Chapter

Climate Smart Interventions of Small-Holder Farming Systems

Asmat Ullah, Ishfaq Ahmad, Habib-ur-Rehman, Umer Saeed, Ashfaq Ahmad, Abid Mahmood and Gerrit Hoogenboom

Abstract

Agriculture is very vulnerable to temperature and drought in semi-arid and arid regions. Farming communities are especially vulnerable to the potential impact of climate change on crop and livestock. For Pakistan, a potential increase of 2.8°C for the maximum day temperature and 2.2°C decrease in night temperature by the mid-century has been reported. The goal of this chapter is to introduce climate-smart interventions as mitigation and adaptation strategies coupled with crop diversification through the introduction of climate resilient crops in existing cropping systems. Firstly, it describes the impacts of climate change in context to current food security situation in Pakistan and, secondly, potential climate smart interventions to combat changes in the country. Crop models, their application for developing adaptations, modeling technique and its integration with breeding, remote sensing and its application, policy interventions and resource smart interventions in context to changing climate are imperative means to favor the farming community in future farming. Introducing climate resilient crops can be rescued and recognized in dry and hot areas of Pakistan using climate smart interventions and resource use efficiency may be determined with the aid of computer and decision support IT tools in resource inefficient areas.

Keywords: climate change adaptations, strategies, farming systems, small farmers, Pakistan

1. Introduction

Agriculture is significantly affected by temperature variability and other climatic variables (events) all over the world including Pakistan. Farmers are feeling the worst impressions of climate change and variability on produces and livings. We must ensure nutritious food for all through increasing production even up to 60% in 2050 [1], while fighting changes in climate in the world.

In such conditions, it is important for a country to make its agriculture sector efficient to ensure and enhance food security. In recent decades, high temperature has been recorded in most parts of Asia and Pacific regions. According to the global climate risk index (CRI) 2015, Pakistan is the 10th most vulnerable country to climate change with a CRI score of 31.50, 3989 million US$ loss and 141 events during 1994–2013 [2]. The other countries are Honduras, Myanmar, Haiti, Nicaragua, Philippines, Bangladesh, Vietnam, Dominican Republic and Guatemala.

Less developed countries (LDCs) are generally more vulnerable to climate change than industrialized countries. In context to future climate change, CRI may assist as an alarm for previously current vulnerability that may further extended in regions where risky events will become more recurrent or more severe due to climate change. The Fifth Assessment Report of IPCC stressed that the risks associated with extreme weather events will further increase regularly. These risks are likely to get worse and uneven distributed in tendency.

There are two main growing seasons of crops in Pakistan, namely winter (Rabi) and summer (Kharif) season. The performance of winter season crops (wheat, chickpea, barley, sugar beet, etc.) and summer season crops (cotton, pearl millet, etc.) depends upon specific weather conditions. Each crop has its own tendency to face climate change impacts which depends on its genetic makeup. While management options (irrigation, fertilization, planting geometry and density, etc.) applied to get good yields by a farmer. The response of each crop to change in climate is different. Climate change commonly affects crops through changes in temperature and precipitation. In Pakistan, it is assessed that temperature will increase by 3°C by 2040 and 4–6°C by the end of this century. Due to this scenario, Asia can lose 50% of its wheat production [3].

Wheat, rice and maize are important cereals bearing huge population pressure in context of food demand all over the world including Pakistan. But these cereals are at more risks to climate change. The wheat and rice production may decrease up to 15 and 17%, respectively by midcentury (2040–2060) due to changes in temperature in Pakistan. It has been projected that day temperature of 2.8°C will significantly increase with 2.2°C decrease during nights by the midcentury (2040–2060) [3]. In such harsh conditions, growth and production of crops will be affected severely. The scientists must anticipate the possible solutions of climate calamities through introducing climate resilient crops and recognizing climate smarts production options for safe and secure food.

Climate resilience improvement is in common use now a day to inform crop management options. In view of current and future climate change and variability, interest among researchers to apply such technique is increasing to strengthen the climate resilience in crops of hot and dry areas [4, 5]. Climate resilience is quite resemblance to vulnerability and commonly defined as "the ability to bounce back after an external shock or stress". Resilience of a system can also be illustrated through its components including system disturbance, maintaining system & control and returning to stable state [6, 7]. Agriculture system is affected by extreme weather events associate with climate change, therefore adaptative measures are needed to mitigate the negative impacts of climate change. Keeping in views, the current study was planned to adapt climate change by developing climate smart practices for sustaining the agriculture productivity.

1.1 Land use and patterns

Pakistan is rich in natural resources, with half of the total area (36 million ha) lies under agricultural. About 84% of its land is arable, while remaining 14% is permanent pasture. The country is very poor in forests reserves which are 2% of total land as compare to world average ~30%. Uncontrol deforestation is further reducing its area at the rate of 0.2–0.5% per year. The area under agricultural production systems has remained stable over the last few decades. The high cropping intensity and use of fertilizer are main components to get high production in the country. Approximately 160 kg/ha fertilizers are used in Pakistan across all cropping systems. The land holding classification showed that 43% farmers are small scale (<1 ha) as compare to 36% large scale (>2 ha) [8].

Agroecological based agricultural production systems are different in different zones in Pakistan. However, the redefining of agroecological zones in Pakistan is importantly needed in the context of changing climate. Sugarcane, rice, cotton and wheat are more dominated along the Indus River. This zone is highly productive and lies in Punjab province. Chickpea crop is usually cultivated in Thal desert region of southern Punjab. It contributes >80% of chickpea production in country. As this crop is rainfed, hence the most affected by the climate variability in the region.

The rainfall patterns determine the cropping seasons in the country. These are "Kharif" (April to June), suitable for rice, sugarcane, cotton, maize, millet, mung bean, and the "Rabi" (October to December) season is suitable for wheat, barley, lentil, rapeseed, mustard and sugar beet. Tunnel farming in vegetables has got importance in the country due to high economic return. Climate variability, climate change, value chain, market monopoly and pest pressure are the main challenges to crop productivity [9].

1.2 Food supply and security

Natural disasters and economic instability and malnutrition are main challenges to country food security over the past decades. Pakistan ranks 78th out of 113 countries in the global food security index. It is alarming that 60% of population is experiencing food insecurity. The average food supply of 2440 kcal/person/day in the country is yet insufficient to meet the demand [5]. In Pakistan 62% of total energy is meet through cereals (wheat > rice > maize) after milk and vegetables in terms of calories consumed. In Pakistan, 44% of household's income is spent on their food, which is higher than any other commodity. The ratio is quite higher in villages (48%) [10].

1.3 Challenges fostering climate change

Although agriculture is the main stay to the country's economy, but still this sector is facing many challenges including population growth, rapid urbanization and reduction in water resource availability. The population of Pakistan has more than doubled in the past two decades. It is growing very fast, approximately at the rate of 2% yearly and expected to be 244 million in 2030 and 300 million in 2050. This ever-increasing population will ultimately put horrible strains on already vulnerable agricultural production system of Pakistan [10].

Industrial extension and low priority to village life are the main reasons for rapid urbanization in Pakistan. These activities seriously affect the agricultural areas by deteriorating the quality and safety of food products through harmful chemicals. The crops near these areas are often irrigated with waste water, which heavily absorb heavy metal and become part of food chain.

Water resources are limited all over the world; availability of water and its management are main problems in Pakistan. The per capita availability of water was 5300 m^3 in 1950, which is reduced to <1000 m^3 now a day in Pakistan [4]. This availability is projected to go down (800 m^3 per capita) in 2025. While a country is declared water scarce if its per capita water availability is <1000 m^3 and absolute scarce in <500 m^3 water availability [11]. These finite conditions are big threats to Pakistan. Changing climate conditions such as erratic rainfall patterns, variable temperature and humidity multiply these threats.

1.4 Climate change profile of Pakistan

It is obvious that agriculture is significantly affected by the climate variability and climate change. The country is ranked 7th among the top ten climate vulnerable countries in the world in global climate risk index and have diversified geography. The stress (heat & drought) followed by devastating floods are common in the country and have contributed to low crop yields, and disturbing food chain. The main reason for climate change is reduction in rainfall in the semiarid and arid region of Pakistan. The mean temperature across the country has increased by 0.5°C during the historical period (last 30 years) [4].

The projections show an increase of 1.4–3.7°C by mid-century in Pakistan. The temperature is expected more increase in winter than summer in Pakistan. Projections for rainfall have some unclear results due to uncertainties in performance of climate models; however, the trends are decreasing rainfall in future. The increase in temperature altered the phenology of crop i.e. leaf development, anthesis, harvest, fruit production and in asynchrony between anthesis and pollinators [7]. The rise in temperature also resulted in high respiration rates, reduction in pollen germination, shorter grain filling period, lesser biomass production and low yields. Pre and post flowering heat waves at 35°C led to yield loss in wheat, barley and triticale. High temperature above 35°C in combination with high humidity and low wind speed caused a 4°C increase in temperature, resulting in floret sterility in cereals [12].

In view of above, we must adapt such interventions which may create resilience in agricultural production systems to combat the climate variability and long-term climate change in the country.

2. Climate smart interventions

Global food production could be doubled by 2050 to contest the population and income growth in Asia and Africa. Pearl millet, sorghum are the important component of global food security in both continents. Owing to challenging anxieties for land, water, labor and capital, there is need to improve crop production per unit of land and water, as these resources are dwindling. Keeping in view the condition, sustainable increase in agricultural productivity is vital to the future of food security of Pakistan. Practices to adapt agriculture to climatic risks, take time to root and become effective for each. In such cases, approaches that enhance climate smart agriculture are the most apt starting point for sustainable agriculture. Climate smart intervention approaches are derived from the CSA-climate smart agriculture (**Figure 1**). CSA is usually defined as the "the agriculture that agriculture that sustainably increases productivity, enhances resilience (adaptation), reduces or removes greenhouse gases where possible and enhances achievement of national food security and development goals [1]. CSA aims to strengthen livelihoods and food security, especially of smallholders, by improving the management and use of natural resources and adopting appropriate methods and technologies for the production, processing and marketing of agricultural goods. The agricultural productivity, adaptations and mitigations are the main pillars of CSA.

2.1 Adaptations through crop modeling interventions

Crops models have capability to frame adaptation packages with in no time as a strategy for further implementation in the fields. However, experimentation through field setting is time consuming and utilize much resources unless the results are applicable or not. Climatic adaptations deal with effective investments/changes in technologies/policies in response to future climate change. While non-climatic adaptations focus on agronomic management options. Crop model frame comprehensive, cost effective and reliable adaptation packages by changing

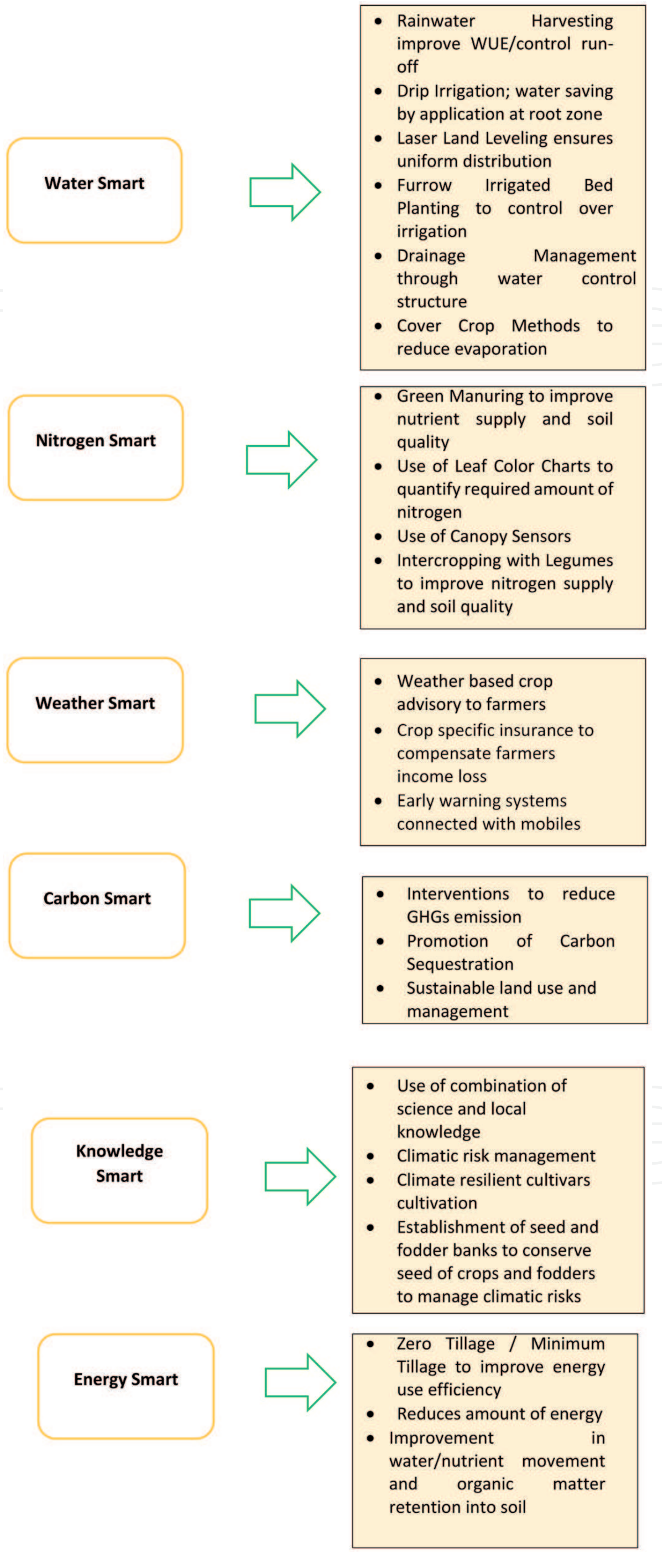

Figure 1.
Climate smart interventions in agriculture sectors.

the planting time, fertilizer dose, planting geometry, cultivar/hybrid and residue management. Increasing number of grains and crop growth rate, re-fitting crop season length by changing growing degree days (GDD) to anthesis and maturity, adjusting grain filling period, decreasing root length of crop are important elements of adaptations in crop model configuration. These elements of adaptations give sound genetic concepts as an important intervention in designing cultivar [4]. Various crop models are being used in improving natural resources to evaluate the impact of future potential climate on crop production [5]. Crop simulation models are appropriate tools for the assessment of crop production options for an environment, including inorganic fertilization levels, plant spacing, planting times and others management options [13, 14].

Development in crop improvement through plant breeding on molecular basis is inadequate by our skill to predict phenotype of plant which based on its genotype, specifically for multifaceted traits [15, 16]. In addition to this, there has been an extended history of designing and application of crop growth and development models for prediction in crop management [17]. The use of such modeling interventions for genotype to phenotype prediction are at beginning [18, 19]. Current studies encouraged that use of crop models have considerable potential to face the genotype-phenotype prediction for application in plant breeding. However, the competence of existing crop models for these type of applications is uncertain [20, 21] and need improvements. The intervention of integration of simulation with plant breeding is an important aspect to design a "virtual cultivar" which can guide to breeders and further recommendation for general cultivation in area. This type of simulation can assemble a virtual variety with acclimatize characteristics for site specific cultivation. Hence, this approach can also elevate the farming to the extent of revolution and have ability to feed the world in safe and healthy style (**Figure 2**). DSSAT (crop modeling) [22], APSIM (crop modeling) are used to assist all type of stakeholders in decision making [23]. PLABSIM (marker-assisted backcrossing) [24], PLABSOFT (plant breeding) [25], QU-GENE (genotype-by-environment interaction) [26] and E-CELL (whole cell simulation) [27] are useful tools being used in computer simulation in breeding programs.

2.2 Weather smart intervention

The risks associated with change in rainfall and temperature at different crop growth stages are directly linked with increase or decrease in pearl millet production. The stakeholders must be linked to automated weather stations and site

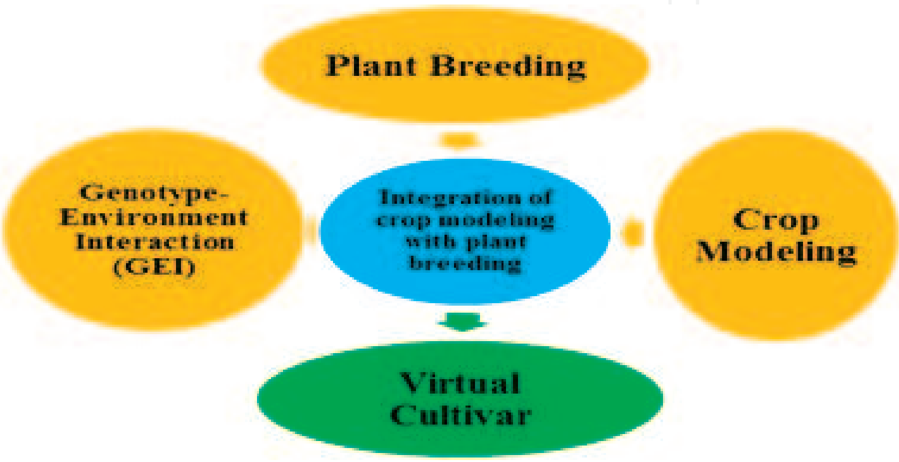

Figure 2.
Integrated approach of crop modeling and breeding.

specific agro-advisories through radio shows, television, newspapers and mobile phone voice messages. Agricultural Weather Network (AgWeatherNet) is a good example of this intervention. The current and historical weather data along with a range of models and decision aids can be accessed through this system. The weather data, advisories, weather data products and decision support systems provided by AgWeatherNet is very helpful to improve production and product quality, efficient resource use and reduce environmental impact on crops. Early warning system is also the important component of AgWeatherNet [28].

2.3 Remote sensing and its application

The role of geo-spatial technology is vital in precision agriculture, crop monitoring and yield forecasting. Remote sensing is a potential tool to monitoring crop health and condition. Abiotic stresses; high temperature, insects attack, diseases, moisture deficiencies, fertilizer stress and area affected by these stresses can be detected earlier for quick mitigation. Time series data and maps using remote sensing help to understand the spatial and temporal changes and their drivers. Climate change, biotic and abiotic stresses, and their impacts on crop can be monitored using remote sensing. It depicts and reveals area under crop and its trend over the years. There are many people who are involved in selling, purchasing and pricing of their farm produce. Crop yield forecasting using satellite imagery well before the time of harvest helps to devise policy for crop import and export. Remotely sensed data can be assimilated in crop models to forecast yield on regional scale and for site specific crop production technology [29]. The current innovation in remote sensing sciences is use of higher spatial resolution satellites imagery for precision agriculture and to monitor within field variability. Crop production and management practices can be improved and modified by obtaining information using higher resolution multispectral and hyperspectral data. Use of same input for larger area is wastage of resources and causes crop yield reduction because significance within field variability exists. Pearl millet is grown with diverse distribution in country. Estimation of area, production and average yield through conventional method is a tough job. Remote sensing figures out all these aspects quickly before maturity of crops. Using this type of intervention, we can point out historically, the potential areas, low and high yielding areas of pearl millet with in Pakistan for its retrieving using better management options. Future trends of area and production of field crops can also be predicted using various techniques of remote sensing such as normalize difference vegetation index (NDVI) and random forest as statistical tool which not only assist in decision making for policy makers but also help to evade food insecurity in country [29].

2.4 Policy interventions

Changes in climatic conditions are affecting agricultural produce and would become more calamitous in future. We need to be proactive to figure out solutions and make Pakistan a food secure country through better policy interventions. Mitigation and adaptation strategies to reduce climate risks are the best policy interventions if the policy makers strictly regularize those polices. Reducing greenhouse gases (GHGs) emissions to mitigate climate change should be encouraged as a measure through different schemes that convince farming communities without loss to their crops and production. Afforestation and reforestation are healthy activity to improve carbon sinks and should be an important component of policy intervention to mitigate the impact of climate change. Use of renewable energy resources should be accentuated to mitigate the impact of changing climate. Climate compatible agriculture should be endorsed as an adaptation strategy in country. Genetic divergence and biotechnology can also play an imperative role to develop crop varieties which can tolerate drought, heat stress and submerge conditions. Use of information technology (IT) in agriculture has become crucial to quantify the impact of climate change. Monetary protection of farmers by insurance companies and government should be promoted in the country against natural catastrophes. An index-based insurance schemes should be introduced to cover risks associated with changes in rainfall and temperature at the different stages of crop growth. Early warning systems and automatic weather stations to alert farmers with weather data are good tools those must be installed at district level [10].

Globally, all research institutes are non-profitable and funded with sufficient finance to carry smooth research activities. Contrarily to the facts, most of the research institutes in Pakistan are considered profit-oriented by fixing financial targets each year. Hence, as a policy intervention, research institutes in Pakistan should be declared as non-profitable. This approach enables scientists to work without restrictions rather than making profit. In addition to this, investment in research and development must be increased in country to develop site specific adaptation strategies for changing climate. These adaptations must be fit in new designed agro-ecological zones.

3. Resource smart interventions

3.1 Water smart

Water is limiting resource throughout the world and must be used professionally to ensure a safe and plentiful food supply. Explanations to water shortage glitches will necessarily include adoption of innovative water conservation measures, flexible water delivery systems and precision irrigation. Better control and management of water applications are important components for any crop in this action [20]. Irrigation efficiency of system is 40% which is quite poor in Pakistan. Smart water management practices aim to enhance the efficiency and productivity of water which are very important interventions. These might be comprised of water course improvement, precision land leveling, bed planting, furrow planting of row crops and high efficiency irrigation systems, aquifer recharge, community management of water and water conservation [30] which have potential to save water in the range of 20–70%. These interventions can be resulted into increase in crop yields by 20–30% and increase in net income to the farmers by 20% under changing climate scenarios of Pakistan. In climate smart water, irrigation plays a major role in stabilizing agricultural production. Climate smart irrigation is good irrigation approach for the given agro-climatic and societal context that may result directly or indirectly from the different aspects of climate change, it aims to increase per unit production and income from irrigated cropping systems. These interventions through climate smart agriculture, aim to reduce the exposure of farmers and their irrigation systems to short term risks. Adaptations are generally developed to strengthen resilience by developing their capacity in the face of shock and other stresses.

Irrigation is applied usually to overcome the stress due to spatial and temporal variability in rainfall on crop growth and its quality. Characteristically, climate smart irrigation practices are founded in the mix of technical and non-technical measures. These may be included;

- The source of water must be reliable; however, the reliability of water sources largely depends on the policy interventions for regulating, protecting and sustainability of natural resources.

- Building of sound infrastructure to extract and convey water from the source to where it is needed. The policy interventions again play an important role in managing and maintaining all types of irrigation conveyance systems.

- The role of irrigation management systems and water user association is important to implement the innovations like; weather or soil sensors, control devices etc. according to certain schedule.

- Drainage infrastructure is often needed to reduce the risks of waterlogging and soil salinization.

- Farmers must be given land and water tenure that gives right to use both resources and, the incentives to invest in activities aimed at improving the productivity and resilience of their irrigation systems.

- The agriculture production system is declared to be climate smart, when the cropping systems are well adapted to relevant biophysical factors (agro-climatic conditions, soils, extreme events) and societal factors (markets, labor availability). Policy interventions to support farmers and farming systems, credit services, suppliers of seeds and irrigation related infrastructure, suppliers of irrigation and agricultural equipment, etc.

- Value chains are the most important aspects that connect farmers to markets. They ensure returns on investment and minimize risks of post-harvest losses. In these context, the interventions are needed to support farmers and traders in trading related legislation.

3.2 Carbon smart

Total organic carbon is the amount of carbon related to living organisms or derived from them. Increasing carbon content in the soil may reduce atmospheric carbon dioxide and improve soil quality. Recent interests in carbon sequestration have raised many questions about how much carbon can be stored in the soil. The organic carbon content in soil can be improved through agricultural practices such as agroforestry, livestock, manure management, conservation tillage, diversified land use systems and residue management. As millet crop is grown on mostly marginal land with low organic matter (OM). Improving OM using different interventions can boost the pearl millet yields in Pakistan where soils of most areas are low in organic matter [31].

3.3 Nitrogen smart

Conventionally, climate resilient crops (pearl millet, sorghum, quinoa etc.) are grown on marginal soils (low fertility) without application of nitrogen. Nitrogen application should be considered as an important component of dryland, rain-fed and irrigated systems. Soil fertility along with climatic risks are obstructing crop productivity in arid and semi-arid environments of Pakistan. Nitrogen smart interventions are those strategies in precision agriculture where most of the people do not focus before growing crops, especially the ignoring

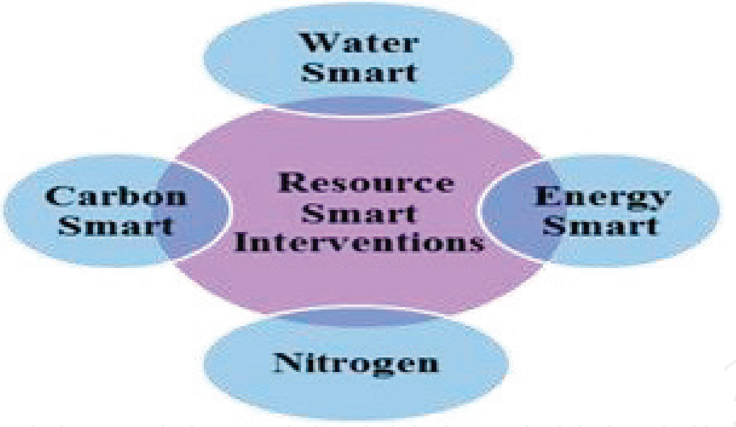

Figure 3.
Resource (water, carbon, nitrogen and energy) smart interventions.

crops (pearl millet, sorghum, quinoa etc.) and started to prepare their lands for cultivation. Applying the right source of N, at the right rate, at the right time, and in the right place is another important aspect in nitrogen management. In climate smart interventions, farmers must use leaf color charts, handheld crop sensors, and nutrient decision-maker tools to decide the most appropriate dosage of nitrogen fertilizers for crops. The use of crop canopy sensors is a good example of the interventions and an important precision agriculture tool into the decision-making process. These interventions not only save costs, but also cause decrease in greenhouse gas (GHG) emissions especially from puddled rice fields [32].

3.4 Energy smart

Energy is also a limited resource which must be used sensibly to secure the safe, healthy and nutritious food for the growing population in country. Promotion of biofuels, high efficient agro machineries, residue management and conservation practices (reduce tillage) are the important energy smart interventions to conserve energy and reduce GHGs [33]. Use of biogas systems through manure slurry from intensive dairy initiatives is also appreciated as energy smart approach in most part of the world (**Figure 3**).

4. Knowledge gaps and the way forward

- The effect of land use and land cover patterns on food production and food security may be focused in studies in context of current changing climate.
- Agro ecological based temporal and spatial models to be developed coupling with climate smart interventions.
- Integrated impact assessment on different agro ecosystems still needed to improve agricultural production system's efficiency.
- Impact of shocks/extreme weather events on crop plants require more attention.
- Food safety and food security in the countries like Pakistan may be linked with incentives. The mechanism of incentives must be properly examined.

- The researchers and extension workers may be fully equipped with nutrients and SOC kits.
- The mobile applications related to weather predictions and early warning systems may be developed locally.
- Subsidies may be provided to those technologies that support more diverse climate adapted agricultural production systems.
- The impact of climate change related projects may be evaluated or reviewed from the agro climatologists.
- The new adapted species may be integrated with conservation practices and supported with favorable policy interventions.
- The regions for research on climate change may be selected based on the most vulnerability and risk within country.

5. Conclusions

Agriculture is significantly hit by temperature variability and other variable events all over the world including Pakistan. Farming communities are feeling the worst impacts of climate change and variability on crops and livelihoods. In such conditions, climate resilient crops like pearl millet prove to be a robust, climate smart grain crop. It endures to out yield more nutritious grain sustainably, thereby cheering the fight against poverty and food insecurity due to its resilience. Because it is selected as water saving, drought tolerant and climate change complaint crop. Crop modeling and its application, computer simulation in plant breeding and resource smart approaches supported with policy interventions can present better picture under changing climate scenarios of Pakistan.

Acknowledgements

The authors acknowledge the critical review of this chapter from K. Grace Crummer, Coordinator, Institute for Sustainable Food Systems, University of Florida, USA.

Conflict of interest

There is no ‘conflict of interest’ among the authors.

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