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SHORT COMMUNICATION

ADDRESSING VULNERABILITY OF AGRICULTURE SECTOR TO CLIMATE CHANGE IN PAKISTAN

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ABSTRACT

Agriculture sector, being the dominant user of fresh water (70%) is highly vulnerable to climate change in Pakistan. Increase in frequency of floods and drought, rising temperatures and changes in rainfall pattern across the country during the recent years are clear indicators of changing climate. Climate change has serious repercussions for national food security as farmers have limited knowledge and technologies for mitigating the adverse effects of climate change on crop productivity. This situation is expected to decrease yield of major food crops. There exists dire need to make an intensive analysis of situation to identify existing knowledge and technology gaps and suggest doable measures for multiple stake holders like policy makers, scientists and farmers accordingly. This review paper covers the impact of climate change on agriculture and presents strategies to adapt to climate change. Strategies at policy/government level include increased funds for research, improvement of national capacity building (training of trainers) and development of a localized smart early warning system for climate change related events. Key research areas being identified to address vulnerability include development of innovative water use efficient technologies, zone specific agronomic research, applied root research, organic farming to increase soil resilience and research on ground water recharge and quality using simulation models. Farmers shall be sensitized about the issue of climate change through education and every effort shall be made to make proper use of existing farm resources and technologies to live with the changing climate so that national food security is not compromised.

Keywords: awareness, crop production, drought, floods, technology, weather pattern

INTRODUCTION

Food security in Pakistan is at high risk due to climate change. According to German Watch, a German Think Tank, Pakistan was ranked among top ten countries most affected by climate related events over the last two decades (Eckstein *et al*., 2020). The financial losses due to climate change put extra pressure on agro-based weak economy of the country (World Bank and Asian Development Bank, 2010). Agriculture contributes about 20% towards Pakistan's Gross Domestic Production (GDP) and is adversely affected by changing climate (Akram and Hamid, 2015). Shifts in rainfall pattern, rising temperatures, drought, floods and glacial retreats are the indicators of climate change in Pakistan (IPCC 2014; Safdar *et al*., 2019). The population of Pakistan is expected to reach 350 million by 2050 and to feed this population, country will require 40 million tons of wheat and 10 million tons of rice (Kugelman and Hathaway, 2010). Climate change may reduce yield of main crops from 6 to 16% (Akbar and Gheewala, 2020).

Water is a key factor for agriculture as 93% of Pakistan's water resources are utilized by the sector (Afzal and Ahmad, 2009; Qureshi and Ashraf, 2019). Poor water governance, lack of conservation measures and low water use efficiency are contributing to food insecurity (Raza *et al*., 2012; Parry *et al*., 2017). The country's ageing water infrastructure requires re-alignment (Memon and Thapa, 2011). Due to rising temperatures, glacial retreat will generate extra water and existing infra-structure may be inadequate for storage of available water (Qureshi, 2011). Per capita water availability in Pakistan may become less than 1,000 m^3 (water scarce) by 2030 (Briscoe and Qamar, 2005; Hassan *et al*., 2019).

Water shortages are the greatest threat to the viability of Pakistan as a state and society.

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Country is currently facing a water shortage of 50 billion cubic meters (Lieven and Hulsman, 2007) that is expected to exceed 100 billion cubic meters by 2025 (Toufiq *et al*., 2004). Pakistan ranks third in the world in the use of its scarce water after India and China (Nabi *et al*., 2019). Rivers originating from India are the main source of surface water whose flow is expected to decline in future (World Bank, 2005) as new water reservoirs are being built by India on these rivers (Shakir *et al*., 2011; Lohano and Marri, 2020). Ground water is becoming saline due to sea water intrusion/seepage and inadequate drainage (Pakistan Meteorological Department, 2012). In Punjab, 23% and in Sindh, 78% of the area has hazardous ground water quality (Haider, 2000; Basharat, 2012). The lowering of ground water table and high cost of pumping may further aggravate the problem of water scarcity (Nabi *et al*., 2019).

The total land of Pakistan is 79.6 million hectares, out of which 70 million hectares is arid to semi-arid (Government of Pakistan, 2010). Drought in Pakistan occurs frequently particularly if the monsoon season fails to deliver the necessary rains. Pakistan has witnessed drought in 1998-2002 (worst in 50 years), 2004-2005 and 2009-2010 (moderate to low intensity drought). The drought is expected to be more frequent in coming decades due to rising temperatures (Amin *et al.*, 2019). Rise in temperature and decrease in rainfall may lead to the development of drought like situation. It is predicted that by 2100 temperatures may increase up to 4^{o}C in Pakistan and region (Pakistan Meteorological Department, 2012; Muhammad *et al.,* 2018) that can reduce yields of major crops (Chaudhry, 2017). Drought and floods may slow the economic growth of country.

Soils supporting crop production have undergone considerable deterioration due to continuous mining of nutrients and are in a poor state of health (Lal, 2009). Organic matter that serves as buffer against adverse effects of climate change is inherently low in Pakistani soils (less than 1%) (Azam *et al*., 2001; Hobbs and Govaerts, 2010). Current farming practices are less effective in increasing soil resilience as they tend to decline soil organic matter (Raza *et al*., 2018; Aryal *et al*., 2019). There is a need to identify management interventions that can sustain productivity and increase soil resilience to extreme weather conditions. The current situation entails to undertake a critical review of the impacts of climate change on agriculture sector and components associated with the sector to develop educated policy guidelines for main stakeholders (policy makers, researchers and farmers). This paper will provide a brief account of the impacts of climate change on soil, water and crops to identify gaps and recommend policy, research and management interventions to address vulnerability of agriculture sector to climate change.

Impact of climate change on various resources and agricultural components

Impact of climate change on water resources

Water is going to be a limiting factor for crop production. Climate change has undeniable impacts on water that is currently being used injudiciously (Hussain and Mumtaz, 2014; UNDP, 2017). Pakistan's water storage capacity is only 30 days of average demand against standard value of 120 days (Hassan, 2016). Efficiency of the world's largest gravity driven canal irrigation system in Pakistan is on a continuous decline due to inadequate maintenance (Memon and Thapa, 2011). In a changing climate, excessive amounts of water will be temporarily available through excessive glacial retreats (Jeelani *et al.*, 2012; Rasul and Molden, 2019). Besides water losses to the sea during the peak summer season, there is no effective mechanism to monitor and utilize the water that infiltrates the soil following a flood or rains. Ground water is turning brackish rapidly in Sindh and Punjab along with an increase in the depth of the water table across the country (Briscoe and Qamar, 2005). High pumping cost of ground water prevents many small farmers from using it (International Monetary Fund, 2015; UNDP, 2017).

The agriculture sector relies heavily on rivers originating from India mainly Jhelum, Chenab and Ravi. Water supplies from these rivers are expected to decline in the future due to construction of many small and large dams in India (Irfan *et al.*, 2019; Kalair *et al*., 2019). Competitive demands for water by other sectors (industry, domestic, recreation, etc.) may lead to a decrease in the share of water received by the agriculture sector. Water shortages are expected to intensify in less developed, arid regions of the country that already suffer from water, food, and health problems (Ahmed *et al*., 2016) . High temperatures and changing rainfall patterns may reduce yield of crops as majority of farmers do not have knowledge and technology to deal with the impacts of climate change (Qadir *et al*., 2003; Mancosu *et al*., 2015; Qureshi and Ashraf, 2019).

Impact of climate change on soil resources

The key climate change events that may affect soil include floods and drought (Watanabe *et al*., 2018). Climate change may have variable impacts on soils across the country. The impact may vary depending on the magnitude of the climate-related event, soil cover, soil management history and technology and knowledge available with farmers to adapt to climate change (Hamidov *et al.*, 2018). Floods may render the soil unfit for cultivation due to damage to the soil structure by erosion, loss of top productive soil layers, water logging and anoxia (Misra, 2013; Hafeez *et al.,* 2019). Climate change may reduce organic matter levels in soils and may negatively affect soil fertility through impact on carbon and nitrogen cycles (Brevik, 2013; Pahore *et al.,* 2016)

About 5 million ha of the cultivated area (24% of the total cultivated area) in Pakistan is rain-fed (GoP, 2010). Rain-fed agriculture is vulnerable to climate change as poor economic conditions of farmers and limited availability of water hamper the adoption of technological interventions (Bakhsh and Kamran, 2019). Managing soils under climatic change is a challenge for scientists across the world as well as in Pakistan. Scientific soil management assumes a high priority in the context of a developing country like Pakistan where soils are inherently low in organic matter (Srinivasarao *et al.*, 2019). It is noteworthy to indicate here that we do not have locally conducted and published work on impacts of climate change on soil resources of the country.

It is important to understand the effect of alternate wetting and drying of soils on properties like bulk density and organic matter content (Chidthaisong *et al.*, 2018). We must first understand how continuous drying and wetting will affect water retention, nutrient dynamics and soil productivity in a given agro-ecological zone to improve our understanding of the effects of drought and floods. Further we must be able to identify the key crop and soil management interventions that can be adopted for sustainable production under changing climate.

Impact of climate change on livestock

Livestock is an important component of agriculture as it contributes 11% to GDP (Sohaib and Jamil, 2017). Climate change events may affect performance of livestock negatively trough reduction in milk and meat production (Mittal *et al.,* 2019) by affecting the availability of water and fodder to the animals. Drought adversely affects the water and fodder availability to animals under rain-fed conditions. Floods may disrupt fodder availability in coastal areas and can cause the outbreak of diseases leading to mortality of animals (Escarcha *et al*., 2018). The importance of livestock under rain-fed conditions lies in the fact that animals serve as security against crop failure. If, for example, wheat crops fail due to non-availability of water, farmers maintain their livestock as an insurance measure to offset the losses from drought. Limited water availability and poor efficiency of water and nitrogen (N) use under rain-fed conditions limit the crop productivity and reduce the net benefits to farmers resulting in poverty.

Farming under rain-fed conditions is associated with uncertainty as rainfall is erratic and suitable interventions cannot be introduced due to limited water availability. Identification of suitable crop rotations and management interventions that can enhance overall efficiency of the farming system is a pre-requisite for sustainable economic development of water scarce areas in Pakistan. Water remains a focal point of all interventions in rain-fed areas. Any intervention that can improve water use efficiency is ultimately going to affect productivity of the system. Livestock is an integral component of a rain-fed farming system and contributes over 40% towards the annual income of millions of families in Pakistan. However, livestock production is constrained by non-availability of suitable fodder crops and crop varieties. Diversification and sustainable intensification of fodder production systems offers great prospects for improving the livestock component in an integrated farming system (Xie *et al*., 2019).

Impact of climate change on food security

Food security in Pakistan is at high risk due to climate change, rapidly increasing population and degradation of land and water resources. Pakistan currently produces 23 million tons of wheat and by the year 2030, the country will require over 33 million tons of wheat to meet its domestic requirements (Rajaram *et al*., 1998; Nazli *et al*., 2012; Imran, 2018). Overall impact of climate change on yield of major crops is expected to be negative (Ali *et al*., 2017; Akbar and Gheewala, 2020). Pakistan is under immense pressure to ensure food security because besides wheat the country needs to produce fiber, sugar, oil seeds, horticultural crops, and dairy and meat products. The two key options to increase food production include increase area under production or increase existing crop yield from available land resources. The option of increasing land for production requires huge investment in terms of development of infra-structure for expansion of agriculture sector. This will be done at the expense of clearing forest lands that may trigger climate change and evoke resistance from environmental protection groups. The second option of increasing crop yield from available land resources seems viable but is constrained by input availability at critical stages of production and attitude of small farmers who do farming activity for subsistence (McLaughlin and Kinzelbach, 2015).

There are diverse issues that threaten food security in Pakistan, but water remains the key issue that needs to be addressed on priority basis. The results of improved crop varieties or management practices cannot be fully realized in the absence of water. Climate change may influence crop production both positively and negatively depending upon the location and extent of climate change events. In some areas there will be an increase in crop production due to a favorable shift in rainfall and temperature while in other areas, devastating floods may destroy existing crops (Raza *et al*., 2019).

Measures to address vulnerability of agriculture sector

Policy related measures

Allocation of funds for research

Pakistan currently spends only 0.29% of its GDP on research, compared to the developed nations that spend up to 5% on research. The government current expenditures on climate change research are meagre. The government shall spend more to mitigate and adapt to climate change and shall also exploit the funding available from foreign initiatives like Green Climate Fund etc. The country needs to revisit its priorities both in terms of applied and policy research on key issues related to a changing climate to ensure food, water and energy security. In developed countries like USA, UK, one million acre feet (MAF) of water generates an economy worth $3 billion, in India $1 billion and in Pakistan around $0.5 billion. Pakistan is in need of a well devised irrigation policy aimed at improving the efficiency of water resource management (Ministry of Water Resources, 2018).

Increase in storage capacity

There is a dire need to increase the national water storage capacity to make effective use of seasonal peak water flows. Building mega hydroelectric dams has become controversial and may become a source of contention among provinces. It would be better to construct several small and medium dams at appropriate places across the country to increase water storage capacity (Khan, 2019). This will help to overcome water shortages during dry summer months. Additionally, available technologies to make efficient use of available technologies may be given due consideration for a given set of conditions based on technical advice of water management experts.

Capacity building

Pakistan needs to develop an effective and sustainable master trainers' program for training communities to withstand the adversities of climate change. This can be done either by establishing an academy dedicated to develop master trainers or already existing rural development academies can be assigned this task. Experts from universities and research institutes could develop training modules and materials for dissemination to end-users. This national capacity building program on climate change should be sustained through funding from the public sector initially and later on public-private partnerships should be evolved to sustain this much needed activity.

Development of a smart early warning system

Early warning on the possible occurrence of extreme weather events enables concerned departments and communities to make necessary arrangements to reduce the impact of floods and drought. Early warning systems have been effectively used in many parts of world to minimize damage from climate-related vulnerabilities and such systems need to be strengthened in Pakistan as well. Early information that drought or flood is likely to occur in a given area could allow disaster management departments to make relevant arrangements accordingly (Funk *et al*., 2019; Ray-Bennett *et al.,* 2020).

Research related measures

Zone specific agronomic research

Climate change will alter the environmental conditions for crop growth and crop management practices will have to be adapted to a new climate (Laux *et al*., 2010; Lehmann *et al*., 2013). Research on agronomic issues shall be given high priority as farmers will be growing crops in an environment much different than from today. It is critical to identify key research gaps and conduct agronomic research using experimental and modeling approaches to answer research questions and develop appropriate packages of production technology to equip farmers with relevant techniques and know-how to sustain crop production under changing climatic conditions (Mishra *et al*., 2019).

Simulation models should be used to guide new crop management. Unfortunately, in Pakistan, they have been ignored despite the fact that simulation models have enormous potential to analyze multi-dimensional scenarios simultaneously for guiding mitigation and adaptation strategies to sustain productivity under climate change (Balogun *et al*., 2020). The choice of water use efficient varieties is a key factor in improving water use efficiency and shall be prioritized by researchers. Breeders seldom select varieties that have higher yields per cubic meter of transpired water due to non-availability of water measurement devices to calculate changes in soil water storage following water balance approach (Ehlers and Goss, 2003).

An improved understanding of the effects of climate change, especially elevated levels of carbon dioxide (CO_2) on plant production, is critical to developing strategies for mitigating the adverse effects of climate change. The relation between water and N uptake is not clear from earlier published research particularly under long-term exposure to elevated CO_2 (Ayad *et al*., 2010; Shimono and Bunce, 2010). Usually increasing levels of CO_2 increase growth and yield in C_3 plants like rice until sufficient N is available in the soil, indicating that N uptake is a bottleneck for yield enhancement under climate change (Zhang *et al*., 2013). In a warming global climate where water supplies are dwindling (Wilkinson and Hartung, 2009), strategic N fertilization may provide an opportunity for moderating plant water demands (Pathak *et al.,* 2016). Research on N management of crops under varying levels of water and CO_2 should be conducted to develop reliable recommendations for farmers.

The use of cover crops in rotations remains under-researched in the country and suitable cover crops need to be identified to conserve soil and water under both irrigated and rain-fed conditions. There is a dire need to conduct zone specific applied agronomic research to develop technical guidelines for farmers to adjust their crop and soil management strategies for sustaining crop productivity and maintain soil fertility under a changing climate. This needs an integrated approach to develop research based environment friendly package of production technology with minimal wastage of resources at the farm level and adoption of climate smart cropping systems and management practices. Agronomic practices offer great prospect to improve yield and water use efficiency and site specific recommendations shall be developed to improve yield and water use efficiency. Soil management practices that promote buildup of soil organic matter shall be encouraged as organic matter contents in our soils are not improved as we return very smaller amounts of crop and animal wastes to our soils.

Applied root research

Plant roots are key contributors towards the survival of plants under adverse climatic conditions, maintaining supplies of water and nutrients (Plett *et al*., 2020). Higher costs of chemical fertilizers necessitate the development of crop varieties that can maintain productivity under climate change scenarios with minimal inputs. Research on improving nutrient and water use efficiency of crop varieties is needed in the era of climate change. It is imperative to study the response of plant roots to high temperatures and CO_2 concentrations under varying levels of water and nitrogen availability to improve our understanding of how plant roots will respond to increase in temperature. This will help us to identify management interventions for sustaining productivity under climate change. Research on modifications in root architecture to favor efficient water and nutrient uptake for various contrasting situations across the country offers promising new research areas (de Vita and Taranto*,* 2019).

Evaluation of innovative water use efficient technologies

Decreased availability and highly competitive demands of water necessitate increasing the efficiency of its use in crop production (Qureshi, 2019). Improvement in irrigation water use efficiency is likely to come by adjusting the amount, method and time of irrigation. Traditional methods of flood irrigation need to be gradually replaced with modern and efficient irrigation methods that require a higher investment and additional site specific research. Research on the water footprints of key crops and products consumed at the national level is needed to inform people how much water is being required for each utility and service being used (Kumar and Joshiba, 2019).

Application of simulation models

Simulation models are used in developed world for identifying management and breeding interventions to combat the impacts of climate change. These models allow us to study the impact of several combinations of variables related to crop, soil, weather, and management on the crop bio-dynamism (Dettori *et al*., 2011; Ahmad *et al*., 2020). Their application is constrained by lack of data sets for developing regions of the world, especially the arid regions including Pakistan. Local research needs to be strengthened to generate reliable data sets on soil and crops for use with simulation models. We can also apply simulation models to predict the effect of a changing climate on quality and recharge of ground water and snow melt (Liu *et al*., 2020) and information generated can be used to develop policy and research guidelines to live with the adversaries of climate change.

Organic farming to increase soil resilience

Soil resilience is the ability of soils to resist or recover their healthy state in response to destabilizing influences (Falk *et al*., 2019). Pakistan's soils have poor resilience capacity due to low organic matter contents. Organic matter improves the capacity of soils to withstand and recover from adverse effects of drought as it helps to improve their water holding capacity (Anwari *et al*., 2019). Soils in a given farming systems are more resilient if they are less dependent on external inputs as is the case with organic farming systems (Gupta and Nair, 2012). Low organic matter contents of soils result in poor aggregate stability and water holding capacity, making soils prone to erosion. We need to switch over to sustainable farming solutions to increase soil resilience by improving their organic matter contents. Organic farming provides sustainable farming solutions to developing countries like Pakistan (Ali *et al.,* 2019).

Research on organic farming is in infancy in Pakistan. Public sector research institutes and agricultural universities shall focus on organic farming research. Effects of organic farming practices need to be evaluated experimentally in comparison with conventional farming practices to convince farmers for adopting environment and soil friendly systems. There is need to conduct a series of field experiments to identify the management interventions best suited for a specific agro-ecological zone. We must identify research based management interventions for building up soil organic matter content and fertility.

Breeding and biotechnological research to evolve climate smart crop varieties

New climate smart crop varieties that can tolerate weather extremes need to be developed using breeding and biotechnological tools. Breeding programs at international level had already achieved success in this regard using conventional and mutation breeding approaches (Raina *et al.,* 2016; Taranto *et al.,* 2018; Das *et al*., 2019). National breeding programs need to divert focus on developing zone and province specific well adapted crop varieties under current scenarios of changing climate. The breeders need to develop crop varieties that can tolerate high temperature, drought and floods and are efficient in utilization of available resources. Development and deployment of seeds of newly developed climate smart crop varieties are a sustainable solution to live with changing climate and offer enormous potential for sustaining crop production under changing climate (Thierfelder *et al*., 2016).

Management related measures

Soil management practices

The objective of soil management practices should be to build up long-term soil fertility and increase soil resilience. This objective can be achieved by following the principles of organic farming. Organic farming systems help conserving and improving organic matter, water holding capacity, porosity, biodiversity and productivity. These systems encourage minimum losses of nutrients by working within closed nutrient cycles and encourage maintaining a good vegetative cover to protect the soil from extreme weather. Organic farming systems may contribute towards increased soil resilience due to their documented positive effects on soil health (Sandhu *et al*., 2010, Eyhorn *et al*., 2019). Use of organic amendments is not popular due to their limited availability and higher transportation costs. This problem can be partly overcome by strengthening the livestock component of farm systems, especially in rain-fed areas of the country.

Land management practices have a direct relationship with soil resilience. Tillage practices affect the turnover of soil organic carbon and N that make up a dominant part of soil fertility (Zhang *et al*., 2007; Jin *et al*., 2009). Management practices for drought prone areas should focus on conservation tillage to minimize soil disturbance and water losses through evaporation. Management practices for flood prone areas may include breaking hard soil pans to increase water infiltration and decrease runoff. The effects of management practices may vary with soil texture, rainfall pattern, management history of soils, cropping systems and weather. Soils having higher organic matter contents can usually withstand water shortages over a longer period of time (Hatfield *et al*., 2001; Rasool *et al*., 2008). Soil cover in the form of vegetation and cover crops may be a strategic option to minimize the adverse effects of floods. Soils having good vegetative cover are less vulnerable to water erosion and can quickly recover from the adverse effects of floods depending on the severity of flooding, soil texture, soil management history, extent of vegetation cover, and weather conditions (Trnka *et al*., 2016). Due to climate change, a partial shift from conventional farming to organic farming systems is needed to preserve precious natural resources such as soil and water for coming generations.

In Pakistan, organic farming is not common, so soils are more vulnerable to climatic extremes. We must be able to develop a package of technologies that is available to the farming community in drought and flood prone areas of Pakistan to safeguard the soils. Interventions should be based mainly on principles of organic farming systems as it is a new and promising area of soil management and has the potential to increase soil resilience to drought and floods (Jordan, 2017).

Crop management practices

Crop management practices need an adjustment in relation to a changing climate. These may include changes in crop varieties, crops, cropping patterns, sowing dates, fertilizer and irrigation management practices (Abraha and Savage, 2006). These adjustments should be made keeping in mind weather extremes, farmer preferences, market volatility and technical guidelines from experts. The identification of suitable water and N use efficient varieties, cropping systems and management practices shall be made available to improve the overall efficiency of the farming system and increase net returns to farmers (Anderson *et al*., 2020).

Any practice that increases yield and net returns should be adopted to make farmers more secure under changing climatic conditions. Changes in crop management assumes high priority on account of poor financial conditions of farmers particularly under rain-fed conditions. Enhancing resource use efficiency at farmers' fields is the key to unlocking the potential of both irrigated and rain-fed areas. Great focus needs to be put on increasing the efficiency of inputs used in crop production (Meena *et al.,* 2016). Wheat-fallow-wheat is the dominant rotation in many rain-fed areas of the country and needs to be replaced with other suitable legume-based rotations to build up long-term soil fertility and improve soil water conservation.

Use of potash based chemical fertilizers is not quite common by farmers in Pakistan assuming that our soils are not deficient in this nutrient element. Farmers shall be encouraged to apply potassium based on soil test as its use will help the crops to better withstand high temperatures and drought like conditions (Ahmad *et al*., 2016; Zhang *et al*., 2019).

Water management practices

Water management in a broader perspective should focus on increasing national water storage capacity and developing an integrated approach to ensure its effective utilization by addressing all related components across the chain involving policy, research and management issues. Water finds a central position in devising strategies to minimize the impacts of climate change on crop production (Scott and Lennon, 2020). As the main concern is diminishing water supplies due to population growth, greater focus needs to be put on increasing water use efficiency at the field scale. Irrigation water management at the field level needs to be improved with the core idea of obtaining more crops per drop of water in order to increase the overall efficiency of the system. A detailed guideline on techniques for improving water use efficiency has already been provided in earlier published work (Raza *et al*., 2012; Zahoor *et al.,* 2019).

Advances in irrigation technology should be used by farmers under current scenario of water scarcity. A partial shift from flood irrigation to other less water consuming methods like sprinkler and drip irrigation should be encouraged where applicable. Irrigation should be based on the needs of the soil and crop (García-Tajero *et al*., 2020). Considerable amounts of water can be saved by applying the amount of water that is needed to refill the soil to saturation. This requires periodic monitoring of soil water content and irrigation only to be applied when soil water content drops below field capacity. A comprehensive review of improving irrigation efficiency by using sensors and wireless technologies is given by Greenwood *et al*., (2010). Sensor technologies coupled with simulation models and drip and sprinkler irrigation offer enormous potential to improve crop water use efficiency at field scale (García *et al*., 2020).

If Pakistan has to ensure food security for its future generations, it has to act wisely and promptly to increase the water use efficiency of the system. Increase in water use efficiency can be achieved following different approaches vis-à-vis research, management and policy (Raza *et al*., 2012). Success in water use efficiency is more likely to be achieved by simultaneously improving (i) available water supplies (irrigation system), (ii) varieties (research and development) and (iii) management practices. Hsiao *et al*. (2007) demonstrated that an overall increase in the water use efficiency of the system is likely to come through improvement of these three components along the chain. Addressing any of these three components in isolation will not bring a remarkable increase in the system's water use efficiency.

Tree plantation and maintenance of newly planted sapling

One key technical intervention to mitigate the adverse impacts of climate change is tree plantation and protection. Trees have a moderating effect on the environment and can help plants and humans withstand warm temperatures. They also assist in mitigating the drivers of climate change by removing CO_2 from the atmosphere during photosynthesis, storing carbon above and belowground (Singh *et al*., 2019). It should be a priority to plant and protect as many trees as possible, both with and without government support, with the objective that our efforts in tree plantation yield desirable outputs in terms of minimizing the adverse impacts from climate change.

Awareness at community level

Well informed communities can create the public opinion needed to encourage policy makers to make necessary policy adjustments for enhancing national capacity to cope with the phenomenon of climate change. Communities need to be informed and educated about climate change, how it can affect their lives, and how they can survive and adapt to climate change. An effective communication strategy needs to be developed for disseminating information related to climate change using print and electronic media. A master trainers program is needed to educate communities on withstanding vulnerabilities of climate change (Mees *et al*., 2019).

As we are mainly concerned with vulnerability of agriculture sector to climate change and expect a decline in per capita water availability in coming years, we need to put a great focus on increasing awareness among the masses on the need to avoid wastage of water and water related products (given that water is needed for almost every agricultural and industrial application). A reliable solution lies in determining the amount of water consumed in the production process, especially in the agriculture sector at it is a dominant user of fresh water resources. However, a knowledge gap exists between water consumption and water availability that hampers policy formulation dedicated to sustainable management of water resources. Water footprints are a potential indicator of sustainability and can be used for environmental impact assessment (Tian *et al.*, 2019). It is vital that responses to climate change must focus on water.

CONCLUSION

Agriculture being practiced under natural conditions is highly exposed to climate change and addressing vulnerability of this sector becomes vital due to dominant role of agriculture sector in gross domestic production. Climate change may affect soils, crops, livestock and water resources and can have serious repercussions for national food security. Overall effects of climate change on food security in Pakistan may be negative as extreme weather events may reduce crop yield, milk and meat production and render the soils unfit for long term production through erosion, loss of organic matter and soil fertility. Vulnerability of agriculture sector to climate change can be reduced through devising strategies at management, research and policy level. Organic farming practices are recommended to increase soil resilience and to withstand adversaries caused by extreme weather events besides focusing on improving the efficiency of input use in crop production.

In order to conserve soils for coming generations, a partial shift needs to be made from conventional chemical farming practices to a blend of chemical plus organic farming to optimize yields with minimal or no losses to the productive potential of soils. Water is a highly vulnerable component (input) for crop production under climate change. An integrated system approach needs to be developed to ensure its efficient utilization. Sustainability of current irrigation practices (flood irrigation) has become highly questionable and the issue needs to be addressed through identification and adoption of site specific interventions for improving conservation and efficient utilization of available water. The country must focus on increasing water storage capacity, renovate ageing water infrastructure and ensure scientific water management in all sectors of production to particularly minimize the impact of the water-related vulnerability on the agriculture sector. A commitment by the government is required to allocate more funds for research and national capacity building on a sustainable basis to address vulnerability of agriculture sector to climate change. We suggest that the key research and policy gaps presented in this paper should be made part of a national research and policy agenda after extensive discussions with relevant think tanks and stake holders to address vulnerability of agriculture sector to climate change.

AUTHOR'S CONTRIBUTION

A. Raza: Structured and wrote the entire article (70%)

M. Imtiaz: Provided technical input for improving the article (10%)

Z. Ali: Assisted in search of literature for article (10%)

S. A. Ali: Proof reading, editing and type set of article (10%)

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