Adoption of Sustainable Cotton Farming Practices: A Pathway to Eco-Friendly Agriculture

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Abstract

Cotton is one of the key cash crops in Pakistan, significantly contributing to the economy and supporting the livelihoods of the farming community. However, this promising sector faces major threats from global warming and climate change. A study was conducted in District Muzaffargarh to assess the adoption of sustainable cotton farming practices. This area was chosen as it is a major cotton-producing region in Pakistan. A total of 270 cotton growers were randomly selected for data collection. The data were analyzed using the Statistical Package for Social Sciences (SPSS). Additionally, five focus group discussions were conducted to gather qualitative insights. The results revealed that a limited number of cotton varieties were cultivated in the region, with SS, CKC, IUB, BS, and NIAB being the most common. An overwhelming majority of the farmers had cotton fields of up to 5 acres. Hand sowing was the most common planting method. Among water stewardship practices, irrigation after weather forecasts, cleaning of watersheds, and reduced use of flood irrigation were prevalent. In terms of soil improvement practices, foliar spraying, soil analysis, reduced pesticide usage, and reliance on farmyard manure were widely adopted. Regarding Integrated Pest Management (IPM) practices, rotavating crop residue, proper disposal of cotton sticks, the use of recommended pesticide doses, and the application of appropriate active ingredients were the most common practices.

Keywords: Sustainability, Water Stewardship, IPM, Soil Improvement, Biodiversity.

Introduction

In Pakistan, agriculture is the backbone of the economy, supporting millions of people, especially in rural communities. This vital sector not only supplies raw materials to industries but also sustains livelihoods by providing food, feed, and shelter. Among the country's major crops—cotton, wheat, rice, maize, and sugarcane—cotton plays a particularly crucial role. It has shown

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impressive resilience, with production increasing steadily year after year. Cotton ginning alone contributes 1.34% to the agricultural sector and 0.32% to Pakistan's national GDP, experiencing a remarkable growth rate of 47.23% (GOP, 2024). Clearly, cotton is a pillar of the economy. Yet, this promising future faces significant threats from global warming and climate change. According to the Intergovernmental Panel on Climate Change (IPCC), climate change could drastically reduce agricultural output, particularly in developing countries like Pakistan. Cotton is especially vulnerable to rising temperatures, erratic rainfall, and other environmental changes. In Pakistan, the optimal temperature for cotton growth is around 28.5°C, but temperatures during the cotton season frequently soar between 40°C and 45°C, sometimes even surpassing 50°C (Malik and Ahsan, 2016). These extreme heat levels reduce yields, while also worsening pest and disease issues, which further threaten cotton production. The increased use of pesticides and fertilizers in response to these challenges not only harms the environment but also raises concerns about human health.

Despite these hurdles, Pakistan remains the sixth-largest cotton producer in the world and the third-largest in Asia for spinning capacity. Thousands of ginning and spinning units power the country's textile industry, and in the 2021-22 season, Pakistan ranked as the third-largest producer of Better Cotton globally. This industry supports the livelihoods of around 1.5 million smallholder farmers. As water shortages push farmers away from sugarcane cultivation, many are turning to cotton due to its natural drought resistance (BCI, 2024). However, conventional cotton farming in Pakistan is heavily dependent on agricultural chemicals, which poses serious environmental and health risks. Alarmingly, 70% of the country's imported pesticides are used on cotton, making it one of the most pesticide-reliant crops. This extensive use of chemicals not only harms ecosystems but also impacts community health. Moreover, cotton farming consumes a significant portion of Pakistan's freshwater, presenting further sustainability challenges (Makhdum et al., 2011).

Cotton has gained a reputation as one of the "dirtiest" crops due to its heavy pesticide use, which accounts for about 33% of input costs. Many farmers, particularly those in developing areas, lack the necessary training for effective pest management, leading to excessive pesticide use. This not only endangers public health but also reduces financial returns for farmers and degrades the environment (Yasin et al., 2021). The shift toward sustainable cotton farming is critical. Governments and consumers must embrace eco-friendly practices, pushing for greater environmental stewardship. Cotton farming currently uses more insecticides than any other crop, accounting for 30% of global pesticide use. Runoff from cotton fields contaminates air and water, leaving toxic residues that enter the food chain, even affecting breast milk (Shuli et al., 2018). Moving towards sustainable practices in cotton farming is not just a goal but a necessity for the well-being of the planet and future generations.

Methodology

The techniques and approaches used to conduct the study are described in detail. This includes how data was collected, the tools or instruments used, and how the data was analyzed. Here's a breakdown of key elements typically covered in this section:

Study Area and Population

District Muzaffargarh was chosen as the study area, as it is fall in the southern Punjab. Southern Punjab is the cotton belt While Muzaffargarh is main hub of the agriculture production especially contributed as a major part in the cotton production. It was impossible to cover all the district for the purpose of study, therefore, Tehsil Muzaffargarh was chosen purposively as it has the

maximum number of registered farmers and area under agriculture. All farmers of the study area constituted the population of the study.

Sample Size

The study was conducted in Tehsil Muzaffargarh, from the selected area 30 villages were selected randomly, from each selected village 9 farmers were selected randomly, thus it make the sample size of 270 farmers.

Preparation of Data Collection Tool

An interview schedule was prepared while keeping in view the objectives of the study. It includes all the relevant questions. An interview schedule was preferred as the majority of the farming community in the study area have less literacy level.

Validity and Reliability of Data Collection Tool

It was necessary to ensure the reliability and validity of interview schedule, otherwise chances of irrelevant and poor data chances increase. For the purpose of reliability of the tool, Cronbach alpha value was computed by using Statistical Package for Social Sciences (SPSS), after the carful observation and correction of the interview schedule the alpha value was calculated which was 0.78, this value depicts that tool was reliable.

For the purpose of ensuring validity, the services of cotton experts were taken. Changes and amendments were made on the recommendation of the experts.

Data Collection

The data were collected face to face from each individual. The questions were asked in the local language as the mostly farmers were not literate. Therefore, they were not aware of the technical words and English term used in the interview schedule.

Besides this quantitative data, qualitative data were collected by Focus Group Discussions, five focus group discussion were conducted for collecting the in-depth information. One focus group discussion took almost 30-40 minutes. The purpose of this was to ensure the knowledge level and to check the compatibility of their response with the quantitative data.

Data Analysis

For the purpose of quantitative data analysis, a statistical tool, Statistical Package for Social Sciences (SPSS) was used. Different statistics values were computed by the software. On the other hand, the content analysis was carried out for the qualitative data.

Results and Discussions

Table 1: Verities of cotton cultivated in the area

Name of variety	Frequency	Percentage
BS-20, BS-15	25	9.2
BT	4	1.5
CIM-663, CIM-600, CIM 602	1	0.4
CKC-01, CKC-06	46	17
FH-114, FH-142, FH-490, FH-492	25	9.2
IUB-13, IUB-222,	21	7.8

LALAZAR	7	2.6
MNH-1016, MNH-1020, MNH-1026	8	3
NIAB-545, NIAB-878, NIAB-1048	20	7.4
CYTO-226, CYTO-124	16	5.9
SS-32	96	35.6
RH-668	1	0.4
Total	270	100

Farmers were asked about the types of cotton they cultivate, and the data revealed that they were limited to certain varieties. The primary reason for this was their lack of awareness and knowledge about the verities of cotton, largely due to low literacy levels among many farmers. During discussions, it was revealed that they were cultivating few varieties for an extended period. Among the most widely grown cotton varieties in the area, SS was the most cultivated, with approximately 36 % of farmers planting it. This was followed by 17 % of farmers who reported planting CKC varieties, while about 10 percent cultivated BS. Additionally, 8 % of farmers were growing IUB, and nearly 9 % were cultivating FH varieties. Other varieties mentioned included CYTO, MNH, and others.

Cotton Area

Farmers were asked about the acreage of land on which they are cultivating cotton. This information was essential to understand their landholding size and their preference for cotton compared to other crops.

Table 2: Area under cotton

Area	**Frequency**	**Percentage**
0-5	246	91.1
>5-10	22	8.1
>10-15	1	.4
>15	1	.4
Total	270	100

Farmers were asked about the area they were on how much area they were cultivating cotton. According to the figures provided, the majority of farmers were cultivating cotton on 0-5 acres, while only a few were cultivating cotton on more than 10 acres. The data suggests that most farmers in the region were small-scale cultivators. The data depict in the study area, the land holding of the farmers was very low.

No of spray

From land preparation to the final stage, several pesticides are required in cotton fields. Some are used to control weeds, while others target various insects-pests. With this in mind, farmers were asked how many sprays they typically apply in their cotton fields.

Table 3: Number of sprays applied in the cotton filed

Number of spray	Frequency	Percentage
1-3	126	46.7
4-6	144	53.3
Total	270	100

According to the table, about 47% of the farmers reported that they applied 1-3 sprays on their crop and more than half of the respondents reported that they applied 4-6 sprays during the cropping season. During the discussion farmers revealed that there is need to clean the cotton field from the weed and herbs, for this purpose almost every farmer applies the pre-emergence weedicides i.e. Pendimethalin, Acetachlor and S-Metolachlor. The most popular post emergence weedicides and herbicides were Glyphosate, Fluzaifos-P-Butyle, Flumetron Prometryn, Haloxyfop and Quizalofop used by the farmers in the study area.

Some of the weeds were reported and identified by the farmers in their fields reported by one farmers in detail, but he told the local name of the weeds i.e. According to him “it, Madhana grass, Janglicholai, Qulfa, Tandlah, Hazardani and Daila etc. All of these are local names of the cotton weeds are the major weeds of the cotton”.

It is interesting to know that some farmers were aware about the name of ingredients that were applied to control different insect-pests. For the control of Jassids Insecticides bearing the active ingredients such as Flonicamid, Furan, nitenpyram, Sulfoxaflor and Dimethoate were being used in the area. For the control of whitefly, Pyriproxyfen , Spirotetramat, diafenthiuron, Acetamiprid, Buprofezin, Flonicamid and Pyri + fluconazole were most common in the area.

Thrips were a major problem for cotton growers, as revealed by many farmers during the discussion. To control thrips, farmers commonly used Chlorfenapyr, Acephate, and Spinetoram. Chlorpyrifos was applied for termite control. For aphid management, a mixture of Imidacloprid and Fipronil was used. To combat mites, Fenpyroximate, Etoxazole, Spirodiclofen, and Hexythiazox were found to be effective. The dusky cotton bug, which deteriorates cotton quality, was managed using a combination of Imidacloprid + Fipronil and Beta-cyfluthrin + Triazophos. Against the mealybug, Profenofos, Methidathion, Cypermethrin + Profenofos, and Malathion were used. In the case of spotted bollworm, Lambda-Cyhalothrin and Bifenthrin were commonly used. For controlling pink bollworm, farmers used Lambda-Cyhalothrin, Triazophos, Gamma-Cyhalothrin, Bifenthrin, and Spinetoram. To manage American bollworm, Emamectin and Spinetoram were used. For controlling army bollworm, Flubendiamide, Lufenuron, Emamectin Benzoate, and Methoxyfenozide were applied.

Sowing Method

The selection of suitable sowing equipment can play an imperative role in suitable crop establishment by maintaining the sowing depth appropriately (Tanveer et al., 2003). The optimum plant population and row to row distance can only be achieved if appropriate sowing machinery is used. The main reason for low crop yield in Punjab is scanty plant population (Iqbal et al., 2015). With this in mind, farmers were asked whether they were sowing cotton by hand or using a planter, in order to assess the importance of mechanization in the area.

Table 4: Method of cotton sowing adopted by framers

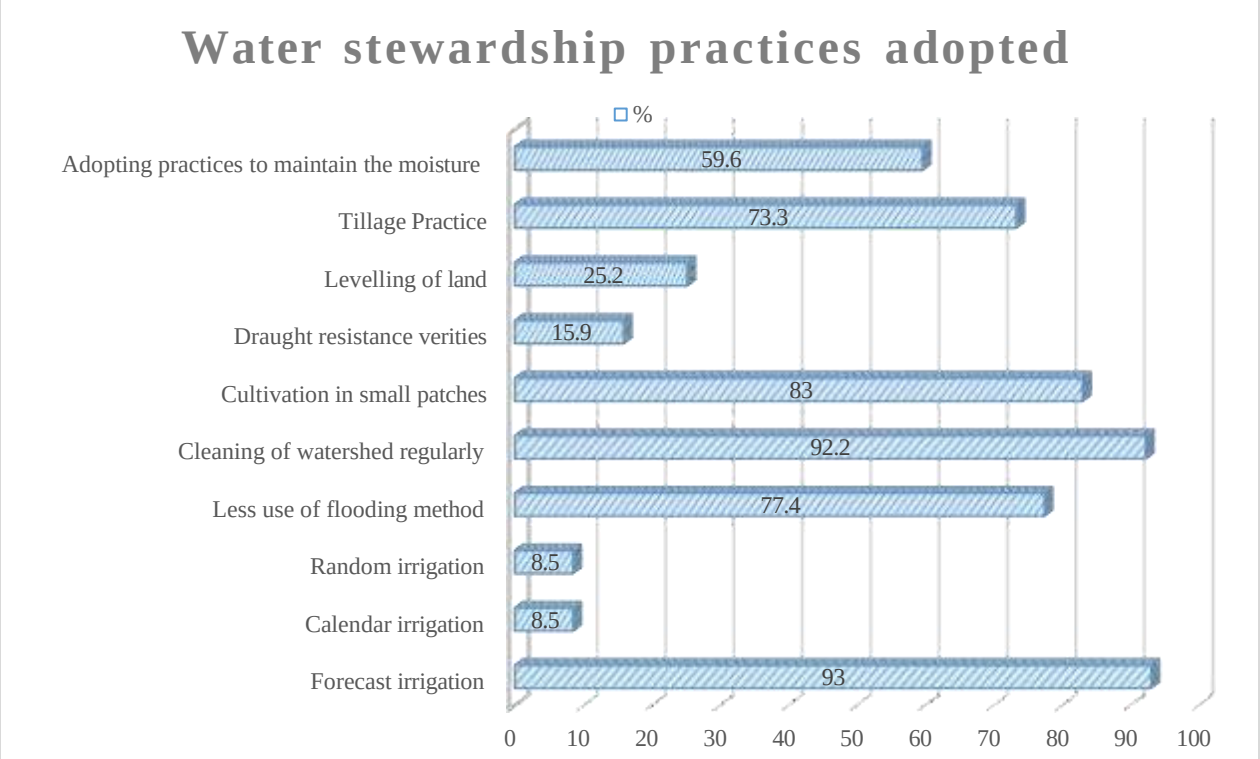
Method	Frequency	Percentage
Hand sowing	237	87.8
Planter Sowing	33	12.2
Total	270	100

According to the table, in the study area the hand sowing method was adopted by an overwhelming majority (87.8%) of the farmers. While only some farmers (12.2%) were using the planter for sowing of the crop.

Water stewardship practices

A major challenge in agricultural production is to grow more food with less water, which can be accomplished by improving crop water use efficiency (Fan et al., 2018). As water is an essential for all living things on the planet, its efficient use should be ensured to guarantee availability for future generations. so that they can be benefitted through its use. In the following graph, farmers were asked about the practices they are implementing in their cotton fields to ensure better water use.

Figure 1: Water stewardship practices adopted



According to the data, an overwhelming majority (93%) of farmers reported that they irrigate their crops after reviewing the weather forecast. If there is a chance of rain, they avoid spraying, as the rain could wash away the spray, rendering it ineffective. Similarly, another overwhelming majority (92.2%) of farmers also mentioned that they clean the water channel before irrigating to ensure that water flows unobstructed and reaches the crop effectively. Additionally, 83 percent of the

farmers stated that prefer to cultivate in small plots as it prove helpful in conserving the water. Farmers also revealed the information about the number and method irrigation applied in the cotton field. One of the farmers elaborated in a good way according to him

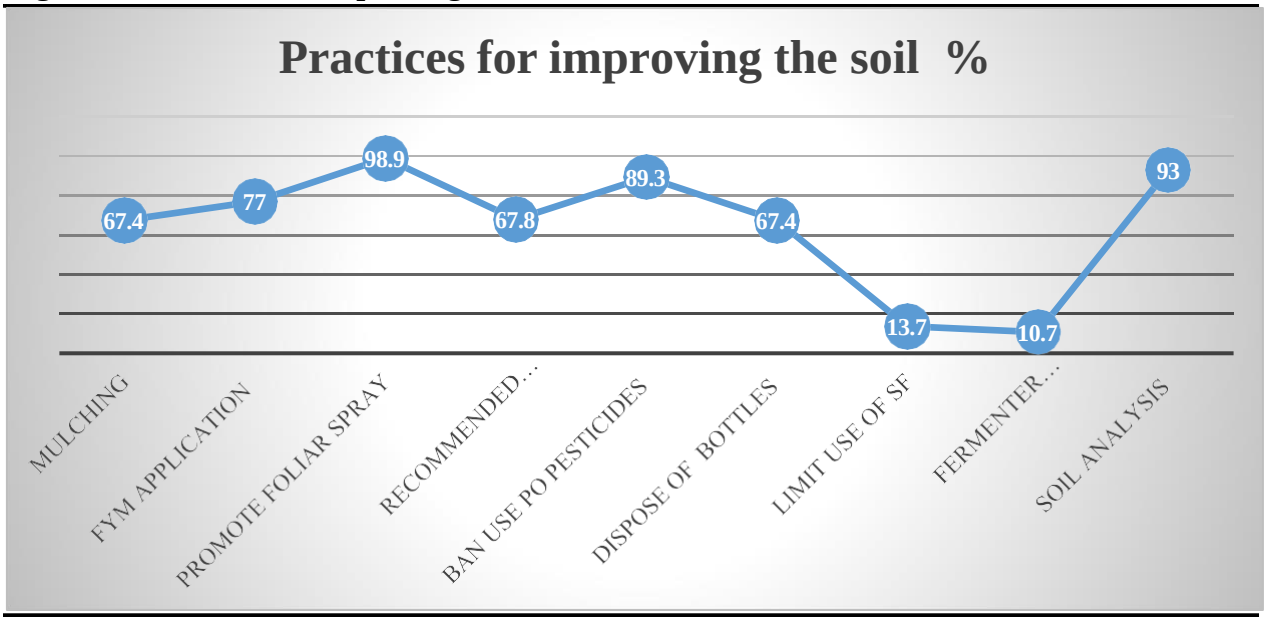
> If cultivation is done using a drill, the first irrigation should occur 30 to 35 days after sowing, with subsequent irrigations applied at intervals of 12 to 15 days. In contrast, in handsowing, the first irrigation should be given 3 to 4 days after sowing. The second, third, and fourth irrigations should be applied at intervals of 6 to 9 days, with further irrigations adjusted based on the crop's needs.

During the discussion, farmers shared their experiences and efficient practices for irrigating cotton fields. One farmer explained,

> In case of water scarcity, better production can be achieved by irrigating alternate rows of crops. In this method, during the first irrigation, water is applied only to the odd-numbered furrows, keeping the even-numbered furrows closed. During the second irrigation, water is applied to the previously dry (even-numbered) furrows, while the previously irrigated (odd-numbered) furrows remain closed.

Some other farmers also practiced this technique and supported the insights shared by their fellow farmer. It was observed that drip irrigation technique that is purely a water saving method was not practiced in the area. However, in India, drip irrigation has been adopted by some farmers, as reported by Aujla et al. (2005). These farmers adopted the system knowing it allows for more efficient water use. In Pakistan, such practices should also be adopted as water scarcity increases daily, and communities should work to prevent the depletion of underground water, as reported by Bakhsh et al. (2012). Canal water is becoming scarce in many parts of the province, forcing farmers to rely on expensive tubewell water due to rising diesel and electricity costs. Although bed or ridge sowing requires more frequent irrigation, it consumes less water compared to other methods, such as drill sowing. Therefore, farmers should prefer bed or ridge sowing practices.

Figure 2: Practices for improving the soil



Mulching and the application of animal dung were adopted by the vast majority of farmers, while nearly all of them used foliar sprays for insect pest control. Approximately 68% of farmers reported applying the recommended fertilizers and doses in their fields. An overwhelming majority (89.3%) of farmers were aware of the phased-out pesticides and stated they had banned their use due to their highly hazardous effects on both the environment and human health. A large proportion (67.4%) of farmers disposed of plastic bottles after spraying, either by burying them away from the field or burning them. The use of synthetic fertilizers (SF) remained common, with only 13.7% of farmers reducing their usage. Similarly, the adoption of fermenter technology was low. Interestingly, soil analysis was widely practiced in the area, with 93% of respondents adopting this practice. During the discussion farmers were asked about the type of soil which is best suited for the cotton cultivation, farmers answered in different ways, one of them explained in detail. According to him.

> Land is the most crucial asset for farmers, significantly influencing agricultural productivity. If the soil is sandy or possesses acidic or basic, crop yields can be adversely affected. Therefore, maintaining soil health is essential for optimal production". Some of the farmers also reported that practice of soil sampling should be adopted, one of them stated that "Farmers can make their land more productive by regularly monitoring (soil sampling) it and applying fertilizers or other inputs as needed. They should manage the land's micro and macro nutrients while considering the specific requirements of the soil.

Similarly, another farmer also added a point during the discussion, according to him "the best approach is to make the use of animal's dung mandatory and deep plowing periodically will help improve the soil structure". According to farmers' yard manure improve the quality of the nutrient in the soil as stated by Khan et al. (2010), Farmyard manure (FYM) has a significant impact on soil physical properties and overall health. It plays a positive role in maintaining soil structure, as its slow decomposition process enhances soil quality over time. FYM notably increases saturated hydraulic conductivity under deep tillage methods and reduces soil bulk density. Additionally, it improves the soil's physical characteristics by enhancing hydraulic conductivity. One of the farmers reported elaborated the property of good land for cotton. According to him

> The ideal soil for cotton cultivation should be highly absorbent and durable. Cotton plants can tolerate slightly acidic to basic soils. The best soil for cotton contains at least 1% organic matter or more. However, the soils in Pakistan are generally deficient in organic matter and other important nutrients.

As reported by Maqsood et al. (2016) that most soils in Punjab are nitrogen-deficient, so there is a constant need to enhance soil fertility through fertilizer amendments to address nutrient deficiencies. Different practices adopted for improving the fertility of the soil too as reported by Khan et al. (2021), farmers were applying the rationale amount of inorganic fertilizers and average amount of organic fertilizer for improving the soil. On the other hand, a study conducted by Mehmood et al.(2024), according to their finding a significant majority of farmers (69.7%) were not using organic manures.

Pest Management Practices

Farmers typically use all available methods to control insect pests in cotton field. Therefore, they were asked which insect and pest management methods they were adopting. The different methods reported by them are listed in the table below.

Table 5: Practices of Pest management adopted by the farmers

Practices	Yes		No	
	f	%	f	%
Inter Cropping	38	14.1	232	85.9
Trap crop	55	20.4	215	79.6
Rotavate Residue	242	89.6	28	10.4
Proper Dispose of stick	262	97.0	8	3.0
Recommended doses of pesticide	233	86.3	37	13.7
Recommended Active ingredients	229	84.8	41	15.2
Less use of Pesticide	239	88.5	31	11.5
Insect Replant	68	25.2	202	74.8
Mixed Verities	56	20.7	214	79.3
Yellow sticky Traps	25	9.3	245	90.7
Pheromone Traps	28	10.4	242	89.6
Biocontrol	100	37.0	170	63.0

From the table, it is clear that farmers properly rotavate the crop residue, dispose of cotton sticks, and use the recommended doses and active ingredients of insecticides and pesticides. Farmers also reported being less dependent on pesticides, adding that they only apply them when they feel it is necessary. It is interesting to know that more than one third (37%) of the respondents were practicing Biocontrol agents for managing the insect-pest in the field.

Some farmers adopted practices such as intercropping, trap cropping, using insect repellents, cultivating mixed varieties (BT and non-BT), and installing yellow sticky traps and pheromone traps. There is a need to raise awareness and motivate farmers to use these less expensive methods of insect control. Additionally, farmers should be educated on how to prepare yellow sticky traps locally. These practices included in the best management practices, they reduce the cost of production as reported by Khan et al. (2021), they said that adopters of best management practices (BMPs) significantly reduced pesticide usage, both in terms of overall quantity and the specific pesticides used to control cotton pests.

During the discussion with the farmers one of the farmers stated that “insecticides are used because they provide immediate control of insects, while other methods (e.g., biocontrol, insect repellents, intercropping) that take longer to be effective. However, chemical control methods are costly but they tend to be more effective.”

Therefore, farmers prefer using insecticides and pesticides, and later, all farmers reinforced this viewpoint. But some of the farmers were also aware about the harms of chemicals on the humans, animals and on different beneficial insect. As reported by Jiang et al. (2009) and Sultana et al. (2014) that pesticides are widely used worldwide to protect agricultural commodities from pests and pest-transmitted diseases. Agricultural soils are exposed to these harmful pesticide residues through various pathways, including direct application to the soil, runoff from plant surfaces, spray drift, air transportation, and improper disposal.

The use of all possible methods to control insect pests is known as Integrated Pest Management (IPM). There are various ways to manage insect pests besides using pesticides (Shuli et al., 2018). Farmers were asked for their views on alternative methods to insecticides and pesticides, but they showed little interest in these approaches. One farmer explained that

> "Methods such as pheromone traps, yellow sticky traps, and biological controls can be effective, but farmers are reluctant to adopt them due to time constraints and the

> effort required for installation or preparation. Consequently, farmers are more likely to use chemical methods, which are perceived as more convenient and less labor-intensive."

Similar findings were also reported by Mehmood et al. (2024), according to the results IPM practices such as biological control, physical control methods, cultural control methods are not adopted by majority of the farmers. There is need to educate the farmers about these efficient method of insect-pest control as mostly farmers are unaware about these. As reported by Arshad et al. (2009), farmers had limited knowledge about natural enemies and diseases in their fields. They continued to rely heavily on chemicals for pest control in cotton, often influenced by advertisements from pesticide companies.

During discussion some farmers reported that after observing their filed and pest scouting they sprayed different insecticides and pesticides, farmers were well aware about the different insect pests of cotton crop, according to one of them

> There are different types of insects in a cotton field, which can be broadly categorized into two groups. The first category is sucking insects, which includes thrips, jassids, mealybugs, aphids, whiteflies, and mites. The second category is chewing insects, which includes spotted bollworm, pink bollworm, American bollworm, and armyworm.

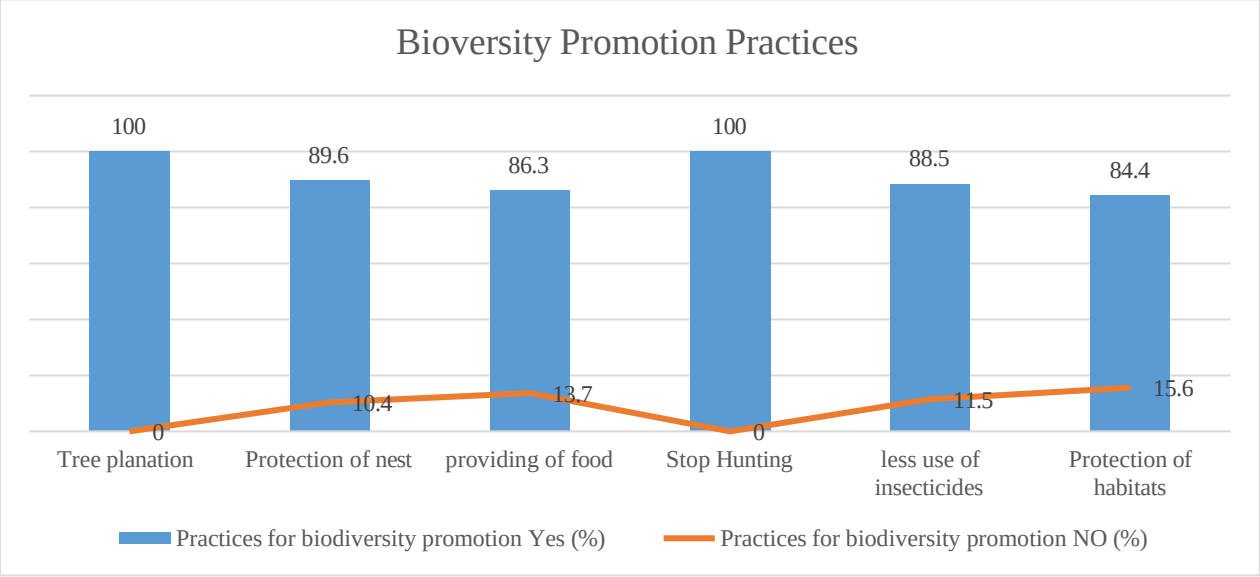
Farmers were asked about the Economic Threshold Level (ETL) of different insect-pests. One of the farmers reported ETL in a good way, he was the expert in farming. according to him

> For thrips, the ETL is 8-10 adults or nymphs per leaf. For whitefly, it's 5 adults or nymphs per leaf or collectively five. For mealybug, it's the presence of an attack in the field. For mites, it's the observed damage, and for jassid, the ETL is one adult or nymph per leaf.

Practices for Biodiversity Promotion

Biodiversity refers to the wide range of plant and animal life found on Earth (Corker, 2003). There are many insects and birds in the cotton fields, some of which are beneficial, while others are harmful. Therefore, farmers were asked what measures they take to control harmful insects and promote beneficial ones. The following are the farmers' responses.

Figure 3: Biodiversity promotion practices



All the farmers believed that they promote planting, while a large number said that they protect bird nests in their crops or fields and also provide food for these birds. All the farmers were of the opinion that bird hunting is completely prohibited in their area and people used to hunt in olden times and now no one is attracted towards it. Farmers also believed that they use pesticides to a minimum and spray poisons only when necessary. A study conducted in Balochistan by Sherani (2020), the major reason behind the biodiversity loss were cutting of forests, pollution, increase in human population, over extraction of resources, climate change, illegal hunting and urbanization. According to Khan et al. (2007), for the conservation of biodiversity farmers were limiting the use of pesticides and avoiding the use of highly hazardous pesticides.

During the discussion, farmers revealed that they adopt various measures to protect biodiversity. According to the farmers, they instructed the labor working in their fields to preserve the nests and habitats of beneficial organisms. One farmer explained that

> We advise cotton pickers to avoid damaging nests in the crops during harvesting and to take precautions to protect baby birds and eggs. Additionally, cotton sticks should not be burned. Burning them not only degrades the soil but also destroys the nests that may be present in the cotton filed.

As reported by Kumar and Joshi (2013) crop residue severe as a source of land and water pollution on both local and regional scales, while also negatively impacting the soil's nutrient balance.

Highly Hazardous pesticides prove harmful for all type of living on the earth, moreover also effected the atmosphere including air, water and soil. Therefore, such pesticides should be banned.

> Some insecticides and pesticides are highly toxic to humans and other organisms, and their use has been reduced due to their harmful effects on the environment, soil, and beneficial insects. While these chemicals are effective in controlling harmful pests, they also negatively impact beneficial insects. Therefore, farmers are encouraged to minimize or avoid their use. Extension staff and various organizations dedicated to farmer welfare guide farmers in adopting alternative methods for insect-pest control.

Discussion

The findings presented in Table 1 indicate that farmers are relying on a limited number of cotton varieties. This dependency can be attributed to several factors, including farmer illiteracy, the unavailability of diverse pure varieties in the market, and constraints posed by limited land holdings and resources. Garcia et al. (2003) note that small land ownership is a significant contributor to low agricultural productivity in Pakistan. In Punjab, over 70% of farmers cultivate less than 2 hectares of land, and many impoverished farmers struggle to adopt innovative technologies, leading to lower productivity compared to their larger counterparts. Abid et al. (2011) highlight that smallholders, already lacking resources, cannot bear the increasing costs of inputs.

To alleviate these challenges, the government should consider providing subsidized inputs to small farmers, coupled with robust extension services. This approach could not only enhance cotton productivity and profitability but also improve the living standards of smallholder farmers. Moreover, there is an urgent need for judicious resource management, particularly regarding water usage, as it is becoming increasingly scarce. Abid et al. (2011) emphasize that effective management of available water requires motivating farmers to use it at the right time and in the right quantities.

Additionally, promoting cost-effective pest control methods is crucial. It is essential to reduce reliance on chemical pesticides, which contribute to climate change. Blaise and Kranthi (2019) suggest practices such as planting two rows of sorghum, pearl millet, or maize around cotton fields in North India to deter whiteflies. Intercropping with cowpea, soybean, or black gram can help foster predator populations that control sucking pests in the cotton ecosystem. Mollaee et al. (2019) advocate for cover cropping, the judicious use of fertilizers, drip irrigation systems, and sub-soiling as means to combat soil degradation, compaction, and salinity issues that often arise in intensive cropping systems.

Education on best management practices is vital, as Midega et al. (2012) found that limited information on pest control methods is available to farmers. Approximately 80% of surveyed farmers reported never receiving any guidance on pesticide usage, and none received information about cultural, physical, or biological pest control methods. Crop diversification emerges as a promising strategy to enhance the sustainability of agricultural production systems while contributing to biodiversity conservation (Keller et al., 2024). Since synthetic pesticides and fertilizers are prohibited in organic farming, strategies such as crop rotations, intercropping, and the strategic use of green manure and border crops are essential for pest and disease management, as well as meeting crop nutrient requirements.

Although diverse cropping systems may be more labor-intensive and necessitate substantial knowledge of local agricultural practices (Rodriguez et al., 2021), they present a viable path forward. Over 70% of cotton farmers in India are smallholders with land holdings under 2 hectares (Government of India, 2020a). Shah et al. (2021) identified various factors hindering their adoption of improved practices, including land fragmentation, limited financial resources, lack of information and expertise, inadequate machinery and infrastructure, market scarcity for diversified crops, limited access to crop insurance and credit, and insufficient collaboration between public and private institutions.

Conclusion

In conclusion, the study conducted in District Muzaffargarh highlights both the successes and challenges in cotton farming in the region. Farmers have made progress in adopting sustainable

practices, particularly in areas like water management, soil improvement, integrated pest control, and promoting biodiversity. However, some issues remain. The reliance on only a few cotton varieties suggests the need for greater diversity to better withstand climate change and pest threats. Additionally, the widespread use of hand sowing and the dominance of small-scale farming point to limitations in farmers' access to modern agricultural tools and resources.

The use of water-saving techniques, such as irrigating based on weather forecasts and cutting back on flood irrigation, is a positive sign that farmers understand the importance of conserving water. Similarly, efforts to improve soil health through methods like foliar spraying, soil testing, and reducing pesticide use indicate a move towards more sustainable farming. However, there is still room to increase the adoption of more advanced pest control strategies to lessen the harmful environmental effects of pesticide use.

Efforts to promote biodiversity, like planting trees and protecting natural habitats, are encouraging and show a growing awareness of the need for ecological conservation. That said, it is essential to keep raising awareness and offering support to farmers to help them embrace a broader range of sustainable practices. This will be key to ensuring the long-term success of the cotton industry. Policymakers, agricultural extension services, and other relevant institutions need to collaborate to address these challenges, promote sustainable farming methods, and strengthen the resilience of cotton production in the face of climate change.

Recommendations

To improve cotton production and sustainability, the following recommendations are proposed for cotton farmers:

1. Farmers should be educated about a wider range of cotton varieties available for cultivation to enhance yield and adaptability.
2. Efforts should be made to motivate farmers to increase the land allocated for cotton crops.
3. Farmers should be encouraged to adopt climate-friendly practices to mitigate the effects of climate change.
4. The number of chemical sprays for weed, insect, and pest control should be minimized to reduce environmental impact and promote sustainable farming.
5. Farmers should adopt the recommended cotton production practices to improve productivity and efficiency.
6. The agriculture extension department should promote best practices, such as land leveling, the use of drought-resistant varieties, mulching, and the application of farmyard manure.
7. Climate-friendly insect pest management practices should be adopted, and farmers should be motivated and supported in implementing these methods.

References

- Abbas, S. (2020). Climate change and cotton production: an empirical investigation of Pakistan. *Environmental Science and Pollution Research, 27*(23), 29580-29588.
- Abid, M., Ashfaq, M., Hassan, S., & Fatima, N. (2011). A resource use efficiency analysis of small Bt cotton farmers in Punjab, Pakistan. *Pak. J. Agric. Sci*, *48*(1), 65-71.
- Arshad, M., Suhail, A., Gogi, M. D., Yaseen, M., Asghar, M., Tayyib, M., Ullah, U. N. (2009). Farmers' perceptions of insect pests and pest management practices in Bt cotton in the Punjab, Pakistan. *International Journal of Pest Management, 55*(1), 1-10.

- Aujla, M. S., Thind, H. S., & Buttar, G. S. (2005). Cotton yield and water use efficiency at various levels of water and N through drip irrigation under two methods of planting. *Agricultural Water Management, 71*(2), 167-179.
- Bakhsh, K., Hassan, I., Khurshid, W., & Hassan, S. (2012). Econometric analysis of adoption of water conservation practices: a case of cotton crop. *J Agric Res, 50*, 445-455.
- Better Cotton Initiative (2024). *Better Cotton in Pakistan.* Available at: https://bettercotton.org/where-is-better-cotton-grown/better-cotton-in-pakistan/.
- Blaise, D., & Kranthi, K. R. (2019). Cotton production in India. *Cotton production*, 193-215.
- Corker, B. (2003). *Biodiversity and conservation.* Available at: http://www.countrysideinfo.co.uk/biodvy4.htm.
- Delate, K., Heller, B., & Shade, J. (2021). Organic cotton production may alleviate the environmental impacts of intensive conventional cotton production. *Renewable Agriculture and Food Systems, 36*(4), 405-412.
- Fan, Y., Wang, C., & Nan, Z. (2018). Determining water use efficiency of wheat and cotton: A meta-regression analysis. *Agricultural Water Management, 199*, 48-60.
- Garcia, O., Mehmood, K., & T. Hemme. (2003). *A review of milk production in Pakistan with particular*
- GOP. (2024). *Economic survey of Pakistan 2023-24.* Ministry of Finance: Islamabad, Pakistan.
- Government of India. (2020a). *All INDIA Report on Agriculture Census 2015-16* (New Delhi: Ministry of Agriculture and Farmers Welfare, Department of Agriculture Cooperation and Farmers Welfare)
- Iqbal, M. A., Iqbal,A., Afzal., Akbar, N., Abbas, R.N. and Khan, H.Z. (2015). In Pakistan, agricultural mechanization status and future prospects. *American-Eurasian Journal of Agricultural & Environmental Sciences, 15*(1), 122-128.
- Jiang, Y.-F., Wang, X.-T., Jia, Y., Wang, F., Wu, M.-H., Sheng, G.-Y., et al. (2009). Occurrence, distribution and possible sources of organochlorine pesticides in agricultural soil of Shanghai, China. *Journal of Hazardous Materials, 170*(2), 989–997.
- Keller, C., Joshi, S., Joshi, T., Goldmann, E., & Riar, A. (2024). Challenges for crop diversification in cotton-based farming systems in India: a comprehensive gap analysis between practices and policies. *Frontiers in Agronomy, 6*, 1370878.
- Khan, L. A., Awan, Z. A., Imran, A. U., Saleem, M., Sufyan, F., & Azmat, M. (2021). The impact of better management practices (BMPs) among cotton farmers in Punjab, Pakistan. *Journal of Agricultural Science, 13*(7), 74.
- Khan, M. A., Iqbal, M., & Ahmad, I. (2007). Environment-friendly cotton production through implementing integrated pest management approach. *The Pakistan development review,* 1119-1135.
- Khan, N. I., Malik, A. U., Umer, F., & Bodla, M. I. (2010). Effect of tillage and farm yard manure on physical properties of soil. *International Research Journal of Plant Science, 1*(4), 75-82.
- Kumar, P., & Joshi, L. (2013). *Pollution caused by agricultural waste burning and possible alternate uses of crop stubble: a case study of Punjab.* In Knowledge systems of societies for adaptation and mitigation of impacts of climate change (pp. 367-385). Berlin, Heidelberg: Springer Berlin Heidelberg.
- Makhdum, A. H., Khan, H. N., & Ahmad, S. (2011, February). *Reducing cotton footprints through implementation of better management practices in cotton production; a step towards*

Better Cotton Initiative. In Proceedings of the Fifth Meeting of the Asian Cotton Research and Development Network, Lahore, Pakistan (Vol. 1).

- Mehmood, H. Z., Alotibi, Y., Ali, A., Ali, A., Ali, S., Muzamil, M. R., & Shah, S. I. A. (2024). Socio-economic advantages and climate adaptation in sustainable vs. conventional cotton: evidence from Pakistan. *Frontiers in Sustainable Food Systems, 8,* 1435747.
- Midega, C. A., Nyang'au, I. M., Pittchar, J., Birkett, M. A., Pickett, J. A., Borges, M., & Khan, Z. R. (2012). Farmers' perceptions of cotton pests and their management in western Kenya. *Crop Protection, 42,* 193-201.
- Mollaee, M., Mobli, A., Mutti, N. K., Manalil, S., & Chauhan, B. S. (2019). Challenges and opportunities in cotton production. *Cotton production,* 371-390.
- Radhakrishnan, S. (2017). *Sustainable cotton production. In Sustainable fibres and textiles* (pp. 21-67). Woodhead Publishing.
- Raza SH. (2009). *Cotton production in Pakistan. A grower's view. Presentation (ppt.) at the 68th ICAC Plenary Meeting. International Cotton Advisory Committee (ICAC).* United States of America.
- Shah K. K., Modi B., Pandey H. P., Subedi A., Aryal G., Pandey M., et al. (2021). *Diversified Crop Rotation: An Approach for Sustainable Agriculture Production, in Advances in Agriculture.* Ed. Fahad S. (London, UK: Hindawi), 8924087.
- Sherani, S. H. (2020). Biodiversity and its Conservation in Balochistan, Pakistan. Haya. *The Saudi Journal of Life Science, 5,* 260.
- Shuli, F., Jarwar, A. H., Wang, X., Wang, L., & Ma, Q. (2018). Overview of the cotton in Pakistan and its future prospects. *Pakistan Journal of Agricultural Research, 31*(4), 396.
- Sultana, J., Syed, J. H., Mahmood, A., Ali, U., Rehman, M. Y. A., Malik, R. N. (2014). Investigation of organochlorine pesticides from the Indus Basin, Pakistan: sources, air–soil exchange fluxes and risk assessment. *Science of the Total Environment, 497,* 113–122.
- Tanveer, S. K., I. Hussain, M. Sohail, N. Kissana, & S. Abbas. (2003). Effects of different planting methods on yield and yield components of wheat. *Asian Journal of Plant Sciences, 2*(10), 811-813.
- Yasin, M. A., Bakhsh, K., Ali, R., & Hussain, H. I. (2021). Impact of better cotton initiative on health cost and pesticide exposure of women cotton pickers in Punjab, Pakistan. *Environmental Science and Pollution Research, 28,* 2074-2081.