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SUSTAINABLE COTTON FARMING PRACTICES: A COMPARATIVE ANALYSIS OF INPUT UTILIZATION

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ABSTRACT

Sustainable production involves the conscious use of resources to prevent their depletion while preserving them for future generations. The current study, entitled Sustainable Cotton Farming Practices: A Comparative Analysis of Input Utilization, was conducted to examine the practices of cotton farming that is a cash crop in Pakistan that significantly contributes to the national economy and sustains the textile industry. Despite its importance, many farmers in the country still practice traditional agricultural methods. To address this issue, various organizations are working to raise awareness among farmers about sustainable farming practices to minimize the environmental impact of their activities. This study aimed to evaluate whether farmers were adopting sustainable practices, identify the ones being implemented, and highlight areas requiring improvement. Cotton was chosen as the focus crop due to its intensive requirements for pest management and other farming practices. District Muzaffargarh, located in southern Punjab and known as a cotton belt, was purposively selected as the study area. One tehsil of the district was conveniently chosen, and 100 registered cotton growers were randomly selected for data collection. The data were analyzed using statistical software and Microsoft Excel. The findings revealed that farmers largely refrained from using advanced machinery, such as planking and laser leveling, due to high costs and small landholdings. Regarding irrigation, 34% of farmers irrigated their cotton crops up to ten times, while the remaining irrigated more than ten times. Additionally, about one-third (31%) of farmers did not apply farmyard manure to their fields. Although farmers were aware of biological, physical, and cultural pest control methods, they predominantly relied on insecticides and pesticides for pest management. The study emphasizes the need to educate farmers on adopting environmentally friendly and resource-efficient farming techniques. It is crucial to avoid using banned pesticides that are hazardous to humans, organisms, and the environment. Promoting the conscious use of resources will not only reduce farming expenses but also enhance farmers' profitability. By addressing these challenges, sustainable cotton farming can become a reality, benefiting both the environment and the agricultural economy.

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Keywords: *Cotton, Sustainability, Insecticides, Pesticides.*

INTRODUCTION

Globally, Gossypium hirsutum L. accounts for approximately 95% of the total cotton cultivation area, which covers about 33–35 million hectares, representing about 2.5% of the world's arable land. Cotton generates an annual economic impact of around $600 billion, making it the most widely produced and traded natural fiber worldwide. The cotton industry operates in about 150 countries, providing livelihoods to nearly 100 million families (Ashraf et al., 2024). Cotton is Pakistan's most significant cash crop, often called "white gold" by farmers for its revenue-generating potential. It plays a vital role in the national economy, serving as a primary source of foreign exchange and contributing directly to the country's GDP (Ali et al., 2019). The cotton industry employs 250 million people globally, with 7% of the labor force in developing countries. It is the leading non-food agricultural commodity, with five countries producing 74% of global output. Supporting 150 million livelihoods in 75 countries, the sector is vital to developing economies and the 2030 Sustainable Development Agenda (Amrouk et al., 2021). In Pakistan, nearly 1.7 million farmers grow cotton as a key means of livelihood. The country's textile sector, which includes 10 industrial sub-sectors, over 1,000 ginneries, 8,000 mill looms, more than 250,000 non-mill looms, over 13 million spindles, 700 knitwear units, 4,000 garment units, 300 oil expellers, and nearly 2,000 small-scale oil expellers, relies heavily on cotton production for its sustainable operations (Mukhtar, 2024).

Cotton farmers in Pakistan have traditionally relied heavily on pesticides to protect their crops from insect pests, diseases, and weeds (Khan et al., 2011), with this dependency escalating to critical levels by the late 20th century (Khan et al., 2002). Cotton cultivation alone accounts for 80% of the total pesticide usage across all crops in Pakistan. The excessive use of pesticides has led to economic losses for cotton producers, as it has not resulted in productivity gains despite the increased costs (Zulfiqar and Thapa, 2016).

Sustainability encompasses environmental, economic, and social aspects across all cultures. Cotton farming systems are highly diverse, with challenges influenced by environmental, agro-ecological, climatic, socioeconomic, and political factors (Radhakrishnan, 2017). Sustainable cotton production faces significant challenges due to climate variability and diminishing resources for agriculture. With the global population projected to reach nine billion by 2050, there is an urgent need to enhance cotton production to meet rising demands. Key obstacles include poor soil health, water scarcity and quality issues, complex insect pest infestations, and unpredictable climatic conditions (Ghaffar et al., 2020)

Cotton, a summer crop, often leaves the soil exposed during winter. A key challenge in cotton cultivation is the minimal crop residues left on the soil surface after harvest compared to other crops. This lack of residues affects soil organic matter content and, consequently, cotton productivity (Vitale et al., 2024). Cotton production, particularly in Pakistan, is highly vulnerable to climate change, making sustainable yields essential to meet future demands. Climate change adversely affects cotton yield, fiber quality, and the socioeconomic well-being of farmers across major cotton-growing regions (Rahman et al., 2020). Pakistan ranks among the top 10 countries most affected by climate change, with recent evidence including heat waves in March, April, and May 2022, followed by early monsoons in June and heavy, erratic rainfall in July and August 2022. These events caused widespread flooding, severely impacting agriculture (Imran et al., 2022). Climate change is anticipated to impact cotton yields, water use efficiency, and nitrogen productivity, potentially reducing water use efficiency by up to 20% without soil amendments. This underscores the importance of effective soil fertility management practices (Amouzou et al., 2018). Cotton production faces significant threats from drastic climate changes and extreme weather conditions, with forecasts predicting a 20-30% decline in the coming years due to these impacts (Wajid et al., 2014). Pakistan's highest annual temperatures coincide with the critical flowering and boll-forming stages of cotton. In 2022–23, climatic changes severely impacted the cotton crop, leading to a 41.0% decline in production (4.910 million bales compared to 8.329 million

bales the previous year), despite an increase in the sown area (Govt. of Pak, 2023).

Cotton productivity in Pakistan is impacted by various factors, including its vulnerability to insect pests, which are primarily managed with insecticides. Other significant challenges include poor seed quality, diseases like cotton leaf curl disease, drought, heat stress, labor-intensive picking, unpredictable pricing, and shifting cropping patterns in cotton zones (Ali et al., 2019) Short-duration cotton varieties simplify pest management compared to long-duration ones. Effective IPM includes inter-cropping with legumes, controlled fertilizer use, neem treatments, biological controls, and traps for monitoring. Avoid insecticide mixtures and pyrethroids early in the crop cycle to prevent pest outbreaks (Kranthi, 2017). Sustainable cotton production requires genetic diversification to handle stresses and climate change, along with adopting conservation agriculture practices like reduced tillage, cover crops, and narrow row spacing to enhance soil health and weed control. Holistic modeling approaches and efficient by-product utilization can address production challenges and opportunities. Science and technology must collaborate to ensure a profitable, sustainable, and eco-friendly cotton production system (Mollaee et al., 2019). The growing vulnerability of cotton crops to insect and pest infestations, declining yields, excessive groundwater usage, and the adverse impacts of chemical-based conventional agriculture on natural resources and human health have sparked serious concerns regarding the system's long-term sustainability (Imran et al., 2018).

Sustainable cotton production offers numerous benefits. It reduces the environmental impact of cotton farming by cutting down on synthetic pesticides and fertilizers, thereby lowering water and soil pollution. Practices such as organic farming and integrated pest management support biodiversity conservation and safeguard ecosystem services. Additionally, it improves soil health by increasing organic matter, enhancing soil structure, and reducing erosion, leading to better fertility and higher productivity. Sustainable practices also boost climate resilience through water conservation methods like drip irrigation and rainwater harvesting, helping to combat drought and water scarcity. By adopting these approaches, cotton farmers can adapt to climate change and contribute to a more sustainable, resilient agricultural system. Considering the challenges in cotton production and the need for sustainable cotton production practices, the present study was designed to assess the extent to which these practices were being adopted by farmers.

Objective of the Study

1. To identify the intercultural practices adopted by cotton growers.
2. To assess the inputs utilized by farmers.
3. To compile recommendations for sustainable cotton production based on the study's findings.

Methodology

Population and Sample Size of the Study:

The population for this study comprised all cotton growers in the district of Muzaffargarh. This district was purposively selected as it is located in southern Punjab, a region well-known as a core cotton belt. The district was also chosen because various organizations were actively working there to raise awareness and provide guidance to cotton farmers.

These organizations established different types of units, referred to as Producer Units (PUs). Each PU comprised multiple Learning Groups (LGs), each containing 25–40 registered farmers, including a lead farmer. On average, each PU consisted of approximately 100 LGs. In total, eight PUs were established in the district of Muzaffargarh.

For the purpose of this study, one PU from tehsil Muzaffargarh was selected conveniently. From the selected PU, 10 LGs were chosen randomly, and from each LG, 10 farmers were randomly selected, resulting in a total sample size of 100 farmers.

Interview Schedule Preparation, Data Collection, and Analysis:

An interview schedule was developed in alignment with the study's objectives. The tool was pretested by collecting data from five respondents who were not part of the final sample.

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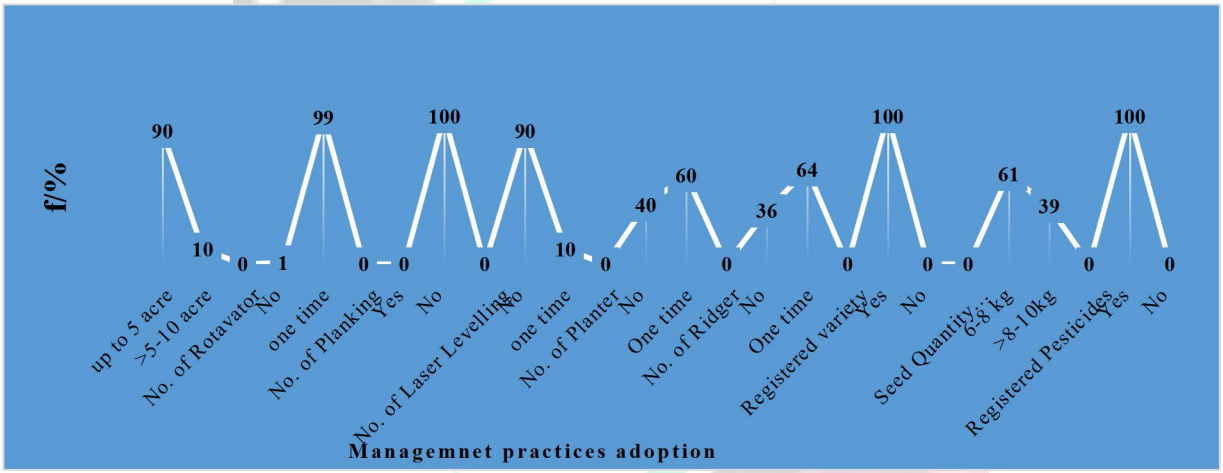
Based on the pretesting results, necessary amendments were made to ensure the reliability and validity of the instrument. The finalized interview schedule was then used for data collection.

Data were collected through face-to-face interactions with individual farmers. The interviews were conducted in the farmers' local language to ensure clarity and understanding. Rapport was established before data collection, as some farmers exhibited initial suspicion. The purpose of the study was explained to the farmers to gain their trust and encourage honest responses. The collected data were analyzed using statistical software and Microsoft Excel (2016 version). Various statistical values were computed, and detailed results are presented in the Results and Discussion section.

Results and Discussion

Adoption of different management practices

Farmer awareness and adoption of recommended practices are crucial for determining the success of a crop. Key practices include selecting the right seed type and quality, proper land preparation, efficient irrigation, and appropriate fertilizer application. These factors directly impact crop profitability and productivity. Therefore, farmers should have knowledge and access to advanced technologies and subsidized inputs as well as adoption of recommended practices as these can significantly boost cotton production (Anwar et al., 2009). Farmers were inquired about the practices and their response is mentioned below



Farmers were inquired about the different management practices that they adopting in the cotton cultivation. An overwhelming majority of the farmers has the land up to 5 acres while only 10% farmers had the land >5-10 acres. This data depicts that the land holdings is very limited in the study area. A similar result reported by Bajwa et al. (2015) in the same area, farmers owned the less landholdings 58% of farmers owned 1–2 acres, 33% had 2–3 acres, and only 9% owned 3–4 acres of land. Land preparation is an important component as reported by Yu et al. (2017) that proper land preparation is a highly effective ecological practice for minimizing water erosion and significantly influences the physicochemical properties of soil. McDonagh et al. (2014) stated that land preparation significantly alters soil structure by reshaping fragile slopes and creating varied micro-landforms. It impacts soil's physical, chemical, hydrological, and biological processes by influencing surface runoff rates and removing fine soil particles. According to the above given data 99% of the farmers were applying ploughing the land with the help of tractor and they were applying this practices one time before the crop sowing. While one farmers stated that he is not practicing this as he has less land and prepared the land manually or get the help of bull for this purpose. Farmers also applied the land levelling techniques for saving the water and using the water in efficient way for the crop. Not any single farmer was practicing planking for preparing the land, only 10 farmers were adopting the laser leveling technique, according to the farmers laser

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levelling is necessary for saving the water. There is need to educate the farmers about using this technique because this method proves helpful in using the water in efficient way and hinder the wastage of water as reported by Abdullaev et al. (2007) reported that laser leveling of irrigated lands is commonly recommended as one of the most effective methods for saving water. The practice of ridger application for making the furrow was also common in the area but not adopted by all of the farmers.

Farmers were also inquired about the type of cotton variety, amount of seed and type of pesticides used by them, all of the farmers reported that they are cultivating the registered cotton varieties for getting the best production. While all of the farmers reported that they are using less than 10 kg seed/acre for cotton, while for controlling the insect pest framers were using the registered insecticides and pesticides. During the discussion, it was revealed that some farmers were preparing the seed from their own cotton, while some farmers also started that they purchase the cotton from the farmers, those have good production and prepare seed from this. Farmers those do not have their own seed they purchase from the dealers of their area. There are many chances of impurity of the seed as reported by some farmers. As reported by Imran et al. (2018) that the primary reason for poor cotton yields is the limited availability of certified seeds, with only 12% of farmers using them. The government should take measures to ensure the production and equitable distribution of certified cotton seeds, making them accessible to farmers at their doorstep. Most of the farmers were not aware about the names of pesticides and insecticides, they stated that they purchase the insecticides and pesticides by telling the name of the insect-pest to the dealers. Farmers claimed that all of the insecticides and pesticides used by them are registered and legal to apply for the insect-pest control. There are different types of insect-pest which harms the crop as reported by Qayyum et al. (2024) that more than 230 different insect species have been documented as pests of cotton crops worldwide. Cotton, being one of the most extensively cultivated crops, is particularly vulnerable to insect attacks. Remarkably, it is estimated that 16% of all pesticides used globally are applied to cotton crop alone.

Use of Fertilizer

Fertilizers play a crucial role in cotton production, as most soils are deficient in nitrogen. To address nutrient deficiencies and achieve optimal yields, it is essential to apply fertilizers. Using a balanced fertilizer with the appropriate levels of nutrients is vital for maximizing cotton production (Abid et al., 2011). The majority of soils in the Punjab are deficient in nitrogen, therefore it is essential to enhance soil fertility through fertilizer application to address nutrient deficiencies (Maqsood et al., 2016). Balanced fertilization involves not only adding specific proportions of nitrogen, phosphorus, potash, and other nutrients in the correct ratios but also considering the nutrients already available in the soil (Elahi et al., 2015). So farmers were asked that what type of fertilizers they are applying in their field.

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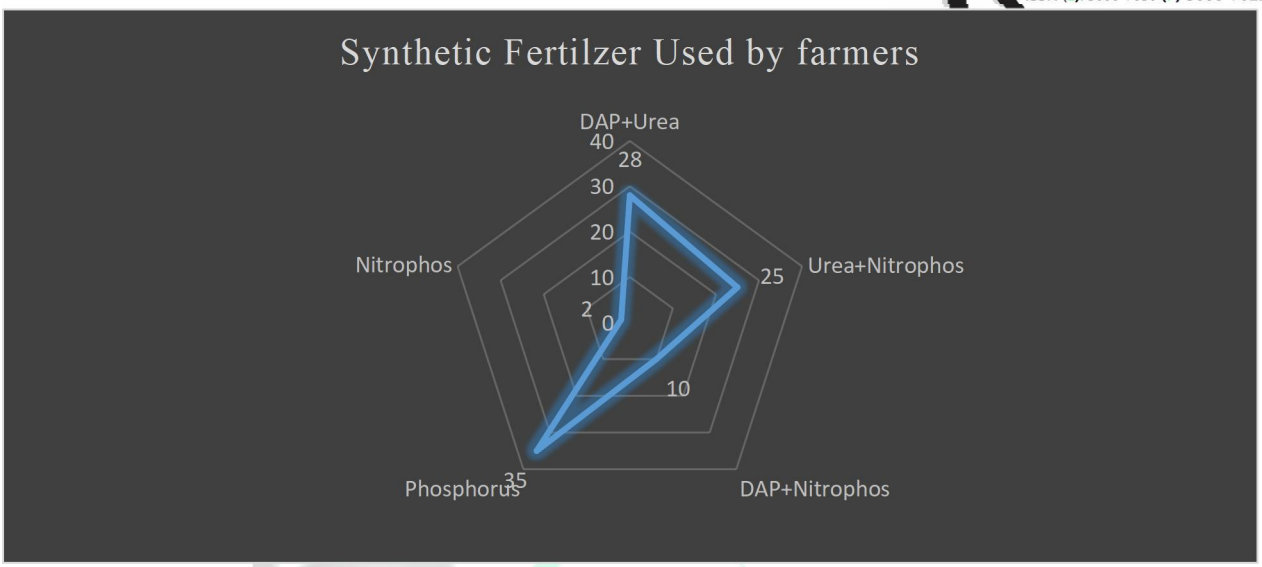

According to the data given above in a graph, 35% of the farmers were using Phosphorus, Urea+ DAP was applied by 28%, Urea+Nitrophos applied by 25% farmers, 10% farmers were applying DAP+Nitrophos and only 2% farmers were using Nitrophos in their cotton field. According to framers they applied nutrients to their land in the form of fertilizer, these fertilizers are needed to compensate the deficiency of the nutrients which are observed by the previous crop or leached down in the land due to excessive irrigation. Similar fertilizers were reported by Imran et al. (2020), according to them, an average of 192 kg of nitrogen, 27 kg of phosphate, and 10 kg of potash per hectare was applied. The quantity of fertilizer was different from the present study, as the nature of soil and requirement of nutrient varies from area to area. But it was also observed that farmers were applying the fertilizer without knowing the properties of their land by soil analysis technique. In this way they waste their resources as well as deteriorate the property of soil and also effected the plant growth and production as reported by Marschner (2001) that excessive nitrogen application promotes extended vegetative growth while delaying the onset of reproductive development. Shah et al. (2017) state that delayed squaring, flower initiation, and boll opening in cotton plants were significantly observed under higher nitrogen fertilization (92 kg ha−1) compared to the unfertilized plot, with intermediate delays noted at moderate nitrogen application rates (68 kg ha−1). There is a need to educate farmers on the mindful use of fertilizers and other chemicals to prevent soil degradation and environmental pollution. This approach can also help conserve resources and increase profits by reducing expenses.

Number of Irrigation, Farm yard manure and Pesticides application

There are different types of inputs are needed for the proper growth of crop. Such as water as reported by Abid et al. (2011) that agricultural production directly relies on the availability and efficient utilization of water, which is a critical input for any crop's growth and development. Application of insecticides are also necessary as Bt cotton is considered resistant to various pests; however, in Pakistan, a pure Bt cotton variety is not yet available to farmers. The currently sown Bt cotton remains susceptible to various sucking pests and certain bollworms, necessitating increased pesticide usage. On the other hand, attack of weeds and attack of diseases induces the farmers to spray of weedicides (Bakhsh et al., 2005). Keeping in view this, farmers were inquired about the input used by them, detail is mentioned below.

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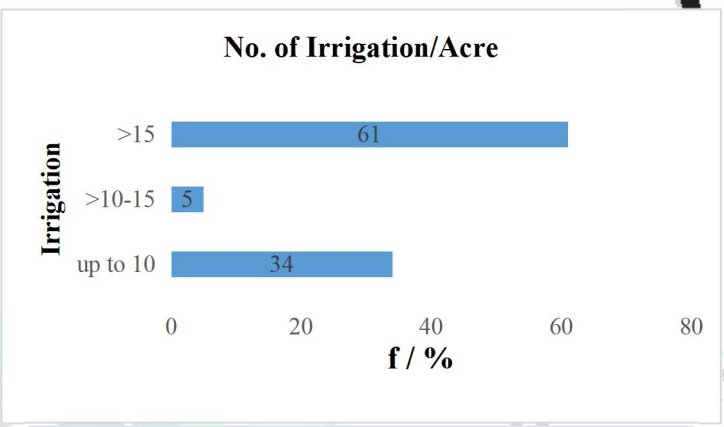

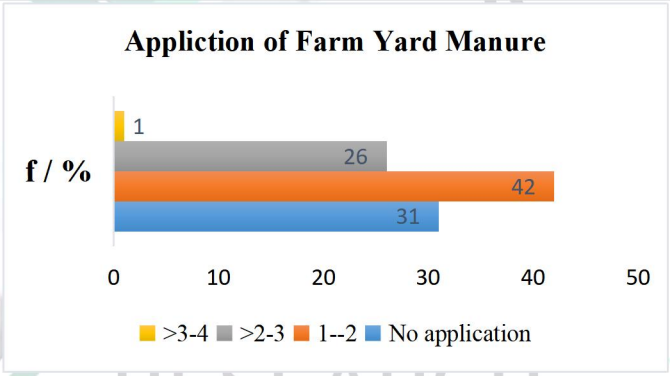

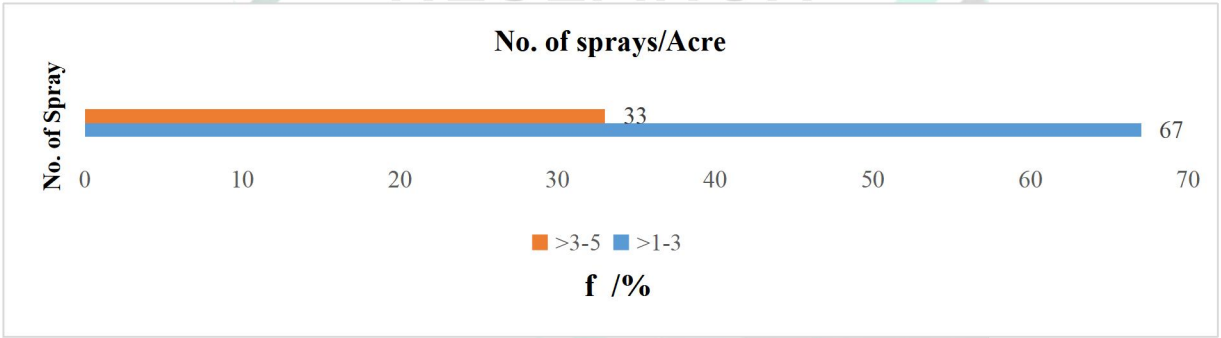

Farmers are consulted about other inputs because these factors significantly influence their profit or loss. Additionally, these inputs determine the yield obtained from the crop. Every crop requires a specific amount of water, and exceeding this amount can harm the crop rather than benefit it. This principle applies particularly to cotton, as it is highly sensitive to water levels. Excessive water can damage the crop by causing root rot, as cotton roots cannot withstand prolonged exposure to excess moisture. As reported by Abid et al. (2011) that water is a scarce resource globally. Its efficient utilization is primarily a management challenge, requiring farmers to be motivated to apply water in the right quantity and at the right time. The data show that 34% farmers were irrigating the cotton crops up to ten times, 5% farmers were irrigating 10-15 times and majority (61%) of the farmers were irrigating more than 15 times. These findings are contradicting the findings of Imran et al. (2020), according to them farmers were irrigating the cotton crop 15 times in a year.

According to the data, 42% of farmers applied farmyard manure (FYM) 1-2 times a year, 26% applied it 2-3 times, and only 1% applied it 3-4 times annually, while 31% of farmers did not apply FYM to enhance soil fertility. These results are significantly better than those reported by Mehmood et al. (2024), who found that about

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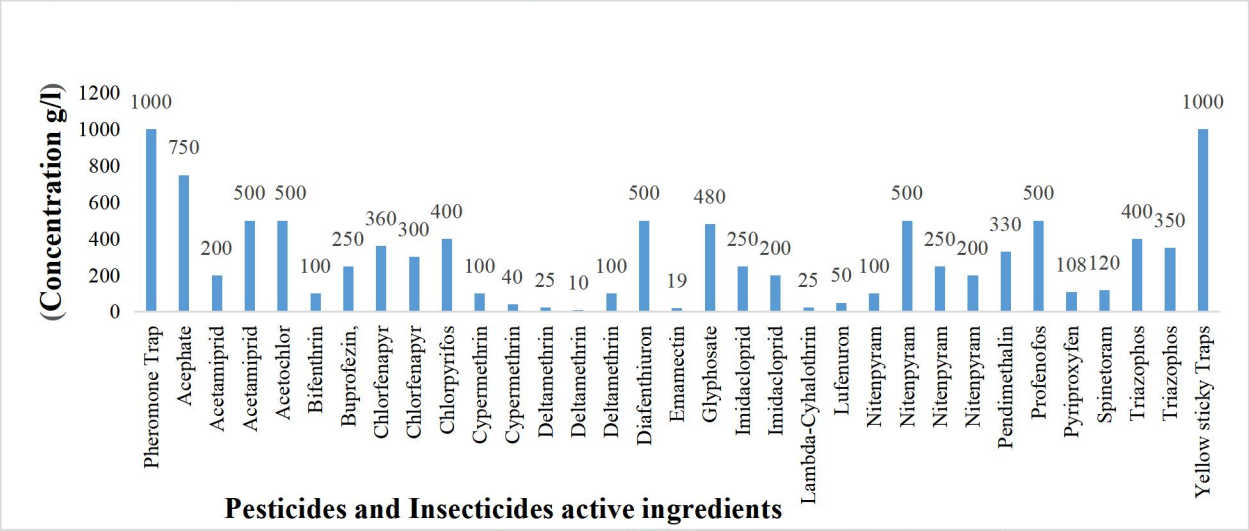
70% of farmers were not using organic fertilizers on their land. Farmyard manure is considered a cost-effective way to improve soil fertility, as noted by some farmers. Khan et al. (2010) reported that FYM significantly improves soil health and physical properties. Its slow decomposition enhances soil structure, increases hydraulic conductivity, and reduces bulk density, particularly when combined with deep tillage methods. Farmers who were aware of the importance of FYM were found to apply it regularly in their fields.

For the insect-pest and for controlling the weed farmer sprayed the crop, 67% of farmers were spraying >1 to 3 times and remaining (33%) farmers were spraying >3 to 5 times in a year. The findings contradicting the results of Imran et al. (2020), they reported that in Muzaffargarh district farmers were applying about nine spray on the cotton during crop duration.

Use of Pesticides and Insecticides

There are different type of insects-pests attack on the crop of cotton and damage the crop. Some of them are sucking insect-pests i.e. Bemisia tabaci (Genn.), Aphis gossypi (Glover), Thrips tabaci (Lind.) and Amrasca bigutella bigutella (Dist.) and severely damage to crop (Ghori et al., 2019). To suppress pest populations and reduce infestation levels, various groups of pesticides have been applied either individually or in combination (Sattar et al., 2022). Farmers were inquired which insecticide and pesticide used by them.



From time to time different type of insect pest attack on the cotton and effected the crop badly, especially during the June to October, the infestation of insect pest increase such as attack of Thrips, Whitefly and farmers used different insect management strategies as reported by Sattar et al. (2022) that Whitefly, jassid, and thrips were the predominant insect pests, with their populations typically peaking between June and October, and generally diminishing after October. For the effective control different insecticides were applied, for controlling the sucking pests farmers were acetamiprid and imidacloprid, similar pesticides were also discussed by Asif et al. (2016), according to them Thiamethoxam, thiacloprid, acetamiprid, and imidacloprid, belonging to the neonicotinoid group, are highly regarded for their insecticidal activity and remain widely recommended for managing sucking pests on Bt cotton. Farmers were worried from the attack of white fly and they were using Diafenthiuron, Acetamiprid and Buprofezin as reported by Saleem et al. (2024) that for whitefly control, Pyriproxyfen, Spirotetramat, Diafenthiuron, Acetamiprid, Buprofezin, Flonicamid, and a combination of Pyri and Fluconazole were the most commonly used pesticides in the area. According to Ghori et al. (2019) Acetamiprid, Buprofezin, Clothiandin, Diafenthuron, imidacloprid, Matrine and Spintoram were effective for the whitefly control.

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For the control of Jassid, nitenpyram, lambda cyhalothrin, bifenthrin were beings used by the farmers. According to farmers these active ingredients proved helpful in controlling the Jassid. This is actually sucking insect pest, which suck the saps from the lower side of the leaves and from leaf buds. When the population of the jassid increase it stunted the growth of the effected plant and cause heavy fruit loss, Imidacloprid and Dimethoate pesticides prove effective for the control of jassid. For the cultural control of jassid, avoid excessive use of fertilizer, jassid attracted more towards crop having higher in Nitrogen, crop should be cultivated from 5 April to 31 May for escaping the Jassid attack (Hasnain et al., 2013). It has been confirmed that neonicotinoids, such as nitenpyram and imidacloprid, are highly effective in reducing jassid populations to levels below the economic threshold level (Ahmed et al., 2014). Imidacloprid also prove effective in controlling the Jassid, whitefly and thrips (Asif et al., 2016). For controlling the whitefly Lambda cyhalothrin, carbosulfan, bifenthrin, Nitenpyram were being used by the farmers, similar pesticides were also reported by Asif et al. (2016) in their study, according to them After 72 hours of application, whitefly populations were significantly reduced, with imidacloprid showing the highest efficacy (77.73%), followed by nitenpyram (72.96%), bifenthrin (71.73%), lambda-cyhalothrin (68.19%), and profenofos + cypermethrin (65.90%). By 7 days, efficacy declined, with imidacloprid still leading (63.24%), followed by nitenpyram (51.38%), profenofos + cypermethrin (48.61%), lambda-cyhalothrin (46.04%), bifenthrin (43.47%), and carbosulfan (42.09%).

Most farmers were unaware of the active ingredients in the products they used, recognizing only the product names. The researcher identified the active ingredients by examining the packaging of the insecticides and pesticides. Discussions revealed that farmers did not follow the recommended doses or the prescribed sequence of pesticide application. It was also observed that due to their limited education or lack of qualification, farmers often used pesticides with the same active ingredients from different companies to control the same pest. However, this approach often failed to achieve effective pest control. The failure was attributed to their use of less effective pesticides or improper preparation methods that did not adhere to the recommended procedures. During data collection, it became evident that farmers excessively use chemical pesticides to control insect pests. They often apply the same active ingredients multiple times in quick succession, seeking immediate results. Lacking awareness, they fail to allow sufficient time for the chemicals to take effect and unknowingly repeat applications. As reported by Rehman et al. (2019), these chemical inputs in agricultural systems pose significant, irreversible threats to public health while also degrading the quality of water and soil environments. Soares et al. (2009) reported consequently, the risks to public health and the growing ecological pollution caused by these pesticides have led to escalating challenges in their continued use. Damalas et al. (2006) therefore, it is essential to provide fundamental education on pesticide handling and safe usage, along with consistent emphasis on basic safety measures. These steps are crucial to correcting harmful practices among growers that may pose serious risks to their health.

Conclusion

The study highlights the importance of adopting recommended management practices in cotton cultivation to enhance crop productivity and profitability. Despite limited landholdings in the study area, most farmers were aware of basic practices such as land preparation and fertilizer application. However, there were significant gaps in the adoption of advanced techniques such as laser leveling and soil analysis. While farmers generally used registered cotton varieties, insecticides, and pesticides, they lacked knowledge about active ingredients and safe usage, leading to inefficiencies and potential risks. Excessive pesticide use, improper fertilizer application, and limited awareness of integrated pest management pose serious threats to environmental sustainability and farmer health. The findings underscore the urgent need for targeted education and support to improve farming practices and resource utilization.

Recommendations

Farmers should promote the use of advanced land preparation techniques, such as laser leveling and planking, to significantly enhance water efficiency and prevent wastage. Ensuring access to certified seeds by strengthening supply chains and launching awareness campaigns about the risks of unverified seeds is vital for improving crop quality. Optimizing fertilizer use through soil testing services and educating farmers on balanced fertilization will help prevent excessive nitrogen use and its environmental impact. Training programs on pesticide safety, dosage, and integrated pest management can reduce reliance on chemicals, while encouraging organic farming practices, including the use of farmyard manure, to enhance soil health and sustainability. Addressing irrigation management through education on efficient water use and improved systems is critical for reducing over-irrigation. Capacity-building programs, such as farmer field schools and partnerships with agricultural extension services, provide practical training on modern techniques. Additionally, policy support through subsidies for advanced tools, certified seeds, and soil testing, along with strengthened regulatory frameworks, can ensure the quality of agricultural inputs and drive sustainable farming practices.

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