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Prevailing of Black Shadow on White Gold by Impacting Climate Change, Suggestions and Recommendations for Revival of Cotton Production in Pakistan

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Abstract
The Indus river basin is one of the largest cotton-growing areas in Pakistan. Cotton cultivation in this region is facing severe challenges from rapidly declining groundwater levels and the increasing number of droughts and floods, infestations of cotton insect pest complex. Predictable climate changes are expected in the future adding the uncertainty of cotton production in this region. The overall goal of this article provides and recommends, how to revive the cotton production and control of insect pest complex through Integrated Pest Management (IPM) and preserving the beneficial insect with the reference to climate change. Pakistan is ranked fifth on the 2019 Global Long-Term Climate Risk Index and it is severely impacting the negative effects of climate change on cotton production. Various emission scenarios predict that climate change will have an increasingly serious effect on the hydrology of the Indus Basin. Due to significant climate change, increase in the average temperature of the globe, the change in precipitation amounts, their patterns, and the impact of their location on cotton production. On the other side climate change conditions cotton pest especially sucking e.g. Whitefly, thrips, mealybug, aphids and mites, chewing pest like pink bollworm and armyworm have adapted to the climatic elements that help them to survive, grow, reproduce and spread based on host abundance and interaction. The impacts of climate change on cotton crops could also have a serious socio-economics implication for the rural and urban people living in the Indus Basin. In response to these climate change threats, several measures are needed to sustain cotton production and enable sustainable growth of the sectors related to cotton crops in a manner that reduces poverty, increases resilience, and achieves food security. This research article will help to shift a new paradigm to revive cotton production by successfully adapting the suggestions and recommendations to climate change and able to sustain their livelihoods in Pakistan.

Keywords: *Climate change. Hydrology. Temperature. Cotton pest. Cotton production.*

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1. Introduction:

Cotton, a lifeline of the economy of Pakistan and a significant cash crop, adds about 0.8% to the GDP of the country and about 4.5 percent (Pakistan Economic Survey 2019-20) of the value-added in the Agriculture sector. Pakistan stands fifth largest cotton producer (1.3 million metric tons) after India (6.6 million metric tons), China (5.9 million metric tons), the USA (4.3 million metric tons), and Brazil (2.9 million metric tons), followed by the other countries: Turkey, Uzbekistan, Greece, Benin and Australian (Monthly Economic Letter –May 2020).
Current estimates of world cotton production are about 26.7 million metric tons or 122.7 million bales of 480 lbs., accounting for 2.5 percent of the world's cultivated land. Pakistan's share in the world's cotton production is around 7 percent, with still having potential for improvement. The cotton area was 2.527 million hectares in 2019-20 and it fluctuated from 2.961 to 2.373 million hectares during 2014-15 to 2018-19. The highest production of 13.96 Million bales and an average yield of 802kg per hectare was witnessed in 2014-15 (Pakistan Economic Survey 2019-20). The cotton and textile industries play a dominant role in

the country's export earnings, and Pakistan has a 14 percent share of the world's cloth exports. The textile industry is mainly dependent on cotton and 58.5 percent of Pakistan's export earnings are from the cotton made-up and textile products which add around $10 billion to the national economy. Hundreds of ginning factories and textile mills in the country depend upon the cotton crop. Cotton crops face important challenges like environmental, plant protection measures, uncertain procurement price, and other competing crops. Cotton is broadly adapted to growing in temperature, subtropical and tropical environments, growth might be challenged by future climate change (Bang *et al.,* 2016). Temperature significantly influences cotton growth and development by defining rates of fruit production, photosynthesis, and respiration (Turner *et al.*, 1986, Hearn and constable,1984). The growth of cotton changing at varying stages of not development with plant organs (Burke and Wanjura, 2010) and the optimum temperature for cotton cannot be defined. The yield and growth of cotton are directly affected by a high temperature, hot weather conditions increase the evaporative demand in cotton plants showing more intense water stress (Hall, 2000). At high temperatures, irrigation becomes critical, especially during flower and boll development. A report published by the International Trade Center "reduce the availability of water for irrigation, in particular in Xinjiang (China), Pakistan, Australia, and the Western United States" as a prominent impact of climate change on cotton. Cotton is a vertical taproot that makes it damage from floods and unexpected heavy rains because waterlogged roots cannot uptake suitable amounts of nutrients and oxygen from the soil, this slows the cotton plant's growth and development. Higher carbon dioxide levels in the atmosphere affect cotton production but CO2 boosts cotton growth in some environments, might be useful, increase cotton yield because cotton is a C_3 crop (Kimbell, 2016) but increased growth will require more water and nutrients. The adverse effect of CO2 also boosts weed growth and is predicted to reduce the effeteness of herbicides in controlling the competition for food.
Planting of transgenic genetically modified F_1 hybrid BT cotton expressing endotoxins of the soil bacterium *Bacillus thuringiensis* for the control of lepidopteran pests began in 2002. (Kranthi *et al.*,1999). On the Bt cotton, the main problems are the effect of temperature on cotton crop, weeds infestation, an outbreak of cotton pests especially pink bollworm & sucking pest complex especially whitefly, less germination capacity of seed, the prevalence of diseases, decreasing population dynamics of natural enemies of cotton pest, shortage of irrigation water, adverse effect of pesticides, the unpredictable occurrence of floods and droughts are the main factors which affect the cotton production.

2. Impact of Climate Change on Cotton Crop

The cotton belt extends over about 1,200 km along the Indus River and its tributaries, soils vary from sandy loam to clay loam with clay dominant towards the South (Gillham *et al*., 1995). Temperatures in May and June are as high as 40º C to 45º C, often reaching 50º C on individual days. Winter temperatures often fall below freezing in Punjab and upper Sindh but the lower Sindh is frost-free. In Pakistan, two main cropping seasons for summer for Kharif crops start from April to October and the winter season for Rabi crops starts from October to April and some short-season crops are sandwiched between these main cropping seasons. The main crops are wheat, cotton, rice, and sugarcane (Gillham *et al*., 1995). Raza (2009) stated that the cotton growing in a hot climate, the boll weight of United States, Egypt and Australia is 5-6 grams per boll and Turkey is 4-5 grams per boll while boll weight of Pakistan is 2-3 grams which are less than half from USA, Egypt and Australia and a half from Turkey. Agriculture especially cotton crop is the major source of Green House Gases (GHGs)which contribute to the greenhouse effect and climate change. These changes have a long-lasting effect on cotton production, which is a real challenge to the food security and economy of Pakistan. There are lots of factors that contribute to Earth's climate. Climate changes can occur through both natural and human-induced causes. Climate change may be due to natural processes or due to human influences such as changes in the composition of the atmosphere or land use (Hatfield *et al*., 2014: Mckibben, Bill.2011).

3. Impact of temperature and carbon dioxide on cotton production.

The Intergovernmental Panel on Climate Change (IPCC) fifth assessment report predicted a 1.5 °C increase in global surface temperature, and the increased difference in precipitation between wet and dry regions over the twenty-first century (IPCC 2013). Independent observations by the National Oceanic and Atmospheric Administration (NOAA) and the National Aeronautics and Space Administration (NASA) presented that globally, temperatures in 2016 were 0.99 °C warmer compared to records from the twentieth century, and the third year in a row to set a new record high temperature (NASA 2017). Global CO2 concentration is the main driver of the recent environmental pollution climate change. The global concentration of CO2 in the atmosphere reached 400 parts per million (ppm) for the first time in recorded history in 2013, the trend has continued, with the 2016 estimate at 404.4 ppm (NASA 2013, 2016). Cotton plants respond to changing environments, the response depends on the stage of development of cotton plants e.g. conditions at the time of planting, plant development in the early season, flowering, boll formation, and conditions towards the end of the Season. The higher temperature in cotton-producing regions already harms cotton crops, increasing the shedding of flowers and buds. Boll retention is more sensitive to high temperatures than any other condition, except for nutrient deficiency. The effect of nutrition is easy to correct but impossible to avoid the effect of high temperature, can produce bud shedding which is the main reason for the loss of fruits forms. (Reddy et al., 1992). (Reddy et al., 1999) observed that temperature regimes alter boll development, boll size, and the maturation period, which decreased as the temperature increased. Reddy et al., (2000; cited in ICAC, 2007) observed that boll growth decreases significantly and fruit is shed 3–5 days after blossom when temperatures reached over 32º C. The longer growing seasons and rise in temperature above 40º C could induce sterility and inhibit boll formation, breeders have to focus on heat tolerance varieties (ICAC, 2009). With more atmospheric CO2, greater numbers of branches and fruiting sites develop which results in higher lint yields (ICAC, 2007). According to (Reddy et al., 2004), at temperatures greater than 30º C most of the fruit was terminated regardless of CO2 concentration. (Mauney 1998) stated that at high temperatures, nutritional and water shortages are responsible for fruit loss. (Bibi et al., 2008) stated that the optimum temperature for photosynthetic carbon fixation of cotton was about 33o C and that photosynthesis in cotton decreased significantly at temperatures of 36o C, above caused a decrease in yield signifying high-temperature stress. Tactics to increase soil carbon, such as organic manures, residue management should be encouraged to reduce the impact of climate change.

4. Impact of climate change on Irrigation.

Water constitutes about 70%-90% of plant fresh mass, plant development, and physiological processes are highly dependent on its availability and quantity. The important role of water in plant physiology, nutrient transportation, transpiration, and enzymatic reactions prescribes that water stress can cause changes in the anatomy, morphology and change physio-biological processes (Kramer, P.J.,1980). Plants need adequate water to grow and to maintain their temperature within an optimal range. Without water for cooling, plants may suffer and feel heat stress. The limited supply of canal water, climate change, drought-prone, massive groundwater extraction by tube-wells and turbines, rapidly declining groundwater table, and increasing salinity also affect cotton production in Pakistan. Less water available in the Kharif season, less germination observe in Bt varieties, and increasing soil salinity also affect germination which causes lower plant populations in the fields. Water scarcity in Pakistan is increasing day by day and the regular occurrence of drought affects cotton production. In Pakistan, irrigation water is used to maintain adequate growth and maintaining temperature conditions for cotton production. The amount and timing of water availability during the growing season, through precipitation or irrigation, are very important for cotton. If water supply unpredictability increases, it will affect plant growth and cause reduced yield (Karl *et al.*, 2009). Pakistan Indus valley, with increasing demand and competition for fresh water supplies, water availability in Pakistan has become an important factor for limiting cotton yield. Cotton affects freshwater both quantitatively and qualitatively, through fertilizers and pesticides plays an important role in soil degradation through a rising water table and salt deposition in surface soils (WWF, 2005). Water deficits bound the growth and productivity of cotton plants, and the harshness of the problem may increase due to changing world climatic trends, (Le Houérou,1996). Plant water deficits depend both on the supply of water to the soil and the evaporative demand of the atmosphere, climate change also affects water availability for irrigation and potential effects on agricultural production (Elliott *et al.*, 2014). Due to very limited rainfall 150–750 mm agriculture in the Indus Valley depends entirely on irrigation, cotton takes the third biggest share of freshwater in Pakistan (WWF, 2005). Water is supplied every week, supply is regulated through a series of dams that store water until it is needed during relatively dry periods. Supply cannot be varied according to crop water requirements (Gillham *et al*., 1995). The declining accessibility of water resources resulting from climate change will increase race for these resources between irrigated cotton and other crops, also environmental uses. These issues highlight the need for continual improvement in the whole farm and crop water-use efficiencies.

5. Impact of Climate change on weeds of cotton crop
Higher atmospheric carbon dioxide gas impact weed growth more vigorously, competition with nutrition, weeds is critical when cotton is in the seedling stage. The cotton planting and development start earlier as temperatures rise the same development was observed in weeds. The critical period in the development of cotton and weeds coincides. Cotton which is a C3 plant and most weeds are C4 plants show less reaction to CO2, that is why cotton can compete with weeds more effectively under conditions where there is enough water and nutrition (Kaynak, 2007). Climate change affects the entire cotton-weed relationship. Climatic change more helpful to weeds because genetic differences and selective ecological adaptations are more developed in weeds than in cultural plants (Grenz and Uludag, 2006). Weed species carrying tropical characteristics can benefit from increasing temperatures and may turn into dangerous species (Kaynak, 2007). Weed control becomes more critical to achieving ideal cotton plant development and yield. The efficiency of herbicides is decreased with the early increase of temperature and atmospheric CO2 has been exposed to increase directly the severity of some invasive weeds (Ziska 2003), their tolerance to herbicide (Ziska *et al.*, 1999, Ziska *et al.,* 2004), and influences the susceptibility of some crops to attack by pests.

6. Impact of winds on cotton crop
Winds also can affect the cotton plant which leads to increase or decrese the yield of cotton. When it blows from south to west may decrease pest infestation in Sindh, Baluchistan, and Punjab of Pakistan. When south-west winds blow to the north-east in summer (locally called Dakhan). This type of wind blows from the sea side which is loaded with salt and dry which modifies the temperature and humidity, in turn, decrease the evaporative demand significantly and create a good impact on the cotton crop. (Cetin *et al.*, 1996) stated that the maximum seed cotton yield was obtained in all the irrigation methods, where lowest the wind speed was recorded. In Pakistan sowing time of cotton crop started in April and May, hot winds blow along with the deserts belt of Baluchistan, Sindh, and Punjab which affect germination and seedling of the cotton crop. Winds in the early stage of cotton damages to plants occurring during the first 3 to 6 weeks after emergence, when winds pick up hot soil particles, affect early seedlings stage and even flowering of the cotton crop. According to (Puri *et al.*, 1992) stated that an area having a windbreak-like tree belt was selected and cotton was raised in agricultural fields, dependent upon the location of the tree belt, an increase in cotton yield was found to be 4% to 10%.

7. Impact of climate change on insect pests complex of cotton crop especially pink bollworm and whitefly
Insect pest of the cotton crop is considered the major factor that contributes to the decrease in cotton production. The cotton insect pest complex in Pakistan is diverse i.e., Jassid (Amerasca devastans Dist.), Thrips (Thrip tabaci Lind), Whitefly (Bemisia tabaci Gennadius), and Aphids (Aphid gossypii Glov); bollworms such as pink bollworm (Pectinophora gossypiella Saunders), Spotted bollworm (Earias bvittella Boisduval) and American bollworm (Helicoverpa armigera Hubner) recorded in abundance (Chamberlain *et al.*,1996). Insects have recognized threats to cotton production throughout the world, most insects can adapt their body temperature to the temperature of the environment. Global warming has some unavoidable effects on pests because pests can better adapt their body temperatures to their environment. Atmospheric CO2 levels and higher temperatures may also have an impact on the effectiveness of certain pest management tools currently in use, such as certain seed varieties or insecticides. Wu *et al.*, (2007) report that genetically modified *Bacillus thuringiensis* (Bt) cotton shows less Bt toxin after exposure to elevated CO2, which might affect plant-bollworm interactions. Global warming affects insects' metabolism, allowing them to increase their multiplication rate. Rising temperatures open new areas for colonization by insects and spread to newer areas. Increases in insect population such as bollworms, as a result of higher multiplication rates, diapauses

during winter to avoid colder temperatures. The effects could be further augmented under conditions where alternate host plants are already available for wintering (ICAC, 2007). Research on the thermal biology of insects has exposed that the ability of insects to tolerate extreme temperatures is one of the most crucial biotic factors defining the distribution of most insects, which allegations in the face of global climate change (Bowler and Terblanche 2008; Cui *et al.,* 2008; Ma *et al.,* 2014). Morning relative humidity had positive effects and evening relative humidity had a negative influence on the larval population of pink bollworm (Ramesh Kumar *et al.,*2007). Whiteflies are significant global agricultural pests (Oliveira *et al.,* 2001). Whiteflies have a wide host range and are very adaptive to different environmental conditions (Oliveira et al. 2001; CABI 2017). It causes damage to crops directly through phloem-feeding as well as the excretion of honeydew leading to the growth of sooty molds that reduce photosynthesis. Whiteflies also cause indirect damage through the transmission of economically important viral plant pathogens (Navas-Castillo *et al.,* 2011; Tzanetakis *et al.,* 2013; Polston *et al.,* 2014). Climatic change is upsetting the agricultural and natural ecosystems and directly affects the development, reproduction, survival, population dynamics, potential distribution, and abundance of whitefly species (Bonato *et al.,* 2007; Gilioli *et al.,* 2014). Temperature and hostplant effecting on development, mortality, and fecundity rates in whiteflies population. Temperature increases within the thermal optimum lead to a decrease in developmental time (Sengonca and Liu 1999; Han *et al.,* 2013). Temperature also effects on increase in life-history traits include decreasing fecundity (Xie *et al;*2011) and decreasing longevity (Sengonca and Liu 1999). Temperature and environmental factors are very important factors for affecting the life-history of whiteflies but also other factors influence the life-history of whiteflies towards climate change, for example, adaptation to environmental stress e.g., insecticides like thiamethoxam increase thermotolerance which could be beneficial to B. tabaci in the light of climate change (Su et al., 2018). Nutrition and defensive chemistry of host plants (Jiao *et al.,* 2018) could also affect the response of whiteflies to climate change. (Horowitz 1986) also stated that the atmospheric humidity, temperature, and rainfall influence the population dynamics of whiteflies. Investigate the role of integrated management as a means for providing better management options for cotton ecosystems.

8. Impact of climate change on diseases of cotton

Cotton leaf curl virus (geminivirus), Boll rot (Phomopsis spp., Diplodia spp., and Fusarium spp) attack on cotton in high humidity and rainfall. Bacterial blight (Xanthomonas campestris pv. Malvacearum) occurs in wet weather. Root rot (Phytophthora megasperma) occurs from June to September when soil temperatures reached 28 °C. Fusarium wilt (Fusarium oxysporum f.sp. vasinfectum) occurs whenever cotton is grown. Cotton seedling diseases: Stem rot (Rizoctonia stem rot) and damping-off (several fungi) Rhizoctonia solani, Pythium spp, Phoma exigua (Ascochyta), and Fusarium spp, the fungi cause damping-off, stem rot that lives in soil on dead plant debris and infects new seedlings during germination, all three fungi cause the death of seedling before and after emergence. Root-knot nematode (Meloidogyne incognita) have a very wide host range and remain in the soil for many years, female of nematode borrows in young roots produces hormones that cause gall around her. Above mention diseases of the cotton crop may affect by climate change, which decreases the yield of the cotton crop. CLCuD disease incidence is dependent upon climatic factors that affect the population dynamics of the whiteflies vector. Periods of high rainfall before planting promote the growth of weeds, which serve as hosts of whiteflies and as reservoirs of the virus. Cotton is the primary site of infection as the virus is transmitted by viruliferous whiteflies rising from infected weed hosts. Secondary spread occurs within infected cotton fields and can be extremely rapid under moderate-to-high vector population level. Cotton leaf curl virus disease is caused by the CLCuD-complex of begomoviruses is endemic in Pakistan. Cotton leaf curl disease CLCuD, caused by whiteflies B. tabaci transmitted single-stranded DNA viruses belonging to the Genus, Begomovirus family, Geminiviridae in association with satellite molecules., is responsible for major economic losses in cotton production. The globally rising temperature affects some disease control methods as a result of changes in the pathogen emergence time. Chemical control methods may also become less effective due to the possibility of faster decomposition of chemicals under higher temperatures. (Chakraborty *et al.,* 2002) observed that higher CO2 levels increase the severity of diseases, induce fungal growth and spore formation, and destroy more plant tissue. The disease problem in cotton crops becomes more important in changing scenarios of climate change (ICAC, 2007).

9. Impact of climate change on the use of pesticides.

The pesticide is a term that covers three areas of crop production like insecticide which controls worms, bugs, and other insects that can easily consume crops in the fields, herbicides that control the weeds from overcoming the crops and lowering the harvest, and fungicides which control diseases that attack our crops. To avoid the effect of climate change farmers must use integrated pest management techniques, use a variety of methods to grow, and protect the crops with chemical control when it is a better option. Pests like weeds, insects, and fungus are the greatest threat to growing any crop, without pesticides some crops could not be grown on a large scale. Most farmer relies upon chemicals to get rid of serious pests, chemical control is effective but due to tremendous increase in pesticide application in the world during the last decades especially in countries like Pakistan, many plant protections issues like resistance, resurgence and indiscriminate use of reported (Bhatti *et al.*,1993). The continuous and indiscriminate use of insecticides, besides creating the problem of health hazards and environmental pollution, has also been reported in the development of resistance to a large number of insect pests. (Dinther, 1972) Indiscriminate use of pesticides kills the natural enemies resulting in a flare-up of the pest population (Sharma *et al.,* 2001) stated that reduce the use of insecticides resulted in higher net return, environmental safety, and conservation of beneficial insects. The use of insecticide is unsustainable because of increasing pests resistance, residues, and environmental impact (Van Steenwyk *et al.*, 1975, Bariola, 1985). The insecticide used for the control of pink bollworm caused ecological disruption due to the destruction of natural enemies to outbreak formerly secondary pests, insecticide resistance, adverse ecological and human health effects (Van den Bosch R;1978, Dedbach P, *et al.,* 1991). The use of pyrethroids and organo-phosphate insecticide induced outbreaks of the whitefly (Bemisia tabaci) and other pests that proved more damaging and difficult to control pink bollworm (Kranthi KR *et al.,* 2009, Karl *et al.*, 2009) stated that higher temperatures reduce the effectiveness of certain classes of pesticides (pyrethroids and spinosad).

10. Impact of climate change on beneficial insects.

Ladybird beetles, spiders, oreus bugs, dragonflies, and chrysoperla are the main beneficial insects of the cotton crop. *Chrysopa carnea* common name is green lacewing. C. carnea adults feed only on nectar, pollen, and aphid, whitefly honeydew, but their larvae are active predators, occur in a wide range of habitats. Several species of aphid, red mites, thrips, whitefly, eggs of leafhoppers, moths, leaf miners, small caterpillars, beetle larvae, and tobacco budworm are reported to prey. (*Henn et al.,* 1990). The number of eggs laid by C.carnea females is affected by the quantity and quality of the larval and adult food as well as by environmental conditions like temperature, photoperiod, relative humidity *(Principi and Canard,*1984*)*. The spray of protein hydrolysates mainly yeast with sugar has been used as artificial honeydew of high quality *(Tauber et al., 2000)* for attraction in a cotton field under trees, along with water channels where the temperature is relatively below and more humidity. C.carnea adults are attracted to protein hydrolysates *(Canard* 2001*)* and this behavior has been used in conservation biological control. Crisopid larvae have been found to highly resistant to the effects of pesticides on other predatory insects (Nordlund *et al.*, 2001). By the use of beneficial insects for the control of cotton, the pest could get an advantage in the Integrated Pest Management (IPM) Programme in cotton. The review of IPM confirmed that biological control has been economically successful, ecologically sound in modern progressive and intensive agriculture systems. (Romeis & Shanower 1996) stated that Trichogramma species have the great potential to control bollworms in the cotton integrated pest management (IPM) Programme. (Wang and Zhang, 1991) showed that temperature and relative humidity during august to November were conducive for the survival and activity of bollworms and their parasitoids. The establishment of parasites and predators in the field might be influenced by crop microclimate particularly in the crop grown in rows. (Jones 1992) stated that crop microclimate is influenced by plant size density, architecture, and has been shown to have a substantial effect on Trichogramma augmentation (Kot 1979; Orr *et al.*, 1997). Stop any unnecessary loss of nutrients for the farming system, through burning of crop residues which eliminate the population of beneficial insects in burning fields.

Suggestions and Recommendations.

• Breeders must select for plants that can use water efficiently during extended droughts and provide viable pollen and bolls even during height waves, breeding cotton variety for the more extensive root system to increase water uptake during droughts, use genes wild, perennial cotton to improve the ability of cultivated cotton to cope with climate change. Tolerant specious of the cotton crop might be a significant source of the gene for resistance to biotic and abiotic constraints. Such verities showing high levels of resistance to insects can be developed to use extensive hybridization to increase the level and diversify the basic resistance to the target insect pest.

• One of the main reasons for poor cotton yield is the non-availability of certified seed at a wider scale. The Government should make necessary arrangements for the preparation of true-to-type basic and certified seed production and judicious distribution among farmers at their doorsteps. The Government should be involved progressive farmers take on board for the production and distribution of certified seed in the vicinity at market price to establish a good stand and enhance yield with a professionally applied seed treatment with suitable fungicide, insecticide, nematicide, and biopesticides.

• Test the fertility levels in the soil of individual fields at least every other year. Use recommended soil sampling techniques from your extension experts to establish your soil pH and residual nutrient levels and apply them to fertilize keeping in view the soil sampling report.

• The Government provides cotton-growing related machinery like bed planter, spray machines, laser levelers on 50% subsidy rate should be prioritized to cotton grower where irrigation water shortage.

• Applying farmyard manure, cotton residues, recommended dose of fertilizer, hand hoeing of weeds, and low tillage practices saving of soil moisture, effectively utilization of inputs act as mitigation strategies in cotton production. A combination of no-tillage practice and mid-planting of the cotton crop can potentially minimize the yield losses due to climate change to some extent. Sowing of border crops (Sorghum, maize fodder, sesame, pigeon pea), around the cotton field for propagation of natural enemies of cotton pests to reduce the impact of climate change.

• Must apply irrigation water at critical stages of the cotton crop, yields are significantly reduced if miss the irrigation at critical stages. If one irrigation is available it should be provided at flowering stage, if available for two irrigations, it should be provided at flowering and boll formation stage, if available three irrigation, it should be provided at seedling, flowering, and boll formation stages, if the water is not limited, irrigation should be provided every 15 days and water stagnation should be avoided.

• Avoid excessive use of fertilizer, fertilizer should be applied to cotton crops according to the 4 R principle, i.e. right dose, right time, right place, and right method. Optimize the efficiency of fertilizer use where required, because of its costs and carbon fuel print. Most soils of Pakistan are calcareous, the application of phosphorus and potash had been fixed and rendered unavailable for crop uptake, the application of FYM had a significant effect on soil moisture conservation and availability of P & K status in the soil. In a climate change scenario, fertigation of phosphors and potash is a successful technique for increasing cotton yield compare to the conventional broadcast method.

• Plant population is a very serious issue in cotton-growing areas in changing scenarios plant spacing directly influences soil moisture extraction, light interception, humidity, and wind movement. These factors, in turn, influence plant height, branch development, fruit location and size, crop maturity, and ultimately yield reductions. Sowing of cotton lines in the direction of north to south to get the maximum benefit of wind blows from seaside, which is dry and decreases the effect of climate change.

• Dense plant population stands suffer delayed square initiation, more fruit shed, and slower node development, this condition favors the whitefly population. As a result, more time is required to set up the crop and consequently, maturity is delayed due to immature bolls which attract pink bollworm for hibernating continuation for the next generation. So, 44500 to 54500 plant population per hectare is sufficient for the Pakistani climate.

• It is the dire need of the time for enhancing the training opportunities for all stakeholders e.g. agriculture agents, agriculture service providers, progressive farmers, community representatives, and irrigation department about the adverse effect of climate change on cotton crop.

• For integrated pest management (IPM) strategy spray of protein hydrolysates with sugar used as artificial honeydew of high quality on trees near cotton fields, in water channels where the temperature is relatively low (Tauber et al;2000). Chyrsoperla adults are attracted to protein hydrolysates (canurd, 2001) and this behavior has been used in the conservation of biological control to reduce the impact of climate change.

• For soil moisture conservation technique like contour bunding, narrow or broad ridges or beds separated by furrows, ridges, and furrow, the opening of furrow after every row of cotton, use of black polythene mulch (25 microns) and spread of crop residues are decrease the risk and uncertainty imposed by climate change.

• Avoid frequent used of broad-spectrum insecticides (those labeled against many pests) because these pesticides also kill predators and parasitoids, long-term use of insecticides with the same mode of action may lead to the growth of populations of cotton pests that are resistant to insect ides. Insecticides may also cause injury to plants (Phytotoxicity), apply pesticides during the early morning or late afternoon to avoid the hottest part of the day, irrigate the cotton field one or two days before applying the pesticides to minimize the effect of climate change.

• Keep target cotton fields free of weeds that can serve as a whitefly host. Avoid excess irrigation and fertilization to the cotton crop which may increase the susceptibility of plants to whitefly. Area-wide management strategy with neighbors' growers including a tight planting window adoption, so that whitefly does not migrate to successive planting.

• When cotton grower spray insect growth regulator (IGR) prevents insects from molting to the next development stage (i.e. eggs do not hatch, juveniles do not become adults and female are infertile) during the immature stages, prevent adult whitefly development, these products generally do not kill adult whitefly present at the time of spray. In this connection proper pest scouting, proper guidance is needed to the farming community for proper pesticides which control both nymph and adult whitefly at the time of spray.

• For better control of whiteflies mix of insecticides in proper dose (100–120-liter water per acre) use pressure sprayer like power sprayer and boom sprayer against whitefly at early morning or late afternoon, which wash away honeydew and sooty mold accumulations resulting reduction in the population of whitefly effectively. In the early stages of development of cotton crop spray bio-pesticides like neem, tobacco, and corettoma extraction before establishing of whitefly colony that can preserve and protect beneficial insects which decrease the adverse effect of climate change.

• Spray against pests of cotton, use soft pesticides, proper pesticides (rotation between chemicals groups with a different mode of action) proper water, proper nozzle, proper time (limiting the period during which an insecticide can be used). Judicious and proper use of insecticides not only preserve natural enemies but also reduce health and environmental risks like climate change.

• For popularization of biological control of cotton pest, Government can achieve the target by rearing, importing, and releasing natural enemies from areas where pest propagate, by purchasing and releasing commercially available natural enemies of cotton pest by involving coordinated efforts of agricultural Universities, research organizations, agricultural nuclear institute, CABI, agricultural extension agents.

• Cultural practices are used as the overall strategy for a white fly moment, efficient weather forecasting system available to the cotton-growing farmers, changing planting dates remain an easy and effective tool to reduce pest pressure. Whitefly threat may result from climate change depend heavily on improving understanding of complex interactions between whitefly species, host plants, natural enemies, and the components of climate change that affect them in each of Pakistan major ecological zones.

• Cultivation of disease-resistant variety is the only safe measure of all different diseases, eradication including collection and burying plant debris in deep soil may help to control seedling, root, and boll rots as well as bacterial blight, because disease inoculums may also survive through open placing plant debris. Use of healthy seed, acid delinting, and fungicide treatment minimized disease incidence. Crop rotation with non-host i.e. sowing of sorghum for 3 to 4 years is useful for control of seedling and root rot, mixed cropping with kidney been or fodder and leguminous crops saves the cotton crop from root rot.

• Plant mapping and monitoring of cotton crop for growth, square size, flowers, bolls, node distance, and fruit retention help to enhance cotton yield and fiber quality. Many factors, such as cotton varieties, soil moisture, plant stress, soil type, and nutrition affect growth rates, and the rate of growth can be regulated through the application timing of growth regulators like Mepiquat chloride and other chemicals.

• The majority of crop residues are burnt in cotton-based cropping systems (cotton – wheat) resulting in the emission of greenhouse gases, in addition to the loss of Nitrogen, Phosphorus, Potash, and Boron and eliminating of beneficial insects. Restoration of soil fertility is possible by incorporating crop residues, which decrease the impact of climate change. In management practices such as minimum tillage and cover, crops can help mitigate the effects of climate change because these methods allow farmers to reduce water loss, especially in low irrigated areas of Pakistan.

• The use of insecticides for the control of cotton pests has been highly criticized, and therefore, it is forced to switch from insecticides to eco-friendly approaches such as intercropping, use of beneficial insects, cultural control and use of soft pesticides are main techniques to rejuvenate cotton productions and help to mitigate against climate change.

• In the early stages of the cotton crop, larvae of a pink bollworm attack on internal parts of fruit and later stitches the petals together, preventing flowers from opening, this condition is known as "rosette flower "should be picked by cotton growers' families or school going boys, in this connection agriculture extension agents play their role for identifications and guidance to cotton growers can minimize the use of insecticides to reduce the effect of climate change.

• The best control of pink bollworm can be achieved by the use of sex pheromones through communication disruption technique by using pheromone in cotton Agro-eco- system and disrupting inter-moth communications. The effectiveness of pheromones application significantly higher when cotton planting lines are perpendicular to the directions of the prevailing wind. Fields treated with pheromone also have a higher population of predators and parasites that are an important component of integrated pest management to avoid the real threat of climate change. For the control of overwintering of pink bollworm larvae include the chemical defoliation of cotton crop and desiccation of crop at the end of the season, removing immature late-season bolls, and use of short-season varieties.

• For mitigation, to climate change use cultural methods to control the pink bollworm and whitefly like land preparation, irrigation, sowing date, weed control, fertilization, crop rotation, use of trap crops and resistant varieties should be preferred. While planning for the next season selection of verities with early maturing, sun drying of seed for 8 to 10 hours, sowing of acid-treated seeds is effective to prevent the attack of pink bollworm. Monitoring the pink bollworm infestation must be taken through pest scouting and sex pheromone traps daily.

• For the control of pink bollworm, offseason management is very important like grazing of animals for remaining bolls at the end of the season, timely crop termination, avoid early planting of a crop, destruction of cotton stubbles immediately after harvesting the crop, avoid stocking of cotton stalks for fuel purpose over a long period, deep plowing to expose the pupae of pink bollworm.

• Defoliate the cotton crop as early as possible to balance the goals of cotton yield and quality. Harvest the cotton crop and defoliate when most boll open. Picking started after 10.00 a.m. when dew not present in cotton fields. If weather or time management delays picking or early in the morning you will likely see a drop in grade and yield.

• It is the dire need of the time to increase the area of Agroforestry having less shading and allelopathic effect in cotton-growing areas that can regulate the water availability from unpredictable rain patterns like drought and flood, decrease soil erosion, increase soil fertility and also provide shelter to beneficial insects (Rijal *et.al.*, 2019, Thorlakson *et.al.*, 2018 and Torquebia E.2013) stated that Agroforestry is considered as a weapon in climate change fight.

Conclusion

The adverse effect of climate change on cotton production can be minimized by adopting a climate-smart agricultural system like water-smart (raising crops on the bed, laser leveling, conjunctive use of water and draining management) energy-smart (minimum tillage), carbon–smart (less use of chemicals) and knowledge-smart (crop rotation and improved verities i.e. tolerant to drought, flood and heat/cold stresses) practices and technologies, communicate to the cotton-growing farming community. Through innovative breeding, sustainable management practices, and recycling technology, foresight full farmers, agricultural scientists, agricultural extension agents, and industry leaders are working to ensure that cotton has the opportunity to play as a big role in our future as it has in our past of Pakistan.

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