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Climate change and agriculture in South Asia: adaptation options in smallholder production systems

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Abstract
Agriculture in South Asia is vulnerable to climate change. Therefore, adaptation measures are required to sustain agricultural productivity, to reduce vulnerability, and to enhance the resilience of the agricultural system to climate change. There are many adaptation practices in the production systems that have been proposed and tested for minimizing the effects of climate change. Some socioeconomic and political setup contributes to adaptation, while others may inhibit it. This paper presents a systematic review of the impacts of climate change on crop production and also the major options in the agricultural sector that are available for adaptation to climate change. One of the key conclusions is that agricultural practices that help climate change adaptation in agriculture are available, while the institutional setup to implement and disseminate those technical solutions is yet to be strengthened. Thus, it is important to examine how to bring the required institutional change, generate fund to invest on these changes, and design dynamic policies for long-term climate change adaptation in agriculture rather than a mere focus on agricultural technology. This is one of the areas where South Asian climate policies require reconsidering to avoid possible maladaptation in the long run.

Keywords Climate change · Adaptation · South Asia

JEL Classification Q18 · Q54

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1 Introduction

Climatic variability explains almost 60% of yield variability and thus a crucial factor influencing food production and farmers' income (Osborne and Wheeler 2013; Ray et al. 2015; Matiu et al. 2017). Climate change influences the start and length of growing seasons (Fiwa et al. 2014; Zhao et al. 2015; Lemma et al. 2016) and the duration and magnitude of heat and water stress in agricultural production systems (Lobell et al. 2015; Saadi et al. 2015; Schauberger et al. 2017). Growth acceleration due to higher average temperature results in less radiation interception and less biomass production (Rosenzweig and Hillel 2015). Besides, above-optimal temperatures directly harm crop physiological processes. A recent analysis demonstrates the effect of climate change in the production and yield of four major crops globally, i.e., maize, rice, wheat, and soybean (Wang et al. 2018). Crop yield studies focusing on India have found that global warming has reduced wheat yield by 5.2% from 1981 to 2009, despite adaptation (Gupta et al. 2017). It is projected that climate change would reduce rain-fed maize yield by an average of 3.3–6.4% in 2030 and 5.2–12.2% in 2050 and irrigated yield by 3–8% in 2030 and 5–14% in 2050 if current varieties were grown (Tesfaye et al. 2017). Despite variability in input use and crop management, there is a negative effect of both season-long and terminal heat stress on rice and wheat, though wheat is considerably more sensitive than rice (Arshad et al. 2017).

Besides its impact on crop yields and production, climate change also affects the natural resources, primarily land and water that are fundamental to agricultural production. Water availability is expected to decline due to climate change, while agricultural water consumption is predicted to increase by 19% in 2050 (UN-Water 2013). For instance, growing reliance of Indian farmers on groundwater to cope with climate-induced drought has led to a rapid decline in the groundwater table, and it may worsen further due to increased climatic variability in future (Fishman 2018). In South Asia (SA), it is predicted that the annual average maximum temperature may increase by 1.4–1.8 °C in 2030 and 2.1–2.6 °C in 2050, and thus, heat-stressed areas in the region could increase by 12% in 2030 and 21% in 2050 (Tesfaye et al. 2017). Projections claim that almost half of the Indo-Gangetic Plains (IGP), the major food basket of the South Asian region, may become inappropriate for wheat production by 2050 as a result of heat stress (Ortiz et al. 2008). Even a relatively modest warming of 1.5–2 °C in SA can severely impact the availability and stability of water resources due to increased monsoon variability and glacial meltwater, thereby threatening the future agricultural productions (Vinke et al. 2017). With its impact on agricultural production and natural resources, climate change will bring greater fluctuation in crop production, food supplies, and market prices and will aggravate the situation of food insecurity and poverty in South Asian countries, which adversely affects the livelihoods of millions of people in the region (Schmidhuber and Tubiello 2007; Bandara and Cai 2014; Shankar et al. 2015; Wang et al. 2017; Aryal et al. 2019b). It is projected that food price changes between 2000 and 2050 are 2.5 times higher for major food crops (e.g., rice, wheat, maize, and soybean) and 1.5 times for livestock products (i.e., beef, pork, lamb, and poultry) with climate change (Nelson et al. 2009). Therefore, in the absence of adaptation measures to climate change, South Asia could lose an equivalent of 1.8% of its annual gross domestic product (GDP) by 2050 and 8.8% by 2100 (Ahmed and Suphachalasai 2014). The average total economic losses are projected to be 9.4% for Bangladesh, 6.6% for Bhutan, 8.7% for India, 12.6% for the Maldives, 9.9% for Nepal, and 6.5% for Sri Lanka. Since agriculture provides livelihood to over 70% of the people, employs almost 60% of the labor force, and contributes 22% of the regional gross domestic product (GDP) in SA (Wang et al. 2017),

these losses of GDP will have major consequences in agriculture-dependent communities in the region (Ahmed and Suphachalasai 2014). Therefore, improved understanding of impacts of climate change in agriculture and the adaptation practices to cope with these impacts are essential to enhance the sustainability of agriculture and to design the policies that reduce poor farmers' vulnerability to climate change in SA.

Adaptation to climate change involves any activity designed to reduce vulnerability and enhance the resilience of the system (Adger 2006; Vogel and Meyer 2018), and therefore, the actual impacts of climate change largely depend on the adaptive capacity (Vermeulen et al. 2012). Adaptation is particularly fundamental to South Asian agriculture for the following reasons: (1) agriculture is a primary source of livelihood; (2) largely rain-fed which makes it vulnerable to extreme climate; (3) fragmented and small land size—less than a hectare—reducing farmers' capacity to adapt to climate change; (4) increased population and high economic growth has further exacerbated the adverse impacts of climate change due to increased demand for land and water from other sectors of the economy mainly driven by search for alternative farm practices; (5) lack of better institutions and policies to address climate risks in agriculture; (6) less developed risk and insurance market to promote adaptation to climate change; and (7) to sustain local food security, especially of the poor and small farmers against the high food price fluctuation under extreme climatic variability.

Farmers in SA use a wide range of resources to adapt to climate change, and thus, households with better access to multiple resources and diverse livelihood portfolios are more likely to better cope with climate risks (Ojha et al. 2014; Bhatta et al. 2017; Brown et al. 2018; Thornton et al. 2018). Given the site-specific nature of climate change impacts on agricultural production together with wide variation in agro-ecosystems and socioeconomic conditions, adaptation strategies must acknowledge environmental and cultural contexts at the regional and local levels.

On this backdrop, this study examines the prospects of the smallholder production system in SA to adapt to climatic variability to minimize the negative impacts of climate change on food systems. We also discuss why farmers use few adaptation measures, if any, despite the prevalence of several measures in light of the existing barriers and policy setup. For this study, SA includes Bangladesh, Bhutan, India, Nepal, Pakistan, and Sri Lanka.

The rest of the paper is organized as follows. Section two documents the impact of climate change on agriculture in SA. Section three presents multiple adaptation measures applied in the agricultural sector. In section four, we discuss the climate change adaptation policies and future prospects of agriculture in SA with a due focus on existing barriers, and the last section concludes the study.

2 Impact of climate change on agriculture in South Asia

Agriculture in SA is highly susceptible to climate change and its variability. For the region, the IPCC has projected 0.5–1.2 °C rise in temperature by 2020, 0.88–3.16 °C by 2050, and 1.56–5.44 °C by 2080 depending on the scenarios of future development (IPCC 2007a). This long-term change in temperature and precipitation patterns is more likely to shift cropping seasons, crop cultivation suitability, and increase the incidence of disease and pests affecting crop yields, productions, and food markets. For example, between 1980 and 2014, spring maize-growing periods in Pakistan have shifted an average of 4.6 days per decade earlier, while sowing of autumn maize has been delayed by 3 days per decade,

severely affecting the yield (Abbas et al. 2017). These changes ultimately affect the livelihood of millions of farmers in the region, particularly those with less capacity for adaptation to climate change.

Studies indicate that the impact of changes in temperature and precipitation patterns on crop production and food security will get worse in SA. These impacts were examined by analyzing a relationship between crop yields and the amount of soil water availability during the growing season of various crops. Prevalence of water and heat stresses during the crop establishment and critical growing period (i.e., flowering, pollination, and grain filling) is detrimental for many crops (Porter and Semenov 2005; Hedhly et al. 2009). If unabated, changes in temperatures and precipitation patterns in SA will have significant impacts on agriculture in the long run (Aggarwal and Sinha 1993; Lal 2011). However, the actual impact of climate change on agriculture varies by crops, locations, and adaptive capacities to climatic risks (Vermeulen et al. 2012), and thus, adaptive capacity also influences agricultural productivity (Panda et al. 2013; Aryal et al. 2018a). For example, people in Hindu Kush Himalayan region, encompassing parts of Pakistan, India, and Nepal, are particularly vulnerable to climate change because of high dependence on agriculture for livelihood, physical isolation, limited access to global markets, low productivity, and poor infrastructure (Rasul et al. 2019).

In the last few decades, many studies examined the impacts of climate change on major food crops (i.e., rice, wheat, and maize) in SA. Results suggest that the yields of these three crops are significantly influenced by the changes in temperature (Table 1) and precipitation patterns/rainfall variability (Table 2) in the region. Comparing the yield level of the 1990s without carbon fertilization effects with that of 2020s and 2050s, Parry et al. (2004) showed that crop yield will reduce by 2.5–10% in several parts of Asia in the 2020s and 5–30% in 2050s. By assessing the possible impacts of thermal and hydrological stresses on agricultural productivity in SA, Lal (2011) indicated that the impact of global warming on food production might not be extremely severe until the 2020s given that water for irrigation is available and agricultural pest can be kept under control. However, after 2050, the productivity of summer crops would reduce with increased climate variability and pest incidence and virulence. Winter crops are likely to be more affected due to the rise in temperature by 2 °C. By the end of this century, the net cereal production in SA is projected to reduce at least between 4 and 10% if the temperature increases by 3 °C. Knox et al. (2012) assessed the projected impacts of climate change on the yield of eight major crops in SA and observed that the average yield of all crops will be reduced by 8% by 2050s. Their study projected that the mean yield of maize and sorghum will reduce by 16% and 11%, respectively, while no mean yield change will be noticed for rice. Lobell and Tebaldi (2014) also showed that there are significant impacts of climate change on crop yield. Table 1 summarizes the results of various studies that assess the impact of the change in temperature on crop production/productivity in different countries in SA.

A wide range of yield losses due to climate change impacts on wheat, rice, and maize crops in SA is observed. Studies on the effect of warming on crop yield in India reported yield decrease by 5%, 6–8% and 10–30% in wheat, rice, and maize, respectively (see Table 1 and references therein). A recent study has shown that such crop-damaging temperatures have led to an increase in the rate of suicides among smallholder farmers in India (Carleton 2017). Nevertheless, lack of crop insurance and the inability to repay loans could be some of the plausible reasons for suicides among farmers.

In some areas such as mountainous regions of Nepal, climate change can have positive impacts on yields, particularly on wheat (Table 1). However, rice and maize yield in the mid-hills and Terai region significantly reduced with increasing temperature. In Bhutan,

Table 1 Impact of change (increase) in temperature (ΔT) on crops in South Asian countries

Country	ΔT (+)	Wheat	Rice	Maize	References[a]
India	< 2 °C	Yield decrease by 0.45-Mg ha^{-1} (1); yield decrease by 0.4 Mg ha^{-1} (2); yield decrease by 5.2% (6)	Yield decrease by 6% (3); yield decrease by up to 8.2% (4)	Yield decrease by 10–30% under 350 ppm CO_2 (5)	[1]Sinha and Swaminathan (1991); [2]Morey and Sadaphal (1981); [3]Saseendran et al. (2000); [4]Mathauda et al. (2000); [5]Kalra et al. (2007); [6]Gupta et al. (2017)
	2–3 °C	Decrease in all regions (1)	Yield decrease by 0.75 Mg ha^{-1} (2); in % yield decrease by 8.4% (3)	Yield decrease by 10–30% under 350 ppm CO_2 (4)	[1]Aggarwal and Sinha (1993); [2]Sinha and Swaminathan (1991); [3]Mathauda et al. (2000); [4]Kalra et al. (2007)
	> 3 °C			Yield decrease by 10–30% under 350 ppm CO_2 (3)	[3]Kalra et al. (2007)
Bangladesh	< 3 °C	Yield loss about 60% (1)	Yield decrease by 2.6–13.5% (2)		[1]Karim et al. (1996); [2]Basak et al. (2009)
	> 3 °C	Yield loss exceed 60% (1)	Yield decrease by 0.11–28.7%)[2]		[1]Karim et al. (1996); [2]Basak et al. (2009)
Nepal	4 °C	Yield increases by 18.4% due to CO_2 fertilization and by 8.6% with an increase in temperature (1)	Yield decrease by 1.8% in Terai and increase in hills by 5.3% and mountainous by 33.3% (1)	Yield decrease by 26.4% in Terai and by 9.3% in hills (2)	[1]Malla (2008); [2]Prasai (2010)
Pakistan	< 3 °C	Yield decrease by 5–7% (1); Yield decrease by 7% in Swat district and 14% in Chitral district (2); yield decrease by 6–9% in sub-humid, semiarid and arid zones (3)			[1]Aggarwal and Sivakumar (2010); [2]Hussain and Mudasser (2007); [3]Sultana and Ali (2006)
	> 3 °C	Yield decrease in arid, semiarid and sub-humid zones, but increases in humid zone (1); yield decrease by 21% in Swat district and 23% in Chitral district (2)			[1]Sultana et al. (2009); [2]Hussain and Mudasser (2007)

Table 1 (continued)

Country	ΔT (+)	Wheat	Rice	Maize	References[a]
Sri Lanka	≤ 1 °C		A loss of 6% rice output (1); yield decrease by 1–5% (2)		[1]GoSL (2000); [2]Vidanage and Abeygunawardane (1994)

[a]Number in the parentheses refers to the corresponding reference mentioned in column six

Table 2 Impacts of change rainfall variability on crops in South Asian countries

Country	Impacts	Crops	References[#]
Bangladesh	Positive and statistically significant effect	Rice	Sarker et al. (2012)
Bangladesh	Negatively affects rice yields	Rice	Mohammad and Mosharaff (2001)
Bangladesh	Variability in rice yields leading to Yield decrease by 8–17% by 2050	Rice	Rahman et al. (2009)
India	More rainfall leads to higher mNDVI in the drier western parts of the basin and lower mNDVI in the eastern parts of the basin (*)	Crops (vegetation)	Siderius et al. (2014)
India	Annual total yield were significantly correlated with all-India summer monsoon rainfall	Wheat and Rice	Kumar et al. (2004)
India	Statistical analysis of state-level Indian data confirms that drought and extreme rainfall negatively affected rice yield (harvest per hectare)	Rice	Auffhammer et al. (2012)
Nepal	The yield of individual cereals is correlated with the seasonal rainfall data	Paddy, maize, millet, wheat, and barley	Bhandari (2013)
India	All-India crop yield index shows a strong relationship with all-India summer monsoon rainfall	Food grains	Prasanna (2014)
Pakistan	Effect of rainfall on the yield of rice, wheat, and maize is negative and nonsignificant except for wheat, which is significant	Rice, wheat, and maize	Ali et al. (2017)
Pakistan	Normal precipitation during vegetative and maturity stages and their deviations from the historical mean (positive) exert a positive impact on the wheat yield	Wheat	Ahmad et al. (2014)

NDVI is Normalized Difference Vegetation Index (*); for the Rabi season, the relationship for those areas with a significant impact is mostly positive

though farming is constrained by the mountainous topography, almost 57% of the people depend on agriculture. The country has been experiencing the impacts of climate change such as crop loss to unusual outbreaks of diseases and pests, erratic rainfalls, windstorms, hailstorms, droughts, flash floods, and landslides (Chhogyel and Kumar 2018). A similar level of yield reduction was also reported in Bangladesh, Pakistan, and Sri Lanka (Table 1).

Temperature change is directly linked to change in water availability, and there are very limited studies that assess the impact of rainfall variability alone on crop productivity. For example, if India continues to deplete its groundwater, negative impacts of increased warming and other climatic variabilities on crop production are going to increase by half (Fishman 2018). One study by Kumar et al. (2004) indicates that a 19% decrease in summer monsoon rainfall reduces the food grain production by about 18%. Table 2 summarizes the results from studies assessing the impact of rainfall variability on crop production.

Most of the studies provided in Table 2 showed that rainfall variability affects crop production negatively, but the magnitude of the effect is less explored. This is one of the areas for further research. Based on this review, an adaptation of agriculture to climate change is almost imperative, particularly to rising temperature, increasing heat stress, waterlogging, and terminal heat effects.

3 Climate change adaptation measures in the agricultural sector in South Asia

By formulating effective adaptation strategies, it is possible to reduce or even avoid some of the negative impacts of climate change on the agricultural sector. However, if unabated climate change continues, limits to adaptation will be reached. Adaptation to climate change refers to the adjustment in natural and human systems in response to actual or expected climate change which moderates the intensity of harm or creates an opportunity to take advantage from IPCC (2007b) and Lasco et al. (2011). Achieving adaptation in agriculture and food security will require both technological (e.g., new varieties, better farming technologies, etc.) and non-technological (market, insurance, social networking, and risk sharing) solutions. Adaptation of the agricultural sector to climate change involves producing more food where needed, reducing or sharing risk, and improving governance (Godfray and Garnett 2014). Adaptation measures in agriculture depend on the attributes of climate change, farm types, locations, and cost to farmers (Smit and Skinner 2002). Rising temperature, waterlogging/excess or low soil moisture due to rainfall variability, terminal heat effect, and flood and droughts are the major climate change variables necessitating adaptation of SA agriculture.

Many current agricultural management practices can be optimized and scaled up to advance adaptation. Among the often-studied adaptation options are on-farm practices and biophysical measures that include increased soil organic matter, improved cropland management, use of local genetic diversity, improved livestock management, crop–livestock mixed system, multiple cropping, improved grazing land management, increased food productivity, prevention and reversal of soil erosion, agroecological approaches, and so on (Altieri and Koohafkan 2008). However, Nie et al. (2016) argued that while integrated crop–livestock systems present some opportunities for climate change adaptation and environmental benefits, there are some challenges, including yield reduction, difficulty in pasture cropping, grazing, and groundcover maintenance in high-rainfall zones, and

development of persistent weeds and pests. Major adaptation options in agricultural sectors in SA are summarized in the following subsections.

3.1 Soil management

As soil upholds all the minerals that are required for crop growth, soil management is one of the most crucial measures for climate change adaptation (Bhattacharyya et al. 2015; Bedano et al. 2016; Chen et al. 2017; Cui et al. 2017; He et al. 2018). Increasing climatic variability and extreme climate events such as heavy rainfall and strong winds can accelerate the process of soil erosion. To prevent wind-induced soil erosion, tree planting and hedgerow planting are used in semiarid areas, while vegetation cover, contour plowing, and contour hedgerows are common in humid and coastal areas. In mountains mini-irrigation facilities, water harvesting and terrace gardening helps control soil erosion. Changing tillage practice and shifting to zero tillage with residue retention help cropping system to adapt to water stress, excess water due to untimely rainfall and high temperature. Sapkota et al. (2015) found that the change in tillage practices moderates the effect of high temperature (reduced canopy temperature by 1–4 °C) and increased irrigation water productivity by 66–100% compared to traditional production systems, thus well adapting to water and heat stress situations. Sequestration of soil organic carbon (SOC) is one of the important strategies not only to mitigate climate change but also to improve soil quality.

Even a small increase in SOC can have positive effects on a range of soil physical properties and thus potentially improve the resilience of soil to stress and contribute to climate change adaptation (Chakraborty et al. 2014; Powlson et al. 2016). Sapkota et al. (2017) found that zero tillage and retention of crop residues increased the soil organic carbon content by 4.66 tons per hectare over 7 years. These practices are also reported to increase water content in the soil. Therefore, such practices act as shields for the farmer from the destructions caused by drought and minimize the risk of crop loss. Better soil management increases water-use efficiency and maintains soil quality that eventually adds to sustainable agriculture.

3.2 Crop diversification, cropping system optimization, and management

Climate change threatens the sustainability of agriculture through its effect on biotic (pest, pathogens outbreaks) as well as abiotic factors (variation in solar radiation, water, temperature). Crop diversification in space (substituting one crop for another) and time (changing crop rotation or cropping system) can be a rational and cost-effective way to build the resilience of agricultural system under climate change (Lin 2011). The more diverse the production systems are, the more resilient they are in enhancing food and nutritional security in the face of climate change. In addition, diverse production systems are important for providing regulatory ecosystem services such as nutrient cycling, carbon sequestration, soil erosion control, reduction in GHG emissions, and control of hydrological processes (Chivenge et al. 2015). Crop diversification improves resilience to climate change by promoting the ability to suppress pest outbreaks while reducing the chances of pathogen transmission that may occur due to increased climatic variability and hence buffering crop production under climatic stress. For instance, disease-susceptible rice varieties, when planted in mixtures with resistant varieties over large tracts of land, had 89% greater yield and 94% reduced fungal blast occurrence than when planted in monoculture (Lin 2011). This also

helps the cropping system adapted to increased water stress. For example, the rice–wheat system in SA is water resource-intensive system requiring 1.9 m^3 of water per kg of output (Pimentel et al. 1997; Akanda 2011) and consequently more vulnerable to rising temperature as irrigation water requirement could increase with temperature. Replacing this cropping system with less water-intensive cropping systems (e.g., maize–wheat system) can enhance the adaptation of the production system to water stress. Similarly, diversification of production systems through the promotion of 'neglected and underutilized species' offers adaptation opportunities to climate change, particularly in the mountains (Adhikari et al. 2015, 2018).

The increase in temperature can affect agriculture through its impact on cropping seasons, increase in evapotranspiration, increase in irrigation water requirements, and increase in heat stress. The introduction of short duration crop varieties and planting early/late maturing varieties may help curtail the adverse impacts of climate risk (Lasco et al. 2011). For instance, the introduction of short duration and improved varieties in pigeon pea, soybean, wheat, and sorghum in India helped to improve yield by 75%, 15%, 27%, and 91%, respectively (Sonune and Mane 2018). Similarly, adopting heat-/moisture-tolerant seed varieties can address the problem of excess heat or moisture. A large proportion of rice-growing areas in India such as Uttar Pradesh (8%), Bihar and West Bengal (40%), and Odisha (27%) suffer from submergence due to flood. Almost 80% of the rice-growing areas in Eastern India are rain-fed and thus suffer either from excess water or from drought depending upon rainfall pattern. Nearly 2.7 million ha land in Bangladesh is vulnerable to drought (Paul 1998; Habiba and Shaw 2014).

Flood-resistant rice variety named *Scuba rice* can withstand 17 days of complete water submergence and yield up to 3 tons ha^{-1} under flash flood conditions (Singh et al. 2009), thereby adapting to these excess water stresses. Similarly, planting drought-tolerant rice varieties such as *Sahbhagi Dhan* and *Sushk Samrat* can help farmers in Eastern India to cope with drought. These varieties have approximately 1 ton ha^{-1} yield advantage in drought years over other varieties under similar condition (Reyes 2009). Drought-tolerant rice variety can provide yield gains between 2 and 9% in SA (Mottaleb et al. 2017).

Increasing soil salinity, especially in the agricultural land in the coastal regions, is another impact of climate change. This is a serious concern in Bangladesh where the coastal areas cover more than 30% of the total cultivable land. As a result, saline-tolerant varieties of rice—CSR 26 and CSR 43—are bred to combat austerities posed by the climate in Bangladesh. Table 3 presents the major stress-tolerant rice varieties in SA.

Effect of drought and flood is equally severe also in maize and wheat in this region. Drought is responsible for 15–20% yield loss in maize in SA. Drought-tolerant maize varieties developed by CIMMYT yield 2–3 tons ha^{-1} under drought conditions in which other varieties yield less than 1 tons ha^{-1} (Zaidi et al. 2004). Similarly, several hybrids of maize have been released in order to address the issue of heat, cold, or frost. For example, HQPM-1 and HHM-1 are tolerant to both cold and frost, while HM-1 is tolerant to frost only. In Pakistan, YH-1898, KJ Surabhi, FH-793 ND-6339, and NK-64017 showed reasonable heat tolerance and produced higher grain yield per unit area as compared to other maize hybrids under high-temperature condition (Rahman et al. 2013). The International Maize and Wheat Improvement Center (CIMMYT), which is collaborating with several national agricultural institutions and private sectors in South Asian countries in developing and deploying improved climate-resilient maize varieties, has achieved significant progress in developing and deploying elite heat-tolerant maize varieties (Cairns and Prasanna 2018). These heat-tolerant varieties help minimize yield loss due to heat stress, helping farmers to adapt to climate change (Tesfaye et al. 2017) (Table 4).

Table 3 Major stress-tolerant rice varieties in South Asia. *Source*: Compiled by authors from IRRI and CSSRI (http://www.cssri.org/index.php?option=com_content&view=article&id=135&Itemid=139) websites, Press Information Bureau, Government of India, Ministry of Agriculture and Farmers Welfare (http://pib.nic.in/newsite/PrintRelease.aspx?relid=123999)

Tolerant against	Variety of rice	Country
Drought	Sahabhagi Dhan, Sushk Samrat, Swarna, IR64, Vandana, Anjali, Satyabhama, DRR Dhan 42 (IR64 Drt 1), DRR Dhan 43, Birsa Vikas Dhan 203, Birsa Vikas Dhan 111, Rajendra Bhagwati, Jaldi Dhan 6, Sookha Dhan	India Nepal
Submergence, deep water, water-logging	SUB_1A, Swarna Sub1, Varshadhan, Gayatri, JalaMani, CR Dhan 505, CR Dhan 502, Jalnidhi, Jaladhi 1, Jaladhi 2, Sambha Mahsuri, $IR6_4$-Sub_1	India Bangladesh
Heat	*O. glaberrima*, *Oryza eichingeri, O. officinalis, O. minuta, O. longistaminata*	Subtropical Asia
Salinity	BRRI Dhan 11, BRRI Dhan 28, BRRI Dhan 29, CSR 26	Bangladesh
	CSR 43, CR Dhan 405, CSR-49, CSR 36, CSR 30 (basmati type), CSR 27, CSR 23, CSR 13 and CSR 10	India
Bacterial blight	X_{a1} to X_{a33}	India

Table 4 Major stress-tolerant maize varieties in South Asia. *Source*: Compiled by authors from CIMMYT website and also with personal communications with CIMMYT maize scientists, Press Information Bureau, Government of India, Ministry of Agriculture and Farmers Welfare (http://pib.nic.in/newsite/PrintRelease.aspx?relid=123999), and Rahman et al. (2013)

Tolerant against	Variety of maize	Country
Drought	Pusa Hybrid Makka 1, HM 4, Pusa Hybrid Makka 5, DHM 121, Buland, MIMH1 and MIMH2	India Sri Lanka
Submergence, deep water, waterlogging	HM-5, Seed Tech-2324, HM-10, PMH-2, TA-5084	India
Heat	YH-1898, KJ Surabhi, FH-793 ND-6339, NK-64017	Pakistan
	BHM14, BHM15	Bangladesh
	RCRMH2, Lall-454	India
	Rampur Hybrid-8, Rampur Hybrid-10	Nepal
Cold and frost	HQPM-1, HHM-1, and HM-1	India

Changing the cropping pattern, introducing new crops or replacing existing crops, or changing crop sequence can be a way to climate change adaptation (Lasco et al. 2011). In drought-prone areas of India, farmers use drought-adapted crops such as sorghum and also adjust their production practices as a mechanism to spread risk such as staggered planting (Satapathy et al. 2011). Farmers use leguminous crops, mostly red grams, mung bean, and peanuts, to supplement nitrogen to the soil which is lost due to soil erosion or excess flooding. In the regions with cool and humid climate, legumes are planted/mixed with the main crop, to protect the fallow land (Satapathy et al. 2011) (Table 5).

A recent study in Ludhiana of India shows that shifting planting date of wheat and transplanting date of rice to 15 days earlier than the usual date could minimize yield loss by more than 4% (Jalota et al. 2013). Likewise, Mall et al. (2004) stated that delaying the sowing dates would be favorable for reducing the yield loss of soybean at all locations in India. A study by Hussain and Mudasser (2007) in the mountain region

Table 5 Major stress-tolerant wheat varieties in South Asia. *Source*: Compiled by authors from CIMMYT and CSSRI (http://www.cssri.org/index.php?option=com_content&view=article&id=135&Itemid=139) websites, Press Information Bureau, Government of India, Ministry of Agriculture and Farmers Welfare (http://pib.nic.in/newsite/PrintRelease.aspx?relid=123999), and Climate Resilient Wheat Innovation Lab, a project under US government's global hunger and food security initiatives (https://www.agrilinks.org/activities/climate-resilient-wheat-innovation-lab). ICAR—Indian Institute of Wheat and Barley Research, Karnal

Tolerant against	Variety of wheat	Country
Drought	PBW 527, HI 1531, HI 8627, HD 2888, HPW 349, PBW 644, WH 1080, HD 3043, PBW 396, K 9465, K 8962, MP 3288, HD 4672, NIAW 1415, HD 2987	India
	Dharabi, Ihsan, FSD-08, Khirman	Pakistan
Heat	Jauhar, Gold, AAS, Ujala, Galaxy	Pakistan
	K1114, NIAW1994, DBW107	India
Salinity	KRL 213, KRL 210, KRL 19 and KRL 1–4	India
	Pasban, Uqab, Sehr	Pakistan

of Pakistan reports that short duration varieties could help adapt agriculture to climate change in mountainous regions.

3.3 Water management

Integrated water management, which promotes an alternative use of waste and marginal water for agriculture, can be an important approach to adapt agriculture to water stress. Water harvesting, an age-old practice of collecting rainwater in India, is another potential way to manage irrigation water deficit across seasons (Satapathy et al. 2011). It is also practiced in rural Bangladesh by approximately 35% of the households in coastal areas (Ferdausi and Bolkland 2000). This also reduces runoff and supplement groundwater table. In the irrigated rice–wheat systems of India, laser land leveling has become a popular method for enhancing water-use efficiency (Jat et al. 2014; Aryal et al. 2015a). For example, laser land leveling in rice fields reduced irrigation time by 47–69 h ha^{-1} $season^{-1}$ and in wheat fields by 10–12 h ha^{-1} $season^{-1}$ (Aryal et al. 2015a). A significant amount of water saving was also observed in rice (26–30%), wheat (26–33%), maize (22–33%), and cotton (26–43%) in laser land levelled fields (Jat et al. 2014). Similarly, the application of a micro-irrigation system (sprinkler and drip) can help to save water from 12 to 84%, depending on location and crops under micro-irrigation (Kumar 2016) (Table 6). System of rice intensification (SRI) is a set of crop, soil and water management practices in which 8–15 days old seedlings are transplanted singly and irrigated intermittently to keep rice fields only moist, but aerated. Compared to flooded system, SRI is reported to increase crop yield by more than 10% with less water consumption (i.e. 25–47% less water) in India (Barah 2009), China (Wu et al. 2015) and Nepal (Reeves et al. 2016). Both by reducing cost of production and by increasing yield, SRI helps increase the farmers' income thereby enhancing their adaptive capacity. Further, SRI crop matures earlier thereby reducing the risk of crop losses and make land available for other crops. In addition, rice plants grown with SRI practices, by having stronger tillers and root systems and tougher leaves, are more resistant to the biotic and abiotic stresses that accompany climate change such as heat stress, drought stress, flooding, storm, and disease damage (Wu et al. 2015)

India has initiated several programs to address water paucity regionwise. Integrated Wasteland Development Programme (2001), Desert Development Programme (1973–1974) and Drought-Prone Area Programme (1977–1978) were started to mitigate causalities of desertification and drought-affected areas, promote dryland farming, create employment opportunities, bring wasteland under cultivation to improve agricultural productivity due to increased demand for grains, and utilize rainwater for irrigation.

3.4 Sustainable land management

Sustainable land management practices such as agroforestry, conservation agriculture, sustainable intensification, and cropping system optimization all contribute to climate change adaptation. Recently, sustainable intensification has received more international attention (Godfray 2015). Sustainable intensification acknowledges that enhanced productivity needs to be accompanied by the maintenance of other ecosystem services and enhanced resilience to shocks (Vanlauwe et al. 2014a, b). Sustainable intensification may be achieved through a wide variety of means. For example, improved nutrient- and water-use efficiency and integrated soil fertility and pest management practices can be part of sustainable

Table 6 Water management practices for climate change adaptation

Practices	Adaptation to water stress	References
Alternate wetting and drying (AWD)	Reduces almost 30% water use in rice production as compared to a conventional flooding system without reducing rice yield	Gathala et al. (2013) and Ye et al. (2013)
Direct seeding of rice (DSR)	Saves water and help adapt to water stress	Pathak et al. (2013)
Improved irrigation methods	Micro-irrigation system (sprinkler and drip) saves 12–84% of water	Kumar (2016)
Laser land leveling	Reduced irrigation time in rice by 47–69 h ha^{-1} $season^{-1}$ and wheat by 10–12 h ha^{-1} $season^{-1}$	Aryal et al. (2015a)
	Water saving in rice (26–30%), wheat (26–33%), maize (22–33%), and cotton (26–43%)	Jat et al. (2015)

intensification (Benton et al. 2018). Farmers in Haryana and Punjab states of India have adjusted their agricultural practices to rainfall variability and declining groundwater table by using laser land leveling and practicing conservation agriculture. Laser land leveling can substantially increase water- and nutrient-use efficiency, thereby adapting agriculture to water stress condition. Using zero till on wheat production system yields both economic and environmental benefits. A study by Aryal et al. (2015b) in Haryana shows that farmers can save approximately USD 79 ha^{-1} in input costs and increase net revenue of approximately USD 97.5 ha^{-1} under zero tillage-based wheat production compared with conventional tillage. They also showed that zero tillage-based wheat production reduces GHG emission by 1.5 Mg CO_2-eq ha^{-1} wheat-season^{-1}.

Agroforestry (i.e., cultivation of woody perennials with agricultural crops on the same unit of land) enables not only to sequester carbon but also to adapt agriculture to droughts, floods, and other natural disturbances (Waldron et al. 2017). Similarly, Silvopastoral systems, which combine the grazing of livestock and forestry, are particularly useful in reducing land degradation, where soil erosion risk is high (Murgueitio et al. 2011). Under the agroforestry system, leaf litter gets decomposed when mixed with an aerobic and anaerobic microorganism. Such a process improves soil fertility, reduces water runoff, and controls soil erosion, which eventually increases resilience to climatic variability. In India, it is common to plant trees like *Eucalyptus* and *Populous* in the agricultural fields, particularly on farm boundaries (Murthy et al. 2013). This provides a win–win situation for rural farmers as they obtain double income: one from trees—producing fruits, timber, flowers, and medicines—and the other from the crops grown. With an objective of enhancing carbon sinks and empowering local communities with appropriate adaptation measures, the Green India mission under the National Action Plan on Climate Change (NAPCC) targets 1.5 Mha of degraded agricultural land and fallows to be brought under agroforestry; about 0.8 Mha under improved agroforestry practices on existing lands; and 0.7 Mha of additional lands under agroforestry (MoEF 2010).

3.5 Crop pest and disease management

Crop pest and disease management is crucial for adapting agriculture to climate change. Increasing climatic variability may create favorable conditions for pests and diseases. With the rising temperature, range of crop pests and diseases are projected to expand to higher latitudes (Rosenzweig et al. 2001). Global yield losses due to insect pests of three staple grains (i.e., rice, wheat, and maize) are projected to increase by 10–25% per degree of global mean surface warming, and such losses will be more acute in temperate regions (Deutsch et al. 2018). Governments in South Asian countries emphasize on integrated pest management to tackle the increasing emergence of pests and diseases and have provided training to farmers (Gautam et al. 2017).

3.6 Risk management

Risk management is an important concept in climate change adaptation of the agricultural system. Risk sharing (co-investment, community engagement), risk transfer (crop/livestock insurance, index-based insurance for scaling up climate-smart agriculture, etc.), improved forecasting and agro-advisory and institutional measures at the local, national, and global

levels are mechanisms for buffering climate change risk. The details of each of these types are as follows:

3.6.1 Crop insurance

Farming is very risky as it is highly dependent on agroecological and climatic condition. Hence, the provision for insurance is an important mechanism to reduce risk. However, in SA, the insurance market in general and particularly the crop and livestock insurance market are underdeveloped. The major limitation of for the expansion of agricultural insurance is that the cost of the insurance product is quite high, which makes it unaffordable for the poor smallholder farmers. Lack of awareness among farmers, lack of legal and regulatory framework, lack of financial capability of the providers, limited range of agricultural product, lack of technical expertise, high cost of the insurance products, and affordability of the farmers and the high administration cost of the micro-insurance are major hurdles for provision of insurance in developing countries.

To secure poor farmers' livelihood during climate extremes, crop insurance scheme based on an area index is introduced as an adaptation strategy in some of the South Asian countries. In 2002, India launched the National Agricultural Insurance Scheme called Agricultural Insurance Corporation for Farmers. Under this scheme, almost 59,000 farmers were insured in 23 states and 2 Union Territories for winter crops from 1990 to 2000. The premium rates of food crops and oilseeds range from 1.5 to 3.5% and are determined on the basis of flat rates or actuarial rates (Hoda and Gulati 2013).

In Nepal, crop insurance is introduced in 2013 by the National Insurance Board. The government of Nepal has allocated NRs. 135 million in the budget to support agriculture insurance program in 2013–2014 and continuously allocating budget to the program. There are also micro-level initiatives to insure farmers through local cooperatives. For example, in Rupendehi district of Nepal, where CGIAR research program on Climate Change, Agriculture and Food Security (CCAFS) has been working for the past few years, local farmers established a cooperative that provides insurance schemes to small farmers (holdings up to 1.33 ha) producing paddy and wheat (Shakya et al. 2013). To insure their crops, farmers need to pay 15% of their estimated production, and in the case of crop failure, they are compensated up to 80% of their loss.

In Bangladesh, crop insurance was introduced through the state-owned insurance company, Sadharan Bima Corporation (SBC) in 1977, and discontinued in 1996 (Climate Change Cell 2009). The major objective of the insurance program was to indemnify farmers against the crop loss due to flood, cyclone, hailstorm, windstorm, drought, plant disease, and pest and insects. Paddy, wheat, and jute crops are insured against variation in yield, and thus, insurance covers 80% of the expected value of production. However, this program was not successful in Bangladesh. Of the several weaknesses, difficulty in estimating crop loss due to defined climatic events and moral hazards are the major issues.

Although agriculture is the backbone of Pakistan's economy, it is vulnerable to the climate-induced disasters which threaten the livelihood of the smallholder farmers who have little or no resilience capacity; hence, agriculture insurance is critical for Pakistan (Siyal 2018). Livestock farmers who adopt insurance to cope up with the climate risk are found to have better well-being (Rahut and Ali 2018). However, agricultural insurance is still in its nascent stage of development, and it started with livestock insurance in 2008 (Arifeen 2017).

3.6.2 Index insurance

Insurance based on a weather index such as rainfall, temperature, or drought rather than actual crop loss due to climatic events is useful to promote climate-smart agricultural practices. A weather index such as flood or drought, which is highly correlated with production loss, is determined, and a threshold level is set based on the recorded level of the specific weather variable at a local weather station. When the weather index crosses the predetermined threshold level, the farmer will get paid. However, the weather index insurance does not cover the actual crop loss incurred to an individual farmer. Unlike crop insurance, the transaction cost of weather index insurance is low because the insurance company does not need to visit the farmers' field to verify the amount of crop loss. As the payout is not associated with the crop loss, farmers' incentive to make efforts for crop survival is high in this case, and thus, unlike other insurance schemes, moral hazards are less associated with this type of insurance. Thus, index insurance shifts more benefits to farmers rather than to intermediaries.

In India, index insurance was first implemented in Andhra Pradesh and Uttar Pradesh in 2003 with the assistance of the World Bank. This project covered 1500 small farmers in Andhra Pradesh and Uttar Pradesh and was scaled up in 2007 with coverage of more than 10,000 farmers. State agricultural insurance company along with other local insurers in India started replicating the index insurance and reached to more than 25,000 farmers in 2004. Index insurance was also used as a development program in 2007 when PepsiCo provided insurance to 4575 potato farmers against late blight disease germinated due to high temperature and humidity (Hellmuth et al. 2009). Another successful insurance project was carried out by Agricultural Insurance Company, India (AICI), which introduced a new rainfall-based insurance product called *Varsha Bima* (rainfall insurance) in 4 states of India (Andhra Pradesh, Karnataka, Rajasthan, and Uttar Pradesh) covering 21 rain gauge stations in 2004 (Nair 2010). The scaling up has gained momentum, and in 2008, about 675,000 farmers in Rajasthan alone participated in this insurance. Aforesaid, for any index insurance to be successful appropriate index, it has to be identified, and adequate data should be available to act upon it. The weather-based crop insurance scheme is publicly subsidized in India, and thus, over 9 million farmers held this scheme policy by the end of 2011 with a premium volume of over USD 258 million and total sum insured over USD 3 billion. These policies covered more than 40 types of crops and 9.5 million hectares (Rao 2011).

Although crop insurance can compensate to farmer's losses from climatic risks, yet it has been beset with several problems such as lack of transparency, high premium, delay in conducting crop cutting experiments, and non-payment/delayed payment of claims to farmers. There is an urgent need to increase farmers' understanding of agriculture insurance program, better design the insurance scheme, and generate site-specific data for loss assessment (Matsuda and Kurosaki 2019).

3.6.3 Social networking and community-based adaptation

Technological solutions alone cannot achieve the adaptation of agriculture to climate change. Adaptation to climate change also has social, economic, and political dimensions which influence how climate change impacts different groups within society and measures to respond to them. Community-based adaptation, which involves the mobilization of community members to assess their situation and to act in accordance with their local needs,

knowledge, capacities, and priorities, is another approach to climate change adaptation. Community-based adaptation needs to start with communities' expressed needs and perceptions, and to address poverty reduction and livelihood benefits besides reducing vulnerability to climate change. This approach needs to incorporate information on climate change, its impacts, and potential coping strategies in the planning process (Reid et al. 2009). This gives an insight into the problems of the vulnerable and sufferers and encourages them to search for solutions based on their knowledge and skills. This enhances the resilience of farm community through strengthened social networks, social capital, and collaboration.

Community Forestry Program in Nepal is commonly known as a community-based climate change adaptation mechanism. It is a self-regulatory and autonomous body in managing the rural forest, which covers almost 2.2 million households in rural Nepal (Bishokarma 2012). In addition to improving the agricultural land, these efforts have led to the diversification of their income by selling timber, fruits, and vegetables (Pande and Akermann 2009).

Smallholder farmers in flood-prone areas of Bangladesh have adapted to water logging by growing vegetable in floating gardens called *Baira* (Lasco et al. 2011). This practice has become a source of vegetable production. Extreme climate events like erratic rainfall and declining water resources also forced the community to take measures such as the construction of check dams and hedge against the river flow, shift to cash crops, and installation of water boring pumps for irrigation. In Kodikitunda of Odisha state of India, where the majority of farmers rely on rain-fed agriculture for their livelihood, farmers suffer from declining crop yields due to lack of irrigation water and soil erosion. In this situation, village communities in conjunction with Agragamee, a local NGO, are able to construct dams, field ponds, and wells, and gully plugging (Satapathy et al. 2011).

Local farmers cooperatives is an institutional mechanism for climate change adaptation in agriculture as this provides an opportunity to implement climate-smart agricultural practices and increase crop yields under changing climate (Shakya et al. 2013). Annapurna Seed Producers Cooperatives Organization Limited (ASPCOL) established in 2007 in Rupendehi district of Nepal stands as an example of such cooperative which was set up by the collective efforts of local farmers. Many members of this cooperative are now shifting from traditional methods of farming to climate-smart farming such as laser land leveling, direct seeded rice, system of sustainable rice intensification, covering the field with green manure, and adopting stress-tolerant varieties of rice and wheat. By adopting DSR, the farmers were able to double their farm income and at the same time contribute to GHG mitigation through reduced methane emission and resource conservation in terms of water saving (Shakya et al. 2013). Some farmers of this cooperative have recently leveled their land using laser land leveling, which help them grow crops with less water (Shakya et al. 2013). Youth farmers' cooperatives in the Haryana state of India are promoting several climate-smart agricultural practices.

3.6.4 Collective international action

There is increasing evidence of the impact of climate change on glaciers of the Himalayas resulting in a rapid meltdown. Receding glaciers will have a significant implication for the rivers system in SA as the rivers Ganges, Indus, Meghna, and the Brahmaputra originate from glacial melt and sustain the lives of millions downstream (Lal 2010). There is a need for international collective action to build synergies with multiple stakeholders at different

levels and a regional vision to address this problem as it affects the entire South Asian region rather than an individual country (Ahmed et al. 2019). For example, glacier melting in Nepal will not only affect agriculture in Nepal but also in India, Pakistan, Bhutan, and Bangladesh as rivers Ganges, Indus, and Brahmaputra are perennial rivers emerging out from the Himalayas. Therefore, regional integration of climate change policies under a suitable institutional framework can help achieve the required level of mutual cooperation to address the future climate risks (Mirza et al. 2019). Regional cooperation is thus essential to lessen the intensity of floods owing to the rise in sea levels which considerably affect fisheries in the coastal areas of India, Bangladesh, and Sri Lanka.

3.6.5 Integrated agro-meteorological advisory services

In 2007, India launched a project to provide agro-meteorological information to farmers with the help of multi-institutional framework, which includes agricultural universities, research units, NGOs, and media institutions. This provides four types of services to farmers: (1) a meteorological information, i.e., weather observation and weather forecasting for the next 5 days; (2) an agricultural component, which reports 'weather sensitive stresses' and advises farmers how weather forecasts can be useful for protecting crops from adverse weather conditions; (3) an extension component, a system for two-way communication between farmers and agricultural scientists; and (4) an information dissemination component by employing mass media. This project currently provides services to over 2.5 million farmers in India and has an estimated economic impact of about USD 10 billion. It is a three-tier project at national, state, and district levels. At the national level, it is prepared for agricultural planning and management requiring cooperation from Crop Weather Watch Group (CWWG), NGOs and State and District Agromet Advisory Service Council. State Agromet works for the fertilizer industry, pesticide industry, irrigation, and seed department. The lowest level District Agromet works with the farmers from the basic step of sowing to harvesting the crop, managing livestock, and disseminating information on agriculture-related aspects to farmers (MoES 2013).

India also established an institution called *Kisan Sanchar Samuha*, which provides weather information to farmers through mobile phones. Under this scheme, farmers receive farm-specific solutions instead of generalized weather information. This also intensified their connectivity with markets outside their local area. Farmers in several states of India are benefited immensely due to timely and appropriate information on the application of inputs like fertilizer, pesticides, and so forth. Overall, uncertainty regarding the impacts of climate change in agriculture is one of the main reasons behind inaction by farmers as well as governments. However, recent studies indicate that no-regrets adaptation, i.e., the actions that benefit farmers regardless of how and when climate change impacts farmers, can be a useful approach to address the issue of inaction (Vermeulen et al. 2013). Such actions support households in building capacity and resilience to risks and uncertainties arising from climate change. For this, local government can play an important role in promoting and educating farmers on climate change adaptation strategies, skill development for mitigating risks, and constructing protective infrastructure.

3.7 Specificity and economic efficiency of adaption options

Given the site-specific nature of climate change effect on agriculture together with wide variation in agro-ecosystems types and management, and socioeconomic conditions, it is essential that adaptation strategies must be developed according to environmental and cultural contexts at the regional and local levels. For example, smallholder farmers in low-income countries such as Nepal, India, and Bangladesh are severely affected by climate change because of poor infrastructure, limited access to the global market, physical isolation, low productivity, and lack of access to formal safety nets. So the overall ambition of agricultural adaptation in these countries is to have systems that are highly climate-resilient while supporting increasing yield to feed the growing population. Even within SA, mechanization and commercialization could be adaptation options in some parts of India, whereas in the mountainous areas of India and Nepal with limited access to the global market and formal safety nets, diversification of production systems through the promotion of neglected and underutilized species (NUS) offers adaptation opportunities to climate change (Adhikari et al. 2017). NUS has the potential to improve food security and at the same time help protect and conserve traditional knowledge and biodiversity.

However, economic efficiency of such incremental adaptation (i.e., adaptation without changing the essence and integrity of a system) should also be considered while making such adaptation decision. For example, South Asian farmers are changing sowing and harvesting timing, cultivating short duration varieties, intercropping, changing cropping patterns, investing in irrigation, and establishing agroforestry in response to various climatic stimuli (Tripathi and Mishra 2017). However, when economic efficiency of such adaptation decreases over time, farmers opt for transformative adaptation (i.e., seeking alternative livelihood or land management measures). For example, rain-fed rice farmers in Eastern India and Nepal replace rice with upland crops such as maize or millet in drought year (authors' personal observation). Similarly, cultural dimensions are important in understanding how societies established food production systems and respond to climate change, since they help to explain differences in responses across populations to the same environmental risks (Adger et al. 2013). Local food systems are embedded in culture, beliefs, and values, and indigenous and local knowledge can contribute to enhancing food system resilience to climate change.

4 Future prospects and challenges to climate change adaptation in South Asian agriculture

Although farmers are continuously adjusting to farm risks, they are more likely to respond to short-term risks which have direct impacts on their farm operations and livelihood rather than the long-term risk of climate change. Therefore, proper assessments of climate risks and their impacts on livelihood are essential. Improved institutional support is required for the effective design and implementation of adaptation measures. South Asian countries have recently devised climate change policies at multiple levels and addressing the problem of several sectors, including agriculture. They initiated a national-level adaptation plan for climate change, though in different nomenclatures. The expertise and costs required to design and implementation of adaptation plans in these countries were mostly done United Nations Development Programs (UNDP) or United Nations Framework Convention on Climate Change (UNFCCC) or other international institutions. Climate change adaptation

costs in all sectors, including agriculture, are one of the crucial issues for sustainable adaptation programs (Amjath-Babu et al. 2018). In view of these matters, the future prospects and challenges to climate change adaptation in South Asian agriculture can be discussed as follows:

4.1 Climate policies at different levels and institutional setups to implement the policies

Enabling the policy and institutional mechanisms are essential to facilitate the scaling up of adaptation throughout the agricultural system. All South Asian countries have signed the international agreements and showed their commitments to Nationally Determined Contributions (NDC) following the Paris Agreement. Agriculture is considered as a priority sector for adaptation given its vulnerability to climate change and contribution to livelihoods of the majority of the people in this region (Amjath-Babu et al. 2018; Totin et al. 2018). Climate policies at national and sub-national levels were designed in these countries. For instance, India released National Action Plans on Climate change (NAPCC) in 2008 with the assistance of the United Nations Framework Convention on Climate Change (UNFCCC). The NAPCC consists of seven national missions, including sustainable agriculture, green India, and climate change (GoI 2008).

National mission on sustainable agriculture aims to promote crop breeding for developing abiotic stress-tolerant varieties and to create better insurance mechanisms and other innovative agricultural practices. Policies to adapt agriculture to climate change also relate to the other policies concerning with the use of natural resources such as water, forest, and land. National Water Mission under NAPCC focuses on ensuring least water wastage, proper recycling of water, and encouraging environmental-friendly methods of water harvesting and conservation practices. Similarly, the National Mission for Green India aims to preserve forests and maintain ecological balance. National Mission on Strategic Knowledge for Climate Change primarily aimed at supporting research on climate change in academics by establishing universities and disciplines in institutions and to enhance private sector initiatives to develop adaptation and mitigation technologies (Ofoegbu et al. 2018). Analogously, other countries in SA also introduced a national adaptation plan for action, recognizing that agriculture is highly vulnerable to climate change. Nepal commenced the National Adaptation Plan for Action (NAPA) in 2010 promoting community-based adaptation. Nepal also developed a Local Adaptation Plan of Action (LAPA) which contributes to bridging the gap between macro policies like NAPA and local realities. Climate resilience and poverty alleviation are some of the priorities of these adaptation programs.

In Bangladesh, the Ministry of Environment and Forest took the lead for preparing NAPA. NAPA follows a holistic approach by bringing together government, local NGOs, and communities to work for climate change adaptation and to achieve sustainable development. Adaptation measures in Bangladesh also focus on promoting adaptation to coastal crop agriculture to combat increased salinity and adaptation to agriculture systems in areas flood-prone areas. Hence, this also prioritizes maize production with no-tillage methods in flood-prone areas. Fisheries are also one of the priority sectors under agriculture in Bangladesh. Therefore, adaptive and diversified fish culture practices are given priority in flood-prone northeast and central regions in the northeast, and culture of salt-tolerant fish species is promoted in coastal areas. In natural disaster-prone areas, coastal afforestation with community participation' was launched to strengthen the adaptive capacity to address situations arising after the disaster has occurred and to enhance carbon sink to control GHG

emissions. These programs and plans have already been initiated in Bangladesh at the community level to increase the resilience of individuals and communities, with the cooperation of CARE international alongside educating local NGOs about climate change adaptation, in the flood-prone areas.

Institutional change and flexibility to enable adaptation are a key challenge as the adaptive management approaches are new to the existing bureaucratic systems in these counties (Ford et al. 2015; Nightingale 2017; Vij et al. 2017, 2018). However, there are limited studies to assess the overall effectiveness of adaptation actions taken at local, sub-national, and national levels (Ford et al. 2015; Rahman et al. 2018). In some cases, synergies between national- and sub-national-level policies are not strong enough to bring the desired effects (Dhanapal 2014; Aryal et al. 2016). For example, Pakistan launched the first national climate change policy in 2012. Despite having different levels of policy for climate change adaptation, there is no clear linkage between national-level and local-level adaptation plans in Pakistan (Chaudhury et al. 2014).

4.2 Financing the climate change adaptation in agriculture

Development of national adaptation plans in SA comes under different provisions of UNFCCC. In the case of least developed countries, 'Least Developed Countries Fund (LDCF)' supports the funding for preparation and implementation of national adaptation plan of action (NAPA). For example, Bhutan received a grant to finance a project to reduce climate-induced risks and vulnerabilities from glacial lake outbursts. Being a lower middle-income country, Pakistan developed NAPA under UNFCCC guidelines rather than support from LDCF (UNFCCC 2012). Although international financing of adaptation goes to countries which are more susceptible to climate change risks, it is challenging to collect adequate fund to meet the increasing cost of adaptation (Betzold and Weiler 2017). Climate change adaptation in agriculture requires large investment (Table 7), which is often beyond the capacity of smallholders in SA.

As farmers in SA have an average farm size of 0.5 ha, their economic viability can be severely threatened by climate change. In most cases, farms under 2 ha are economically not profitable, and thus, proper design of policy to finance adaptation program in agriculture is very crucial (Dev 2012). Given that several agricultural practices have both greenhouse gas mitigation and climate change adaptation benefits, prioritizing those practices can help reduce the overall cost of climate change adaptation programs in agriculture sector (Aryal et al. 2019a).

Table 7 Estimated financial needs of agricultural adaptation in South Asia (2015–2030). *Source*: Adapted from Amjath-Babu et al. (2018)

Countries	Estimated cost (in USD billion)	Estimated cost including adaptation to disasters (in USD billion)
Bangladesh	18	42
Bhutan	0.22	1.22
India	206	332
Nepal	4.24	10.1
Pakistan	40.74	97
Sri Lanka	4.8	9.99

4.3 Understanding of farmer adaptation behavior

Adaptation behavior is complex and dynamic. It depends on several climatic and non-climatic factors (Goodrich et al. 2019). Besides, few studies in SA focus on the determinants of adaptation to climate change with a focus on farmer behavior (Feola et al. 2015). Education and interaction among farmers are found to change their adaptation behavior. Therefore, rather than a top-down approach to the extension, focusing on the farmer-to-farmer communication can help to improve adaptation in agriculture (Aryal et al. 2018b). Changing gender roles and social norms, rising level of education and awareness about climate change among farmers may shift their focus on climate change adaptation, particularly in the use of climate-smart agriculture for climate change adaptation (Aryal et al. 2014, 2018a, b, c). Recent studies show that economic benefits alone may not explain farmer's adoption of climate-smart agricultural practices in India. For example, although laser land leveling is found to be one of the climate-smart agricultural practices that help adaptation to some climate stresses, many farmers in India have adopted it partially (Aryal et al. 2018a). Multiple factors such as gender of the household head, education, and market access are found to have affected adaptation behavior, and thus, policies focusing on adaptation require flexibility to address these factors adequately.

5 Conclusion

Climate change adaptation is essential for agricultural sustainability. Building adaptation in the agricultural system requires simultaneous attention to increasing production by adopting varieties of technologies, adopting sustainable land management practices, building on and use of local knowledge/culture, and formulating enabling policy and institutional setups. Though several adaptations options are available in agriculture, not all of them can be applied to all location, as they are mostly location-specific. All countries in SA have devised national-level policies to climate change adaptation. However, their financing and proper implementations remain critical as most of them are financed through international institutions, and thus, any change in donor priorities can constrain their sustainability. Therefore, institutions at the international and national levels need to work in cooperation to deal with the challenge of climate change.

Alternative adaptation measures in agriculture are continuously being developed. For instance, there are several researches on new varieties that can tolerate climatic stresses. Similarly, policies and institutions in SA are increasingly becoming responsive to climatic risks. Insurance mechanisms and other community-based approaches are also evolving and improved continuously to address the challenges. Although all South Asian countries have come up with national, state, and local policies to address climate challenges, they are not at the same level. Still, there is a need to enhance coordination at different levels of institutions implementing climate change adaptation policies.

Despite the availability of options for climate change adaptation in agriculture, inefficient institution and financing might hinder South Asian agriculture to tackle climate challenges in the future. Several technical measures along with the local knowledge contribute to adapting agriculture to climatic variability. However, the researches related to the magnitude of impacts of climate change on specific crops vary over ecological zones, and this largely depends on the resources that are available to the farmers for

adapting to climate change. As a result, generalizing the impact of climate change and its severity in agriculture is very difficult and seems impractical. Of the impact studies, the assessment of the impact of other climate variables except for temperature on crop yield is limited and thus an area for future research.

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