Climate Change and Farming System: A Review of Status, Potentials, and Further Work Needs for Disaster Risk Reduction

Mukhtar Ahmed

Abstract

Management of farming and food system under changing climate and increased population pressure is critical for the future of biodiversity. High yield farming results in higher emissions of greenhouse gases which are the main driver of climate change, thus damaging the farming system across the globe. The farming system and climate change have strong interactions among each other, and different agroclimatic conditions determine the types of the farming system. Therefore, to have sustainable and resilient farming systems, it is important to understand key drivers that determine farmers' adaptive capacity under changing climate. The main drivers includes environmental pressure, water availability, crop characteristics, and socioeconomic conditions of farmers. However, farmers give less importance to climate change which leads to clear gaps in the implementation of outreach activities. Farmers with small land holdings are more vulnerable to climate change as compared to larger-scale farmers as they have lower resources to adopt new technologies. For designing of effective adaptation policies, it is important to understand what adjustments farmers make to cope with climate change. A previous study about the list of adjustments has shown flaws as more importance was given to climate change as compared to other socioeconomic drivers that alter farmers behaviours. Thus, non-climatic drivers should be part of analysis to design effective climate adaptation strategies and remove potential flaws. Hence after assessing all drivers, the following climate adaptation measures are recommended for farm-level adjustments to minimze the

M. Ahmed (✉)
Department of Agronomy, Pir Mehr Ali Shah Arid Agriculture University, Rawalpindi, Pakistan
e-mail: ahmadmukhtar@uaar.edu.pk

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impact of disaster: altering the planting date, revising and updating crop varieties, implementing crop switching, and promoting diversification. A case study of smallholder crop-livestock system in sub-Saharan Africa was used to suggest possible adaptation and mitigation options under changing climate. These include (1) providing cushions to farmers against risks (e.g. insurance scheme, weather forecasting, and early warnings system), (2) improving skills and capacity of farmers and value chain actors, and (3) fostering farm investments (e.g. credit facilities, land tenure security, and value chain development). The reviewed work also emphasized the implementation of effective insurance schemes and weather-index insurance systems (WIIS) that can significantly benefit smallholder farmers. Furthermore, economic incentives, technical support, and collaborative networks can facilitate adoption of sustainable agricultural practices by farmers.

Keywords

Climate change · Farming system · Diversification · Farm-level adjustments · Adaptation and mitigation options · Smallholder crop-livestock system · Insurance · Weather-index insurance systems

1 Introduction

Farming system research, development, and extension work involves the integration of plants, animals, and soil at the paddock and farm level. A sustainable farming system needs to have five important characteristics, i.e. it should be (1) purposeful (have goals and allocate resources to achieve these goals), (2) dynamic (change over time in response to internal or external factors), (3) stochastic (uncertain future behaviour and difficult to predict), (4) open (interact with the environment), and (5) abstract (conceptual rather than purely physical in nature) as proposed by Dillon (1992). However, climate is the main defining factor of different farming systems across the globe. The farming system and climate change have strong interactions among each other, and different agroclimatic conditions determine the types of the farming system (Hutchinson et al. 2005). Climate change is visible in the form of extreme variations in weather, e.g. wind, precipitation, and temperature. Maskrey et al. (2007) reported that poor agricultural communities of the developing world is the most affected by the climate change although the developing world is only contributing 10% to the global greenhouse gas emissions. The impact of climate change on developing countries is more visible as their economy is predominantly agriculture based which is open to the vagaries of nature. Thus, it poses serious challenges to the socioeconomic and ecological systems. The World Bank also highlighted this aspect in their report and stated that the poorest people in the south Asian regions are suffering most due to climate change. Poor people in the region are in a poverty trap due to the frequent occurrence of extreme weather events in recent decades. The number of warm days and nights has increased and in future intensity, frequency, and length of heat waves will increase across the globe. Climate change will alter the rainfall intensity and duration, and the occurrence of heavy perception will be more in future with spatio-temporal variability (Field et al. 2012). This variability will lead to the change in water availability to crops, thus affecting crop yield and income of the farm. Maon et al. (2009) stated that the occurrence of abnormal disasters has increased from 125 per year to 400–500 since 1980, and it is mainly because of climate change. Furthermore, climate change, food security, and poverty have strong interactions among each other. Climate change impacts will be more visible in coming decades particularly on agriculture as it is the climate-sensitive sector. Around 2.5 billion people will be affected due to climate change and variability. Adaptation can be a good option to reduce the adverse impact of climate change on agriculture. It has been elaborated in many studies that the detrimental impact of climate change on agriculture can be offset by different farm-level adaptation measures (Deressa et al. 2009; Smit and Skinner 2002). Gbetibouo (2009) further highlighted the importance of adaptive capacity of farming community as it can change the degree of impact of climate change on the agriculture sector. Different localized adaptation strategies have been suggested by researchers, and they have been shown in Fig. 1 (Deressa et al. 2009; Hussain and Mudasser 2007; Mendelsohn and Davis 2001; Smit and Skinner 2002). Similarly, some other adaptation measures have been adopted to mitigate the issue of climate change. It includes adjusting the ratio of livestock to cropping or crop area, adjustment in the whole farm water-use efficiency, actions to minimize livestock emissions, and on-farm diversification (OFD) (Hayman et al. 2012; van Zonneveld et al. 2020). Willett et al. (2019) described OFD as a promising strategy for farmers to adapt to climate change. Figure 1 shows that how we need to work with farmers to make good decisions about OFD of pasture, cropping, and agroforestry systems. These seven steps are (Fig. 2) useful for all types of farmers particularly for smallholder farmers. Farmers with small land holdings are more vulnerable to climate change as compared to larger-scale farmers as they have lower resources to adopt new technologies. Thus smallholder farmers should be the main target of climate smart interventions also called as climate smart

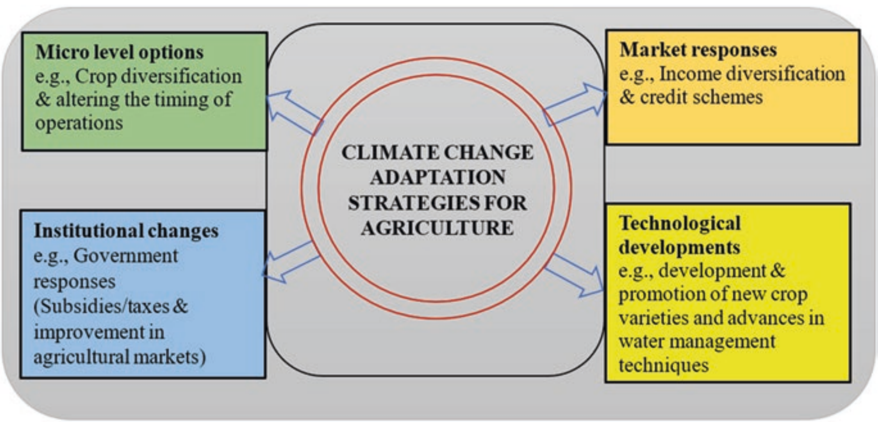

Fig. 1 Possible adaptation strategies for agriculture

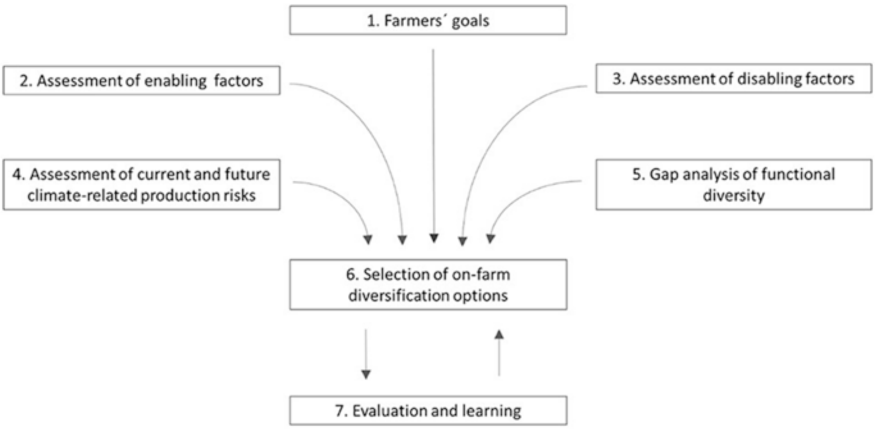

Fig. 2 Steps to develop on-farm diversification strategies for climate change adaptation (Source: van Zonneveld et al. 2020)

agriculture. Lipper et al. (2014) reported that climate smart agriculture can help farmers to adapt to climate change. van Zonneveld et al. (2020) proposed a seven-step decision-making process that can help to connect researchers and practitioners with farmers. Defining farmers goals (Step 1) starts by understanding the goals of different farm households in different farming systems. Schroth and Ruf (2014) stated that farmers do diversification by considering multiple goals as they consider cereals for food security, legumes for nutrition, cash crops for income, and forage and off-season crops for animal production. Step 2 (enabling factors) comprises components of extension, farmer organization, indigenous knowledge, and consideration of underutilized crops, selecting the right variety, insurance, and markets. Disabling factors (Step 3) elaborates successful adoption of OFD, and it depends on farmers' skills and financial status. It includes scale effects, labour constraints, farm size, and land ownership. The identification of climate risks can enable farmers to engage in proactive future planning. These aspects have been highlighted in step 4 (current and future climate-related production risks). Different climate models are available which can be used to develop future climate projections and its impact on crop production (Lobell et al. 2008). These models can also be utilized to develop annual and perennial commodities, aiding in capacity building for farmers. Pulwarty and Sivakumar (2014) emphasized that results of these models should be communicated with farmers so that it can be effective at farming scale. One example of such kind of system is the Famine Early Warning Systems Network that can provide rainfall prediction for the following 10–365 days (Senay et al. 2015).

Identification and filling of gaps in the farming systems can help to increase farm stability and productivity under changing climate, and this has been highlighted in step 5, i.e. gap analysis of functional diversity in farm systems. This is possible via (1) diversification with crops and varieties and (2) diversification of crops/management practices to foster ecological functions. Step 6 considers the selection of OFD options which involve the development of a decision model to select good OFD crops and management practices. Thomas et al. (2007) reported that participatory evaluation is a cost-effective way to evaluate crops, varieties, and management practices, and it is referred to as step 7 (evaluation and learning). The proposed seven steps of OFD plan by van Zonneveld et al. (2020) can help farmers to have diversification plans as an option for climate change adaptation. However, Harvey et al. (2014) reported that OFD is not a good option to reduce the vulnerabilities of climate change, and Hansen et al. (2019) suggested that off-farm diversification could be a better option for farmers to adapt to climate change.

2 On-Farm Diversification: Key Components of Climate Change Adaptation and Mitigation

Diversification is an effective strategy for both adaptation and mitigation to minimize the adverse effects of climate change on farming systems. The benefit of OFD on soil health has been elaborated by Baldwin-Kordick et al. (2022) and concluded that agricultural diversification resulted in higher crop yield, reduced inputs requirements, and decreased environmental footprints. Similarly, Kemboi et al. (2020) reported diversification as an important coping mechanism for climate change. Vernooy (2022) reviewed crop diversification as a climate-resilient strategy and concluded that it can give multiple benefits to the farming communities. The benefits include increased household income and yield, improved nutrition and food security, and reduced poverty. Belay et al. (2017) investigated how smallholder farmers understand climate change and what adaption strategies they used to minimize the impact of climate change. They highlighted the impact of climate change on smallholder farming activities in Ethiopia (Fig. 3). Their results showed that

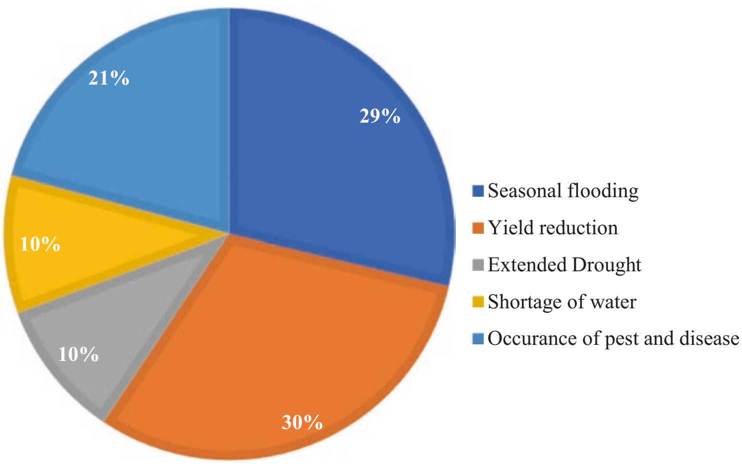

Fig. 3 Climate change impact on smallholder farming activities in Ethiopia (Source: Belay et al. 2017)

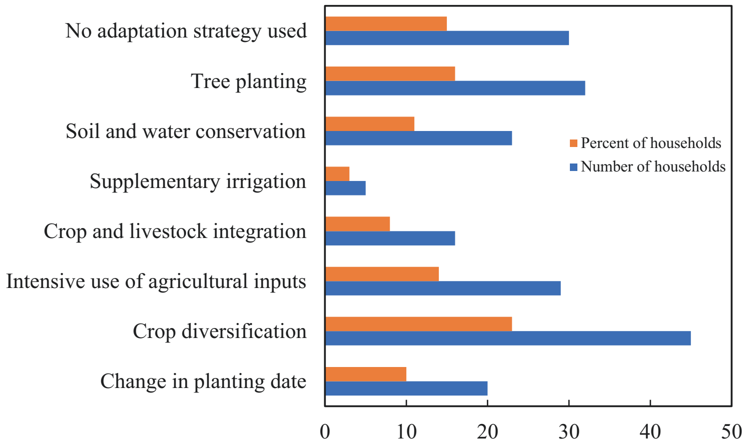

Fig. 4 Possible adaptation strategies to climate change (Source: Belay et al. 2017)

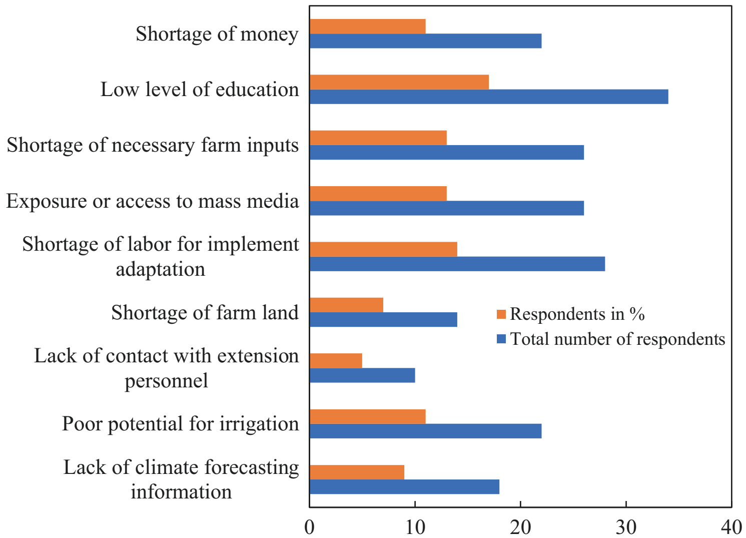

Fig. 5 Primary adaptation constraints to climate change (Source: Belay et al. 2017)

farmers adapt to climate change using practices like diversification, sowing date adjustments, soil and water conservation, change in the intensity of input application, integration of crop with livestock, and promotion of tree plantation with crops (Fig. 4). However, application of these adaptation strategies is not up to mark because of multiple constraints as shown in Fig. 5.

Adaptation strategies like cultivation of a large number of diverse species, integration of livestock with crop production (crop-livestock integration), and use of better adapted crops/varieties have already been recommended by different researchers. The use of legume with cereals could help to improve soil health as well as control pest and insect attacks (Yu et al. 2015). Schlenker and Lobell (2010) suggested the use of crops and crop varieties that can grow well under harsh climatic conditions. These includes sorghum, fonio (*Digitaria* spp), and finger millet for cereals, and cowpea for legumes. Furthermore, varieties with different maturity timings could be suitable for conditions where drastic increase or decrease in temperature or rainfall could disturb the crop yield or survival (Dinar et al. 2012). However, traditional indigenous varieties are also good as they can adapt to climate extremes easily (Vigouroux et al. 2011).

3 Climate-Proof Crops in the Farming Systems

Wild relatives of different staple crops, e.g. wheat, can give 50% higher yield in hot climatic conditions as compared to traditional recommended cultivars as they have less genetic variability. Wheat crop which provides maximum global calories is vulnerable to climate change since it has limited variations. Hence, it is important to consider wild relatives as potential options to develop climate-proof crops. This type of work is going on in CIMMYT so that we can have genetic resources that can have climate resilience (Fig. 6). Satori et al. (2022) reported that climate change will be a big threat for smallholder farming systems. Thus, to combat this threat development of climate-resilient crops is needed using crop wild relatives. Nair (2019) presented the potential use of crop wild relatives to combat global warming and enhance global food security. Similarly, Renzi et al. (2022) reviewed possible adaptive traits that can be used to improve the performance of cultivars in extreme environments.

Fig. 6 Drone shot at the CIMMYT wheat fields, near Sonora, Mexico. Photo credit: CIM

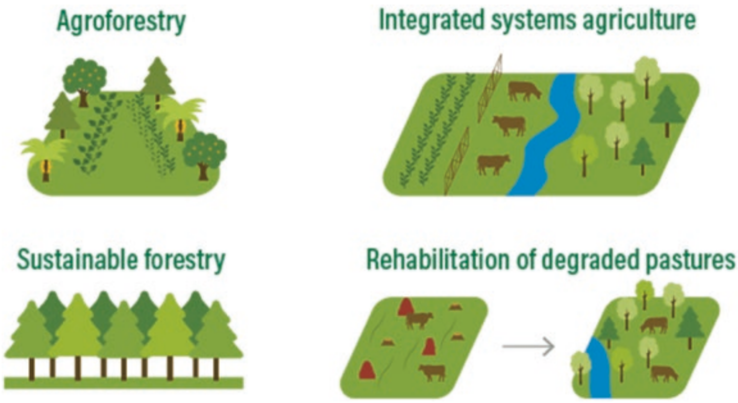

Fig. 7 Four agricultural interventions that can power climate adaptation (Source: WRI)

4 Climate Change and Farm-Level Adaptation

Farm-level adaptation response to climate change is an effective approach to design adaptation strategies at the national and regional scale. A list of farm-level adaptation measures has been recommended by different researchers, and it includes crop diversification, crop switching, changing and updating crop varieties, tree plantation, conservation agriculture, and changing the planting date (Tessema et al. 2019). However, to have accurate farm-level adaptations a new approach proposed by Tessema et al. (2019) should be used. Estimates have shown that climate change could reduce agricultural productivity by 17% by 2050, thus proving to be a big threat for the farming communities. The World Resources Institute (WRI) suggested four agricultural interventions that can power climate adaptation as shown in Fig. 7. The interventions include (1) integrating crop-livestock-forestry systems, (2) rehabilitating degraded pastures, (3) plant agroforestry systems, and (4) pursuing sustainable forestry. Abid et al. (2019) suggested that adaptive measures of smallholder farmers to climate change could be enhanced by providing up-to-date information and training. Similarly, outreach activities should be focussed on interventions that have adaptive and mitigative properties as suggested by Arbuckle Jr. et al. (2015).

5 Smallholder Crop-Livestock System: Case Study in Sub-Saharan Africa

The impact of climate change is seen in sub-Saharan Africa. Temperatures across the African continent have been increased with the projection of drier climate for southern Africa while wet climate for eastern Africa (Descheemaeker et al. 2016). The effect of climate change on a mixed farming system has been shown in Fig. 8. It shows that climate change is affecting the system by altering the individual as well as interactive component. Amejo et al. (2019) stated that majority of the

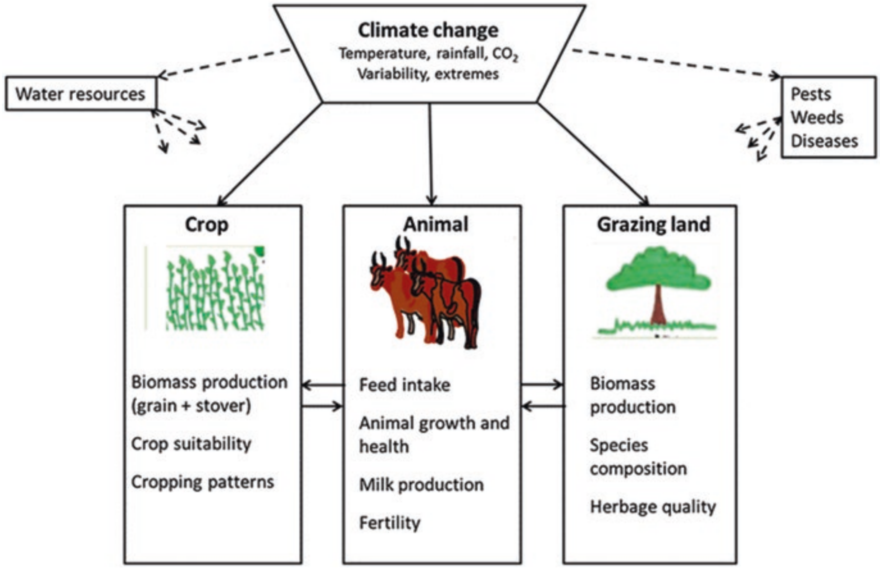

Fig. 8 Effect of climate change on mixed crop-livestock system (Source: Descheemaeker et al. 2016)

smallholder are more vulnerable to climate change due to lack of access to insurance and credit. Furthermore, most of the African smallholders are net food buyers which makes them vulnerable to price shocks under extreme climatic conditions. This shock under climate extremes remains for the longer period, throwing smallholder farmers into poverty traps (Dercon 2004). Crop production in the African continent is not up to mark as 96% of agriculture is rainfed (Cooper et al. 2008). Previous data showed that rainfall intensity and duration have been significantly changed which resulted in the increased occurrence of drought and shortening of growing seasons (Rurinda et al. 2014). A framework was developed to elaborate the vulnerability of smallholder farmers to climate change considering experts and local farmers knowledge (Fig. 9). The framework has three core components of vulnerability, i.e. (1) exposure, (2) sensitivity, and (3) adaptation. Subsystems of this framework include cropping, livestock, and availability of natural resources. Indicators like food self-sufficiency and cattle ownership were used to see the impact of climate change on these subsystems. Climatic features such as frequency of drought, increased rainfall variability, and temperature were identified as main drivers. Adaptation was classified into operational and strategic. However, adoption of these adaptation options depends on the availability of and access to both biophysical and socioeconomic resources as well as support provided by different institutions (Fig. 9).

In mixed smallholder crop-livestock system, livestock's vulnerability depends upon the availability of feed. Generally, crop residues with low nutritive value are used as animal diet and hence it becomes unavailable during dry seasons, thus

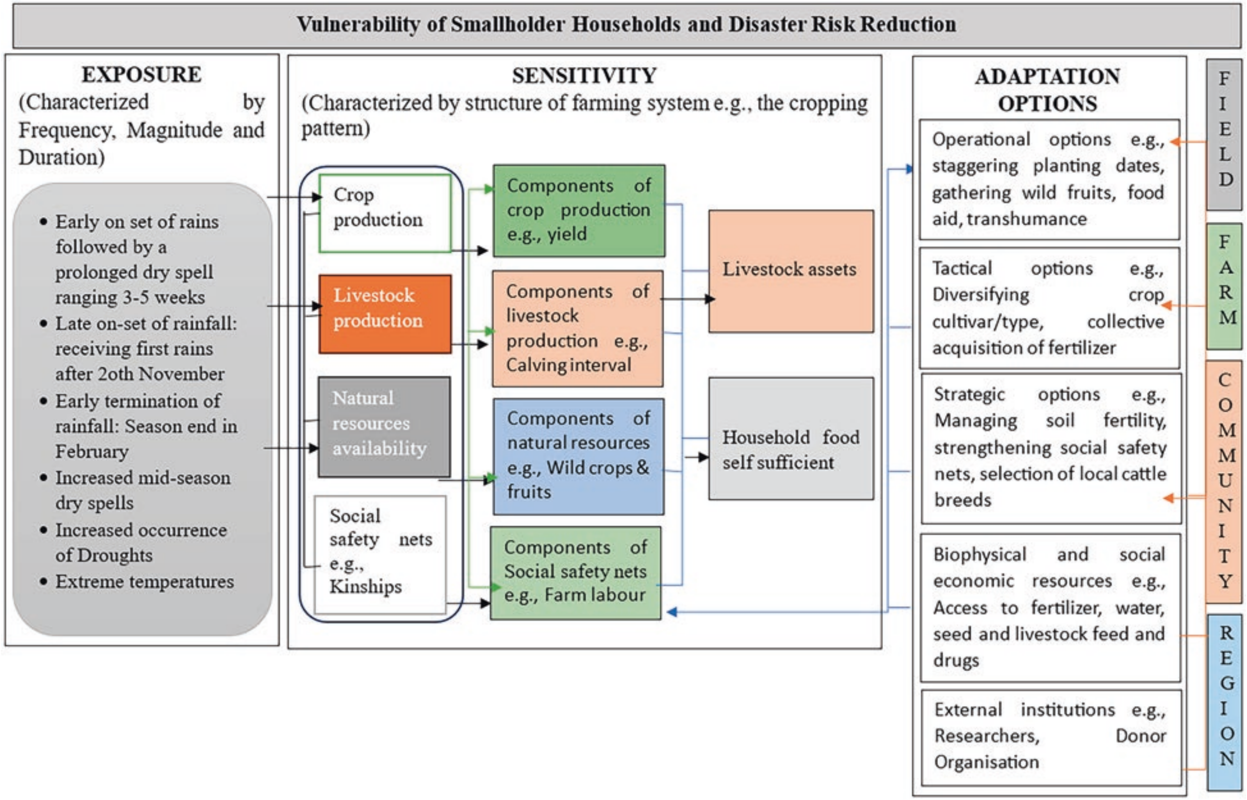

Fig. 9 Vulnerability analysis of smallholders (Source: Rurinda et al. 2014)

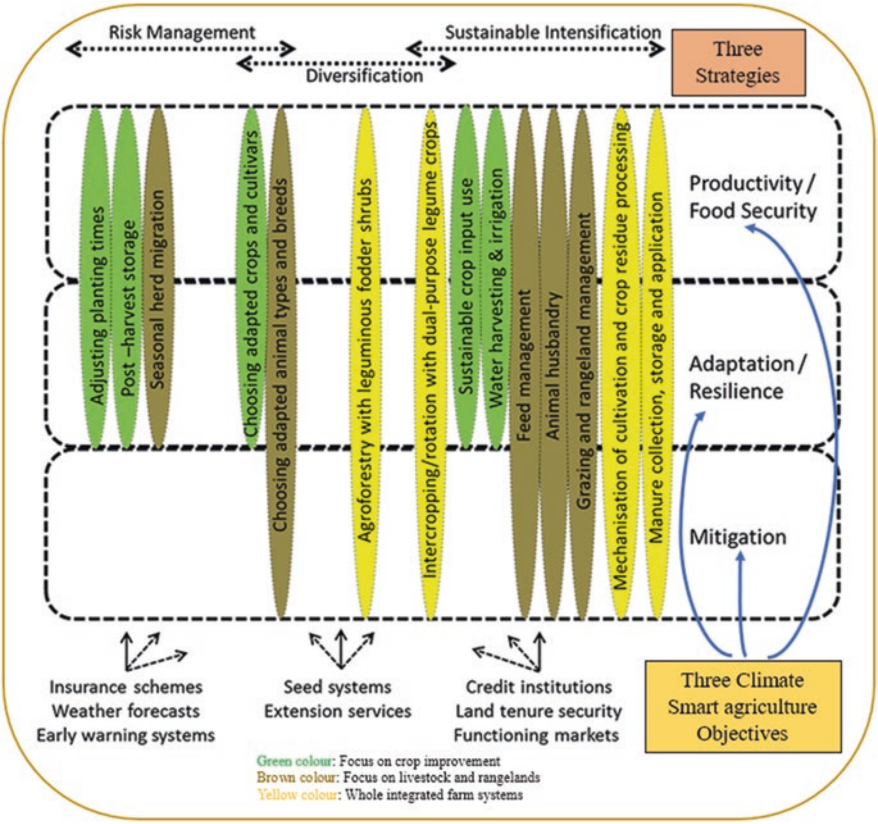

Fig. 10 Farm-level climate smart options (Source: Descheemaeker et al. 2016)

leading to poor animal health (Valbuena et al. 2015). The impact of climate change will be stronger on livestock as climate change will deteriorate crop residues and forage production. Furthermore, in most of sub-Saharan Africa, grazing contributes to the 10–90% animal diet which will be unavailable in future as grazing resources are already under threat due to climate change. Similarly, African livestock systems are contributing more to the emissions of greenhouse gases as compared to other regions. It is mainly due to the usage of fodder sources with low digestibility (Gerber et al. 2013) and emissions from manure during storage, processing, and application (Seebauer 2014). Adaptation and mitigation which are two of three pillars (third pillar: food security) of climate smart agriculture (CSA) are needed to uplift smallholder crop-livestock system. Promising options for smallholder farms have been presented in Fig. 10. which includes (1) risk management, (2) diversification, and (3) sustainable intensification with focus on crops, livestock, and rangeland or on the whole farm system. The suggested objective of risk management is to reduce the variance of an individual or whole system outcome (e.g. fodder or milk yield) while intensification aims to increase the mean of individual or whole system outcome.

However, the objective of diversification is broad as it will shift both the variance and the mean. Figure 10 elaborates that the adaptation or mitigation option is only workable if objectives of increasing food security are fulfilled at first; secondly increasing resilience and capacity building of smallholders is important than mitigation. Suggested adaptation options for the African households include seasonal migration, crop and livestock diversification, tree plantation, use of drought-resistant and shorter duration crops, choice of animal types and breeds, planting dates adjustments, minimization of post-harvest losses, integrated soil fertility management, soil and water conservation, irrigation management, dual-purpose crops as animal diet, improving cereal crop residues palatability and digestibility through chemical/biological treatment or mechanical chopping and grazing management (Campbell et al. 2014; Niang et al. 2017; Milgroom and Giller 2013; Vanlauwe et al. 2015; Oosting et al. 2014; Descheemaeker et al. 2009, 2016).

Mitigation options which can help to improve mixed smallholder crop-livestock system include choosing adapted animal breeds, improved feed through diversification (e.g. agroforestry), better feeding and feed management, improved animal husbandry, keeping fewer better fed animals, improving animal and herd productivity, rangeland and grazing management, and improvement in manure management (Mbow et al. 2014; Hristov et al. 2013; Gerber et al. 2013; Oosting et al. 2014; Thornton and Herrero 2010; Rufino et al. 2006). However, there are challenges in the adoption of adaptation and mitigation options in the African continent, and these include (1) agro-ecological, sociocultural, economic, and institutional dimensions; (2) multiscale constraints (e.g. resource constrained, poor community organization and malfunctioning extension services, poor market infrastructure, inputs cost and unavailability, price uncertainty, and typical communal land tenure system of African rangelands); and (3) farm size, risk, and livestock multi-functionality (e.g. small farm and shrinkage of farm due to population growth) (Ojiem et al. 2006; Jones and Thornton 2009; Cavatassi et al. 2011; Harris and Orr 2014; van Vliet et al. 2015).

Suggested adaptation and mitigation options will improve farm performance by reducing climate vulnerability. However, cultural norms, absence of insurance and credit facilities, and marketing incentives are preventing the suggested options. Similarly, the toughest constraints and barriers to adoption include increased population pressure, small farm size, poor access to inputs, market dysfunction, high investment risk, land tenure insecurity, and less support provided by the institutions. Porter et al. (2014) suggested transformative change as a good option to reduce disaster risks, and it is possible through (1) providing cushions to farmers against risks (e.g. insurance scheme, weather forecasting, and early warnings system), (2) improving skills and capacity of farmers and value chain actors, and (3) fostering farm investments (e.g. credit facilities, land tenure security, and value chain development). Müller (2013) in their work suggested implementation of effective insurance schemes as a risk management strategy which can help to keep large livestock herd. Similarly, Greatrex et al. (2015) emphasized the importance of implementing weather-index insurance systems (WIIS) that can significantly benefit smallholder farmers.

6 Farm Size in Pakistan and Climate Smart Agriculture

Pakistan is an agricultural country as its economy mostly relies on the agricultural sector. However, the agricultural sector is at stake due to the recent extreme climate events. Pakistan is worst affected by climate change despite the fact that Pakistan has been a low producer of carbon dioxide gasses (i.e. 0.2 million metric tons of CO_2) (Smadja et al. 2015). However, environmental disasters are causing a huge economic losses to the country. Pakistan ranks among the top 10 most affected countries in terms of fatalities and mortalities due to long-term climate risks from 2000 to 2019 as reported in the Global Climate Risk Index (GCRI)-2021. Disasters like heatwaves, floods, glacier melting, and droughts are common features of Pakistan climate. Around $30.1 billion loss was caused by the recent 2022 flood and still the economy is struggling to revive as the inflation rate has been seen at its peak. The damage was more severe in Sindh (total loss of $20.4 billion or 68% of the total loss) and Baluchistan province. Since 80% of Pakistan population lives beside Indus basin, they are facing multiple threats due to climate change and climate extremes, also due to poor infrastructure and resource management. Pakistan is also very poor in the three important pillars of disaster risk reduction that includes (i) Preparation (ii) Response and (iii) Rehabilittaion. Furthermore, it has been estimated that it costs $12 billion per annum (4% of the country's GDP) to improve Pakistan's poor water resource management. Pakistan has the largest and longest glaciers where glacial lake outburst flooding (GLOF) is common. A survey was conducted by IPSOS to gather information that how much Pakistanis are familiar with climate change and what are the causes of floods in Pakistan. The survey report shows (Fig. 11) that most of the Pakistanis were not considering climate change as a major problem and consider climate change as a less important factor which contributes to the floods. Hence, it is necessary that people should be informed and guided about recent problems in Pakistan, and it is possible through introduction of climate change as a major subject.

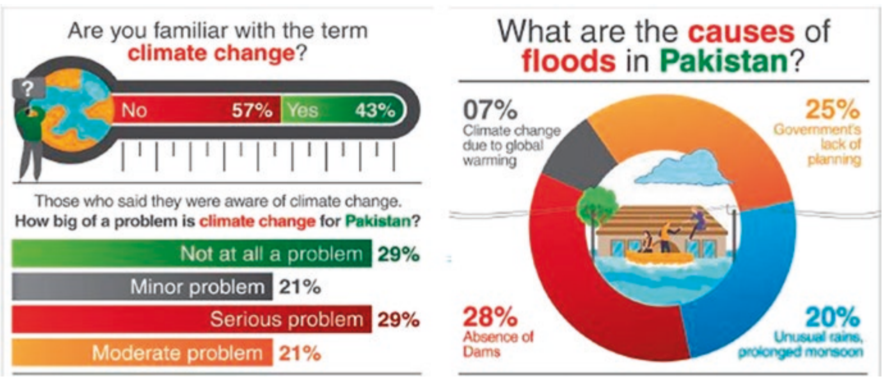

Fig. 11 IPSOS survey report about the terms "Climate change" and "Causes of floods" in Pakistan

Agriculture is still the backbone of Pakistan as it contributes 20% to GDP and gives employment to 43%. Around 2/3rd of Pakistan's population lives in rural areas and directly or indirectly they are connected to agriculture. More than 75% of the total crop output comes from major crops like wheat, rice, sugarcane, maize, cotton, fruits, and vegetables. Hence agriculture is the only sector which can ensure food security and reduce poverty. But the agriculture sector is under threat due to extreme climate variability and climate change acting as a big barrier to achieve foot security and alleviate poverty. Higher temperature has shown impact on the cropping system by increasing evapotranspiration, crop water demands, and heat stress on crops. It has been reported that with 1 °C rise in temperature cereal crops, e.g. wheat yield, will be reduced by 5–7% (Aggarwal and Sivakumar 2011) while it can decline to 7–21% with an increase in temperature of 1.5–3 °C. However, 14–23% increase in wheat yield was reported in Chitral districts of Pakistan due to rise in temperature (Hussain and Mudasser 2007). Ahmad et al. (2013) studied the impact of rise in temperature on rice yield and reported that rice yield will be decreased by 15% from 2012 to 2039, 25% from 2040 to 2060, and 36% from 2070 to 2099. Similarly, decreased rainfall also affects crop production as with 6% decrease in rainfall, net irrigation water requirement could be increased by 29%. Hence almost 1.3 million farms will be negatively affected due to this change. Different adaptation strategies have been adopted to minimize the impact of climate change. It includes sowing date adjustments, shifting to climate-proof crops, usage of stress-tolerant crops, change in the fertilizer, and irrigation usage. However, implementation of these adaptation strategies is difficult due to changes in the farm size.

Farm size in the South Asian countries has been decreasing mainly because of increased population pressures and extreme climate events. Farm size in Pakistan has been decreased from 5.3 ha in 1971 to 2.6 ha in 2010 agricultural census. Hence most of agricultural farming in Pakistan is smallholders. More than 90% farms are smaller than 12 acres out of which 67% are even five acres (2 ha) which will further decrease in future. Some land holdings are so small that they are no longer economically viable. Furthermore, small size is a major limiting factor that hinders in the application of modern tools (Fig. 12). Naseer et al. (2016) and Phambra et al. (2020) reported that natural disasters, pest attacks, access to financial markets, and unfavourable macro-economic policies are threatening the prosperity of small farms; thus climate-smart actions are needed to solve the problems of small farms. Ali and Erenstein (2017) used probit model to identify factors influencing climate change adaptation practices. Determinants of a number of adaptation practices were analysed using CLAD (censored least absolute deviation), and PSM (propensity score matching) was used to evaluate the impact of adaptation options on food security and poverty. Three major adaption options were identified in their studies, and it includes introduction of new crops (25%), change in sowing time (22%), and use of drought-tolerant varieties (15%). Furthermore, results showed that literate and young farmers were more willing to use these adaptation strategies. Farmers with adaptation practices have higher food security (8–13%) and lower poverty levels (3–6%) compared to those who were not opting these practices. Thus, climate change adaptation practices at farm level can reduce weather risks. Climate smart

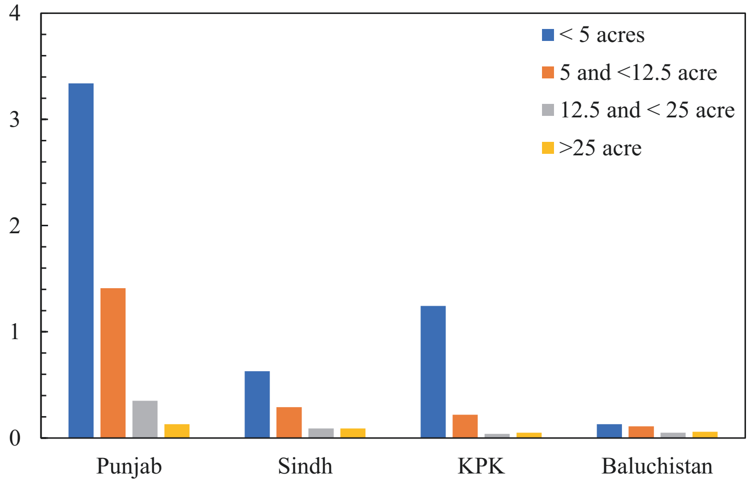

Fig. 12 Province-wise distribution of farm in Pakistan (Source: Pakistan Bureau of Statistics 2017)

agriculture in Pakistan has been further elaborated in the report of International Center for Tropical Agriculture (CIAT) (CIAT 2017).

7 Conclusion

Farming systems are under threat due to extreme climate events, and the impact of climate calamities will be more severe on smallholder farming systems. Hence, farmers, policy makers, and researchers should sit together to develop a framework where they can implement the suggested adaptation and mitigation options to reduce the disaster. This framework should be developed based on real-time data supplemented by modelling studies. Similarly, the range of adaptation and mitigation options should be investigated by considering mixed smallholder crop-livestock system individually as well as whole. Furthermore, changes in the interactions between farm components should also be quantified in response to climate change for designing sustainable adaptation and mitigation strategies. Importance should also be given to the heterogeneity in the biophysical and socioeconomic context as it will also have an effect on the selection of adaptation and mitigation options. This is possible firstly by modelling the effects of climate change, adaptation, and mitigation at the farm level by considering diversity into account. Secondly, conduction of cost and benefit analysis of the proposed adoption strategy will help to make assessments more realistic. Meanwhile a combination of scientific knowledge with indigenous local traditional knowledge via participatory approach will enhance adaptive capacity of local farming communities and can make the system climate smart or climate proof or climate resilient. Finally, long term implementation of policies, early warning system, implementtaion of indigenous techniques/

knowledge, colloborative efforts and climate finance is needed to reach to the end user in a real way.

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