J. Plant Environ. 04 (02) 2022. 211-229 DOI: 10.33687/jpe.004.02.4461

Available Online at EScience Press
Journal of Plant and Environment
ISSN: 2710-1665 (Online), 2710-1657 (Print)
https://esciencepress.net/journals/JPE

Threats and Challenges for Sustainable Cotton Production in Sindh, Pakistan: Climate Change Vulnerability Assessment and Adaptation to Combat Climate Change

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ARTICLE INFO

Article History
Received: October 13, 2022
Revised: December 04, 2022
Accepted: December 16, 2022

Keywords
Heat
Drought
Weather forecast
NDVI
Climate resilient cotton production
FDGs
Farmer's perception
Adaptation and mitigation

ABSTRACT

Current cotton production systems are most vulnerable to climate extremes in the world but particularly in Sindh, Pakistan. There is a drier need to assess the climate vulnerability and develop climate-resilient production technologies and adaptation plan to combat the climate extremes. A study was conducted in three districts of Sindh province (Ghotki, Sukkur, and Khairpur). Both primary and secondary data of cotton growers (small, medium and large land holding) and different relevant departments of cotton was collected. Three data collection tools were used in this study. Primary data was collected directly from farmers by conducting Focus Group Discussions (FGDs) by engaging local cotton growers. Key informant interviews (KIIs) guide was used for the consultation with officials in government and other cotton related departments. Survey of cotton growers/farmers were conducted in these three districts by selecting farmers randomly. HCPL has conducted 13 FGDs with the beneficiary's farmers (men and women). Out of the total, seven FGDs were conducted with male farmers and six FGDs were held with female farmers in three studied districts. In each FGDs 10 to 12 farmers participated actively in the discussion and data collection. In total 130 farmers consulted through FGDs in the studied region. Results showed that, the current cotton production system is vulnerable to climate change and climate resilient site-specific production technologies are required by adopting good management practices. Due to competing crops and unavailability of resources, cotton crop area has been shifted to other crops like sugarcane, so climate adaptation plan is required to reduce the cost of production. Increasing area under sugarcane crop also has negative effect on cotton crop due to high humid climatic conditions and leads to more insect pest infestation. Currently, cotton is being sown after wheat during the month of May, while sub optimum and substandard input like seed, fertilizer, and management practices being used. Farmers are also lacking in climate knowledge, and while there is no weather agro-advisory system available for farmers related to climate extremes conditions (drought, heat, and floods). Financial incentive system is also required for cotton crop just like other crops in the region. Good quality seed and input at lower rates are unavailable in this region. There is knowledge gap existed and farmer's field school are required to develop the capacity building of the farmers to adopt climate resilient production technology. Cotton crop is sensitive to weather while climate forecast is also missing at gross root level, there is need to strength the system to deliver the information to the cotton growers to manage the cotton accordingly. There also need to strength the coordination and productive linkages

with research institutes and academia that are working for the production enhancement of cotton crop. Climate resilient production technology transfer is also required to mitigate the negative effects of climate change. There is need to strengthen the marketing system of cotton for effective functioning of the key cotton value chain actors.

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INTRODUCTION

Cotton is an important cash crop, contributing mainly to the economy of the country. Globally, Pakistan is 5th largest producer while the export and textile product has a share of almost 60% generally in overall export of the country (GOP, 2021). In Pakistan, 26% of farmers grow cotton and nearly 15% area is devoted to this crop in two provinces of Pakistan Punjab and Sindh. Export of cotton and textile products have a share of around 60 percent in overall exports of the country. It contributes around 0.6% in GDP and 2.4% of the value addition in agriculture. Cotton production and yield is decreasing since the last decade and sustainable cotton production is under threat due to climate variability and climate extremes conditions happening in the country (Ahmad et al., 2022; Arshad et al., 2021). There are also other factors of course present that have also affected the area and production of cotton crop in the country, one important factor is the competing crops and supply of inputs during cotton crop seasons. During 2021-22, the cropped area declined to 1,937 thousand hectares (6.8 percent) against last year's 2,079 thousand hectares (GOP, 2021). While cotton bales production was also reduced by 22.8% in 2020-21 as compared with the last year (2019-20). Although, cotton production is estimated to increase and the target was fixed early in the year (2022) but later due to happening of climate extremes (heatwaves, and heavy rainfall), risk and vulnerability in cotton production existed and are threats to a reduction in production and yield in the country and particularly in Sindh province. The climatic conditions are suitable for cotton crop in Sindh province as generally cotton is grown in places that are hot and have low humidity. While rainfall is also low in this region, it is also favorable for cotton.

Climate change is a major threat to cotton production in Pakistan. As the climate of South Asia is changing as a whole the climate of Pakistan has also changed over the past several decades with significant impacts on the environment, crops, and humans (McDermid et al., 2015; Habib-ur-Rahman et al., 2022a). Furthermore, increased heat spells, drought and extreme weather events in some parts of the country impacted other activities either natural or anthropogenic. The increasing global temperature is destroying agriculture productivity and increasing food insecurities (Ahmad et al., 2021). Recent heat waves and then climate extremes conditions especially the flood in 2022 are clear evidence of changing climate. Pakistan ranked 5th in the climate affected countries effected by extreme weather over 1999-2018 caused by climate change (Rahman et al. 2018; Waqar et al., 2022). While due to recent examples of climate change, it is clear that it is most vulnerable to climatic changes. While, previously it has been reported many times by Intergovernmental Panel on Climate Change (IPCC) that climate change and especially the climate extremes can substantially distort agriculture productivity, especially in developing economies (IPCC, 2022).

Pakistan is among the top 10 countries who are suffering from the negative impacts of changing climatic conditions and there is clear recent evidence as heat waves in March, April, and May 2022 then early Monsoon started in June and intense erratic rainfall in July, and August 2022 throughout the country leads to floods and affect the agriculture but particularly the cotton crop in Sindh (personal observations with data). Crops are more sensitive to climate change as rise in temperature, extreme rainfall events, increase in humidity and difference between day and night temperatures. Due to climate extremes plants are more susceptible to disease and insect pest attack, lodging and death of plants ultimately to yield loss (Mollaee et al., 2019; Rahman et al., 2019; Majeed et al., 2021). Due to drastic climatic changes and climate extremes conditions, cotton production is under threat. Cotton production is predicted to decline by 20-30% in upcoming years due to changes in climatic conditions (Wajid et al., 2014;

Rahman *et al.*, 2018). Recently, in 2021-22, the cotton cropped area has declined by 6.8% as compared with last year as of course this cropped area has also been substituted with the other crops due to challenges and issues in cotton production while other crops generated better economic returns (GOP, 2021). While, other than area, cotton production and yield are also dwindling in recent last years due to climatic changes particularly heat waves and drought stress (Morton, 2007; Manzoor et al., 2022). While water shortage during cotton crop season is also a threat, as high temperature and heat waves cause high evapotranspiration that can leads to water stress and affect the cotton growth, development and ultimately the yield and also affect the fiber quality (Haim et al., 2008; Habib-ur-Rahman et al., 2022b). Variations in precipitation from mean value and particularly the intense and erratic rainfall negatively impacts cotton productivity. The increases in temperature and shift in the rainfall cycle affect cotton growth development and threat for cotton production and quality in studied region (Saddique et al., 2021; Ahmad et al., 2021; Iqbal et al., 2021). The optimum temperature required for cotton growth and developed range between 28 °C to 37 °C but in studied region the overall average seasonal temperature is around 37 ˚C during cotton growing season that is higher than the optimum temperature ranges required by good growth and development (Filippi et al., 2021; Rahman et al., 2020). Optimum temperature required by cotton plant for good physiological process is 25-33 °C that can produce maximum biomass and yield. While although cotton plant can survive up to 43°C for shorter period without having any significant losses in growths and yield, it means plant can survive and tolerate some stress periods but actually heat waves that continue more than 7 days and actually in Pakistan where climate resilient genotypes are lacking then it looks difficult that plant even can tolerate the short drought or heat stress period. It is evident from previous studies that the high temperature, heat and drought conditions are the major constraints in cotton production in Pakistan (Wajid *et al.*, 2014; Rahman *et al.*, 2018).

Climate change could also affect irrigation water availability, which would reduce the crop yields, especially for food crops. Although studies are present but in scattered form available for the impact of climate change on cotton crop. While details are lacking particularly the impact of climate extremes (drought, heat and floods) on fiber crops (Wei et al., 2020; Imran et al., 2018). Due to the high temperatures in Pakistan, the average cotton fiber length and the cotton boll weight both are low. Pakistan's cotton crop is grown in conditions ranging from arid to semiarid under irrigated conditions, with high temperatures and low rain most of the time. The vertical tap root system of cotton plants makes them somewhat resistant to high temperatures and water stress. But the crop is sensitive to the amount of water available at flowering and boll formation phases (Hussain *et al.*, 2020). The crop is also more likely to be attacked by pests when the temperature and humidity both are high. The marginal effect of rain is negative for cotton sowing but good for vegetative stage when the crop needs a lot of water. Heavy and erratic rains have also negative effects on boll-forming and picking stages (Mollaee et al., 2019). Heavy and erratic rains are dangerous for cotton production as standing water in cotton crop more than 48 hours leads to suffocation and plant deaths if water stand prolonged. High temperature than the optimum also has negative impacts on plant growth, development and boll production. If the temperature went up by 10 °C during vegetative growth stages and flowering-fruiting stage, the yield would go down by 24.14 and 8%, respectively. During the flowering and fruit forming stages, when the temperature rise by 10 °C, the cotton yield may decrease by 31% due to flower and boll shedding. However, further warming during the reproductive phases, and fruit formation affects the crop because it is already very hot during these months.

Climate change and climate extremes conditions have a negative impact on livelihood of the cotton growers as heat waves, drought and unavailability of quality inputs affects the cotton production and yield which ultimately affects their livelihood. Many studies in recent past related to cotton and socioeconomic conditions have been conducted related to cotton and livelihood of the cotton farmers (Siddiqu et al., 2021; Ahmad et al., 2021; Ghaffar et al., 2020) but the individual and scattered factors were studied. Sustainable and climate smart cotton production is required to meet the country demands, where climate resilient production technology is required to save the cotton from climate extremes. Although, cotton crop requires high temperature for its growth and development to complete its heat units but each development stage is also temperature sensitive, higher temperature above normal for a particular range affects the growth and yield. Resource use optimization is also quite important for cotton crop especially under changing climate scenarios, balanced use of resources

(land, water, fertilizer and labor), and good decision making can lead to climate smart production system. The objectives of current study were to assess the climate vulnerability of cotton crop and cotton farmers' livelihood under changing climatic conditions especially related to changes in weather, rainfall patterns and humidity in the project districts (Ghotki, Sukkur & Khairpur) in Sindh-Pakistan.

MATERIAL AND METHODS

Study region and data collection tools

The study region has the arid climatic conditions where generally high summer temperature exceeds the 50 °C. Historic climate trends showed the heatwaves and drought conditions prevailed in this region. The production of cotton is severely damaged and affected by climate extremes while the study region is most vulnerable due to climate change, so this region was selected to assess the climate vulnerability and develop adaptation strategies for sustainable cotton production. Soils texture are sandy loam to sandy clay loam in district Khairpur and surrounding districts (Shar et al., 2018). Study region consisted of mixed cropping zone, where cotton, and rice are cultivated during summer (Kharif season) while wheat, fodders, and vegetables are also grown in winter seasons. Sugarcane is also competing crop with cotton due to influence of sugar industry and incentive from sugar industry. Both primary and secondary data of cotton growers and different departments were collected. Three types of data collection tools were used in this study. Primary data were collected directly from farmers by conducting Focus Group Discussions (FGDs) by engaging local cotton growers after taking their consent by well developing and well-structured questionnaire. For secondary data collection, Key informant interviews (KIIs) guide was used for the consultation with officials in government and other related departments. Survey of cotton growers/farmers were conducted in these three districts by selecting farmers randomly. While detailed survey was designed for data collection related to crops, crop management and cultural practices and technologies being used at farmer's field.

Sampling for focus group discussion (FGDs)

HCPL has conducted 13 FGDs with the beneficiaries (men and women) farmers. Out of the total, seven FGDs were conducted with male farmers and six FGDs were held with women farmers from the three districts. In each FGDs 10 to 12 farmers participated actively in the discussion. In total 130 farmers consulted through FGDs. The location and participants of the FGDs were selected randomly in consultation with WWF team. However, to ensure the representation, the FGDs were conducted in each tehsil of the target districts. For FGDs those farmers were preferred who had knowledge on the impact of climate change on cotton crop. District-wise break-up of the FDGs is presented below in Table 1.

Sampling for key informant interview (KIIs)

A total of 6 KIIs were conducted which include the official from district agriculture extension departments, Management of WWF and BCI. Details is mentioned in Table 2.

Table 1. The number of FGDs selected by famers and in different studied districts.

	Small Farmers		Medium Farmer		Large Farmers		Total
	Men	Women	Men	Women	Men	Women	
Sukkur	1	2	-	-	1		4
Ghotki	1	2	1	-	-	-	4
Khairpur	1	2	1	-	1		5
Total	3	6	2	-	2	-	13

Table 2. The list of KIIs in selected in different studied districts.

District	Departments	KII	Project Team	KII	Total KII
Ghotki	Cotton Research Station	1	Project team of WWF	1	2
Sukkur	Agriculture department	1	SRSO Team Member	1	2
Khairpur	Pesticide company/Cotton Ginning Factory	1			
Total					6

Survey tools and training of data collection team

HCPL also conducted a short survey with the respondents of each focus group discussion to have better perspective of the vulnerabilities in the region. This quantitative information helped to run cotton vulnerability model analysis and prove them scientifically. HCPL also held one day training for data collection team at WWF office Sukkur. During the training, the data collection team provided skills on data collection methods, data collection techniques and ethics of data collection. After the training a mock focus group discussion and interview was also conducted adopting roleplaying approach.

RESULTS AND DISCUSSION

Observed climatic changes in hotspots regions

Cotton cropped area in 2021-22, declined by 6.8% as compared with last year as of course this cropped area has been substituted with the other crops due to challenges and issues in cotton production while other crops generating better economic returns. While, other than area, cotton production and yield are also dwindling in recent last years due to climatic changes particularly the heat waves and drought stress. While water shortage during cotton crop seasons also a threat due to climate change were high temperature and heat waves causes high evapotranspiration that can leads to water stress and deficiently affect the cotton growth, development and ultimately the yield and also affect the fiber yield. The increases in temperature and shift in the rainfall cycle affected cotton growth development and threaten for cotton production and quality in studied region. The optimum temperature required for cotton growth and developed range between 28 °C to 37 °C but in studied region the overall average seasonal temperature is around 37 °C during cotton growing season that is higher than the optimum temperature ranges required by good growth and development. Optimum temperature required by cotton plant for good physiological process is 25-33 °C than can produce maximum biomass and yield. While although cotton plant can survive up to 43°C for shorter period without having any significant losses in growth and yield.

While recent heat waves in 2022 badly damaged the cotton crop germination and early growth developed stages in all these three studied regions where temperature exceeds than 45 °C in April and then in May when plant was at early development stages (Figure 1 and Figure 2). The germination percentage of cotton crop is decreased due to higher temperature and results in poor stand establishment. Heat waves and drought negatively impact the cotton productivity as high temperature reduce the growth and boll weight as cotton grown under semi-arid to arid regions. Studied region lies under arid climate where generally drought and high temperature prevails, as it is clearly evident from Figure 1 and Figure 2 that there were heat waves occurred in April and May 2022 and then cloud cover prevails more than two months and rainfall occurred where cotton crop also required optimum solar radiation and day length to produce optimum growth and development and then finally the cotton yield (Figure 2). The higher temperature in the months of April and May 2021; also affected the cotton crop to much extent because the temperatures frequently raised above 46 °C between May and August. Last ten years data has a similar pattern of temperature while only year 2022 had totally different patterns of high and minimum temperature so that affect cotton crop badly at early growth phases and then reduced solar radiation and high humidity leads to high badly impact on cotton growth and yield this year (Fig.2. C). About one third of the cotton crop was destroyed due to the heat waves in lower Sindh, while extreme heat waves resulted in stressed plants, stunted crop development, and caused plant mortality, which resulted in reduced cotton crop yield and quality.

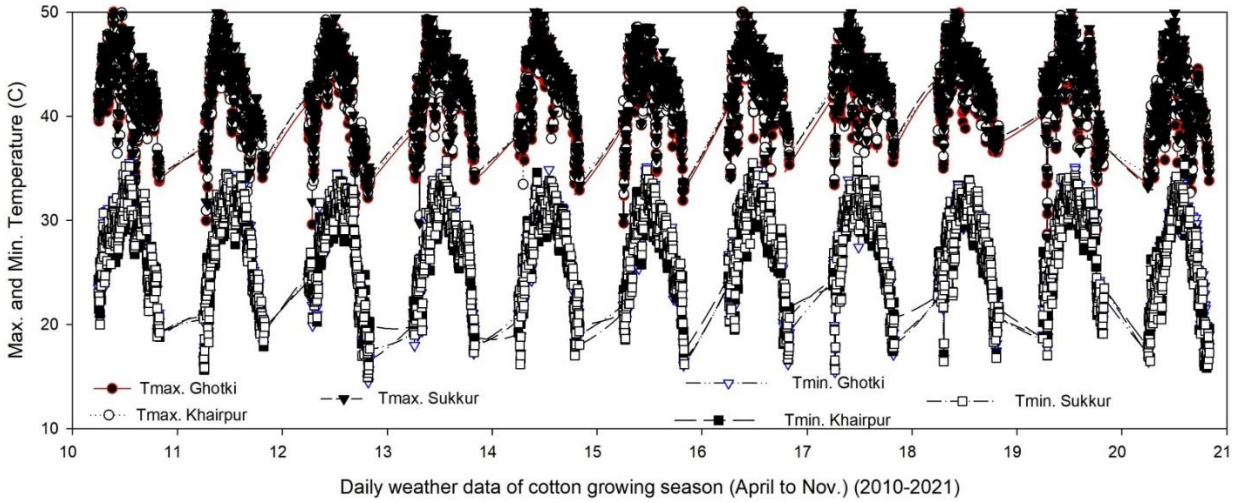


Figure 1. Daily historic climate data (maximum and minimum temperature) (2010 to 2021) during cotton growing seasons (April to November) in three studied districts (Ghotki, Khairpur and Sukkur).

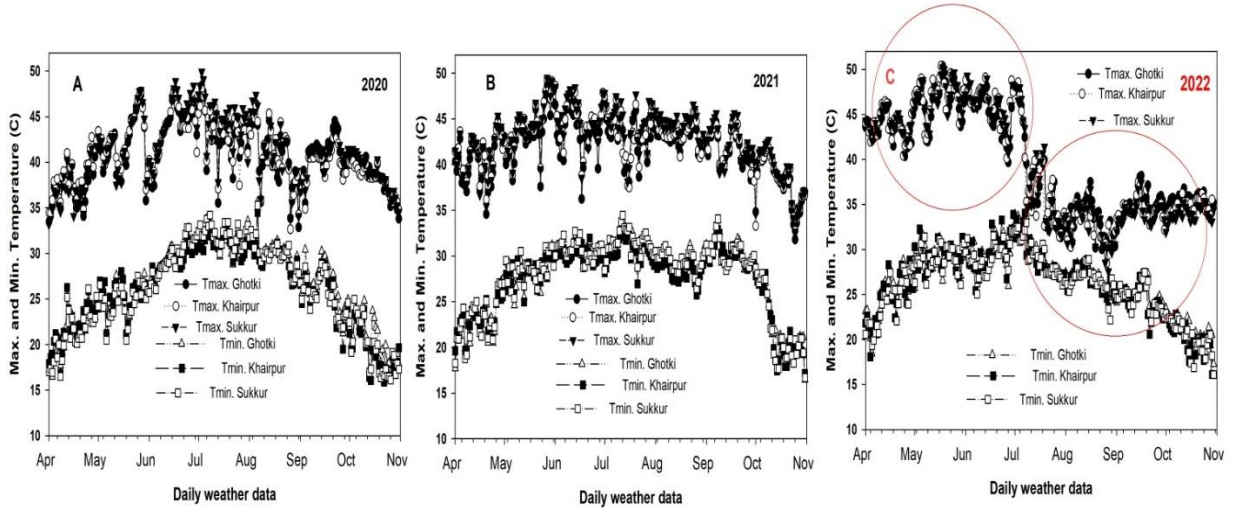


Figure 2. Temperature trends and patterns (maximum and minimum temperature) (2020 to 2022, A, B and C) during cotton growing seasons (April to November) in three studied districts (Ghotki, Khairpur and Sukkur). Deviation among temperature trends is clear by comparing the 2020 and 2021 with 2022 that generally badly affect the cotton growth, development and yield during 2022.

As cotton is also sensitive to water availability as temperatures, during 2022 cotton growing season had high erratic and intense rainfall, that leads to sever affect and damages to cotton crop this year (2022). It is clearly evident from the Fig. 3 that generally the rainfall intensity is not more than a 35 mm per day in whole decade but this year during cotton growing season it was quite high that leads to floods and then river floods destroyed the cotton crop in majority areas while studied region were badly affected due to high rainfall. Generally, floods in province Sindh also destroyed the cotton crop, as Sindh witnessed 442.8mm (726 percent high) of rainfall during the year 2022. The floods destroyed 4.9 million hectares of cropland in Sindh. It is evident from rainfall data that Sindh received more than 3 times its usual rainfall in August, making it the wettest August since 1961. This extreme, erratic and intense rainfall affected 18,000 square kilometers of cropland, including about 45% of the cotton crop (NDMA, 2022). The area affected by floods represents about 35 percent of the total area planted to cereals, sugarcane and cotton during the 2022 "Kharif" season. These extremes high rainfall spells completely devastated almost 88% of the total expected cotton crop production (3.5 million bales).

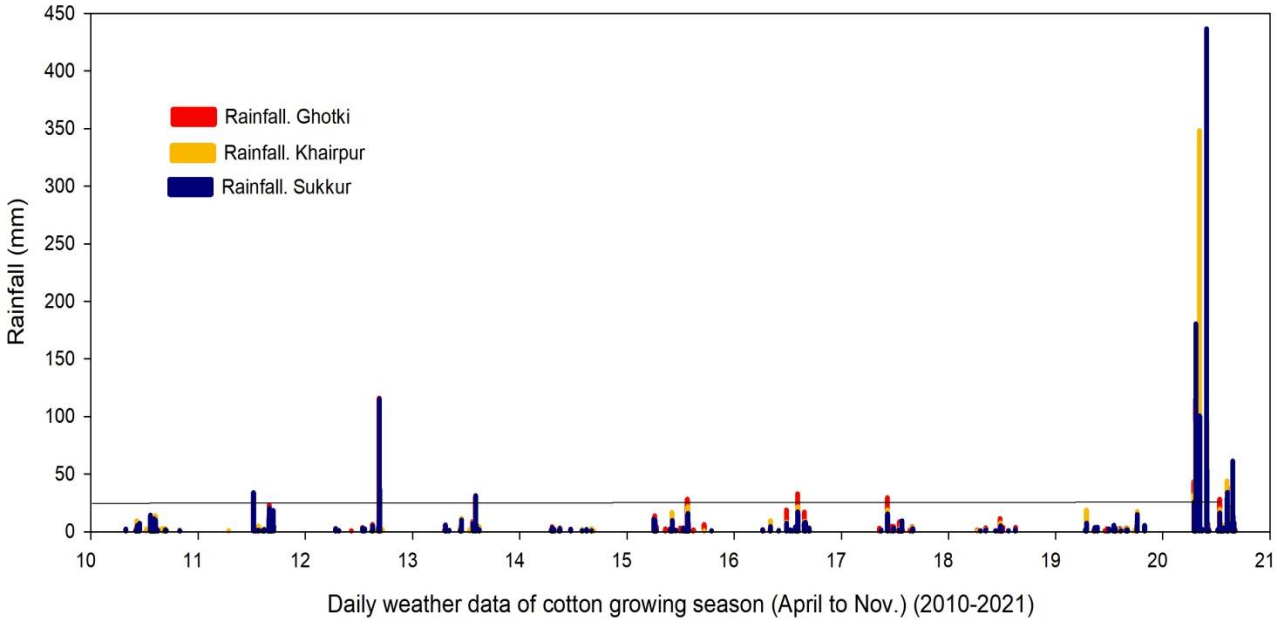


Figure 3. Daily historic climate data of rainfall during cotton growing seasons (April to November) in three studied districts (Ghotki, Khairpur and Sukkur).

Cotton cultivation at farmer field and challenges in studied districts

Land holding, cotton cultivated area and sowing time in studied region: There are different possible reasons for low yield of cotton crop in these studied districts, as farmers are not currently adopted the good management practices from cotton sowing to picking. Although, climate is also among main factors affected the cotton crop, but optimized cotton production technology has also important role to mitigate the negative effects of climate change. Generally, it is evident from the data of these three districts that farmers are lacking with optimized production technology and climate resilient genotypes. Generally speaking, overall total land holding is also low, although on an average land holding is 19 acres in Khairpur district (Figure 4A) but it is low in other two districts. It is also an important factor to optimize the technology and management factors as generally lower land holding due to that the farmers are unable to invest on technology because of poor resources.). Although, on an average sowing time is second decade of May 2022, but overall time range from April to end of May in studied districts (Figure 4B). It is good to sow cotton crop as early as possible just after wheat crop as its base temperature required for optimum sowing time is 12 °C that is available in the month of February, but the challenge is that the same time wheat crop generally stand in the field and harvest of wheat starts in end of March so field preparation and other management practices also take time to sow the cotton crop.

Other possible reason in reduction of cotton area is the competing crops (sugarcane, maize and rice), although data collected from farmers showed that majority of the farmers cultivated cotton in 2022, but the competing crops like the sugarcane is also among important factor as industry is present in this region and better marginal returns and support price is also available for sugarcane that may be the possible reason in cotton area reduction, as cotton crop is most sensitive to climate than the other crops (Figure 5).

Land preparation, and sowing methods of cotton crop: Traditionally land is prepared by ploughing, planking and rotavating. As majority of the farmers are lacking for technology and even do not have the tractor and other implements required for cotton crop management (Figure 6). There are three sowing methods (drill, dibbling and choppa) are adopted in all of the studied regions (Figure 7), although sowing methods are good ones for cotton sowing, but the cotton crop stand another important parameter where generally farmers are not taking care, as optimum plant population can harvest the solar radiation and lead to good yield that totally depends on the good seed availability of genotypes. Although some good genotypes are available, but farmers do not have access to good quality seed that lead to poor crop stand and low yield.

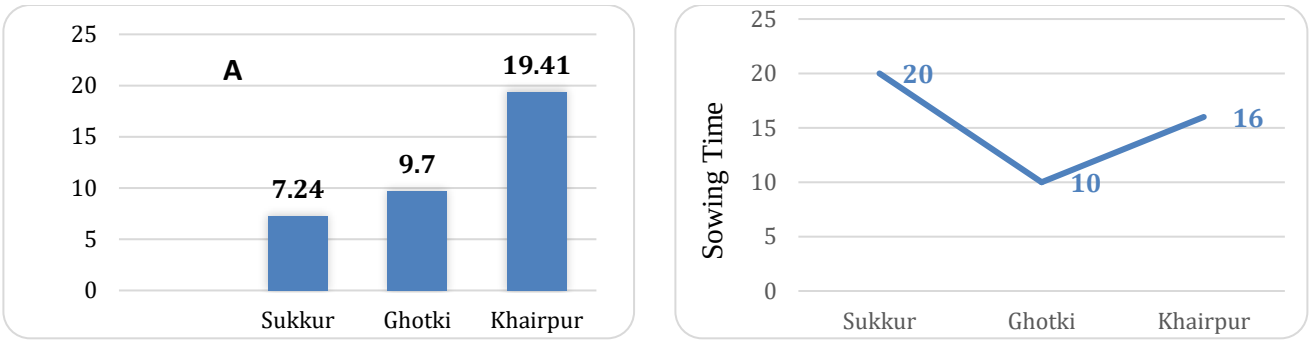


Figure 4. Average land holding (Acres) of farmers in these districts (A). Sowing time of cotton crop in studied districts (10-20 May) (B).

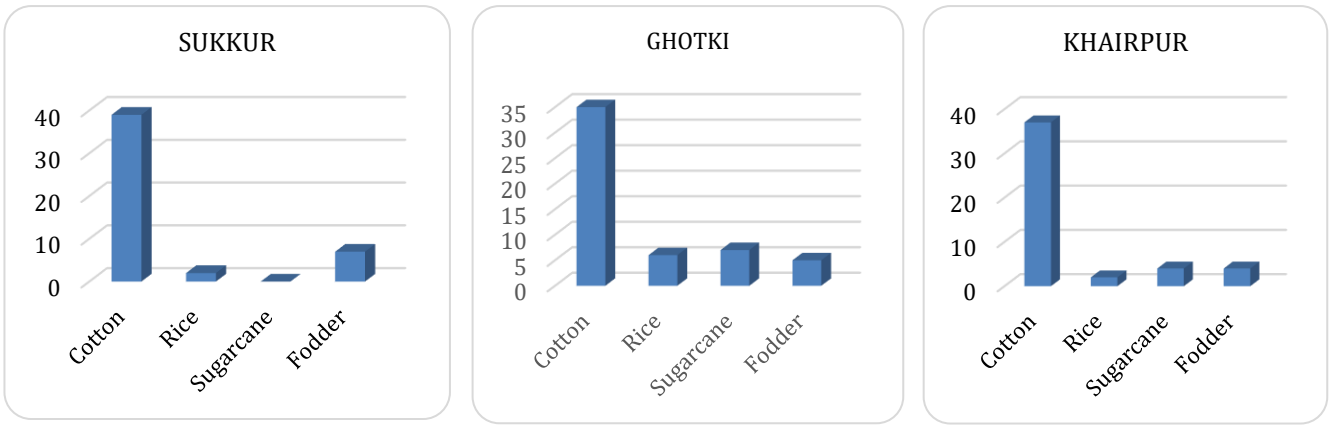


Figure 5. Number of farmers growing different crops during 2022 kharif season (Cotton, rice, fodder and sugarcane) in studied districts.

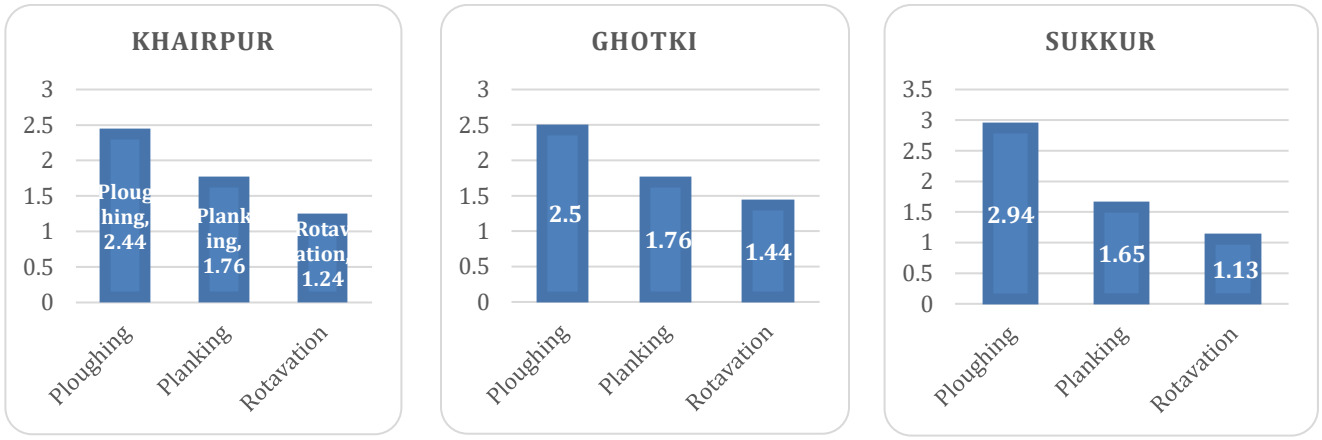


Figure 6. Tillage implements used (number of times in land preparation) for land preparation for cotton sowing.

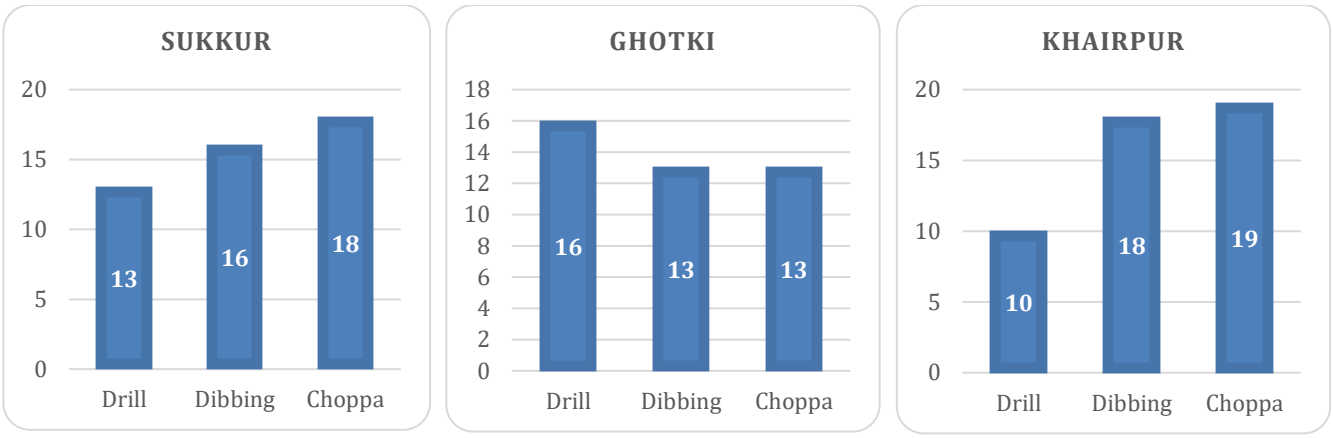


Figure 7. Cotton sowing techniques of drill, dibbling and choppa (in percentage) at farmer's field in studied districts.

Fertilizer and irrigation for cotton crop: The data of fertilizer particularly nitrogen application showed that lower nitrogen was applied by the farmers in district Ghotki while high nitrogen application was applied in Sukhur district while lower DAP fertilizer was applied in all studied district due to high price (Figure 8). Actually, it is phosphorous and potash fertilizer that are required optimum to tackle the heat and drought stress while irregular application of nitrogen promotes the higher biomass growth and lower yield. Balanced application of fertilizer particularly phosphorous and potash required to tackle and mitigate the impact of drought and heat stress. While number of irrigations was also applied lower (6-7) due to high rainfall and lower temperature due to cloud covers in majority of month during monsoon rainfall spells (Figure 9).

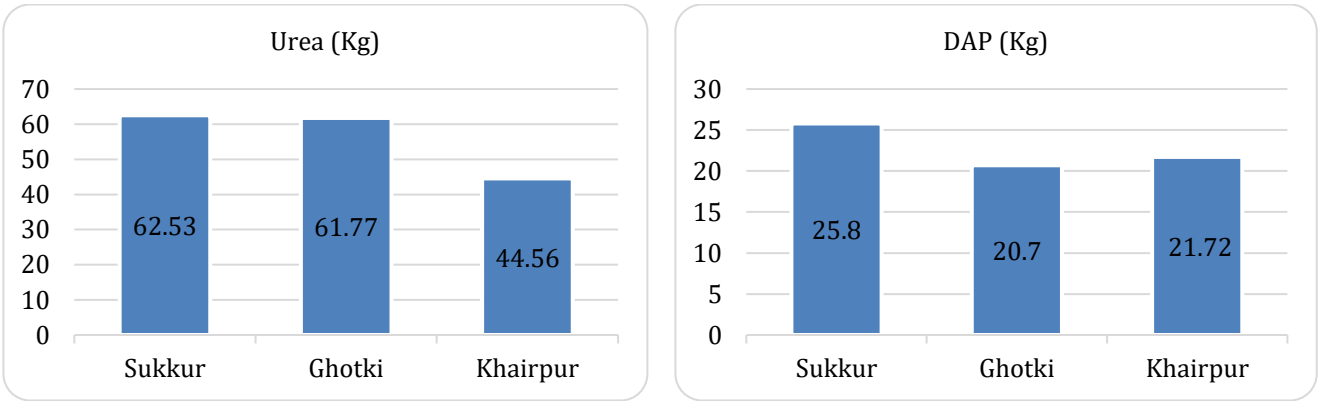


Figure 8. Fertilizer application rate per acre in selected hotspots districts.

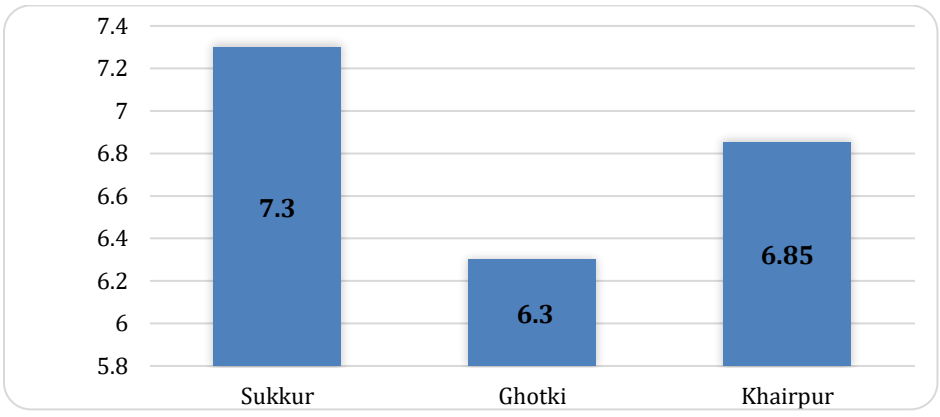


Figure 9. Irrigation application at farmer's field in three selected districts.

Seed Cotton Yield at farmers filed in three districts: As, it is the survey data collected from farmers and there are different types of farmers involved while results showed that high seed cotton yield per acre is recorded in Sukhur district than others while lowest seed cotton yield recorded for Khairpur (Figure 10). Difference might be due to different input use, sowing time, and production technology adoption. While there were no significant differences were found for temperatures trends and heat waves in 2022 among three districts but rainfall was found different, it might also be due to variation among rainfall and management practices made at farmer's field.

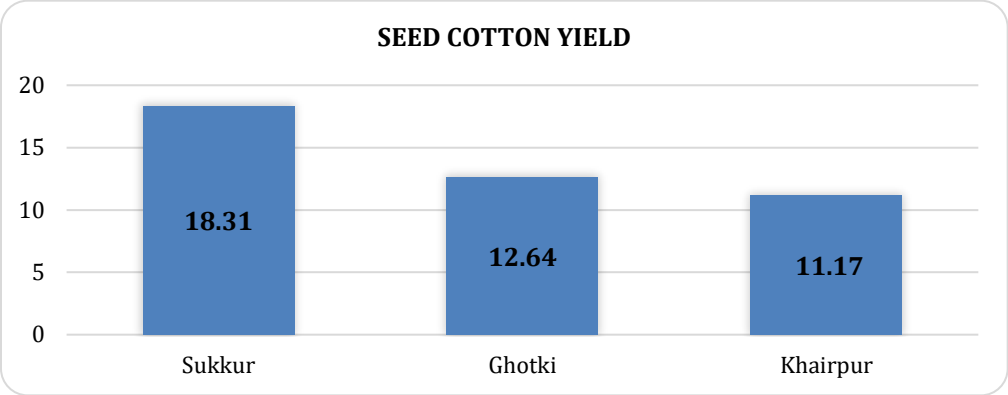


Figure 10. Average seed cotton yield (in mounds) at farmers field in three studied districts.

Vegetation index NDVI and variation among districts: Normalized difference vegetation index (NDVI) is an important vegetation indictor of growth and biomass and indirectly for the estimation of seed cotton yield. NDVI was estimated from Sentinel-2 satellite imagery having 10 m spatial resolution, showed the difference in values among these three districts. The vales ranged from 0.10 to 0.37 during cotton growing seasons and it varied among districts due to many possible factors as different management practices and fertilizer were used so the variations are existed (Figure 11). Although generally these values are lower than the values achieve for high yield, while the yield at farmers field is also found low.

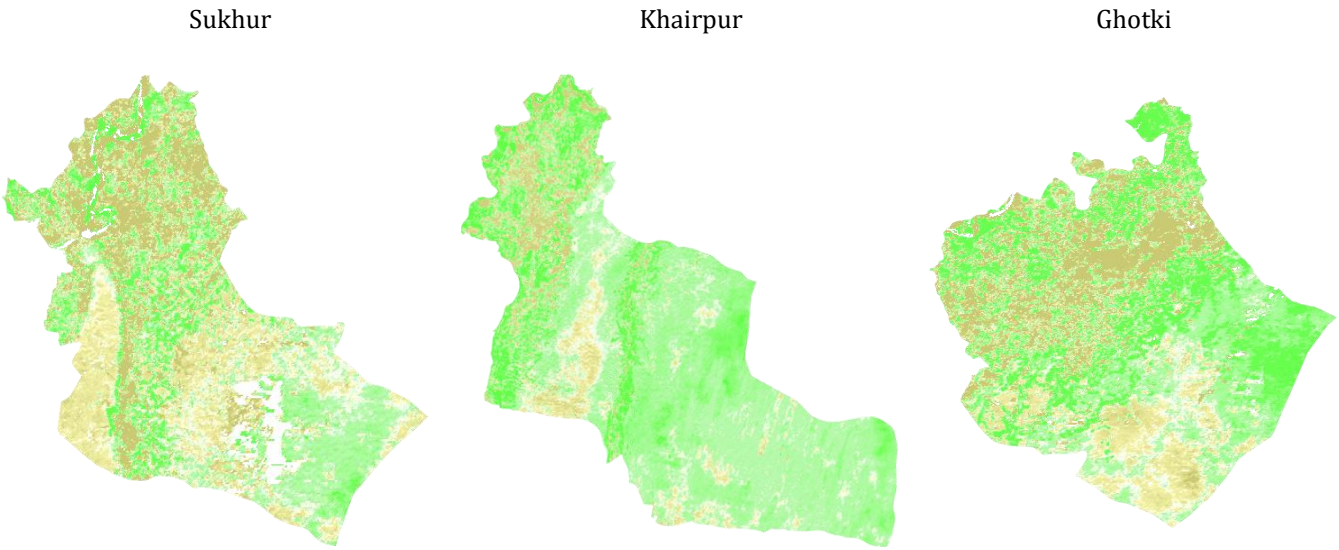


Figure 11 (a/2). NDVI values in three studied districts based on Sentinel-2 satellite images (20 m resolution) *Different color represents the values of NDVI in study region.

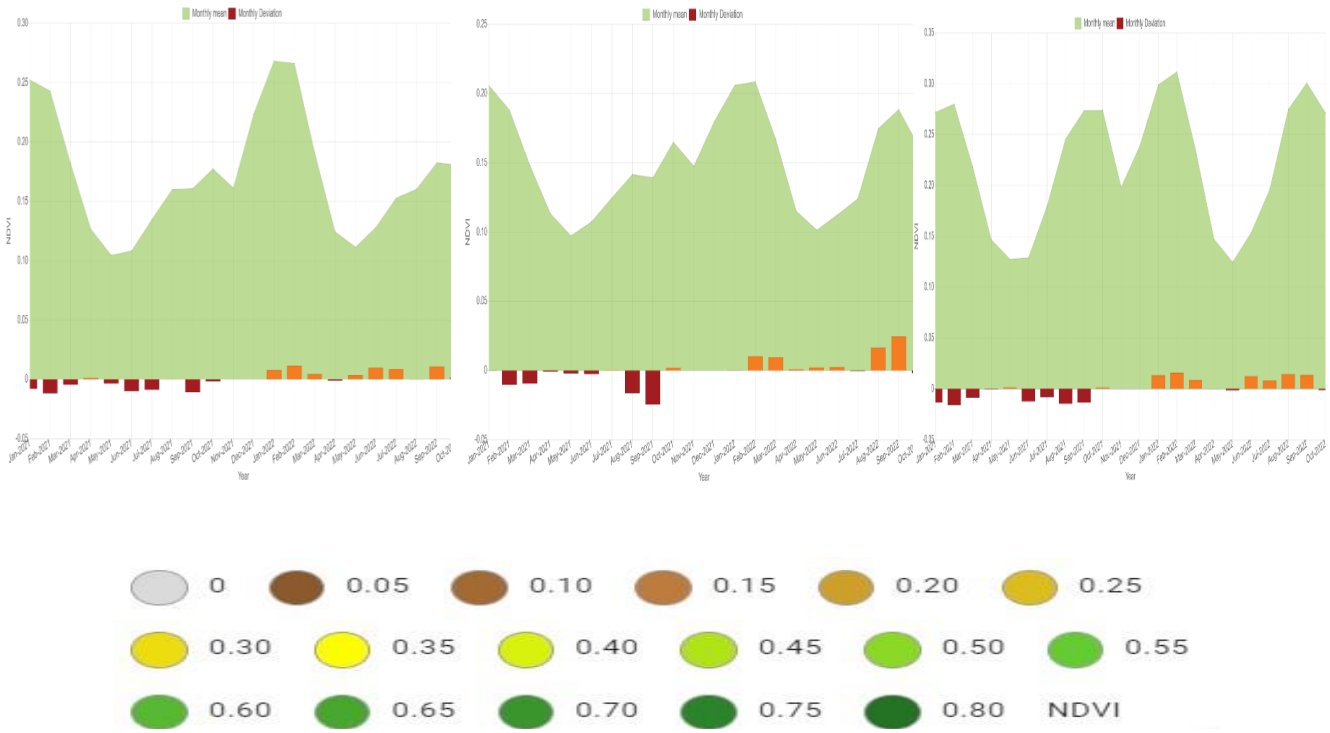


Figure 11 (a/2). NDVI values in three studied districts based on Sentinel-2 satellite images (20 m resolution) *Different color represents the values of NDVI in study region.

Causes of low yield and challenges at farmers' field: Climate variability and climate extremes conditions particularly the drought, heat waves and unavailability of climate forecast information as majority of the farmers point out this reason. While, unavailability of quality and certified seed of cotton genotypes are also mentioned by majority of the farmers. Area under cotton crop was also reduced due to competition among crops and shifting of cultivated areas to different crops during Kharif season. While, major of the farmers also claim the unavailability of technology and optimum production technology. High price of phosphorous fertilizer leads to lower application than recommended and ultimately lead to low yield.

Qualitative Data Findings

The same findings bring to light valuable knowledge that respondents possess. The gathered responses and word cloud generated by NVivo suggested that small farmers are lacking knowledge about climate change, and they are following traditional cropping patterns. All key informant interviews were tape-recorded and transcribed. Data analysis was guided by content analysis, a qualitative technique used to determine the presence of certain concepts in texts (Nasir *et al.,* 2019). The text was read line by line to determine recurring themes, checking them against the data collected from key informant interviews. The qualitative data analysis was done using NVivo software. NVivo is a robust qualitative tool that facilitates to identify themes by analyzing the content in form of creating and managing codes better on computer package then manually (F. C. Zamawe, 2015). Content analysis is a powerful tool to compress large amount of data into key thematic words based on rules of coding (Saleem et al., 2021). Content analysis was used to evaluate messaging in social process. A word cloud is a powerful tool used to highlight the most frequently used words in a study. The word cloud generated by NVivo in figure 1 outlines the terms most emphasized upon by the respondents i-e crops, climate, water, production, cotton, etc.

The provinces of Sindh and Punjab account for 95% of the total cotton cultivation. The In the focus group discussions and key informant interviews, we explored the types of vulnerabilities in the Sindh cotton production area of three districts. This Study focuses on understanding the climate change effects and vulnerabilities faced by the cotton farmers in Sukkur, Khairpur and Ghotki. The Study's findings generated evidence on how cotton farmers in these districts are affected by climate impacts, and more importantly, how social economic variables determine the level of vulnerability of different farmers, categorizing them as

small, medium and large farmer.

Vulnerabilities assessment of cotton crop and factors: Cotton is considered a sensitive crop that is affected badly by sudden climate change events (flood, droughts) or continuous effects of climate change throughout time. The most significant vulnerabilities identified in key informant interviews and focus group discussions is presented in Figure 12.

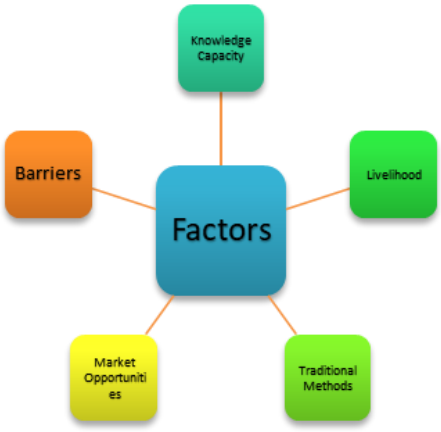


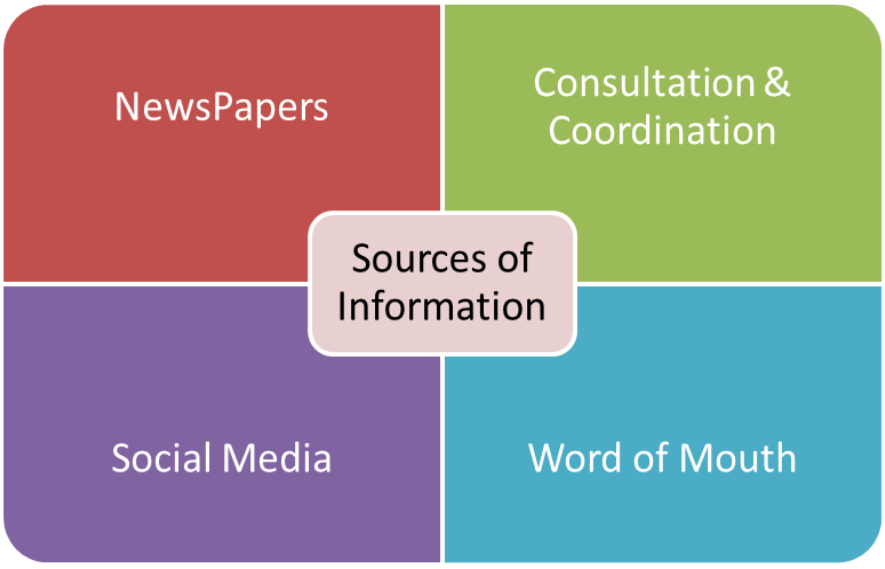
Figure 12. Vulnerabilities assessment of cotton crop and factors in studied region.

Knowledge Capacity: The male respondents in focus group discussions were found to have basic knowledge about climate change and its impact, but female participants lacked the knowledge and skills. But there is need to understand the medium of information sources considering social media and mainstream media. The newspapers are mainly used for information sharing, and radio, as mainstream media was used to for announcements and weather warnings. Consider the following response from a subject expert during the interview.

"The media tool that we have been using so far is the newspaper if you ask myself when I last read a newspaper in the last year I would not remember. These days people don't read the newspaper anymore."

Further another expert elaborated in probing question about farming pattern considering the climate change vulnerabilities and pointed out knowledge gap is one of the factors by saying.

"We remain in touch with the people through two ways. First through the four-time meeting, we get together, and the learning groups are being visited by the facilitator timely. He tries to meet the maximum number of farmers and discuss this issue. The agenda of these meetings is based on the field observations. Based on these observations we make our agenda for the whole season".



Barriers in sustainable cotton production: The farmer's highlighted different sorts of difficulties and problems that they are facing in better production of cotton. In the analysis we coded them as barriers in the NVivo software. Their problems ranging from low quality of seeds, heavy rain fall, changing pattern of rainfall to societal issues of growing on loan, pests and increasing prices of fertilizers. A respondent summary this in the following response as:

"Well, there are 4 or 5 issues. Seed is the first one. Besides that, there is the issue of pests. There are two types of pests in Sindh. In this region the White Fly is common. They were a major hurdle for us back in 2020. In the other region of Sindh, Sindh is divided into lower and upper Sindh based on the difference in climate, Pink Fly is more common. So, these are the two types of pests that attack cotton crops here. Thirdly the farmers get the pesticides on loan, so they do not research on the efficiency and effectiveness of pesticides. They buy from the company that is giving them on the loan. And last not the least livelihood vulnerabilities. ".

Crop Pattern and Traditional Methods: In the Study we tried to understand the cropping pattern of cotton in the three districts. For a farmer, climate variability and extreme events are more important than climate change. They informed cotton is major crop in this area in Kharif season and in winter we have wheat crop, but also, we cultivate sugarcane crop and fodder crop for animals. During an interview the reasons of traditional methods are expressed as follows:

"I believe there are two reasons for this, either the traditional methods have a strong hold or no hold at all. In either case it is not working. The reason could be that they are reluctant to adopt new technologies, or they have entirely given up on farming as a profession.".

Livelihood and Opportunities: The livelihood vulnerability needs to explore with the lenses of food security instead of purchasing power or societal status. One thing that was common among all the respondents was that they grow the yield on loan basis. It is important to understand the process. In most cases the land is also not their own, they are cultivating it on someone's else land per annum on mutually agreed amount either in shape of yield or in cash. But they pay this amount after getting the income from the crop. They purchase the seed from agriculture/trusted seed centers, and they do not have much choice on selecting the fertilizers and pesticides. The pink and white pests attack the plants often, and the cost of the fertilizers and pesticides are extra burden on their pockets, so they purchase these from the agency on loan and pay them either in installment or after selling the crop that ends them to pay heavy mark up as well. The usual expenditure pattern is likely to be common like any Lower/middle class household in Pakistan. Other than food and clothes they have to spend on health issues, education of kids and community events (occasionally e.g., wedding). These put the farmer on the edge to stress level to think about the loss (Figure 13). A male respondent pointed out in discussion.

"We almost buy everything on loan, and we back money after getting income from crops. In this area women cannot decide decision regarding crop because almost man can decide, even sale or buy everything man can do. Like this year, we did not have flood warning this year, so we were not prepared.".

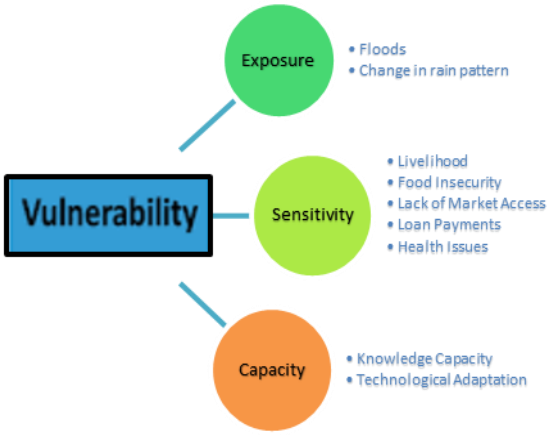


Figure 13. Climate Vulnerability Assessment Factors for Cotton in Sukkur, Ghotki and Khairpur.

Adaptation to climate change: Adaptive capacity plays a major role in reducing climate and social vulnerabilities and building resilience to climate impacts. As documented above, access to education and resources (both physical and financial), livelihood diversification, consultations with peer groups (CSOs) and social networks that promotes knowledge exchange are some of the key attributes of adaptation. Using these as variables, we can develop a strategy of adaptive capacity to implement for better and enhanced production minimizing the climate vulnerabilities. Most of the adaptation brings by the experts in the key informant interviews than the focus groups discussions.

Knowledge and climate resilient seed varieties: The respondents are not educated in terms of literacy and knowledge exposure to "Concepts of Climate Change and Adaptation". They are getting information in bits and pieces through social media, word of mouth and rumors in different period of time. This makes them confuse and more vulnerable. An agriculture expert suggested:

"There is need to demonstrate to the farmers the results of adopting new technologies. Like a decrease in cost, or increase in production, or better production."

The farmers are now aware of the qualities of the seed, and they demand the efficient seeds from the centers but again their knowledge is based either on past experience or community experience. They did not have any assessment of seed according to soil quality (department has done it but farmers are not aware of the seeds).

"There is a whole process behind that. We haven't yet tested all the available varieties; we should test them first and we must have a check if we are following the basic practices."

During an interview in Sukkur, it is brought to the discussion to make the agriculture governance better so that a local and small farmer can have better knowledge and better understanding of the seed.

Efficient Use of Water and Biodiversity: Farmers to use water in a way that is environmentally sustainable, economically beneficial, and socially equitable. This water stewardship approach can improve crop yields, strengthen resilience to climate change, minimize negative impacts on water quality and enable fair water access for all users in a catchment area. We also support farmers to adopt cotton varieties that are best adapted to the region's current and forecasted climatic conditions and soil characteristics (Better Cotton Policy). There is mix response from the participants that their yield has affected by drought and flood as well. According to the respondents of focus group discussion in Ghotki.

"Cotton crop requires a proper amount of water for its proper growth and maximum production. Situations like that of drought reduce the production of cotton crops. Due to drought strictly reduces the development of plants, such as affecting plant height, leaf dry weight, and stem dry weight etc.".

On the other hand, some participants in Khairpur explained that their yield has been damaged by flood. Farmers in conserving and enhancing biodiversity on their land and in adopting practices that minimize the negative impact on habitats in and around their farm, whilst simultaneously promoting sustainable land-use practices and protecting High Conservation Value (HCV) areas (Better Cotton Policy).

Short to medium term adaptation plan for climate change mitigation and adaptation for sustainable cotton production has also been proposed, details can be found in Supplementary Table 1.

Summary, Recommendations and Way Forward

Based in the findings of sample-based survey and qualitative study through focused group discussions and key informants' interviews, following are the key recommendations and way forward:

1. Effects of climate change on agriculture in general and on cotton crop in particular are evident from the current study. Based on the findings of the study WWF need to devise a comprehensive strategy for cotton focused climate smart and climate resilient agriculture practices in the target districts. The strategy must focus on climate resilient agriculture practices with minimum/consumptive use of chemical fertilizers and pesticides along with promotion of good agriculture practices. The strategy implementation with farmers will reduce the negative impacts of climate change on cotton crop.
2. Due to the climate change effects the area of cotton crop is reducing and farmers are shifting to the alternate crops like sugarcane as the sugar industry is growing in the area. The WWF need to focus on this shift in cropping pattern and must promote the climate resilient agriculture with preferred focus on cotton productivity enhancement and conduct the cost benefit analysis of cotton crop to communicate the cotton crop benefits to farmers.
3. Increasing sugarcane cultivation in the target areas is also affecting the sugarcane environment as

sugarcane is hydrophilic crop and increases the humidity level in the surrounding and it also negatively affects the cotton crop in the neighboring areas as hydrophilic conditions attract more pests like whitefly that seriously damages the cotton production.

4. Availability of short-to-long term weather and climate information for cotton producer is required to provide, in order to decide about the sowing time and efficient crop management
5. WWF need to focus on strong financial incentive system for the cotton crop like financial incentive system is in place for sugarcane farmers by the sugarcane industry to reduce the shift of cropping pattern.
6. There is also needed to initiate the farmer's trainings and capacity building plan on good agriculture practices to enhance the cotton production in the area and enhance return for the farmers from cotton crop. Good agriculture practices (climate smart and resilient cotton production techniques) will reduce the crop losses and enhance farmers return especially better management of white fly and pink bollworm that are serious concern in the cotton production.
7. Need to have better coordination and productive linkages with research institutes and academia that are working for the production enhancement of cotton crop. The research and academia findings related to climate smart and resilient cotton production must be communicated to the farmers and supported for the adaptation.
8. WFF need to work on improved technology transfer for climate smart and climate resilient agriculture techniques to farmers to tackle the climate change issues on cotton crop and enhance cotton production in the target districts. Farmers need to make adjustment in cropping time with changing climate conditions that need to be addressed through networking with research institutes and through farmer's capacity building programs.
9. There is need to strengthen the marketing system of cotton for effective functioning of the key cotton value chain actors which is not functional at its best in the target area as farmers are bound in credit system with middlemen and they have to sell their cotton produce to middlemen at lesser prices than the market price. The key value chain actors are not very positive to change their practices and not providing the financial incentives to the farmers. This will need to be addressed through better engagement with high end value chain actors such as ginners, to create a more favorable market environment which provides real incentives for climate resilient cotton production.

REFERENCES

Ahmad, S., I. Hussain, A. Ghaffar, M.H. Rahman, M.Z. Saleem, M.W. Yonas, H. Hussnain, R.M. Ikram and M. Arslan. 2022. Organic amendments and conservation tillage improve cotton productivity and soil health indices under arid climate. Scientific Reports, 12: 14072. https://doi.org/10.1038/s41598-022-18157-0.

Ahmad, S., W. Huifang, S. Akhtar, S. Imran, H. Yousaf, C. Wang and M.S. Akhtar. 2021. Impact assessment of better management practices of cotton: A sociological study of Southern Punjab, Pakistan. Pakistan Journal of Agricultural Sciences, 58: 291–300.

Arshad, A., M.A. Raza, Y. Zhang, L. Zhang, X. Wang, M. Ahmed, and M. Habib-ur-Rehman. 2021. Impact of Climate Warming on Cotton Growth and Yields in China and Pakistan: A Regional Perspective. Agriculture, 11(2):97. https://doi.org/10.3390/agriculture11020097.

Filippi, P., B.M. Whelan, R.W. Vervoort and T.F.A. Bishop. 2021. Identifying crop yield gaps with site- and season-specific data-driven models of yield potential. Precision Agriculture, 23: 578–601 doi: 10.1007/s11119-021-09850-7.

Government of Paksitan. Economic Survey. 2021, Finance Division, Economic Advisor's Wing, Islamabad, Pakistan

Ghaffar, A., M.H. Rahman, H.R. Ali, G. Haider, S. Ahmad, S. Fahad and S. Ahmad. 2020. Modern Concepts and Techniques for Better Cotton Production. In: Ahmad, S., Hasanuzzaman, M. (eds) Cotton Production and Uses. Springer, Singapore. https://doi.org/10.1007/978-981-15-1472-2_29.

Habib-ur-Rahman, M., A. Ahmad, A. Raza, M.U. Hasnain, H.F. Alharby, Y.M. Alzahrani, A.A. Bamagoos, K.R. Hakeem, S. Ahmad, W. Nasim, S. Ali, F. Mansour and E.L.A. Sabagh. 2022a. Impact of climate change on agricultural production; Issues, challenges, and

opportunities in Asia. Frontier in Plant Science, 13: 925548.
doi:10.3389/fpls.2022.925548.

Habib-ur-Rahman, M., A. Raza, H.E. Ahrends, H. Hüging, and T. Gaiser. 2022b. Impact of in-field soil heterogeneity on biomass and yield of winter triticale in an intensively cropped hummocky landscape under temperate climate conditions. Precision Agriculture, 23: 912–938. https://doi.org/10.1007/s11119-021-09868-x.

Haim, D., M. Shechter and P. Berliner. 2008. Assessing the impact of climate change on representative field crops in Israeli agriculture: A case study of wheat and cotton. Climate Change, 86: 425–440.

Hussain, S., M. Mubeen, W. Akram, A. Ahmad, M. Habib-ur-Rahman, A. Ghaffar, A. Amin, M. Awais, H.U. Farid, A. Farooq and W. Nasim. 2020. Study of land cover/land use changes using RS and GIS: a case study of Multan district, Pakistan. Environmental Monitoring Assessment, 192: 1-10.

Imran, M.A., A. Ali, M. Ashfaq, S. Hassan, R. Culas and C. Ma. 2018. Impact of Climate Smart Agriculture (CSA) practices on cotton production and livelihood of farmers in Punjab, Pakistan. Sustainability, 10: 01-08

IPCC, 2022. Climate Change 2022. Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)].

Iqbal, R., M. Habib-ur-Rahman, M.A.S. Raza, M. Waqas, R. M. Ikram, M.Z. Ahmed, M. Toleikiene, M. Ayaz, F. Mustafa, S. Ahmad, M.U. Aslam, M.W. Waqas, M.T. Khan, M.M. Aslam and I. Haider. 2021. Assessing the potential of partial root zone drying and mulching for improving the productivity of cotton under arid climate. Environmental Science Pollution Research, 28: 66223–66241.https://doi.org/10.1007/s11356-021-15259-6.

Majeed, S., I.A. Rana, M.S. Mubarik, R.M. Atif, S.H. Yang, G. Chung, Y. Jia, X. Du, L. Hinze and M.T. Azhar. 2021. Heat stress in cotton: A review on predicted and unpredicted growth-yield anomalies and mitigating breeding strategies. Agronomy, 11(9): 1825.

Manzoor, S., M.H. Rahman, G. Haider, S. Ahmad, M. Afzal, F. Nawaz, R. iqbal, M. Yasin, T. Haq, S. Danish and A. Ghaffar. 2022. Biochar and slow-releasing nitrogen fertilizers improved growth, nitrogen use, yield, and fiber quality of cotton under arid climatic conditions. Environmental Science and Pollution Research, 29: 13742–13755. https://doi.org/10.1007/s11356-021-16576-6.

McDermid, S.P., G. Dileepkumar, M.D.M. Kadiyala, S. Nedumaran, P. Singh, C. Srinivas, B. Gangwar, N. Subash, A. Ahmad, L. Zubair and others. 2015. Integrated Assessments of the Impact of Climate Change on Agriculture: An overview of AgMIP regional research in South Asia. In Handbook of Climate Change and Agroecosystems: The Agricultural Model Intercomparison and Improvement Project (AgMIP) Integrated Crop and Economic Assessments, Part 2. C. Rosenzweig and D. Hillel, Eds., ICP Series on Climate Change Impacts, Adaptation, and Mitigation, vol. 3, Imperial College Press, pp: 201-218. doi:10.1142/9781783265640_0018.

Mollaee, M., A. Mobli, N.K. Mutti, S. Manalil and B.S. Chauhan. 2019. Challenges and Opportunities in Cotton Production. Cotton Production, 371–390.

Morton, J.F. 2007. The impact of climate change on smallholder and subsistence agriculture. Proceedings of the Natlional Academy of Sciences U.S.A, 104: 19680–19685.

Nasir, J., M. Ashfaq, A. Adil and S. Ahmad. 2019. Impact assessment of climate change in cotton wheat production system Socioeconomic Impact Assessment Of Climate Change In Cotton Wheat Production System Of Punjab, Pakistan. Journal of Agricultural Research, 57:199–206.

Rahman, M.H., I. Ahmed, A. Ghaffar, G. Haider, A. Ahmad, B. Ahmad, M. Tariq, W. Nasim, G. Rasul, S. Fahad, S. Ahmad, and G. Hoogenboom. 2020. Climate Resilient Cotton Production System: A Case Study in Pakistan. In: Ahmad, S., Hasanuzzaman, M. (eds) Cotton Production and Uses. Springer, Singapore. https://doi.org/10.1007/978-981-15-1472-2_22.

Rahman, M.H.U., A. Ahmad, A. Wajid, M. Hussain, F. Rasul, W. Ishaque, M.A. Islam, V. Shelia, M. Awais, A. Ullah, A. Wahid, S.R. Sultana, S. Saud, S. Khan, S. Fahad, S. Hussain and W. Nasim. 2019. Application of CSM-CROPGRO-Cotton model for cultivars and optimum planting dates: Evaluation in changing semi-arid

climate. Field Crop Research, 238: 139-152.

Rahman, M.H.U., A. Ahmad, X. Wang, A. Wajid, W. Nasim, M. Hussain, B. Ahmad, I. Ahmad, Z. Ali, W. Ishaque, M. Awais, V. Shelia, S. Ahmad, S. Fahd, M. Alam, H. Ullah and G. Hoogenboom. 2018. Multi-model projections of future climate and climate change impacts uncertainty assessment for cotton production in Pakistan. Agricultural and Forest Meteorology, 253: 94-113.

Saleem, M.A., W. Malik, A. Qayyum, S. Ul-Allah, M.Q. Ahmad, H. Afzal, M.W. Amjid, M.F. Ateeq and Z.U. Zia. 2021. Impact of heat stress responsive factors on growth and physiology of cotton (Gossypium hirsutum L.). Molecular Biology Reports, 48:1069–1079.

Shar, S.H., A.R. Mahar, I. Rajpar, M.A. Saand, A.A. Mirbahar, K.A. Ansari, R. Saeed and M.H. Sirohi. 2018. Assessment of Soil Quality of Taluka Thari Mirwah, District Khairpur, Sindh, Pakistan. International Journal of Economic and Environmental Geology, 9: 13–18.

Siddiqu, A., A. Anwar, M.M. Anwar and J.U. Rehman. 2021. Cotton yield and Climate Change Adaptation in Pakistan: Application of Multinomial Endogenous Switching Regression Model. Journal of Business and Social Review in Emerging Economies, 7: 491–502.

Wajid, A., A. Ahmad, M. Hussain, M.H. Rahman, T. Khaliq, M. Mubeen, F. Rasul, U. Bashir, M. Awais, J. Iqbal, S.R. Sultana and G. Hoogenboom. 2014. Modeling growth, Development and seed-cotton yield for varying nitrogen increments and planting dates using DSSAT. Pakistan Journal of Agricultural Sciences, 51: 639-647.

Waqar, M., M. Habib-ur-Rahman, M.U. Hasnain, S. Iqbal, A. Ghaffar, R. iqbal, M.I. Husain, A. EL Sabaghet al. 2022. Effect of slow release nitrogenous fertilizers and biochar on growth, physiology, yield, and nitrogen use efficiency of sunflower under arid climate. Environmental Science and Pollution Research, 29: 52520–52533.. https://doi.org/10.1007/s11356-022-19289-6.

Wei, W., Z. Mushtaq, A. Ikram, M. Faisal, Z. Wan-Li and M.I. Ahmad. 2020. Estimating the Economic Viability of Cotton Growers in Punjab Province, Pakistan. SAGE Open, 10: 1-12.

Zamawe, F.C. 2015. The Implication of Using NVivo Software in Qualitative Data Analysis: Evidence-Based Reflections. Malawi Medical Journal, 27:5-13.

Supplementary Table 1. Adaptation plan for climate change mitigation and adaptation for sustainable cotton production.

Adaptation plan for future	Baseline values/data	Year 1	Year 2	Year 3
Agro-advisory and weather forecast and weather station	15% farmers are getting climate information	Strength and increase the climate advisory services and improve till 25% of the farmers	Strength and increase the climate advisory services and improve till 45% of the farmers	Strength and increase the climate advisory services and improve till 55% of the farmers
Early sowing and harvesting of wheat crop	End October early November	Mid October (depends on current weather conditions)	Early October to Mid-October (depends on current weather conditions)	Early October (depends on current weather conditions)
Early sowing of seasonal cotton after wheat crop	May 10-20	Mid to End of April	Early to Mid-April	Early to Mid-April
Availability of irrigation water	Late availability of irrigation water	Timely availability of irrigation water during Rabi and Kharif season will lead to timely sowing of wheat and cotton		
Early cotton sowing by modification in crop rotation and cropping schemes	May Sowing Cotton-Wheat	Early to Mid-April Introduction of oil-based crop to adjust the early cotton sowing e.g., Cotton-Barely/Oat/Early wheat verities	Early to Mid-March Canola/Raya – Cotton Fodder – Cotton Seasonal and early seasonal vegetables (Onion) – Cotton	Mid-February to Mid-March Fodder (Berseem –Cotton), Canola/Raya – Cotton Onion – Cotton Winter vegetables – Cotton
Competitor Crops and Crop Zoning	Sugarcane/Maize Need to develop crop zoning (considering climate, soil, crops, industry and social factors)	Reduce the area of competitor crops (10%) by developing policy or give incentive to farmers to sow oil seed crops. Develop the crop zoning to improve the cotton area	Reduce the area of competitor crops (20%) by developing policy or give incentive to farmers to sow oil seed crops. Develop the crop zoning to improve the cotton area	Reduce the area of competitor crops (30%) by developing policy or give incentive to farmers to sow oil seed crops. Develop the crop zoning to improve the cotton area
Reduce Tillage practices	Conventional tillage (2-5)	Reduce tillage (2-4)	Reduce tillage (1-3)	Reduce tillage (1-2) and minimum or zero tillage while deep ploughing after 2-3 years
Provision of quality seed and inputs (fertilizer)	Currently, there are not such system to provide the quality seed and inputs	Subsidies on input like seed, fertilizer and machinery	Subsidies on input like seed, fertilizer and machinery	Subsidies on input like seed, fertilizer and machinery

Balanced and optimum use of Fertilizer	Below optimum fertilizer being used	Optimum and balanced use of fertilizer (kg ha^{-1}) 160-80-70 (N-P-K)	Optimum and balanced use of fertilizer (kg ha^{-1}) 150-90-80 (N-P-K)	Optimum and balanced use of fertilizer (kg ha^{-1}) 140-100-90 (N-P-K)
Capacity Building and Technology Transfer of site-specific production technology	Farmers are lacking for provision of climate resilient technologies	Provision of technology and demonstration of plots having state of the art technologies to improve resource use efficiency, Model farms for cotton crop, Cooperative farming may also provide the solution for adoption of technology, Training of cotton growers/dealers about production technology of cotton varieties, spraying techniques and installation		
Site specific cultivars	Mixed cultivation of cultivars and varsities at farmers field	Farmers training and seed system (value chain) need to improve the supply the good quality seed and need to provide area specific cultivation in one district	Farmers training and seed system (value chain) need to improve the supply the good quality seed and need to provide area specific cultivation in two districts	Farmers training and seed system (value chain) need to improve the supply the good quality seed and need to provide area specific cultivation in three district
Research and development	Current system is lacking	Need to strength the research and development of good cotton seed		
Marketing system and support price	Current system is lacking	Need to strength and regularize the marketing system and cotton support price in one district	Need to strength and regularize the marketing system and cotton support price in two districts	Need to strength and regularize the marketing system and cotton support price in three districts
Clean picking	It is lacking in current market system	Price can be adjusted with respect to quality		