to increase crop yields and the efficiency of the water system (Frenken 2011). In recent years, water-saving technologies like sprinkler and drip irrigation have been used.

In Pakistan, 90 % of the country's food grain production comes from rice (*Oryza sativa* L.) and wheat (*Triticum* spp.). Key resource conservation technologies

Fig. 1 HDPE-lined farm pond at Namakkal, Tamil Nadu

include zero tillage, direct seeding, parachute transplanting, bed planting, laser land leveling and crop residue management (PARC-RWC 2003; Ahmad et al. 2007). Resource conservation technologies (RCTs) in Pakistan have improved the field irrigation efficiency (Gupta et al. 2002; Humphreys et al. 2005) and saved water. However, the water-saving impacts of RCTs beyond the field level are not well documented. It is possible that real water savings are much lower than assumed when field-level calculations are extrapolated to broader scales (Ahmad et al. 2007).

In Sri Lanka, policymakers have focused on alleviating seasonal water scarcity in the dry zone using large-scale storage tanks and inter-basin transfers (Ariyabandu 2008). An unlined rooftop rainwater harvesting (RRWH) pond concept is practiced by the poorest rainfed farmers living in the more vulnerable and marginal areas of Sri Lanka. Farmers realized that household food security increased using RRWH and that there was an indirect impact on the local microenvironment around the system, particularly the survival of vegetation during dry spells. In general, a sensitivity analysis under various scenarios indicated that RRWH pond investment was economically viable under the given circumstances (Bandara and Aheeyar 2010).

In Nepal, community management of watersheds and water systems has been popular (Pretty 2003). Many irrigation systems use surface irrigation methods such as basins and furrows, and limited areas in the hills and mountains use sprinkler irrigation. In Nepal, there are public irrigation systems and farmer-managed irrigation systems (FMIS); in 2008, 70 % of the irrigated area was under FMIS. In non-FMIS areas, some systems are managed by Water User Associations (WUAs), while others are jointly managed by the government and WUAs. Farmer- and community-managed systems are more efficiently managed than government-managed systems (Frenken 2011); however, the government plays a crucial role in research and development, extension services, and other regulatory fiscal and non-fiscal mechanisms. Government assistance in the rehabilitation and repair of irrigation systems is essential to sustain farmer-managed systems (MOIR 2005).

2.1.2 Soils

As with the climates, the soils of South Asia are equally diverse (Lal 2006). The predominant soils are Alfisols and Vertisols in the semiarid regions, Inceptisols and Entisols in the alluvial plains of the main river systems, and Aridisols in the arid regions or desert climates. In terms of land area, Entisols (169 Mha) > Aridisols (122 Mha) > Inceptisols (95 Mha) > Alfisols (79 Mha) > Vertisols (60 Mha) > Ultisols (42 Mha), Mollisols (19 Mha), and others. Challenges persist in the alleviation of soil physical constraints such as crusting, compaction and hard setting which lead to high runoff, erosion, frequent drought stress and low soil fertility.

Soil organic carbon, which is the seat of major soil processes and functions, is <5 g/kg in rainfed soils of India, while the desired level is 11 g/kg. Maintaining or improving soil organic matter is a prerequisite for ensuring soil quality, productivity and sustainability. Srinivasarao et al. (2013b) summarized the results of several long-term manure experiments conducted under rainfed conditions. In a groundnut-based system, the highest soil organic carbon (SOC) stock (t/ha) was found with applicastion of 50 % recommended dose of fertilizer (RDF) + 4 t/ha groundnut shells (47.2) followed by 100 % RDF (36.2) and the control (32.2). In finger millet (*Eleusine coracana* L.) monocropping, the profile SOC stock (t/ha) was the highest in the Farmyard manure (FYM) 10 t/ha + 100 % NPK (85.7) followed by 100 % NPK and control (63.5) treatments. In the groundnut–finger millet rotation, the SOC stock (t/ha) was the highest in the FYM + 100 % NPK (73.0) and lowest in control (51.7) treatments. Sorghum (*Sorghum bicolor* L. Moench) had the highest SOC stock (t/ha) in the 25 kg N (crop residue) + 25 kg N Subabul (*Leucaena*) (68.5) followed by 25 kg N (crop residue) + 25 kg N (urea) N (65.8), and the control (49.0). In the pearl millet (*Pennisetum glaucum* (L.) R.Br.) system, the profile SOC stock (t/ha) was the highest in 50 % recommended dose of nitrogen (RDN) (fertilizer) + 50 % RDN (FYM) (25.5) followed by 50 % RDN (FYM) (23.4) and the control (17.9). On-farm generation of organic matter with appropriate policy support needs to be promoted to maintain soil health and crop productivity (Srinivasarao et al. 2014b).

Soils in most parts of India are not only deficient in NPK but also in secondary nutrients (S, Ca). Magnesium (Mg) deficiency is also prevalent in many rainfed areas. A study done by CRIDA across diverse agroecological regions highlighted the extent of Mg levels in major Indian soil types and recommended further attention on Mg nutrition in current intensive agriculture (Srinivasarao et al. 2015a) and micronutrients (e.g., B, Zn, Cu, Fe, Mn). Balanced nutrient application to crops based on the nutrient requirement to produce a unit quantity of yield and the native nutrient supplying capacity of the soil, improves crop yields while minimizing nutrient losses and cultivation costs. In Andhra Pradesh and Telangana (states of India), eight districts addressed nutrient deficiencies within farmers' fields using balanced nutrition, with promising results. For example, in Warangal, balanced nutrition significantly improved cotton yields in many farmers' fields by 10–25 %, reaching up to 1.6 t/ha (Srinivasarao 2011).

Community tanks in peninsular India collect and store rainwater, as well as the nutrient-rich topsoil, eroded from catchment areas. Analysis of tank silt collected from several tanks in 100 districts identified the potential of tank silt for supplying organic carbon and several nutrients to improve soil health. Tank silt application in degraded Alfisols of Telangana improved yields in maize (*Zea mays* L.) and castor (*Ricinus communis* L.) as well as soil physical, chemical and biological properties.

Sodic soils occupy 3.6 Mha in India (Bhargava 1989). The establishment of permanent tree cover with suitable salt-tolerant species is an important option for the reclamation of such soils (Gill and Abrol 1991; Garg and Jain 1992). Of the fuelwood species evaluated, mesquite (*Prosopis juliflora* Sw. DC.) is reportedly the most widely-adapted to alkaline soils and produces the most biomass (Singh 1989). Egyptian pea (*Sesbania sesban* L. Merr.) and salt cedar (*Tamarix dioica* Roxb. ex Roth.) also exhibit good adaptability. Growing salt-tolerant woody species like *Prosopis juliflora*, babul (*Acacia nilotica* L. Del.), casuarina (*Casuarina equisetifolia* J. R. & G. Forst.), athel tamarisk *(Tamarix articulata* Vahl.) and sprangle top *(Leptochloa fusca* L. Kunth.) improve the quality of salt-affected soils (Singh et al. 1994). Some grasses are also useful for reclaiming sodic soils (Gupta et al. 1990), especially when grown in association with trees. Salt-tolerant trees and forage species are valuable for reclaiming sodic soils in Pakistan (Qadir et al. 1996). In addition to improving structural properties, trees affect the salt balance by increasing the depth of the water table leading to a net downward leaching. Similarly, bioremediation of sodic soils by the silvopastoral system is economically and ecologically feasible (Singh et al. 1998; Kaur et al. 2002).

Soil erosion is a major problem on the 82 Mha affected by water erosion and 59 Mha affected by wind erosion in South Asia. Afforestation, reforestation, reducing deforestation, and controlling grazing on steep land prone to erosion are needed to reverse the degradation trends of erosion. Establishing forest plantations of *Eucalyptus* spp., subabul *(Leucaena leucocephala* Lam. de Wit), casuarina (*Casuarina equisetifolia* J. R. & G. Forst.), *Prosopis* spp., teak (*Tectona grandis* L. f.), sissoo (*Dalbergia sissoo* Roxb. ex DC.), etc has numerous benefits including reductions in soil erosion and nonpoint-source pollution. Other important biological measures include establishing contour hedges of perennial grasses (e.g., vetiver or *Vetiveria zizanioides* L.) Nash ex Small; NRC 1993; Prasad et al. 2003) and shrubs, buffer strips, riparian zones (Ranada et al. 1997), and converting marginal lands to restorative uses through afforestation and nature reserves.

2.2 Farming Systems

The term 'farming system' refers to a particular arrangement of farming enterprises that is managed in response to physical, biological and socioeconomic environments in accordance with farmers' goals, preferences and resources (Shaner et al.

1982). “The household, its resources and the resource flows and interactions at the individual farm levels are together referred to as a farm system” (FAO 2001). A common characteristic of integrated farming systems is that they invariably have a combination of crop and livestock enterprises and, in some cases, may include combinations of poultry, agroforestry, horticulture, apiary, etc. Further, there are synergies and complementarities between different enterprises that form the basis of the concept of Integrated farming system (IFS) (Lightfoot and Minnick 1991; Jitsanguan 2001; Radhammani et al. 2003). Integration usually occurs when outputs (usually by-products) of one enterprise are used as inputs by another within the context of the farming system. The difference between mixed farming and integrated farming is that enterprises in the integrated farming system are mutually supportive and depend on each other (Csavas 1992). The synergy between enterprises increases with on-farm diversity and is fundamental to the IFS concept. Diversification of farming activities improves the utilization of labor, reduces unemployment in areas where there is a surplus of underutilized labor, and provides a source of living for those households that operate their farms as a full-time occupation.

In South Asia, annual crops, perennial tree crops, ruminants and non-ruminants are maintained in integrated farming systems. However, on the small farms, ruminants are more widely reared than non-ruminants. More than 90 % of the total population of large and small ruminants is kept on mixed farms in the South Asian region (Devendra 1983). In rainfed annual cropping systems, ruminants graze native grasses and weeds on roadside verges, on common property resources, or in stubble after the crop harvest. In India, in regions with 500–700 mm of rainfall, farming systems should be based on livestock with the promotion of low-water-requiring grasses, trees and bushes to meet fodder, fuel and timber requirements of the farmers (Vittal et al. 2003). In 700–1100 mm rainfall regions, crop, horticulture and livestock-based farming systems can be adopted depending on the soil type and the marketability factors. Runoff harvesting is a major component in this region in the watershed-based farming system. In areas where the rainfall is more than 1100 mm, the IFS module integrating paddy with fisheries is ideal (Fig. 2). There are several modules of rainfed rice cultivation, along with fisheries, in the medium to lowlands of rainfed rice-growing regions in the eastern states of India.

There are few examples of improved pastures being used in these systems; in Sri Lanka, integrated perennial-tree-crop–animal systems include coconut/fruits/cattle/goats, where the ruminants graze the understorey of native vegetation or leguminous cover crops. However, these systems can evolve into more intensive production systems depending on the availability of feed, markets, and the development of cooperative movements. This is evident in South Asia, e.g. Bangladesh, where root crops are produced, and pig production is based on cassava and sweet potato (Devendra and Thomas 2002). Rearing livestock such as small and large ruminants at home by transitory vulnerable-category communities for different livestock products has been a traditional activity in rainfed Pothwar areas of Pakistan; also an important means to fulfill the livelihood requirements of people below the poverty line (Zahra et al. 2014). Range-based small ruminant production is the major activity in the area coupled with rainfed agriculture. Sheep and goats are the main live-

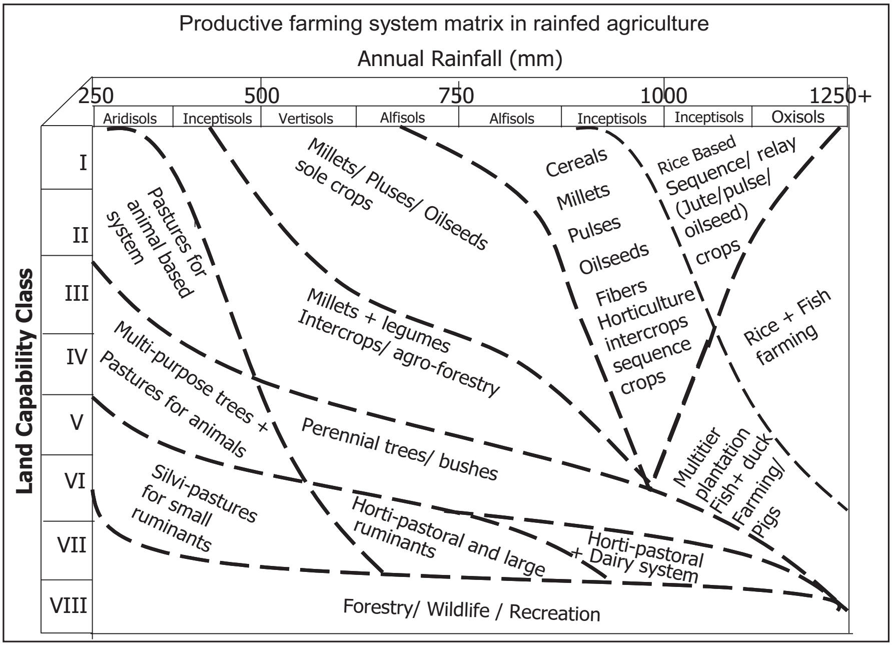

Fig. 2 Productive farming system matrix in rainfed agriculture in India

stock of the province. In Baluchistan approximately 87 % of the people directly or indirectly drive their livelihood from livestock rearing (Heymell 1989).

Farmers in the drought-prone areas of the Gulmi District of Nepal grow drought-resistant crops like elephant foot yam (*Amorphophallus paeoniifolius (*Dennst.) Nicolson), taro (*Colocasia spp* (L.) Schott), cassava (*Manihot esculenta* Crantz), winter bean (*Vicia faba* L.), air potato (*Dioscorea bulbifera* L.), cush-cush yam (*Dioscorea trifida* L.f.) and brinjal (*Solanum melongena* L.). Similarly, in the marginal areas in the dryland Gulmi District, farmers grow cassava, winter bean, elephant foot yam, taro, sugarcane (*Saccharum officinarum* L.), turmeric (*Curcuma longa* L.), ivy gourd (*Coccinia grandis* (L.) Voigt) and legumes (Regmi et al. 2009).

Based on an ex-post facto study involving 120 farmers, Desai et al. (2009) identified the most economical rainfed farming system models for Andhra Pradesh, Karnataka and Tamil Nadu states in India (Table 4). They observed the prevalence of different farming systems across farm sizes and states. The major components of the farming systems were cereal crops, oilseeds, vegetables, fruits, bovines and caprines.

The inclusion of perennial components like trees and grasses in dryland farming systems imparts stability to farming by reducing the effect of yearly variations in rainfall on these components, protecting the crops from water and wind erosion, and improving soil fertility. The returns in arid/dryland ecosystems are much higher when trees are associated with crops/grasses in silvi-pasture, agri-horti and agroforestry systems. In addition to the economic benefits, tree-based systems improve soil

Table 4 Farming systems providing higher economic returns in different rainfed regions of India

State	Farm size			
	Marginal	Small	Medium	Large
Andhra Pradesh	Maize–paddy–caprine (Rs. 14,334)	Castor–maize–bovine (Rs. 18,625)	Castor–paddy–bovine (Rs. 28,581)	Maize–paddy–pulses (Rs. 18,886)
Karnataka	Pulses–bovine (Rs. 13,180)	Bajra–pulses–groundnut–bovine (Rs. 17,690)	Sorghum–pulses–sugarcane–bovine (Rs. 16,280)	Pulses–banana (*Musa* spp. L.)–sugarcane–bovine (Rs. 1,74,105)
Tamil Nadu	Paddy–sorghum–onion (*Allium cepa* L.)–bovine–poultry (Rs. 30,082)	Groundnut–sesame–onion–bovine–caprine (Rs. 19,490)	Paddy–sesame–vegetables–bovine–caprine (Rs. 23,500)	Paddy–sesame–groundnut–bovine–caprine (Rs. 29,058)

Source: Adapted from Desai et al. (2009)

fertility through the build-up of organic matter and nutrients in the soil. Studies have found that multiple-use species such as bamboo (*Bambusa nutans* Wall.ex Munro) have the potential to help bind soil nutrients during the restoration of abandoned shifting agricultural lands (*jhum* fallows) in northeastern India (Arunachalam and Arunachalam 2002). Shelterbelts or windbreaks with *Eucalyptus* spp. in farm bunds or the borders of farm land can save crops from the desiccating effects of the wind in dry and sandy areas of dryland Mastung of Balochistan (Mohammad and Ehrenreich 1993). Planting shelter belts and windbreaks can enhance agricultural crop yields in these areas (Mohammad and Ehrenreich 1993). In this area, Rehman (1978) reported increased wheat yields of 8, 15 and 14 % with one row of French Tamarisk (*Tamarix gallica* L.), two rows of French Tamarisk + Giant Reed (*Arundo donax* L.) and three row shelterbelt of French Tamarisk + Giant Reed + Phog (*Colligonum polygonoides* L.), respectively. Soil moisture in this study in the 0–150 mm layer in the plots protected by the belts was consistently 26 % higher than in the unprotected plots.

Perennial grass components, besides imparting stability to farming systems in dryland areas, also act as vegetative filter strips to prevent wind and water erosion. Some important tree species which are compatible with the grass component for silvi-pasture are siris (*Albizia lebbeck* L. Benth.), desert teak (*Tecomella undulate* L.), mopane (*Colophospermum mopane* J. Kirk ex Benth. J. Leonard), gum Arabic tree (*Acacia senegal* L. Willd), umbrella thorn (*Acacia tortilis* Forssk.), jujube (*Zizyphus nummularia* Burm. F. Wight & Arn.) and wild jujube (*Zizyphus rotundifolia* Mill.). Of the pasture legumes, blue pea (*Clitorea ternatea* L.) and Indian bean (*Lablab purpureus* L.) are compatibile with sewan grass (*Lasiurus sindicus* Henr.) and buffel grass (*Cenchrus ciliaris* Linn.) (Samra 2004). Promising multipurpose trees, fruits, crops and grasses for various agroforestry systems in dryland areas of arid and semiarid regions in India are summarized in Table 5.

Table 5 Promising plant species for dryland systems in India

Country	Zone	System	Promising species		
			Forestry plants	Fruit plants	Crops/grasses/shrubs
India	Arid	Agri-silviculture[a]	Khejri (*Prosopis cineraria* L. Druce.), Desert Teak, Anjan (*Hardiwickia binata* Roxb.) and Wild Jujube	Indian Plum (*Ziziphus mauritiana* Lamk.) and Date Palm (*Phoenix dactylifera* L.)	Crops: Mung bean (*Vigna radiata*), Moth bean (*Vigna aconitifolia* Jacq) Marechal), Cowpea (*Vigna unguiculata* L. Walp), Cluster bean (*Cyamopsis tetragonoloba* L. Taub), Pearl millet and Sesame
		Silvi-pasture[a]	Mopane, Jujube and Anjan	Caper (*Capparis decidua* Forssk. Edgew), Indian Plum and Khejri	Grasses: Buffel grass,irdwood grass (*Cenchrus setigerus* Vahl.) Sewan grass and Marvel grass (*Dicanthium annulatum* Forsk. Stapf.)
		Shelterbelts[a]	Umbrella thorn, Kassod tree (*Cassia siamea* Lamarck Irwin et Barneby), Mesquite, Siris and Neem (*Azadirachta indica* A. Juss.)	–	–
	Semiarid	Agri-silviculture[a]	Babul, Tree of Heaven (*Ailanthus excelsa* Roxb.), Sissoo, Khejri, Cottonwood (*Populus deltoides* Bartr.) and Anjan	Indian plum, Mango (*Mangifera indica* L.), Guava, Citrus, Amla and Bael (*Aegle marmelos* L. Correa)	Crops: Pearl millet, Sorghum, Cluster bean, Pigeon pea, Cowpea, Mung bean, Sesame and Groundnut
		Silvi-pasture[a]	Babul, Sissoo, Khejri and White Bark Acacia (*Acacia leucophloea* Roxb. Willd.)	–	Seasonal grasses: Rat's tail grass (*Sehima nervosum* Rottl. Stapf.), Blue Panic grass (*Panicum antidotale* Retz.) and Buffel grass
		Farm boundary[a]	Babul, *Eucalyptus* spp. Cottonwood, Butter tree (*Madhuca latifolia* Roxb.) and Sissoo	–	–

(continued)

Table 5 (continued)

Country	Zone	System	Promising species		
			Forestry plants	Fruit plants	Crops/grasses/shrubs
Pakistan	Arid	Silvi-pasture[b,c]	Khejri, Toothbrush tree (*Salvadora oleoides* Decne.), Tamarisk (*Tamarix aphylla* L. Karsten.), Desert teak Babul, gum Arabic tree, Baonli (*Acacia jacquemontii*). Mulga (*Acacia aneura* F. Muell. ex. Benth.), *Acacia victoriae* Benth. sens lat. and Meswak (*Salvadora persica* L.)	–	Shrubs: Phog, Giant milkweed (*Calotropis procera* Ait. Ait. f.), Khereit (*Salsola foetida* Del.ex Spreng.) and *Haloxylon* spp.
					Grasses: Lemongrass (*Cymbopogon* spp.) and Sabth grass (*Pennisetum divisum*)
	Arid to semiarid	Silvi-pasture[b,c]	Babul, Khejri, Toothbrush tree, Tamarisk, Indian plum, Jujube, Indian Mulberry (*Morus alba* L.), Siris, Phulai (*Acacia modesta*), *Acacia victoriae* Benth. sens lat., Mulga, Desert teak and Baonli		Shrubs: Phog, Salt cedar, Giant milkweed and Jujube
					Grasses: Wiregrass (*Eleusine compressa*), Sewan grass, Sugarcane and Blue Panic grass
		Rainfed farm boundary[d]	*Populus euramericana* and River Red Gum (*Eucalyptus camaldulensis* Dehnh.)		
		Agri-silviculture[e]	*Populus euramericana*, Cottonwood, Varnish tree (*Ailanthus altisima* Mill. Swingle) and River red gum		Crops: Wheat, Maize, Sugarcane and different vegetables
		Agrosilvopastoral system[f]	Phulai, Mulberry (*Morus nigra* L.) and Sissoo	Jujube	Shrubs: Egyptian pea, Subabul and *Acacia* spp.
					Grasses: Native species

Sri Lanka	Low country dry zone	Live fences[g]	Hill mango (*Commiphora caudata* Wight & Arn.), Portia tree (*Thespesia populnea* L. Soland. ex Correa), White gul mohur (*Delonix elata* L. Gamble), Gliricidia, Aal (*Morinda coreia* Buch. Ham), Drumstick (*Moringa oleifera* Lam.), Subabul, Teak, Neem, Indian balm of gilead (*Commiphora berryi* Arn.) and Indian Labernum (*Erythrina indica* Lam.)	Custard apple (*Annona squamosa* L.), Betelnut palm (*Areca catechu* L.), Jack fruit (*Artocarpus heterophyllus* Lam.), Palmyra (*Borassus flabellifer* L.), Papaya (*Carica papaya* L.), Coconut (*Cocos nucifera* L.), Indian wood-apple (*Limonia acidissima* L.), Mango, Cassava, Wild date palm (*Phoenix sylvestris* Roxb.), Guava, Indian blackberry (*Syzygium cumini* L.) and Tamarind tree (*Tamarindus indica* L.)	Shrubs: China rose (*Hibiscus rosa-sinensis* L.), Gunja (*Lannea grandis* (Dennst.) Engl.) Wild sage (*Lantana camara* L.), Castor (*Ricinus communis* L.), Crepe jasmine (*Tabernaemontana divaricata* R.Br. Ex Roem. & Schult.) and Yellow oleander (*Thevetia peruviana* (Pers). K Shum)
		Home gardens[h]	Neem, Cashew (*Anacardium occidentale* L.) and Coconut		
Bang-ladesh	Dryland	Traditional home gardens[i]	Neem, Big leaf mahogany (*Swietenia macrophylla* King.), River red gum and Teak	*Ficus* spp., Monkey jack (*Artocarpus lakoocha* Roxb.), Jack fruit, Drumstick, Indian blackberry, Guava, Wild date palm, Palmyra, Coconut, Pomegranate, Indian plum, Kadam (*Anthocephalus cadamba* Roxb. Miq.) and Bael	

Source: [a]Venkateswarlu (2004); [b]Rahim and Hasnain (2010); [c]Gintings and Lait (1994; [d]Ali et al. (2011); [e]Subhan (1990); [f]Amin (1987); [g]Jayavanan et al. (2014); [h]Mattsson et al. (2015); [i]Mustafa and Haruni (2002)

The hilly terrain of the North-Eastern Hill (NEH) region of India is suitable for sustainable multi-enterprise systems. As an alternative to shifting cultivation in NEH, Satapathy (2003) suggested using watershed-based farming systems that involve appropriate soil conservation measures, mixed land use of agri-horti-silvi-pastoral systems, a subsidiary source of income through livestock rearing, and the creation of water harvesting and silt retention structures at lower reaches. Economic analysis of different micro-watershed-based farming systems namely dairy farming, agro-pastoral and agri-horti-silvi-pastoral systems have shown the economic viability of these systems as an alternative to shifting cultivation.

Coastal areas offer tremendous opportunities if proper strategies are adopted using well-focused action plans under an integrated farming systems approach so that agriculture will be more productive, profitable, sustainable, competitive and ecofriendly. In these regions, land holdings are small and fragmented, operational resources are scarce, and rice continues to be the major crop. The rice-based farming system is the single most important source of income and employment for most of the people in this tract and is a viable option for meeting their livelihood requirements. Rice-based farming systems such as rice + fish, rice + duck, rice + fish + duck, rice + fish + *Azolla,* rice + fish + poultry/duck + vegetables + fruits + agroforestry are practiced particularly in the rainfed lowlands of coastal areas (Nanda and Garnayak 2010).

2.3 Institutional Mechanisms

Institutions play a major role in agricultural development along with other resources like technology, capital and enterprise. In small producer-dominated situations like Indian agriculture, the role of institutions becomes more crucial as there are structural- and enterprise-specific constraints like high transaction costs, lack of market integration, and interlocking of factor and output markets which only institutions and organizations can tackle effectively. Institutions help small farmers by reducing transaction costs, managing or reducing risk, building social capital, enabling collective action, and/or readdressing missing markets (Singh 2013a, b). Institutional innovation occurs when there is a "change of policies, standards, regulations, processes, agreements, models, ways of organizing, institutional practices, or relationships with other organizations" so as to "create a more dynamic environment that encourages improvements in the performance of an institutions or system to make it more interactive and competitive" (IICA 2014). Institutional innovations needed for agricultural transformation in South Asia are distinct due in part to the unique nature of the sector. Most farmers are resource-poor, face diverse challenges particularly under dryland ecosystems, and have specific needs that must be addressed.

Timely access to farm machinery for sowing, harvesting, etc. is a major component of any adaptation strategy to deal with climatic variability. The sowing window in rainfed areas is mostly very short and access to farm machinery is poor for smallholder farmers. As a result, many farmers are not able to sow the crop in a timely fashion and incur significant yield losses. In India, an innovative institutional arrangement in the form of a Custom Hiring Center (CHC) for farm machinery has been created in 100 selected villages in 100 districts. Farm implements and machines available to hire include ferti-seed drills, zero-till drills, power weeders, harvesters, threshers, power tillers, sprayers, rotavators for residue incorporation, sprinklers, chaff cutting machines, and weighing machines. Some of the implements are common across districts, but there are district-specific items at each center depending on local needs. The village committee decides the price to hire each farm implement on a consensus basis which is displayed at the CHC. The income generated by the CHCs goes to a common account. Of the 100 CHCs, most are performing well (Srinivasarao et al. 2013b).

Producer companies are another legal institutional innovation providing more business-like entities to primary producers for organizing and conducting business without any bureaucratic/government control or interference (Singh 2008). In India and many other developing countries, traditional cooperatives were mostly organized under the cooperative structure, e.g. the State Cooperative Societies Acts in India. However, for several reasons, the cooperatives lost their vibrancy and became known for their poor efficiency and loss-making ways. In light of these experiences of traditional cooperatives in India, it was felt that more freedom should be given to cooperatives to operate as business entities in a competitive market. This led to the amendment of the Companies Act, 1956 in 2003, which provided provision for incorporation of producer companies. At present, there are more than 130 producer companies in India, promoting agencies, crops and products, and types of primary producers.

3 Challenges in Dryland Systems

The climate in South Asia varies widely, from the warm humid and subhumid tropical climates predominating in the south-eastern and southern-most regions to the semiarid and arid subtropical regions of western India and Pakistan. These variations in climate are largely determined by latitude and altitude gradients. The variability in rainfall is greatest in drier zones, particularly in Pakistan and western parts of southern India, making them among the high-risk areas for rainfed agriculture. Most of the Himalayan mountain region, which covers part of Nepal and northern India, is climatically unsuited to agriculture (Pender 2008). The main constraints to rainfed agriculture include frequent drought, soil degradation, low SOC content, multiple nutrient deficiencies, low external inputs, low investment capacity, and poor market linkages (Srinivasarao et al. 2015b). Furthermore, agriculture options available in these regions depend on the prevailing socioeconomic conditions. As developing and underdeveloped nations, many hiccups underly such as declining natural resource base, climate change, and food and nutritional insecurity etc . Any improvement in or adaptation to these hiccups, may bring a change.

3.1 Declining Natural Resource Base

The scarcity of soil and water resources, exacerbated by soil degradation and environmental pollution, are the principal challenges to enhancing dryland agriculture production in South Asia. High population densities and high growth rates have accentuated the demands on soil, water, vegetation, and other natural resources (Lal 2006). The per capita renewable freshwater resources are likely to be a severe constraint by 2050 in Afghanistan, Iran, India, and Pakistan (Table 6). The shortfall in water availability in Pakistan was 40 million acre feet (MAF) in 2000, which was projected to 150 MAF by 2025 (Afzal 2001). Consequently, some 30 million Pakistanis face food insecurity due to water shortages (Afzal 2001). Furthermore, water pollution is a serious issue since industrial and urban affluents are often discharged into rivers. Surface and groundwater resources are also prone to nonpoint-source pollution by runoff from agricultural lands, especially in densely-populated regions of India (Pachauri and Sridharan 1999).

About 70 % of the Indian population lives in rural areas, and most depend on rainfed agriculture and fragile forests for their livelihoods (World Bank 2011). The mean annual rainfall varies from less than 100 mm in the western part of Rajasthan to around 11,700 mm in Chirapunji in Meghalaya (Kumar 2011). The per capita annual water availability in India decreased from 5177 m^3 in 1951 to 1654 m^3 in 2007 (MOWR 2008). According to the Central Ground Water Board, 15 % of districts are overexploited and growing at a rate of 5.5 % per year (Rejani et al. 2015a). The groundwater level in the 16 states of India has dropped by more than 4 m from 1981–2000, with the most substantial decline in north-western India. In many parts of Gujarat and Rajasthan, the groundwater level declined by more than 16 m (Sheetal Sekhri 2012).

Similarly, there is significant spatial variation in rainfall in Pakistan, with most of the country receiving very low rainfall. The whole of Sindh, parts of Baluchistan, most of Punjab, and central parts of northern areas receive less than 250 mm of rainfall while northern Sindh, southern Punjab, and north-western Baluchistan receive less than 125 mm of rainfall (Kumar 2011). Soil salinity, waterlogging and

Table 6 Per capita renewable fresh water resources (m^3/person) in South Asia

Country	1955	1990	1995	2025	2050
Afghanistan	5137	3020	2543	1091	815
Bangladesh	56,411	–	19936	14153	10,803
Bhutan	12,9428	–	53,672	26,056	18,326
India	5227	2464	2244	1496	1360
Iran	6203	2025	1719	816	690
Nepal	19,596	8686	7923	4244	3170
Pakistan	10,590	3962	3435	1803	1310
Sri Lanka	4930	2498	2410	1738	1600

Sources: Engelman and LeRoy (1993), Gardner-Outlaw and Engelman (1997) and Lal (2006) soil erosion are the prevailing land degradation issues in Pakistan (Sharda 2011). Irrigation systems in Pakistan are now underperforming, and groundwater use is increasing, leading to soil salinity. The major challenge is to improve productivity levels by managing water resources in an integrated way to benefit the people and the environment (IWMI 2015).

Sri Lanka has per capita water resources availability of 2400 m^3 with an average annual rainfall of 1712 mm (Ariyabandu 2008). Rainfall ranges from less than 1250 mm in the northwest and southeast to more than 5080 mm in the southwest. There are two rainfall zones in Sri Lanka namely, dry zone and wet zone (Kumar 2011); some districts of Sri Lanka experience prolonged dry periods due to the high temporal and spatial variability of rainfall. Sri Lanka has the second highest annual variability of rainfall of 22 Asian and Pacific countries. Even though the per capita availability of water is higher than many other countries, the scarcity of water is starting to threaten Sri Lanka's development (Ariyabandu 2008). Demand for water has increased and, at the same time, its availability has been affected by prolonged dry spells and droughts, and the pollution of sources. The Ministry of Environment and Natural Resources (2002) in Sri Lanka states that 85 % of developed water is used for irrigation, 6 % is for domestic use and 5 % is for industry. The number of wells and irrigation pumps has increased resulting in the indiscriminate withdrawal of groundwater from aquifers, which seriously threatens the sustainability of groundwater. Nearly 30 % of the population lives in coastal areas and depends on the shallow lens of freshwater saddled on saline waters for their livelihood, and the precious and limited water resources are threatened by over extraction, pollution, saltwater intrusion and rising sea levels due to climate change. A systematic research program is urgently needed to guide the policy, legislation and institutions that include adaptation to climate change (IWMI 2010).

Rainfall in Nepal varies spatially from more than 1300 mm in Kathmandu to more than 6000 mm along the southern slopes of the Annapurna Range in central Nepal to less than the 250 mm in the north central part near the Tibetan plateau. Rainfall amounts ranging from 1500 mm to 2500 mm are predominant over most parts of the country. High mountains cover nearly 35 % of the geographical area, middle mountains cover nearly 42 %, and the Tarai region covers nearly 23 % (Kumar 2011). Major problems include soil erosion, deterioration of soil quality, waterlogging along canal systems, quarrying which denudes hill slopes, excessive erosion, and the accumulation of debris in rivers (Sharda 2011). The government has adopted the principles of Integrated Water Resources Management (IWRM) and River Basin Management for planning and managing water resources (IWMI 2015). Global warming is expected to cause changes in the timing of monsoonal rains and the release of snow and glacier melt. In Nepal, nearly 30 million people are vulnerable to recurrent floods, landslides and droughts, and more than 80 % of the population depends on agriculture, which consumes 99 % of water withdrawn, but only 24 % of arable land is irrigated. The poorly-managed watersheds increase the stress and decrease the sustainability of water resources. The drying up of water sources, reduced surface and groundwater flows, and pollution are adversely affecting the domestic water supply demands for the increasing population.

Myanmar has abundant water resources, but the problems in this country are related to the uneven spatial and temporal distribution of rainfall. Soil and river bank erosion are the two land degradation issues in Myanmar (Sharda 2011). About 992.1 km^3 of surface water is produced internally per year, of which 453.7 km^3 is groundwater and about 443 km^3 is the base flow of rivers and surface runoff. Rest of the water is annual inflow from other countries About 89 % of the surface water is withdrawn for agriculture. Due to the non-uniform rainfall distribution, the need for irrigation is highest in the central dry zone, but there is concern about drainage and flood protection (Frenken 2011). Despite the availability of groundwater aquifers in Myanmar, their exploitation has been limited to municipal water supplies and intensive irrigation of vegetables and other high-value crops from hand-dug wells.

The mean annual precipitation in Afghanistan is less than 300 mm and ranges from 50 mm in the southwest to 700 mm in the region of Salang. Towards the eastern part of the country, the total annual precipitation is about 100 mm (Kumar 2011). Almost 90 % of irrigation water in Afghanistan comes from karez, springs, wells and rivers, etc. Major water losses are related to the low efficiency of irrigation systems and mismanagement of water distribution (Palau 2012). Areas with an unreliable river discharge and the largest drought deficits are in need of drought mitigation measures on river flows (Eriyagama et al. 2009). There is widespread natural resource degradation including drying of wetlands, with drought compounding the problem caused by improper management of the river basins, irrigation projects and dams. Soil erosion, irrigation and the spread of sand dunes into settlements, agricultural areas and roads has resulted in a scarcity of water potentials. During past years, floods have significantly increased due to deforestation and vegetation losses which have, in turn, decreased the waterholding capacity of the land.

Soils hold the key to productivity and resilience to climate vagaries including drought in rainfed agriculture. The loss of fertile soil due to erosion, depletion of soil organic matter, emerging secondary and micronutrient deficiencies, soil compaction, surface crusting, and loss of soil biodiversity are potential limiting factors for productivity enhancement in these regions (Srinivasarao et al. 2012a, 2014c). The per capita land area is progressively declining, even in southern India, which has a low rate of population growth (Lal 2006). At a medium rate of population growth, the projected per capita arable land area by 2025 will be 0.05 ha in Bhutan, 0.07 ha in Nepal and Pakistan, 0.08 ha in Sri Lanka, 0.12 ha in India and Iran, and 0.17 ha in Afghanistan.

Most soils in dryland regions are prone to human-induced degradation and desertification, which are a serious problem in South Asia (Lal 2006). Soil erosion by water is a principal constraint in mountainous regions and undulating terrains. The land area affected by water erosion is estimated to be 82 Mha, of which 33 Mha are in India and 26 Mha in Iran. In comparison, the land area affected by wind erosion is 59 Mha, of which 11 Mha each are in India and Pakistan, and 35 Mha are in Iran. Closely related to wind erosion is the issue of desertification or the degradation of soil and vegetation in arid regions. Desertification affects 67 Mha of Asia's drylands, of which 60 Mha are in India, 3 Mha in Pakistan and 2 Mha in Iran. Poor soil structure, slaking and excessive tillage lead to crusting in Aridisols (Hemmat and

Khashoei 2003; Barzegar et al. 2002a, b), Inceptisols (Ishaq et al. 2001) and Alfisols (Smith et al. 1992). In addition to crusting, Alfisols in central India are also prone to hard setting (Smith et al. 1992).

The principal constraints to enhancing crop production on Alfisols, which occur extensively in southern Asia, are: (i) low SOC pool, (ii) poor soil structure, (iii) crusting and mechanical impedance, (iv) high runoff and erosion, (v) high soil temperatures, (vi) severe drought stress, and (vii) low soil fertility (Lal 2006). In India, Alfisols occur mainly in southern parts of the country and constitute about 30 % of the soils under rainfed farming. Being light-textured and shallow, their available water capacity (AWC) is low. Furthermore, hard setting and structural instability exacerbate surface sealing and crusting. These soils in semiarid climates support a single rainy season crop (*Kharif* or summer) with productivity levels of 0.7–0.8 Mg/ha. These soils are characterized by low SOC and N stocks despite large variations in the cropping system, soil type, rainfall, temperature and supplementary management practices such as manuring and fertilization (Srinivasarao et al. 2012b). The high clay content, high waterholding capacity and favorable moisture release characteristics are important attributes of Vertisols which reduce the severity and duration of drought under conditions of low and erratic rainfall. These soils have numerous constraints especially low infiltration rates, poor internal drainage, inundation, high runoff and erosion, poor trafficability, narrow workable water content range, high evaporation, shrinkage cracks and risks of salinization. Similarly, alluvial soils (Inceptisols and Entisols), dominant in the Indo-Gangetic Plains, are light-textured (sandy and sandy loams), have low SOC concentrations and low inherent soil fertility. Crusting and high soil strength are serious problems on alluvial soils in arid regions (140–180 mm rainfall), which adversely affect seedling emergence and the crop stand. High crust strength reduces the emergence of cotton in Pakistan (Nabi et al. 2001) and elsewhere. However, Inceptisols respond to inputs (e.g., irrigation, fertilizers) and are highly productive under irrigated conditions. Arid climate prevails over 32 Mha of land area in seven states of India alone. Surface crusting, low water and nutrient retention capacity, drought stress, subsoil salinity and wind erosion are severe constraints to achieving high yields.

3.2 Climate Change

South Asia is home to more than one-fifth of the world's population and is the most natural disaster-prone region in the world. The high rates of population growth and natural resource degradation, with continuing high rates of poverty and food insecurity, make South Asia one of the most vulnerable regions to the impacts of climate change. In general, past and present climate trends and variability in South Asia can be characterized by increasing air temperatures, which are more pronounced during winter than in summer. There has been an increasing trend in the intensity and frequency of extreme events such as heat waves, cold waves, untimely and high-intensity rainfall, hailstorms and frost in South Asia over the last century (Sivakumar and Stefanski 2011; Srinivasarao et al. 2015c)

During recent decades, observed increases in temperature in some parts of Asia have ranged from 1–3 °C per century. Across all of Asia, inter-seasonal, inter-annual and spatial variability in rainfall has been observed in the past few decades. Decreasing trends in mean annual rainfall have been observed in the coastal belts and arid plains of Pakistan and parts of northeast India with increasing trends in Bangladesh (Cruz et al. 2007). The intensity and frequency of these events in South Asia have tended to increase in the last century. There have been significantly longer heat waves in many countries of South Asia with several cases of severe heat waves. In general, the frequency of more intense rainfall events in many parts of Asia has increased, causing severe floods, landslides and debris/mud flows. It is interesting that, at the same time, the number of rainy days and the total annual amount of precipitation has decreased, but the rain has been concentrated over fewer days. A long-term analysis of rainfall trends in India (1901–2004) by CRIDA, India indicated a significant increase in rainfall trends in West Bengal, central India, coastal regions, south-western Andhra Pradesh and central Tamil Nadu. Rainfall is likely to decline by 5–10 % in southern parts of India while a 10–20 % increase is likely in other regions (Venkateswarlu 2010). The number of rainy days in most of the country is likely to decrease, which points to a likely increase of extreme events (Venkateswarlu 2010). Recent models projected that the frequency of extreme precipitation days (e.g. 40 mm/day) are likely to rise (Venkateswarlu 2010). Changes in average annual temperatures are expected to increase by 2–2.5 °C. Warming is likely to be more in northern parts of India. A rise in night temperatures is also likely in India except for some small pockets in the peninsular region. This is concerning for agriculture as increased night temperatures increase the crop water requirements, accelerate respiration, hasten crop maturity and reduce yields.

Many parts of South Asia have been experiencing an increasing frequency and intensity of droughts, especially in the tropics and subtropics, since the 1970s (IPCC 2007). Rainfall has also been decreasing, with a 7.5 % reduction from 1900 to 2005 (significant at <1 %). The number of cyclones originating from the Bay of Bengal and Arabian Sea has decreased since 1970 but the intensity of these storms has increased, and the damage caused by intense cyclones has risen significantly in India and the Tibetan Plateau (Sivakumar and Stefanski 2011; Table 7). Melting of the Himalayan glaciers could increase flooding and affect water resources within the next two to three decades. Crop yields could decrease by up to 30 % in South Asia by the mid-twenty-first century.

Projections indicate that climate variations in South Asia will be varied and heterogeneous, with some regions experiencing more intense precipitation and increased flood risks, while others will encounter more sparse rainfall and prolonged droughts (Sivakumar and Stefanski 2011). Both the extent and severity of drought in rainfed areas have increased, and the consequences are poverty, food insecurity and hunger. With climate change, the dry regions of Sri Lanka (northern and eastern provinces), are expected to lose large portions of revenue from dryland agriculture (Seo et al. 2005).

Table 7 Summary of observed changes in extreme events and severe climate anomalies in South Asia

Climatic event	Observed change
Droughts	About 50 % of droughts associated with El Niño; consecutive droughts in 1999 and 2000 in Pakistan and northwest India led to sharp decline in water tables; consecutive droughts between 2000 and 2002 caused crop failures, mass starvation and affected ~11 million people in Odisha, India; droughts in northeast India during summer monsoon of 2006; about 400 million people affected by drought in 2009 in India.
Intense rains and floods	Serious and recurrent floods in Bangladesh, Nepal and northeast states of India during 2002, 2003 and 2004; floods in Surat, Barmer and Srinagar of India during summer monsoon season of 2006; 17 May 2003 floods in the southern province of Sri Lanka triggered by 730 mm rain.
Cyclones/typhoons	Frequency of monsoon depressions and cyclone formation in Bay of Bengal and Arabian Sea on the decline since 1970 but the intensity is increasing causing severe floods with damage to life and property.
Heat waves	Frequency of hot days and multiple-day heatwaves has increased in past century in India with an increase in deaths due to heat stress in recent years.

Source: Adapted from Cruz et al. (2007)

The projected impacts of climate change will vary across sectors, locations and populations. With most of the land area (approximately three-fifths of the cropped area) in these countries rainfed, the economy of South Asia hinges critically on the annual success of monsoons. In the event of a failure, the worst affected will be the landless and the poor whose sole source of income is from agriculture and allied activities. Water scarcity and water stress are big issues that will negatively impact the farmers in South Asia regarding water availability, soil moisture, and insect pest and disease incidence. Again, the worst hit would be the farmers in rainfed areas with small and marginal holdings, and poor financial capacity to cope with climate variability. There is a need to mainstream climate-resilient practices for adaptation to climate change into sustainable development planning in the region. An improved understanding of climate change impacts, vulnerability and adaptation practices to cope with climate change would help this process.

3.3 Food and Nutritional Insecurity

Reducing hunger by half is the first of the Millennium Development Goals (MDGs), and there have been some spectacular success stories in the Asia-Pacific region. However, success in reducing poverty and hunger varies among subregions and is closely associated with economic performance and investment in social capital. Poverty and hunger are particularly serious in South Asia and small islands in the

Pacific (Mukherjee 2008). For some countries, like Bangladesh and India, about 30 % of children are born underweight and run the risk of dying in infancy, being stunted physically and cognitively during childhood, having reduced working capacity and earnings as adults, and giving birth (females) to low-weight babies. The impact of hunger is more prevalent in women and girl children, who eat last, eat the least and eat leftovers. Further, the economic cost of hunger in terms of lost productivity, earnings and consumption run into billions of dollars, apart from the direct cost of dealing with the damage it causes.

The future requirements of food grains should be based on population growth, the composition of rural and urban populations, growth in per capita income in rural and urban areas, and changes in taste and preferences. According to demand projections prepared by Paroda and Kumar (2000) under low- and high-income scenarios, demand in the region will grow by 1 % for cereals and by 1.7 % for pulses. Demand for edible oils is projected to grow by more than 1.6 %. Demand for fruits, vegetables and livestock would rise by around 3 % or more under the high-income scenario. These growth rates can be used to work out feasible levels of agricultural diversification.

The long-term trend in the consumption pattern at the household level shows that the per capita direct consumption of food grains has been declining, and that of livestock products and fruits and vegetables has been increasing in most The South Asian Association for Regional Cooperation (SAARC) countries. Despite this shift in dietary pattern, food grains are paramount for household food and nutritional security because: (1) cereals and pulses are staple foods, and there is no perfect substitute; (2) due to the inadequate intake of almost all foods, increased consumption of other foods, in most cases, will fill any dietary deficiency; (3) food grains are the major and cheapest source of energy and protein compared with other foods, and are vital for food and nutritional security of low-income masses; and (4) increased production and consumption of livestock products resulting from increased per capita income requires high growth in the use of grain as feed for livestock. For these reasons, food grains continue to be the pillars of food security in South Asia and any slack in their production translates into persistent price shocks and adverse impacts on common people (Chand 2010).

3.4 Socioeconomic Issues

The ultimate goal of all development efforts is to improve socioeconomic conditions and, therefore, the wellbeing of people. South Asia is an important region in the world that needs attention as the bulk of the poor live in these nations. The widespread poverty is reflected in the relatively higher prevalence of malnutrition in these countries. Addressing the issue of malnutrition should, therefore, be an explicit objective of any program or intervention intended to tackle food insecurity.

Improving the situation with respect to food security, poverty and nutrition is a recognized goal of all policy interventions, but certain elements in the existing socioeconomic setting can impede these goals. Among them, an important challenge is improving the situation with high population pressure with smaller size of farms. Poor infrastructure, both hard and soft, is another determinant and determined aspect of socioeconomic conditions. At the regional level, the lack of political trust also results in suboptimal policy making which is reflected in poor adherence to or inadequate implementation of various regional agreements.

4 Opportunities for Resilient Dryland Agriculture

The elimination of poverty, improvement in nutrition and the supply of safe food are of prime importance for most SAARC countries. There is renewed emphasis on agriculture for development and on addressing poverty and hunger. Agricultural growth not only offers a pathway out of poverty but it promotes employment in non-farm rural activities and facilitates the migration to non-agricultural avenues without distress. Based on this, growth in agriculture and overall rural development are considered essential for a sustainable exit from poverty (FAO 2002). Agricultural growth helps to reduce poverty and hunger, not only by raising the income of the poor but by keeping food prices in check. Recognition of the importance of agriculture has shifted the emphasis from growth *per se* to inclusive growth (Chand 2010). Growth in output and farm income depends on many factors, such as input and output prices and non-price factors. Increasing growth requires remunerative price for output, access to improved technology, application of quality inputs, and the use of modern machinery. There is vast potential for enhancing agricultural production in dryland agriculture, especially in South Asia. The potential of rainfed agriculture needs to be unlocked through the efficient management of natural resources to increase farm productivity and profitability in South Asian countries. Soil and water management will play a critical role in this.

4.1 Technological Approaches

Technology is the prime mover for agricultural growth. Considering the costs and constraints of resources such as water, nutrients and energy, the genetic enhancement of productivity should be coupled with input-use efficiency. This will be possible only by using the existing improved technology and by developing new technologies (Chand 2010). Agricultural research systems have developed some promising technologies for overcoming the barriers, outlining the needs of farmers to achieve high growth and promoting farming systems to improve the natural resource base. Current approaches in development are aimed at enhancing the resilience to climate change and contributing to mitigation. This is a clear pointer to the potential for raising output through the effective dissemination of agricultural technologies. With advanced management and high input levels, yields could increase by 2–5-fold (Venkateswarlu and Prasad 2012). Specialized dryland management practices such as water harvesting and reducing soil moisture loss can increase yields by an additional 5–15 % on average across the SAT regions and reduce yield variability from year-to-year, producing a more reliable yield (Fischer et al. 2009).

4.1.1 Rainwater Management

Soil and water need special attention for their sustainable use as degradation is evident in all SAARC countries. The optimal use of water resources has three distinct adoption strategies for the sustainable development of dryland agriculture during the 21st century: (i) cropping strategy based on rainfall analysis and moisture availability, (ii) *in-situ* moisture conservation technologies, and (iii) rainwater harvesting and use for crops at critical stress periods (Singh et al. 1999). The rainwater management strategy in arid and semiarid regions involves the selection of short duration and low-water-requiring crops and the conservation of as much rainwater as possible so that crops can escape moisture stress during the growing period. In addition, in relatively high rainfall regions, the surplus water can be harvested for lifesaving irrigation, enhancing cropping intensity and maximizing returns. Apart from enhancing the availability of water, increasing the water use efficiency by arresting various kinds of losses should be the focus. The frequent occurrence of midseason and terminal droughts lasting 1–3 weeks is the main reason for crop failure and low yield (Srinivasarao et al. 2015c). The provision of critical irrigation during this period has the potential to improve yields by 29–114 % for different crops (Prasad et al. 2014). Critical irrigation to high-value vegetables, fruit and flower crops would contribute a higher benefit:cost ratio and higher rainwater use efficiency.

The watershed development approach adopted in India and elsewhere since the 1970s is hydrologically ideal. However, within the large hydrologic unit or watersheds there are many soil types, landscape units, land uses and other social, economic, cultural, and ethnic factors to be considered (Lal 2006). Only a small portion of the entire watershed may be prone to excessive runoff and severe erosion. Rather than treating the entire watershed, it is important to treat those landscape units which are most prone to degradation using the partial area concept. Watershed development programs are silently revolutionizing dryland areas to become a growth engine for inclusive and sustainable development in vast tracts of dryland areas in South Asia. Meta-analysis of 311 watershed case studies from different agroecoregions in India revealed that watershed programs benefitted farmers with enhanced irrigation areas by 33.5 %, increased the cropping intensity by 63 %, reduced soil losses to 0.8 t/ha and runoff to 13 %, and improved groundwater availability. Economically, the watershed programs are beneficial and viable with a benefit:cost ratio of 1:2.14 and an internal rate of return of 22 % (Joshi et al. 2005).

4.1.2 Soil Management

Soils hold the key to productivity and resilience to climate vagaries in dryland agriculture in South Asia. The potential limiting factors for productivity enhancement in these regions are the loss of fertile soil as erosion, depletion of soil organic matter, emerging secondary and micronutrient deficiencies, soil compaction, surface crusting, and loss of soil biodiversity. Soil management systems should not only take into account the risks inherent in the farm and field locations but also in the choice of crops, cultivation methods and/or stocking levels. Soil health restoration can be addressed through better management practices, which include (i) timely tillage at suitable moisture levels to prevent bringing up clods which require more tillage, (ii) reducing secondary tillage, no-till, or ridge–tillage systems to leave crop residues on the soil surface, (iii) using crop rotations which include grasses and legumes where possible, (iv) using cover crops, (v) using manure to build soil organic matter, and (vi) if a crust has formed before the crop emerges, using a rotary hoe to break up the crust to assist with crop emergence. The main emphasis in rainfed farming systems is to build soil organic matter (SOM) for soil health restoration. Management to improve and restore soil health involves a combination of practices that enhance the soil's biological, chemical, and physical suitability for crop production, including erosion control, correction of nutrient deficiencies, reclamation of problematic soils, reducing compaction by decreasing heavy equipment traffic, and using best nutrient management practices such as integrated nutrient–water management (Fig. 3).

Fig. 3 Components of recommended management practices (RMPs) for soil health restoration (Source: Srinivasarao et al. 2015a or b?)

Low SOM in tropical soils, particularly those under the influence of arid, semi-arid, and subhumid climates, is a major factor contributing to poor productivity (Katyal et al. 2001). Proper management of SOM is important for sustaining soil productivity and ensuring food security and protection on marginal lands. Under dryland conditions, the process of organic matter decomposition is faster than irrigated condition; organic matter disappears rapidly due to its rapid oxidation under prevailing high temperatures, low rainfall and high potential evapotranspiration (PET). Therefore, frequent and large quantities of added organic manure are essential to maintaining SOC concentrations. An important general strategy is to add as much organic matter as possible through management practices (*viz.* crop and cover crop residues, manures, the inclusion of legumes in the cropping sequence or as intercrops, green manure crops, green-leaf manuring, tank silt addition, farmyard manure, biofertilizers and vermicompost) (Srinivasarao et al. 2011).

Green manuring is a viable option to increase SOM. The incorporation of Gliricidia (*Gliricidia sepium* Jacq. Walp.) green-leaf manuring technology in the light soils of rainfed tribal and backward districts of Andhra Pradesh and the All India Coordinated Research Project for Dryland Agriculture (AICRPDA) and Operational Research Project (ORP) villages in different regions of India had a significant and positive effect on increasing SOM and macro- and micro-nutrients (Srinivasarao 2011).

The effective management of residues, roots, stubbles and weed biomass can have beneficial effects on soil fertility through the addition of organic matter, plant nutrition and improved soil condition. Agricultural waste is usually handled as a liability, often because the means to transform it into an asset is lacking. Crop residues in fields can result in crop management problems as they accumulate. In India, the availability of biomass (2010–2011) was estimated at 500 million tons/year (MNRE 2009). Studies sponsored by the Ministry of New and Renewable Energy (MNRE) in India have estimated surplus biomass availability at about 120–150 million tons/year (MNRE 2009). Of this, about 93 million tons are burned each year. The lack of availability of proper chipping and soil incorporation equipment is one reason for the colossal wastage of agricultural biomass, and the increased cost of labor and transport is another. Many technologies exist such as briquetting, anaerobic digestion, vermicomposting, biochar, but they have not been commercially exploited.

The correction of nutrient deficiencies can be achieved through site-specific nutrient management (SSNM) and integrated nutrient management (INM). SSNM takes into account all nutrient deficiencies to ensure that crop demands are met, and soil fertility is improved, which in turn ensures higher nutrient use efficiency, crop productivity and economic returns (Dobermann 2004). The results of on-farm demonstrations across crops and soils in India showed that S application increased grain yield by 650 kg/ha (+24 % over NPK) in cereals, 570 kg/ha (+32 % over NPK) in oilseeds, and 375 kg/ha (+20 % over NPK) in pulses (Singh 2001). Cotton yields increased in response to balanced nutrition in the Warangal, Adilabad and Khammam districts of India by 20, 60 and 30 %, respectively, compared with traditional farmer practices (Fig. 4).

Fig. 4 Enhanced growth of Bt-cotton (left) with balanced nutrition compared to farmers' practice (right) in Adilabad and Khammam districts of Andhra Pradesh, India

4.1.3 Conservation Agriculture

Conservation agriculture (CA) is gaining momentum as an alternative strategy to sustain agricultural production due to the growing resource degradation problems, particularly under dryland conditions. Sufficient information is available to indicate that CA practices save time, reduce production costs and contribute substantially towards profitability and sustainability of carbon in soils (Srinivasarao et al. 2013a). However, in dryland ecosystems, having sufficient crop residue to leave on the surface is not feasible as part of CA, nor is the conservation of first rains by deep tillage before the rainy season to allow sufficient infiltration. Hence, typical CA with three principles (minimum tillage/soil disturbance, permanent soil cover and crop rotation/intercropping) needs to be investigated further to include *in-situ* water conservation of rainwater to recharge the soil profile. A modified CA with four principles for dryland agriculture is presented in Fig. 5.

4.1.4 Agricultural Intensification

The goal of agricultural intensification can be realized through the adoption of land-saving technologies which enhance crop yields per unit area per unit time and unit input of off-farm resources (Lal 2006). With available dryland technologies such as rainwater management, crop options, short-duration varieties, and various agronomical practices, more dryland areas can be used for intensive cropping including relay cropping and double cropping. Double cropping is possible in areas with sufficient rainfall (usually more than 750 mm) that have a soil storage capacity of more than 150 mm of available soil moisture, or with rainwater harvested in farm ponds which can be used to establish winter crops. There is plenty of scope for raising farm outputs and income with diversification to high-value crops and by harnessing niche areas particularly in mountainous regions. This will require markets for those

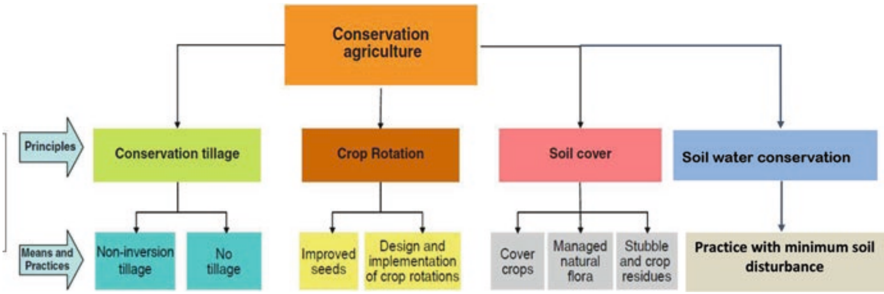

Fig. 5 Modified CA for tropical dryland ecosystems

products, which depend on the private sector, cooperatives or joint ventures of public and private agencies.

Studies on intercropping over time and across locations in India have identified useful and productive crop combinations with matching production technologies. For example, pearl millet and pigeon pea (*Cajanus cajan* (L.) Millsp) (Umrani and Subba Reddy 1999; Srinivasarao et al. 2014d) which has done extremely well in regions where late rains are likely to occur in September/October (Bijapur and Solapur) or where deep, moisture-retentive soils exist (Akola). Cotton and mung bean (*Vigna radiata* (L.) Wilczek), black gram (*Vigna mungo* (L.) Hepper) or soybean are other successful intercropping combinations. Although intercropping has not been recommended for post-rainy or winter season cropping, the system is gaining importance as a major adaptation strategy to cope with the vagaries of climate.

4.1.5 Adaptation to Climate Change

While climate change impacts the agricultural sector in general, dryland agriculture is expected to be more vulnerable given its high dependency on monsoons, and the likelihood of increased extreme weather events due to the aberrant behavior of monsoons. Given South Asia's geographical location and high incidence of poverty, the region is suffering from climate change. Increased temperatures have not only affected cropping seasons but also melted the Himalayan glaciers at an alarming rate. These changes have increased flooding and raised sea levels, severely impacting rural livelihoods in the region. Recurrent natural hazards such as drought and heavy flooding have affected the region's poor population disproportionately. Farmers have reported shortened rainy seasons and increased temperatures over the years (Chatterjee and Khadka 2011). A wide variety of adaptive actions may be taken to face the adverse effects of climate change on dryland agriculture. The Indian Council of Agricultural Research (ICAR) responded to the challenge of climate change and launched NICRA in 2011 with a major focus on infrastructure development for strategic research, and demonstration of best practices on farmers' fields to cope with climate variability. The major achievements of the project include micro-level agrometeorological advisories to cope with seasonal climate variability, tolerant genotypes including a few advanced lines for climatic stresses in wheat, rice and pulses in multi-location testing stage, a strengthened database of greenhouse gas fluxes in various crops and agroecosystems, an assessment of water and carbon footprints, and the identification of climate-resilient technologies with co-benefits of low global warming potential. The TDC of the project, implemented through 121 *Krishi Vigyan Kendras* (KVKs) across the country, identified appropriate location-specific technologies that can enhance resilience to climatic variability. Successful demonstrations to cope with deficit rainfall situations, floods and cyclones were possible through the implementation of climate-focused action plans. On-farm adjustments to climate change would require crop varieties suitable for late/early sowing, new cropping sequences, the supply of seed and inputs on demand, water conservation, diversified production, etc. All of which would require major investments.

Farmers, in particular, and society, in general, have attempted to adapt to climatic stresses by resorting to practices such as mixed cropping, by changing varieties and planting times, and by diversifying their sources of income (Jat et al. 2012). In future, such adaptation strategies would need to be considered along with innovations to cope with climate change. For dryland agriculture to successfully adapt to climate changes and variability, climate-resilient crops and cultivars for different regions need to be identified. Maheswari et al. (2015) have documented the available crop varieties that are suitable for cultivation under stresses like drought, heat, cold, salinity and flooding with details on agroclimatic zones and the possible sources of seed availability in India. Other technical adaptation measures range from changes in production systems such as adjusting planting or fishing dates; rotations; multiple cropping/species diversification; crop–livestock pisciculture systems; agroforestry; soil, water and biodiversity conservation and development by building soil biomass; restoring degraded lands; rehabilitating rangelands; harvesting and recycling water; planting trees; developing adapted cultivars and breeds; and protecting aquatic ecosystems to maintain long-term productivity. Adaptation measures also take into account the establishment of disaster risk management plans and risk transfer mechanisms, such as crop insurance and diversified livelihood systems.

4.2 Institutional Innovations

Institutional innovations are required both at the domestic and regional level in South Asia. Some fundamental aspects of agricultural production are similar between countries. For example, smaller farms lead to smaller marketable surpluses, resulting in less bargaining power for producers and exposure to reduced economies of scale. There are many institutional innovations emerging in these countries that are successfully bringing farmers together to aggregate their small marketable surpluses. There are also efforts to integrate producers with consumers through supply and value chains to increase the producers' share of what the consumer pays for the commodity at the end of the value chain. These institutional innovations vary in that the nature and participation of public, private and civil society sector players varies. Self-help groups—the initiatives of private sectors in linking farmers to the markets (e.g. e-choupal in India)—are one example. There are also community-based initiatives to enhance smallholder access to some key inputs, for example community seed banks, 'seed villages' and CHCs to access farm mechanization. In India, Bangladesh and Nepal, there are several community-based interventions for the management of water resources, the lessons from which could be replicated or adapted to local conditions in other countries. The diversification of agriculture towards high-value crops has been a driver of growth in these south Asian countries. For such a strategy to be effective for smallholders, institutional arrangements such as contract farming and producer supply organizations are needed so that farmers have access to improved technologies and better, more stable markets.

At the regional level, despite some improvement in intra-regional trade, progress has been slower than desired. To further trade within the region, institutions and their protocols should be strengthened, especially in food and agricultural trade, so that the food security concerns are well addressed. The agricultural innovations generated from respective agricultural research systems should be shared as these countries share similar agro-economic settings. There can be a mechanism whereby certain outputs of the national agricultural research system can be identified as regional public goods so that other countries within the region can have. This will require suitable modification and changes to laws and regulations related to intellectual property rights.

The timely completion of agricultural operations has significant benefits both on research farms and farmers' fields. In the recent past, due to a high degree of weather aberrations, the timeliness of agricultural operations has come into focus. Often, the ideal conditions for an agricultural operation such as sowing or intercultural operation only exist for a short period. If the farmer fails to complete the operation within this timeframe, then the output will be compromised. This problem can be tackled by using appropriate agricultural implements to carry out the operations. However, smallholders often cannot afford such equipment. This calls for sharing the cost of implements by innovative institutional arrangements. Recently, the custom hiring of agricultural machinery has been seen as an appropriate institutional arrangement which can promote the mechanization of agricultural operations on small farms.

Weather-based agro-advisory services (AAS) in farming activities are important for accessing real-time weather information, timely agricultural operations, improved crop yields, reduced costs of cultivation, need-based changes in cropping patterns and improved livelihoods. The district level weather forecast could be used along with current crop and weather conditions to prepare district level advisories by respective KVKs or scientists of Agricultural Universities (AU). A pilot methodology for preparing and issuing agrometeorological advisories at the block level has been tested in the Belgaum district of Karnataka, India. The main innovation of this project was to set up a framework involving KVKs, state-line departments and field information facilitation to collect real-time crop data, formulate an appropriate advisory and disseminate what?. Field Information Facilitators (FIF) were appointed in 10 blocks of the district to collect information on weather, crops, disease and pest incidence. They supplied information by phone or email to contact staff at KVK who in turn developed a qualitative Agromet Advisory specific to the village/farmers, in consultation with an agrometeorologist of AU and scientists of KVK.

The increasing frequency and severity of droughts, storms and other extreme weather events associated with climate change reduce the livelihood options for millions of small-scale farmers in South Asia. Weather index-based insurance is an attractive approach to managing weather and climate risk because it uses a weather index, such as rainfall, to determine payouts and these can be made more quickly and with fewer arguments than is typical for conventional crop insurance. The underlying premise of weather insurance is that weather parameters can be reliable proxy indicators for the actual losses incurred by farmers (Singh 2013a). Weather index-based insurance was formally introduced to Indian farmers in 2003 through a program initially supported by the World Bank. The first weather index insurance in India was a rainfall insurance contract underwritten in 2003 by the ICICI-Lombard General Insurance Company for groundnut and castor farmers of the BASIX water user association in the Mahabubnagar district of Andhra Pradesh. By 2007, the national government had adopted it as an alternative to the existing crop-yield-index insurance. Moreover, by 2012, up to 12 million farmers growing 40 different crops on more than 15 million hectares were insured against weather-related losses (CCAFS 2013). There is still gap in these payout structures that need to be refined by the insurance companies in consultation with agrometeorologists and other scientists.

4.3 Agricultural Markets and Trade

Intra-regional trade can enhance food security in South Asia. If South Asian countries trade agricultural produce extensively among themselves, then the region's food security concerns can be addressed in a sustainable manner. Improvement in the performance of agricultural markets, domestic and international, is a means to enhance farmer income in developing countries, and South Asia is no exception. As a region, South Asia is one of the least integrated regions in terms of trade (Weerahewa 2009), and domestic agricultural markets are less developed and integrated. These countries trade more with countries outside the region than with those within the region. The contribution of trade to agricultural GDP is relatively more in the Maldives and Sri Lanka than in other countries. USA, EU and UAE are among the more important countries in terms of the value of exports and imports to these South Asian countries. Within the region, India is the hub of agricultural trade because of its size, demographic, geography and economy. Import substitution has been the driver of development regimes in South Asia and, as a result, trade is characterized by restrictions and interventions by governments. Policies related to trade, especially in India, have changed. Non-tariff barriers, rather than tariff barriers, were hindering intra-regional trade. The lack of variation in comparative advantage and poor infrastructure along with supply-side barriers due to lower productivity levels are the major reasons for relatively lower trade within and outside the region (Nanda 2012).

4.4 Policy Needs

Despite some progress, poverty, food insecurity, hunger and malnutrition continue to be major development goals of the economies of South Asia. Countries in the region should plan and implement strategies that optimize the resources and efforts in a coherent and efficient manner so that the desired progress is achieved. Within agriculture, much of cropping remains rainfed, except in Pakistan, so investing in enhancing productivity and profitability of rainfed agriculture is needed. Some threats facing the region are land degradation, rising input costs, climate change and higher dependence on agriculture for livelihoods. Despite broad similarities within the agricultural frame work, considerable diversity exists between of these South Asian countries. Hence should be adequately recognized by agricultural policy makers to devise policies and interventions for technology generation and transfer in dryland agriculture. Public investment in agricultural research needs to be increased, especially in natural resource management, without which the potential of genetic enhancement and other productivity enhancing technologies cannot be realized. Enhancing the use efficiency of inputs such as water and fertilizer nutrients should attract the attention of researchers and policymakers. Other areas that need attention are land reform and market infrastructure. The former will positively affect the investment decisions of farmers, and the latter will help farmers to obtain better prices for their products. Investments in road and communication infrastructure and processing facilities are needed. Only then, will farmers in South Asia be able to take advantage of expanding global trade. Such investments are needed to encourage diversification towards high-value commodities, which have been identified as a source of income growth in these countries (Joshi et al. 2003). Diversification is more common in regions with less irrigation, but all countries should have regionally-differentiated approaches to technology generation and transfer, with policies and programs flexible enough to accommodate location-specific requirements.

The pursuance of domestic policies for addressing location-specific issues within these countries should be accompanied by better coordination in dealing with issues that have cross-border relevance. At present, trade is hampered by a lack of standardization of procedures and protocols and by inadequacies in soft and hard infrastructure in this regard. Information from research systems and policy making should be shared between countries within the region. Arrangements for conservation and the use of diverse genetic resources in these countries should be strengthened further. The National Agricultural Research System of India is stronger than its counterparts in other countries, and outputs should be shared with other countries where relevant. Some crop varieties developed in India are finding their way into other countries. Formal and informal trade in agricultural inputs such as seed, fertilizers has occurred between India and countries like Bangladesh, which could be optimized by streamlining the procedures.

At the regional level, relevant SAARC Declarations should be implemented with vigor. The SAARC Food Bank initiative must be implemented with greater emphasis and coordination to help poor consumers during food crises. The SAARC countries must collaborate in sharing knowledge and transferring technology as a regional mitigation strategy. Similarly, the concept of the SAARC Seed Bank must be promoted. Poor and marginal farmers should have access to better quality seeds that can resist the vagaries of climate change.

On the whole, policies are needed to put in place programmes and resources that make dryland agriculture more sustainable in the face of emerging threats such as climate change, and that dovetail domestic policies with regional policies for a better-coordinated effort to deal with larger issues such as food insecurity, climate change and globalization of agricultural trade.

5 Conclusions and Future Research Thrusts

The South Asian region sustains the world's poorest people, contributing less than 5 % to the world's GDP. Agriculture is the main source of livelihoods in this region. There is potential to enhance agricultural production in dryland agriculture with the adoption of recommended management practices. These practices are location-specific and involve knowledge-based management of natural resources including soils and rainwater, agricultural intensification, INM, rainwater harvesting and efficient use, and conservation agriculture. The efficient use of water, soil and farm management practices in an integrated approach is both essential and a prerequisite to making dryland farming more economical and sustainable under the increasing frequency of droughts, reduced number of rainy days, and extreme and untimely rainfall. Location-specific needs of soil and water conservation measures *vis-a-vis* changing rainfall scenarios will better address water issues. Public–Private–Partnerships (PPP) that create market links have proved successful in several watersheds sites and created win–win situations for all stakeholders involved, particularly in India. Therefore, it is necessary to formulate a coherent set of guidelines to enable governments and consortium partners to approach the private sector and begin fruitful collaborations in PPPs. These partnerships need to strengthen market linkages and value chains and increase investments by the private sector in watershed development.

Field burning of crop residues must be stopped to minimize environmental pollution; surplus crop residues should be moved into the soil system either as manure or surface cover. Residue management must be taught at all levels, including extension workers and land managers. In addition, a region-specific, needs-based crop residue management plan should be developed. The adoption of various location-specific INM practices in dryland systems should be promoted further and implemented with the help of various government programs. Weather-based AAS in farming activities are needed for access to real-time weather information, timely agricultural operations, improved crop yields, reduced cultivation costs, needs-based changes in cropping patterns, and improved livelihoods. Extension departments should increase exposure visits, training and demonstrations of location-specific farming system models, to increase awareness and capacity building of the farming community towards upscaling relevant dryland technologies.

Despite the broad similarities within the agricultural settings of these countries, the diversity within these countries should be recognized by those concerned with agricultural policy to devise policies and interventions for technology generation and transfer in dryland agriculture. Public investment in agricultural research should be increased, especially in natural resource management, without which genetic enhancement and other productivity enhancing technologies cannot be realized. Researchers and policymakers should focus on enhancing the use efficiency of inputs such as water and fertilizer nutrients. Pursuance of domestic policies to address location-specific issues within these countries should be accompanied by better coordination of cross-border issues. For example, there is potential to address food insecurity at a regional level by improving the functioning of regional institutions, and coordinating and streamlining trade mechanisms.

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