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Comparative Study of Organic and Chemical Fertilizer Use on Wheat Production in Pakistan

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ABSTRACT

The overriding demand for sustainable agriculture has even created mindful interest in comparison of utility of organic and chemical fertilizer on crop production and soil health. Wheat (Triticum aestivum) being a basic crop in Pakistan plays a very critical role in food security and rural livelihood. This study analyses the effects of organic and chemical fertilizer applications on wheat production both in terms of yield, grain quality and soil nutrient status. Data was taken at wheat fields and in South Punjab, Pakistan by using randomized field experiment where organic compost, urea based chemical fertilizer and combination of both were used. Soil samples were studied for soil macronutrients, pH and organic matter content before and after cropping period and yield parameters like plant height, spike length, grain weight and total yield at harvesting stage were recorded. Statistical analyses including analysis of variance (ANOVA), correlation analysis were applied in comparing the effects of treatments, and in finding the relationships between soil fertility and the crop performance. The results indicate that even though the short-term yield has been expanded by a significant margin, organic fertilizers do have an impact on the health of the soil and preserve nutrient availability for a longer period of time. The combination treatment showed the greatest performance overall that suggests combining organic and chemical fertilizers can be used in an optimal way to optimize the wheat productivity and agricultural sustainability to the environment. This study provides some practical information for policy makers, agronomists and farmers for better wheat production while maintaining long term soil fertility in Pakistan.

Introduction

Wheat (Triticum aestivum L.) is one of the most important cereal crop in the world and need as source of staple food in billions of people and is instrumental in food security in developing countries like Pakistan (Khan et al. 2020). For Pakistan, however, wheat contributes U=2.5% of the National GDP and accounts for almost 13 percent of the agricultural output with the South Punjab being one of the most important wheat producing areas due to suitable soil and climatic conditions (Ahmed & Raza, 2021; Farooq et al., 2019). Wheat productivity, however, has its own set of problems such as nutrient depletion of soil, excessive usage of chemical fertilizer, climate variance and water shortage (Hafeez et al., 2018; Malik et al., 2020). Preserving soil fertility and optimizing wheat yield in a sustainable way, therefore, has become an important issue for agronomists, political experts and farmers alike.

Chemical fertilizers particularly urea is rich in N and in the past nitrogenous-rich fertilizers have been used in increasing wheat production as urea is immediately available to plants (Rashid & Jamil, 2022) and wheat is highly responsive to fertilizers. Numerous studies have been conducted in South Asia and have shown that growth - vegetative growth, spike formation and grain filling - is significantly increased in response to the application of chemical fertilisers and short- term yields are increased (Iqbal et al., 2020; Hussain et al., 2019). However, the use of chi could mineralize degraded soil, reduced microbial activity, nutrient imbalances, and environmental pollution leached nitrate and microgreenhouse gas emissions

(Ashraf et al and Manzoor, 2020; Bukhari et al., 2021). This duality of large and fast improving of productivity and long term soil degradation has pushed for an increase of studies on strategies to reach sustainable fertilizer management.

Organic fertilizers such as farmyard manure, compost and vermicompost are a more sustainable option in view of its impact on the soil organic content, it enhances the microbial diversity in the soil, and it releases nutrients slowly over time (Farooq et al., 2019; Khan & Noor, 2021). Organic amendments have been proven to improve the soil's structure, water retention capacity and cation exchange efficiency which builds important for root development and nutrient uptake in wheat [37,38]. However the nutrient availability of organic fertilizers often have a lower level of immediate availability and the effectiveness of organic fertilizer may vary due to the quality of the source, application rate and soil conditions (Hussain & Ali, 2020). As such, integration of organic and chemical fertilizers has become an interesting practice which provides the benefits of accelerated yield improvement and long-term sustainability of soils (Kumar et al., 2020; Malik et al., 2020).

In the light of Pakistan, and especially in the case of South Punjab, there are studies which compare the effect of organic and chemical fertilizer on wheat but they are very limited and mainly region specific (Raza et al. 2018; Mehmood et al. 2021). Given the universal use of chemically manufactured fertilizers as well as the interest in organic amendments, some type of comparative assessment, evaluating both productivity as well as soil fertility, is called for. This research seeks to address this lack of information by investigating the individual together with the combined effect of organic and chemical fertilizers on wheat production in relation to the agronomic performance of fertilizers as well as their soil nutrient dynamics and implications for the sustainable production of crops.

The following are some of the objectives of the current study: (1) to determine the effect of organic and chemical based fertilizers on the growth of the plant and yield parameters of wheat, (2) to determine the effects of organic and chemical based fertilizer factors on parameters of soil fertility, i.e. macronutrients, organic matter content and pH, and 3) to evaluate best fertilizer management practices that will lead to maximum wheat productivity and maintain sustainability in fertile soils. By providing empirical evidence from South Punjab, it is the objective of this study to guide farmers, agronomists and policy makers about best practices of fertilizer management that could contribute towards ensuring food security in the long term and production of wheat in ways that are environmentally sustainable in Pakistan.

Literature Review

Wheat productivity is very much a function of the fertility of the soils, nutrient management and fertilizer application strategies. In Pakistan, wheat is still the backbone of the agricultural sector, but there are still yield gaps due to nutrient depreciation, as well as improper use of fertilizers (Khan et al., 2020; Ahmed & Raza, 2021). Several research studies highlight the fact that chemical fertilizers and specifically nitrogen-based fertilizer compounds, such as urea, has been significant in increasing the production of wheat because of its high solubility rate, and its immediate availability of nutrients (Rashid and Jamil, 2022; Hussain et al., 2019). For instance, Iqbal et al. (2020) observed that application of urea doses at recommended level significantly affected plant height, spike length and grain weight in wheat field of Punjab. However, excess application of chemical fertilizers was referred as the soil acidification and reduced the microbial activity and enhanced dangers associated with leaching of nitrates and thus threatening the sustainability of the soil in the long run (Ashraf & Manzoor, 2020; Bukhari et al., 2021).

Organic fertilisers on the other hand, have been found to improve soil health, enhance the microbial diversity in soil and release nutrients slower for absorption by plants (Farooq et al., 2019; Alam et al., 2021). Farmyard manure, compost and vermicompost are reported to increase soil organic matter, improve water retention and cation exchange capacity which leads to better root development and nutrient uptake in wheat crop (Haider et al., 2022; Khan; Noor, 2021). Studies by Hussain and Ali (2020) emphasized the fact that organic amendments bring a better level of sustainability in wheat production as they bring about a decrease in the dependence on chemical inputs, which can improve the soil structure. However, the nutrient availability of organic fertilizers are slower and also vague in most cases, hence resulting in less immediate yield increases as compared to the chemical fertilizers (Kumar et al., 2020; Malik et al., 2020).

The combination involving organic and chemical fertilizer has become the potential solution for optimization of wheat production while maintaining soil fertility. Raza et al (2018) demonstrated that combined application of urea and farm yard manure was better than their individual application in terms of yield, enhanced grain quality and soil nutrient retention. Similarly, Mehmood et al. (2021) conducted a study that showed improved growth parameters, increase in spike length and grain weight which recorded great synergistic response of integrated nutrient management on wheat crops grown with both compost and chemical fertilizers. This approach corrects the faults of the exclusive use of chemical fertilizers, but also allows keeping the available nutrients sufficient to guarantee the best possible growth of the crop.

Soil's nutrients dynamics is very important in understanding effectiveness of fertilizers. Nitrogen, phosphorus and potassium are primary macronutrients required for growing wheat plant (Farooq et al, 2019; Ahmed & Raza, 2021). Nitrogen plays an important role in growth, production of chlorophyll, protein whereas phosphorus plays an important role in roots formation and filling of grains and potassium helps in regulating water and tolerance of stress (Khan et al., 2020; Rashid & Jamil, 2022). Research has indicated that chemical fertilizers promote these nutrients in readily available forms and thereby leading to the quick response of the crops whereas the organic fertilizers form the vertebrae for the long-term pool of nutrients and microbial-mediated nutrient cycling (Ashraf & Manzoor, 2020; Haider et al., 2022). Therefore, practicing both types of fertilizers helps farmers to secure high yields over a short period and soil fertility over time in consecutive seasons.

Environmental impact of fertilizer use has also been the subject of some recent studies. Over use of chemical fertilizers can lead to ground water contamination, increased emissions of greenhouse gases and acidification of soil (Bukhari et al., 2021; Hussain et al., 2019). Organic fertilizers help to boost the carbon sequestration in soil and boost the activity of microorganisms that will improve soil's health and resistance to climatic stress of the climate change (Khan & Noor, 2021; Haider et al, 2022). Several studies have involved focus in South Asia, Pakistan on need for sustainable fertilizer strategy to balance the high yield of crop with environment protection [Farooq et al., 2019;Raza et al.

Farm level studies have shown a variability in the adoption of organic fertilizers. Many of smallholder farmers of South Punjab highly depended on chemical fertilizers due to the immediate benefits in terms of yield, lack of awareness on organic products, and shortage of quality organic inputs (Hussain & Ali, 2020; Mehmood et al., 2021). Surveys of Alam et al (2021) revealed that only 28% farmers applied compost or farmyard manure in their fertilizer regime in the wheat sector suggesting a huge knowledge gap and potential for extension intervention. Integrated nutrient management strategies coupled with the government policy, training program and accessing to use of organic inputs have demonstrated that they improved wheat yield, soil health and sustainability outcomes (Malik et al., 2020; Rashid and Jamil, 2022).

Comparative field trials also emphasize on the differences in performance of crops by using organic instead of Chemical fertilizations as well. Farooq et al. (2019) reported that wheat plants in the plots under chemical fertilizer revealed higher rates of growth and early development of tillers whereas the plots under organic fertilizer revealed good soil moisture content and nutrient retention during the growth period. Studies by Khan et al. (2020) and Raza et al. (2018) confirm maximumity of both yield and soil fertility enhanced under combined treatments, which proves the synergy of the effect of combining organic and chemical fertilizers. Hematite are landslides that emphases the predominant time as a result basically of too much vegetation and nutrient-rich soil in pot, and the landslide factors are compelling of factors, such as climate and surface conditions of soils in relation to greater ability: for farmers to understand the issue, adaptive fertilizer and some helpful fertilizer by local conditions bypasses Pakistan.

In addition, the type of fertilizer will affect the quality of the grain and its nutritional characteristics. Research has shown that the wheat grains of organic/integrated fertilizer plots and the exclusively chemical fertilizer plots showed more protein content, better micronutrient content and better qualities as per baking results (Kumar et al, 2020; Mehmood et al., 2021). This creates a lot emphasis on the role of fertilizer management not only in terms of the quantity of yield, but also in terms of it being a contributor to food quality and nutritional security.

In conclusion, it has been shown in literature time and again that while chemical fertilizers may have immediate yield benefits, organic fertilizers and integrated management of nutrient supply has sustainable soil fertility and environmental benefits. There are agreement on the combined application of organic and the chemical fertilizer for maximum wheat production with better grain quality and long-term soil health (Ashraf & Manzoor, 2020; Haider et al., 2022; Raza et al., 2018). However, there still remains a paucity of regional studies especially in South Punjab where localised comparative studies are needed which will guide the decisions over fertilizer management by many wheat producers.

Methodology

Research Design

This research work has an experimental research design to test the comparative impacts of organic and chemical fertilizers on the production of wheat. The design included both field trial and soil analysis and it thus allows for a systematic comparison of agronomic performance, soil fertility parameters and yield results. A randomized complete block design (RCBD) has been used so that variability due to heterogeneity of the soil will be minimized and results of the study will be reliable and accurate. Quantitative data, based on direct measurements of wheat growth parameters, grain yield and soil nutrient status obtained, as well as qualitative observations of plant health and farmer practices were obtained in order to complete the quantitative data.

Study Area

The study was conducted in South Punjab in the district of Multan which is known for its high wheat productivity and agro-climatic condition. Multan was selected due to representative soil types, temperature range and farming techniques of the South Punjab. The area has average annual temperature between 24-28oC during the wheat growing season and rainfall between 200-250 mm y-1 giving an opportunity where fertilizer management has significant effect on wheat yield (PMD, 2022). Use of one location allowed control comparisons of fertilizer treatments and minimises factors associated with multiple agro-ecological zones.

Population and Sampling

The population in this area were wheat growers of Multan having active involvement in management of small to medium sized wheat plots. Purposive Sampling technique was used to select those farmers which have uniform experience of growing wheat cultivation in the last five year or more to have experience of fertilizer use and response of crops. A total of 120 plots of wheat were investigated in the research study under three treatment conditions: plots which received organic fertilizer-based fertilizer only (compost/farmyard manure) urea-based fertilizer only with an integrated combination of both. Each treatment was repeated four times to ensure that the results were statistically valid.

Margin Nutrient Management Fertilizer Treatments, Application

The three basic fertilizer regimes that were tested were:

1. **Organic Fertilizer:** Well-decomposed compost and farmyard manure were used at a rate of 5 tons per hectare that ensure homogenous distribution over the plots.
2. **Chemical Fertilizer:** Urea was sprayed at a recommended rate of 120 kg per hectare which was supplemented by phosphorus (DAP) at 90kg per hectare as recommended regionally.
3. **Integrated Fertilizer:** A mixture of organic fertilizer (2.5 tons per hectares) and 50% chemical fertilizer as urea (60 kg/ha), and DAP (45 kg/ha) was used to study the synergistic effect.

Fertilizers were applied during sowing and tillering stage using some standard agronomic protocols to maximize nutrient uptake as well as the crop performance.

Data Collection Methods

Primary data were obtained in the form of direct measurement in the field, sampling of soils. Wheat growth characteristics such as the plant height, number of tillers, spike length and weight of grains were measured in the major growth stages. Data on yield was recorded at harvest using the total grain per plot and converted to the units of kg haem. Soil samples before sowing and after harvest, from the top 0-20 cm layer, were collected in an attempt to understand the pH, organic matter content and macronutrients contents (N, P, K). Laboratory analysis - Standard laboratory methods were utilized to test the samples to insure that the analysis would be done accurately and that the samples would be comparable. In addition to indepth knowledge nuclear data, agricultural inputs, their labor input, the health condition of the crop and their effects of perceived chlorophyll was obtained from farmer through structured interviews.

Variables and Measurement

The dependent variables were yield of wheat, weight of grain, length of spike and plant height and the independent ones was type of fertilizer used (organic, chemical, integrated). Soil nutrient parameters were used as control variables as they sought to consider where the differences in fertility were coming from. Measurement protocols were used which met agronomic standards. Plant height in centimeters spike length in centimeters grain weight in grams the levels of soil nutrients in magnifier/gram (mg/kg). Data quality in the form of replication, calibration of measuring instruments and equal-labouratory analysis was ensured.

Data Analysis

Data was analysed, using the program of Statistics Package and System (SPSS) 25.0. A means of summary of the growth and yield parameters was descriptive statistics, namely mean and standard deviation. A one way analysis of variance of (Anova) was used to analyze the difference in the fertilizer treatment and then pairwise differences were sorted out using a post hoc analysis Tukey. Correlation analysis was done to check the correlation between contents of nutrients in soil and yield of wheat. Results were in the form of tables which were worked into the narrative to provide an overview of the effect of fertilizer types on both yield and soil health.

Ethical Considerations

Objectives of the study informed to farmers and also informed consent taken before data collection. Confidentiality of farm level information was assured and plots were managed to best agronomic practices such that no loss or damage would be incurred. Ethical approval for work of the research had been sought from The Department of Agriculture Research Ethics Committee, respective institute, which are ensuring that ethical research standards are followed in this investigation.

Data Analysis & Findings

Data obtained from 120 plots of wheat in Multan, South Punjab, gave detailed information regarding comparative impacts of organic, chemical fertilizing and integrated fertilizers treatments on growth, yield and soil fertility of wheat. The demographic profile of participating farmers indicated that most farmers had been farming the wheat crop for over 10 years and thus there might have been reliable reporting of crop management practices and yield results. The uniformity of the design in the soil type, methods of irrigation and sowing is responsible in making the variations in the crop performance could be attributed mainly to the fertilizer treatments.

Initial analysis of soils showed the mean content of organic materials in all the plots 0.9%, 7.5 - 7.8 pH values and adequate parameters of nitrogen (N), phosphorus (P) and potassium (K) (Table 1). These preliminary measurements had the advantage of assuring that all the plots began with similar fertilizer situations from which the effects of the confounding variation could have decreased the results of a comparison of treatments.

Table 1. Baseline Soil Parameters Before Fertilizer Application (Multan, 2025)

Parameter	Unit	Organic Fertilizer	Chemical Fertilizer	Integrated Fertilizer
pH	-	7.6	7.5	7.6
Organic Matter	%	0.91	0.88	0.90
Nitrogen (N)	mg/kg	34.5	35.1	34.8
Phosphorus (P)	mg/kg	12.4	12.1	12.3
Potassium (K)	mg/kg	145.3	146.1	145.8

Growth analysis throughout the season suggested life and death amongst treatments. Wheat plots receiving the chemical fertilizers showed rapid vegetative growth characteristics with increased plant height and tillering number were observed. However, organic fertiliser plots had a slower initial stage of growth but a better canopy meaning and foliage coloration throughout the season. Integrated fertilizer plots achieved both benefits from these two fertilizer treatments and showed large vegetative growth without signs of nutrient stress. Average plant heights at maturity was found to be 92.5 cm at organic plots, 101.8 cm for chemical plots whereas it was 105.3 cm for integrated plots and hence it has been proved that integration had increased the overall development of the vegetative structure.

Yield parameters such as spike length, grain weight, and total yield were no different (Table 2). Chemical fertilizer significantly increased the short-term yield especially in those plots which had urea and DAP where spike length averaged 10.8 cm with a 1000-grain weight of 42.5 g. Organic fertilizer plots resulted in slightly lower yield (spikes length having the mean value and 1000 g. weight was 9.5cm and 38.6g) but soil fertility factors like organic matter and nutrient retention improved significantly. The highest yields were recorded for the integrated treatment with average spike length value of 11.2 cm, average 1000 grain weight of 44.1 g and average yield of 4,750 kg/ha which would illustrate the synergistic effect of organic fertilizer plus chemical fertilizer.

Table 2. Wheat Growth and Yield Parameters Under Different Fertilizer Treatments (Multan, 2025)

Parameter	Organic Fertilizer	Chemical Fertilizer	Integrated Fertilizer
Plant Height (cm)	92.5	101.8	105.3
Spike Length (cm)	9.5	10.8	11.2
1000-Grain Weight (g)	38.6	42.5	44.1
Grain Yield (kg/ha)	3,950	4,400	4,750

Soil fertility analysis after harvest time showed there were great differences in the treatments. Organic fertilizer plots showed a 12% increase in organic matter content and minor improvements in the availability of nitrogen, phosphorus, and potassium showing improved soil quality and long-term fertility potential. Chemical fertilizer plots showed limited change in the organic matter, as well as slight increase in nitrogen content, but changes in phosphorus and potassium content did not show much change, indicating the soil's limited improvement in the long term. Integrated treatment plots showed a trade-off, where the organic matter content was expanded by 8%, and nutrient availability including all the studied macronutrients was improved, which confirms how the use of both organic and chemical fertilisers can ensure sustainability of productivity and of soil (Table 3).

Table 3. Post-Harvest Soil Nutrient Analysis

Parameter	Organic Fertilizer	Chemical Fertilizer	Integrated Fertilizer
pH	7.5	7.5	7.6
Organic Matter	1.02	0.89	0.97
Nitrogen (N)	37.5	37.8	38.6
Phosphorus (P)	12.9	12.2	12.8
Potassium (K)	148.0	147.0	148.5

Statistical analysis using application of the Analysis of Variance (ANOVA) was used to confirm that variances of the yield, plant height, spike length and weight of grain collected from the three fertilizer treatments were significant ($p < 0.01$). Post-hoc Tukey tests showed that integrated fertilizer plots was compared with organic and chemical treatments in individual unit for yield improvement of the plots and the difference between organic and chemical plots was statistically significant, especially soil fertility improvement and grain protein content. Correlation results indicated the associations of soil nitrogen of grain weight ($r = 0.68$, $p < 0.01$) and organic matter contents and stability to overall yields were high ($r = 0.62$, $p < 0.01$) which means soil health had a good impact on crops performance.

Farmer observations were in support of these results. Plots which received integrated fertilizers were using medium amounts of labor, were at a consistent level of crop vigor and showed lower levels of nutrient stress symptoms such as yellowing or stunted growth. Organic fertilizer plots were more resistance to heat stress and water shortage and chemical fertilizer plots were a bit sensitive to irrigation management to prevent nutrient burn. In addition, grain quality analysis indicated that the protein contents and grain size of the samples from integrated plots were higher which is in agreement with the findings of the increases in the yield parameters.

In summary, the data show that although chemical fertilizers yield immediate benefits to the farmer, organic fertilizers improve soil fertility and are a part of a long-term sustainable program. The combination use of both organic and chemical fertilizers proved to be the best and resulted in the highest wheat yield, the highest grain quality and soil nutrient balance. These results can guide the farmers to the actionable knowledge and it can be the tools in the hands of the farmers to optimize the production of wheat to support the environmental sustainability of South Punjab.

Discussion

The results of this study clearly shows that the type of fertilizer have significant effect on wheat growth, yield and also on soil fertility of South Punjab. Chemical fertilizers brought about the rapid development of vegetative growth and also brought about taller plant size and initial higher yield which is consistent with the findings in earlier studies that urea and DAP are high in solubility and have nutrient availability (Iqbal et al., 2020; Rashid & Jamil, 2022). However, chemical fertilizer plots also had little improvement of soil organic matter with little long-term benefit on the soil fertility. This substantiates the findings from Ashraf and Manzoor (2020) and Bukhari et al. (2021) which stressed the fact that exclusive use of chemical fertilizers may lead to soil quality degradation in a number of cropping cycles.

Organic fertilizer treatments although slightly reduced yield production, improved the soil structure, organic matter content and nutrient retention. This helps to show the ability of organic amendments in maintaining the soil health and resilience in the long term i.e. report Farooq et al. 2019), Haider et al. 2022. Organic plots were also more resistant to stress from environment, such as heat and water variability, which suggests that organic amendments promote the tolerance of crops to abiotic stress.

A fertilizer treatment integration was found to be superior in which immediate nutrient benefit (from chemical fertilizers) was combined with soil-enhancing properties of organic amendments. Plots with amended fertilizers had the greatest plant heights, spike length, and grain weight and yield while the following soil fertility indicators were also improved. The results of this study support the results of other studies (Raza et al., 2018; Mehmood et al., 2021) which demonstrated the usefulness of integrated nutrient management strategies to maximize wheat yield and improve grain quality and that they help maintain soil health over the long term. Correlation analysis further approved the presence of strong positive relationships for soil nutrients (especially of nitrogen and organic matter) with the yield of wheat, Finally, balanced nutrient management importance for wheat yield was highlighted.

Overall, the research highlights that fertilizer strategy is an element that would be a determinant of performance of wheat. While chemical fertilisers provide yield response gains over the short term a sustainable approach to achieving long term productivity includes a balanced approach and use of organic amendments to ensure soil fertility as well as minimising risks to the environment. These results are the evidences for wheat growers for South Punjab and like agro Climatic zone.

Conclusion

This study concludes that fertilizer type have significant affect on the growth, yield and soil health of wheat in South Punjabi. Chemical fertilizers promote rapid vegetative growth and short term yields but don't contribute much towards enhancement of soil fertility. Organic fertilizers work wonders on the soil structure, nutrient retention, and crop resilience, however, their effects in short term might be little less as far as yields. Integrated fertilizer practices are the best management tool, with the most yield, improved grain quality and improved soil fertility. These results reveal the importance of a good balance of fertilizer management for sustainable wheat production, food security and environmental conservation.

Recommendations

On the basis of study findings, some recommendations are suggested for better production of wheat in South Punjab:

1. **Adopt Integrated Fertilizer Practices:** Farmers are advised to combine organic and chemical fertilizers to get rid of the problem of getting higher yields and ensuring soil fertility and sustainability in the long run.
2. **Enhance Use of Organic Fertilizers:** Promotion of use of farmyard manure, compost and other organic amendments should be given a higher priority, with training programmes conducted for farmers, to ensure that correct application rates and time of application are observed.
3. **Monitor Soil Health** Regular soil testing should be performed to help make fertilizer choices and avoid nutrient imbalances and enhance long-term productivity.
4. **Government Support and Extension Services:** Policy interventions are required for access to good organic fertilizers, incentives for integrated nutrient management and joint to increase knowledge of farmers under extension programs.
5. **Research and Development:** Further studies into crop specific integrated nutrient strategies (taking climatic variability, pest pressures and water availability into consideration) should be performed to optimize best practices for wheat cultivation in Pakistan.

Implementation of these recommendations will help the wheat farmers in the South Punjab to attain high productivity, improve soil fertility, and contribute to the sustainable agricultural practices.

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Soil Salinity Impacts on Cotton and Sugarcane Productivity in Sindh's Irrigated Areas

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ABSTRACT

Soil salinity has become a significant problem for agricultural productivity in irrigated lands of Sindh, Pakistan and the crops (cotton, sugarcane) are also facing the problem. High amounts of soluble salts in the soil decrease the availability of water, interfere with the uptake of nutrients, and affect the plant's growth leading to tremendous yield losses. This study is aimed at the evaluation and ascertainment of the effects of salinity of irrigation water on cotton and sugarcane growth, physiological traits and agro productive potential of sugarcane and cotton in important irrigated areas of Sindh. Soil samples were taken from several fields of different salinity levels and tested for electrical conductivity, sodium adsorption ratio and nutrient content. Crop growth parameters such as plant height, leaf area and biomass were recorded, whereas yield components were measured at harvests. Results showed that rising soil salinity had a negative impact on both crops resulting in a decline in growth and yield that were more noticeable for sugarcane than for the cotton. Salinity stress was related with reduction of chlorophyll content as well as decreased stomata conductance and imbalance nutrients indicating physiological burden of plants during saline condition. These results highlight the need for urgent management of salt, such as better irrigation and use of salt tolerant cultivars and soil amendments to maintain cotton and sugarcane productivities in the irrigated areas of Pakistan's leading sugar cane and cotton producing provinces-Sindh.

Introduction

Soil salinity is a great problem of the agriculture in arid and semi-arid regions, where the over irrigation practice is often followed and soluble salts would be accumulated in the soil profile. In Pakistan particularly the Sindh province is affected owing to huge canal irrigation system and high rate of evapotranspiration leads to salt accumulation in the irrigated lands (Qureshi et al., 2017; Akhtar et al., 2018). Cotton and sugarcane which are two most important cash crops of the region are very sensitive to salinity and their productivity is reduced significantly in saline conditions. Soil salinity affects plants to water relationship, nutrient uptake, photosynthetic efficiency and finally, crop yield (Munns & Tester, 2008; Farooq et al., 2015).

Electrical conductivity (EC) commonly is used as a surrogate for soil salinity and sodium adsorption ratio (SAR) provides information of sodicity of soil that may further affect soil structure and permeability. As the saline environments increasing, high EC value and high SAR values effect to the root development and the water uptake adversely leading to the increase in the drought like stress under adequate irrigation (Rengasamy, 2010, Singh et al., 2019). In Sindh the EC's of more than 4 dS/m have been reported for multiple irrigating plots representing moderately to highly saline condition leading to poor growth of cotton and sugarcane (Ali et al., 2019; Hussain et al., 2020).

Cotton (Gossypium hirsutum) is a medium salt tolerant and greater yield losses are explained by the reduction in vegetative growth and reduction in bol size and poor in fibre quality under salinity stress (Ashraf and Foolad, 2007; Ismail et al., 2013). Sugarcane (Saccharum officinarum) on the other hand since it is highly sensitive to salinity as excessive amount of saline content comes down of the length of the stalk and accumulation of biomass and sugar contents (Singh et al., 2015; Sharma et al., 2018). Salinity stress elicit a cascade of physiological and biochemical reactions such as osmotic adjustment, accumulation of compatible solutes such as proline, variation of antioxidant enzymes activities which will determine in the end the plant tolerance (Parida & Das, 2005; Farooq et al., 2015).

Irrigation methods in Sindh While irrigation plays a very vital role in production of crop but it is one of the major ways of salinization in Sindh. Poor drainage and over irrigation, use of saline canal water leading to accumulation of salt in the root zone of the plant makes the situation even worse with respect to limiting the intake of water and nutrients (Qureshi et al., 2017; Akhtar et al., 2018). In addition, the climate change and the increasing temperature further accelerates the rate of evapotranspiration which implies the salts are able to concentrate in the top soil faster which places more stress on crops (Khan et al., 2020; Rengasamy, 2010).

Several strategies have been proposed for alleviating the salinity effects are the use of salt tolerant cultivars, better irrigation schedule, soil amendment such as gypsum as well as integrated nutrient management practices (Ashraf & Foolad, 2007; Ismail et al., 2013). However the implementation at a field level in the province of sowndh is still small and hence there is need to conduct such research on a region specific basis to quantify the impacts of salinity and to establish the management practices for the same. Understanding the relation of soil salinity and crop productivity is very important for sustaining the agricultural output of this region which plays an important role in economy and food security of Pakistan (Farooq et al., 2015; Hussain et al., 2020).

The major objective of present study therefore is to assess the effect of different levels of soil salinity on growth and physiological characters and yield component of cotton and sugarcane in irrigated areas of Sindh. By analyzes of soils physicochemical characteristics and quantitative determination of crop performances, the research aims to identify the critical threshold of salinity at which salinity start to significantly reduce the productivity, and giving recommendations on how to mitigate the salinity induced yield losses. The results will feed to establish the sustainable ways of managing irrigation and soil to ensure the sustainability of the cultivation of cotton and sugarcane in the region in long-term (Singh et al. 2015; Sharma et al., 2018; Ali et al., 2019).

Literature Review

Soil salinity is a wide-ranging problem in between irrigated agriculture in the world, especially in arid and semi-arid places and is a lead causative which contributes to a decrease in the crop's productivity (Munns, & Tester, 2008; Rengasamy 2010). In Pakistan, irrigated areas of Sindh is extremely vulnerable which occurred due to poor drainage; excessive irrigation or due to use of canal water with high salt content (Qureshi et al. 2017; Akhtar et al. 2018). The salinity stress influence the plants through causing osmotic stress, ion toxicity and nutrient imbalance which finally leads to a decrease in growth and yield (Parida and Das, 2005; Farooq et al, 2015).

Cotton (Gossypium hirsutum) has medium level tolerance to salinity and yield losses is mostly due to the decreased vegetation development and functional disorder of the boll development and decreased fibre qualities (Ashraf & Foolad, 2007; Ismail et al., 2013). Soil salts are formed as a consecutive of accumulations that are formed due to the excessive presence of sodium and chloride in the soil that may interfere to water absorption and photosynthesis that may also lead to retared growth of vegetations and poor yield (Singh et al., 2015. Studies have been carried out in Pakistan and the results show that there is a decrease in the cotton yield with an increase in the soil electrical conductivity (EC) but the soils that have high electrical conductivity (EC more than 4 dS/m) have a higher decrease in the cotton yield (Ali et al., 2019; Hussain et al., 2020). Salt stress also causes physiological changes such as accumulation of compatible solutes such as proline and soluble sugars which is helpful to plants in osmoregulation i.e. to maintenance of turgor pressure i.e. to hold the plant in an erect position (Parida & Das, 2005; Ashraf & Foolad, 2007).

Sugarcane (Saccharum officinarum) is more prone to salinity than cotton due to high concentration of salt in the environment reduce the elongation of the stalk, the accumulation of biomass and sugar content (Sharma et al., 2018; Singh et al., 2015). Excessive sodium brings about the disturbance in the ingestion of nutrients, especially potassium and calcium nutrients, and brings the negative effect on the capacity of producing photosynthesis and causing a further restraint in productivity (Khan et al., 2020). Several researches reported about loss of sugarcane yield more than 30% in those fields with more than 6 dS/m EC comprising the importance of particular management's strategies (Farooq et al., 2015; Hussain et al., 2020).

Physiological responses as stomatal closure,decrease transpiration, decrease chlorophyll content of plant leading to decreased photosynthesis therefore availability of energy to grow, reduced growth (Ashraf and Foolad, 2007; Ismail et al., 2013). Enzymatic and antioxidative systems in plants such as superoxide dismutase, catalase and peroxidase are subject to induction in the plants subjected to the salt stress to limit the oxidative damage by the reactive oxygen species (ROS) (Parida & Das, 2005; Farooq et al., 2015). However, with a high salinity for prolonged periods of time, there is a chance that these defence mechanisms will be overwhelmed leading to a damage to the cell and thereby leading to a reduced crop performance(Sharma et al., 2018).

Irrigation procedures are right correlated to dynamic of salinity. Poor management of irrigation leads to water logging of the low lying areas, and salt getting build up in the root zone increasing the stress on crops [Qureshi et al., 2017; Akhtar et al., 2018]. The use of saline canal water also lead to salinization of soil especially in absence of adequate leach and drainage system (Rangaswami, 2010; Khan et al, 2020). Field studies in Sindh has revealed that fields with high EC of soil are often the fields that have poor drainage facility and repeated irrigation cycles without leaching and hence pose the problem of chronic salinity stress (Ali et al., 2019; Hussain et al., 2020).

For the cotton and the sugarcane, a number of ways of reducing the effects of the salinity have been proposed. The utilisation of salt tolerant cultivars have shown some promise and some of the cotton cultivars are still able to sustain high yield under moderate salinity (Ismail et al, 2013; Ashraf and Foolad, 2007). Sugarcane breeding programmes also take into consideration genotypes having better tolerance to salt etc include availability of efficient ion exclusion, osmotic adjustment (Singh et al., 2015; Sharma et al., 2018). Soil amendments, such as gypsum, organic materials have been reported to improve the soil structure and displace the sodium ions and will increase water infiltration thus countering the negative impacts of salinity (Farooq et al. 2015 ; Khan et al. 2020).

Monitoring and management of the quality of the water in the irrigation is just as important as well. Leaching method, proper irrigation technique and availability of good quality water in canals help controlling lower EC in soil root zone and encouring the growth of crop in saline situation (Rengasamy, 2010; Akhtar et al., 2018). Integrated strategies of tolerant cultivars, improved irrigation and soil amendments are needed for continuance of cotton and sugarcane productivity in irrigated areas of Sindh (Ali et al. 2019; Hussain et al. 2020).

Recent researches have highlighted the importance of knowing the physiology of plants in field conditions since the controlled experiments cannot reflect the complexity of interactions of soil, water and climate (Parida and Das, 2005; Farooq et al, 2015). Studies in Pakistan have revealed regional differences in the amount of salinity impact with some localities showing higher levels of yield reduction owing to the soil texture and irrigation technique coupled with local management decision (Singh et al, 2015; Sharma et al, 2018). Therefore, localized studies are of prime importance in order to build-up effective management strategies found in different agro climatic zones.

In conclusion it can be concluded that the Soil Salinity is one of the of major restricting constraints in productivity of cotton and sugarcane irrigated areas of Sindh. Both the crops show reduction in growth and yield in saline condition sugarcane being more sensitive in comparison to cotton. Physiological and biochemical response in plant is good to cope with the stress but longer duration of exposure to such high salinity overcomes such mechanisms. Effective management strategies such as salt tolerant cultivars, improved irrigation, soil amendments and integrated nutrient management are keys if the productivity is to be sustained. This literature review is a really good foundation for the present study which aims as not only to quantify the salinity effects but also to draw some practical recommendations in order to manage the yield losses caused by salinity in Sindh.

Methodology

Study Area

The study has been undertaken in irrigated agriculture areas of the Sindh province in Pakistan which is a major agriculture producer of cotton and sugarcane. Six representative districts, namely Hyderabad, Sukkur, Nawabshah, Thatta, Mirpurkhas and Larkana on the basis of the irrigation practices, level of salinity and distribution of crops were taken. These areas are characterised by high evapotranspiration, low drainage and periodic water logging - these factors make them susceptible to salinity of soil (Qureshi et al., 2017; Akhtar et al., 2018).

Experimental Design

A field based observational study was done based on the plots classified based on Soil Salinity (EC < 2dS/m, moderate: EC 2-4 dS/m and high: EC < 4 dS/m) level. Each category had 5 replicates fields for both cotton and sugarcane fields such as to get spatial representation. Use made of random samples was attempted to put down the bias in the measurements caused by heterogeneity of soil.

Soil Sampling and Analysis

Composite samples of the soil of the surface layer (0-20 cm) were collected using the method of sterile auger. A total of 15 composite samples per field were collected from each field in five subsamples from each field. Sealed samples of soil were dried at air and sieved (2 mm) and analysed on:

- Exponentially greaterEq**9 units **greater** Exponentially greater
- These sodium, calcium, and magnesium concentrations are used to calculate the following: - Sodium Adsorption Ratio (SAR) (Richards, 1954).
- Soil pH - pH of the soil in a 1:2.5 soil to water suspension as measured by a digital pH meter.
- Review Paper for the Biology of Striga.Review Paper on Biology of Striga.

Crop Growth and Physiological Measurements

For each plot, ten plants were randomly selected for growth assessments:

- **Plant Height:** This is measured from base to apex in maximal vegetative stage.
- **oLeaf Area:** acetone-determinded by the usage of a leaf area meter.
- **Biomass:** (Above ground Fresh and dry weight at the time of harvest).

Physiological parameters included:

- **Chlorophyll Content:** Measurements made with SPAD meter
- **oStomatal Conductance:** Measured using a porometer in order to measure water control during stress from salinity.
- **Relative Water Content (RWC):** Measured after normal gravimetric methods (Barrs & Weatherley, 1962).
- Yield Assessment

Cotton yield components measured were boll number, boll weight and seed cotton yield (per plant). For sugarcane instead, stalk height, cane diameter, number of canes suitable for milling, and cane total yield/ha were measured at harvest.

Statistical Analysis

Data analysis was done using the statistical software analysis (SPSS v26). One way analysis of variance (one way- or One way Analysis Of Variance), (or invariable or invariable analysis of variance) or Analysis of Variance (one way or One way Analysis Of Variance) was performed to identify the difference in soil properties, crop growth and yield between the salinity levels.

Tukey's HSD test was used for post-hoc comparison tests. Pearson correlation coefficients were used to measure the relations of soil salinity information (EC and SAR) with the crop factors of performance. Significance was accepted on $p < 0.05$ level.

Data Analysis & Findings

The results of soil sample analysis from the six irrigated districts in Sindh showed wide variability in salinity level and it affected growth and yield of cotton and sugarcane significantly. Electrical conductivity (EC) values varied between 1.2 and 6.8 dS/m with the high salinity fields mostly recorded in Nawabshah, Thatta and Mirpurkhas. Sodium adsorption ratio (SAR) values were also variable and this showed differential soil sodicity, which affects soil structure and water availability (Qureshi et al., 2017; Rengasamy, 2010).

Cotton growth parameters were reduced by increasing soil salinity. Plant height was reduced from median height of 125 cm for low salinity tolerant to 94 cm for high salinity tolerant fields (Table 1). Leaf area decreased by about 28% while above ground biomass decreased by almost 35%, showing the negative impact of salinity on vegetative growth. Similar trends were found for physiological traits; the chlorophyll content was decreased from 42 SPAD units (low salinity fields) to 31 SPAD units (high salinity plots) and stomata conductance had decreased by 25% indicating osmotic stress and reduced water intake under high salt stress conditions.

Table 1. Cotton growth and physiological parameters across salinity levels

Salinity Level	Plant Height (cm)	Leaf Area (cm^2)	Biomass (g/plant)	Chlorophyll (SPAD)	Stomatal Conductance (mmol m^{-2} s^{-1})
Low	125 ± 4.2	460 ± 15	210 ± 8	42 ± 1.2	280 ± 12
Moderate	110 ± 3.8	395 ± 12	175 ± 7	37 ± 1.0	245 ± 10
High	94 ± 3.5	330 ± 10	136 ± 6	31 ± 0.9	210 ± 9

Growth of sugarcane was even more sensitive to salinity. Stalk height, diameter, and millable cane number decreased gradually with a higher EC, which resulted in a nearly 40% reduction in yield in the high salinity fields compared to the low salinity plots (Table 2). Chlorophyll content and relative water content (RWC) were significantly decreased under high salinity of influence of on decreased photosynthetic efficiency and of osmolar stress (official name of stress by high salinity). These results are in agreement with previous reports indicating that sugarcane is more sensitive than cotton to salinity, and both yield and sugar quality are affected (Singh et al., 2015; Sharma et al., 2018).

Table 2. Sugarcane growth and physiological parameters across salinity levels

Salinity Level	Stalk Height (cm)	Stalk Diameter (cm)	Millable Canes (#/ha)	Cane Yield (t/ha)	Chlorophyll (SPAD)	RWC (%)
Low	220 ± 6.5	3.8 ± 0.1	85,000 ± 1200	95 ± 3	44 ± 1.3	78 ± 2
Moderate	198 ± 5.8	3.3 ± 0.1	72,500 ± 1100	78 ± 2.5	39 ± 1.1	70 ± 2
High	170 ± 5.2	2.8 ± 0.1	60,000 ± 1000	57 ± 2	33 ± 0.9	61 ± 1.8

Correlation analysis showed a high negative correlation between the salinity indicators of soil (EC and SAR) and crop performance parameters. For cotton, EC was negatively correlated with plant height ($r = -0.82$, $p < 0.01$), leaf area ($r = -0.79$, $p < 0.01$) and biomass ($r = -0.84$, $p < 0.01$). For sugarcane, EC was found to be correlated negatively with stalk height ($r = -0.85$, $p < 0.01$), cane yield ($r = -0.87$, $p < 0.01$) and RWC ($r = -0.81$, $p < 0.01$). These results confirm the increasing salinity imposes the osmotic and ionic stress, reducing the water availability, nutrient uptake and overall crop productivity (Ashraf & Foolad, 2007; Farooq et al., 2015).

Physiological changes under salinity stress also resulted into lower values of chlorophyll content and RWC, suggesting low photosynthetic efficiency and water status. Cotton plant in high-salinity field had lower stomatal conductance, which was probably due to stomatal conductance to protect the plant from water loss, the sugar cane had more pronounced reduction possibly due to the higher sensitivity of this plant under high salinity (Singh et al., 2015; Sharma et al., 2018). These results are in agreement with those previously reported of differential tolerance of these crops to salinity stress.

Overall, the obtained data show that the effect of soil salinity is more significant on sugarcane compared to cotton in irrigated lands of Sindh in terms of both vegetative and yield components. Similar to other parts of the world, fields with moderate to high salinity levels consistently showed reduced productivity, hence the urgent need for mitigation strategies (i.e., salt-tolerant cultivars, improved irrigation management and soil amendments; Ismail et al., 2013; Akhtar et al., 2018). The combined study of soil physicochemical properties with crop performance highlights the close relationship of soil salinity, and also the plant response, offering critical information for sustainable cultivation practices in soil salinity-affected areas.

Discussion

The results of this investigation clearly showed that the soil salinity has significant detrimental effect on the growth and productivity of cotton and sugarcane in the irrigated areas of Sindh. Cotton exhibited moderate sensitivity to salinity with a decrease in plant height, leaf area, biomass and chlorophyll content at high EC conditions. Sugarcane was even more susceptible, showing drastic reductions in stalk height, diameter, number of millable canes, cane yield and relative water content. These results are consistent with other research reports that salinity stress restricts water intake, imbalance of nutrients, photosynthetic deficiency, and reduce crop yield (Ashraf & Foolad, 2007; Singh et al., 2015; Farooq et al., 2015).

Physiological assessments showed that the two crops responded to salinity by decreased stomatal conductance and decreased chlorophyll content as indicators of osmotic stress and debilitated photosynthesis. The negative correlations between soil EC and crop growth parameters indicate the direct influence of salinity on the performance of plants (Rengasamy, 2010; Hussain et al., 2020). Sugarcane's superior sensitivity as compared to cotton makes it important to use crop-specific management strategies. The results also indicate that moderate salinity can be tolerated to some degree by cotton but prolonged exposure and high salinity level result in severe reduction in growth and yield.

Soil management practices, irrigation quality were critical soil factors affecting crops performance. Fields with poor drainage and high sodium adsorption ratios and excessive irrigation showed the highest amount of salinity and the lowest yields in terms of integrated salinity management to maintain productivity (Qureshi et al., 2017; Akhtar et al., 2018). The study supports previous results that sustainable scheduling of irrigation, use of salt-tolerant cultivars, and soil amendments are crucial for reducing the adverse effects of salinity on crops (Ismail et al., 2013; Sharma et al., 2018).

Conclusion

This study concludes that soil salinity is a major constraint to the productivity of cotton and sugarcane in irrigated areas of Sindh. High salinity have negative effects on vegetative growth, physiological characteristics and yield components with sugarcane being more susceptible than that of cotton. Soil EC and SAR correlated well with decreased plant performance, suggesting that osmotic stress as well as ion toxicity is responsible for yield losses. Effective management of soil salinity, including enhanced irrigation practices, drainage and the use of salt tolerant cultivars is important in sustaining crop productivity and in assuring long-term agricultural sustainability in the region.

Recommendations

Based on the study findings, the following recommendations are proposed:

1. Adoption of Salt-Tolerant Cultivars: Farmers should take into account varieties of cotton and sugarcane which are provided with proven salinity tolerance potential to reduce the yield losses under moderate to high salinity condition.

2. Improved Irrigation Management: Proper scheduling of irrigation systems, use of good quality canal water, and leaching practices should be adopted in order to avoid salt build up in the root zone.

3. Soil Amendments: Application of gypsum, organic matter or other soil amendments may help to reduce sodium levels, increase the soil structure and assists with water infiltration.

4. Monitoring and Assessment Regular monitoring of soil for EC, SAR and nutrient contents should be done to assist management decisions and maintain the health of soil.
5. Integrated Salinity Management: A combination of crop selection, irrigation scheduling, drainage improvement and use of soil amendments is a holistic management approach to overcome the adverse effects of salinity and maintain productivity.
6. Implementation of these strategies can build resilience of farmers in the irrigated areas of Sindh to sustain cotton and sugarcane yields, protect soil health and ensure the sustainability of agricultural systems in high salinity stress areas in the long run.

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Effectiveness of Integrated Pest Management (IPM) Adoption in Pakistani Farming Systems

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ABSTRACT

Integrated Pest Management (IPM) is an environmentally friendly and sustainable method of managing pests in agricultural systems and minimizing the use of chemical pesticides to sustain crop production. In Pakistan, the traditional pest control systems have resulted in environmental degradation, pest resistance and health hazards. This study assesses the effectiveness of IPM adoption in major farming systems by the Pakistanis, with specific reference to the consequence of its uptake in terms of pest incidence, crop yield, economic return and environmental safety. Field surveys were carried out in three provinces i.e. Punjab, Sindh and Khyber Pakhtunkhwa in order to gather data from farmers practising IPM and conventional pest management techniques. Results show that the use of IPM can lead to a significant reduction of pest population, as well as a reduction in pesticide use by up to 40%, in addition to increased crop yield. Farmers enforcing IPM had been determined to have better internet go back due to decreased farm enter fees and decreased losses of crops. The key elements recognized withinside the examine to persuade IPM adoption are the information of the farmers, extension support, availability of bio manage retailers and education programmes. The effects of this have a look at offer a effective reminder of the significance of advancing empty philosophy in country wide in all elements the arena so that you can develop sustainable agriculture, beautify meals safety, and guard farmer livelihoods.

Introduction

Agricultural productivity in Pakistan has been dependent on chemical pesticides for a long time to fight insect pest, weeds and diseases. While these chemicals have been provided short term effects, the over use has caused environmental pollution, pest resistance and also poses health hazards to farmworkers and consumers (Ahmad et al., 2017; Ali et al., 2019). Over use of chemical inputs has also led to secondary pest outbreaks, soil degradation and contamination of water bodies (Iqbal et al, 2018; Farooq et al, 2015). In response, the concept of Integrated Pest Management (IPM) has developed internationally and is based on a holistic approach to preventing and controlling pest populations at economically acceptable levels with a minimum impact on the environment engendering integration of biological, cultural, mechanical and chemical strategies (Kogan, 1998; van Lantern, 2012).

Adoption of IPM practises is small in Pakistan - Cloutier-Brook, A. and Efferle, H.-L. (2013) IPM adoption in Pakistan despite documented advantages.IPM adoption in Pakistan remains small despite documented advantages. Cloutier-Brook, A. and Efferle, H.-L. (2013) IPM adoption in Pakistan despite documented advantages. Due to socio-economic constraints, lack of farmer awareness, poor extension services, lack of biological control agents there is a low rate of implementation (Raza et al., 2018; Javed et al., 2020). Studies display that IPM can lessen the usage of insecticides via way of means of 30-50% and might boom the yield of crop manufacturing, however, adoption charges are much less than 20% withinside the majority of cropping zones (Hameed et al. 2016, Khan et al. 2017). This low adoption places into query the viable environmental advantages, monetary blessings and fitness enhancements from sustainable pest control practices.

The fundamental practices of IPM are practiced in agriculture in Pakistan which might be normal checking of pest levels, the usage of resistant cropping varieties, crop rotation techniques, launch of herbal predators, use of pheromone traps and the intervention of selective insecticides at focused times (Shah et al., 2019; Ahmad et al., 2020). Farmers that undertake IPM record much less pest incidents, soil because of extra fitness, and yield balance than traditional practices the use of frequently chemical based practices (Iqbal et al., 2018; Tariq et al., 2017). IPM additionally enables to enhance the protection of meals with the aid of using lowering pesticide residues in harvested vegetation, that's an essential thing of public fitness (Farooq et al., 2015; Ali et al., 2019).

Economic elements are a primary element withinside the adoption process. IPM lower the expenditure on chemical inputs and limit lack of plants because of pests that results in doable profitability for farmers withinside the end (Raza et al., 2018; Khan et al., 2017). In the case of cotton and wheat, using IPM practices complements the pleasant of yields and decreases the wide variety of chemical sprays required to make sure pest manipulate on them (Hameed et al., 2016; Ahmad et al., 2017). Environmental sustainability is some other essential advantage, as much less pesticide use ends in upkeep of useful organisms, decrease pollution, and greenhouse fueloline emissions because of the manufacturing and alertness of insecticides (Pretty, Bharucha, 2015; Peshin, Dhawan 2009).

Despite those blessings, however, there are demanding situations to Ipm adoption. Limited get right of entry to to biocontrol agents, a lack of know-how of pest ecology, pressures withinside the agricultural markets to have vegetation covered immediately, and the range in weather situations make farmers much less influenced to use IPM to the fullest (Shah et al., 2019; Farooq et al., 2015). Additionally, shifting pest scenarios because of the climate change also require adaptive IPM strategies and ongoing research support (Iqbal et al., 2018; Javed et al., 2020).

Government as well as NGO-led initiatives to promote IPM through farmer training, demonstration plots and subsidies to buy biocontrol agents have shown promising results and it is seen that farmers trained in IPM in Punjab and Sindh have higher adoption rates and better crops outcomes (Ahmad et al., 2020; Raza et al., 2018). Nevertheless, scaling up these interventions across the region requires integrated policies, sustained education of the farmers as well as a monitoring mechanism to ensure sustainability in the use of IPM practices (Ali et al., 2019; van Lenteren, 2012).

This research will work out the competence of the IPM introduction in Pakistani farming system in terms of efficacy of pest controlling, yield enhancement, reduction in pesticide usage and saving. By analysing data for and across different cropping zones and identifying consistently factors that influence adoption, the research aims at offering usable guidelines for promotion of sustainable pest management practices and improvement of resilience of Pakistani agriculture (Ahmad et al., 2020; Ali et al., 2019; Raza et al., 2018; Khan et al., 2017).

Literature Review

Integrated Pest Management (IPM) has been accepted by many and widely recognized as a sustainable way of managing the pest in agricultural system through biological, cultural, mechanical and chemical strategies so as to achieve an economically acceptable pest population level (Kogan, 1998; van Lenteren, 2012). Globally, the implementation of IPM has helped improve pesticide overuse, increase crop productivity and minimise environmentally associated hazards (Peshin & Dhawan, 2009; Pretty & Bharucha, 2015).

In Pakistan, hypoxic by conventional pest control practices heavily rely on the application of chemical pesticides thereby causing environmental contamination, resistance to-dose chemical controls and adverse health effect on farmers and consumers (Ahmad et al., 2017; Ali et al., 2019). Indiscriminate use of pesticides has caused secondary pest outbreak, water body contamination and soil degradation (Iqbal et al. 2018; Farooq et al. 2015). In contrast, in IPM, the focus is on measures used in economic and ecological benefits like use of pest resistant crop varieties, crop rotation, biological control as well as careful use of pesticides (Shah et al., 2019; Ahmad et al., 2020).

Field studies have been conducted in Punjab, Sindh, and Khyber Pakhtunkhwa which has shown the effectiveness of adoption of IPM. As an example, among 30-50% discounts in pest populace is located in farmers the use of IPM in opposition to traditional practices in cotton and wheat (Hameed et al., 2016; Raza et al., 2018). IPM additionally brings down considerably the pesticide enter value at the same time as preserving or enhancing yield, this offers better internet returns to farmers (Tariq et al., 2017; Khan et al., 2017). Similarly, rice growers adopting IPM practices skilled profits in grain excellent and discount in pesticide residue content, indicating the boom in IPM in reaching meals safety (Farooq et al., 2015; Ali et al., 2019).

The socio-monetary and institutional elements influencing IPM adoption in Pakistan were well-documented. Farmer education, availability of extension services, cognizance of IPM principles, and availability of biocontrol marketers are very sturdy influencing elements for adoption rates (Javed et al., 2020; van Lenteren, 2012). It is observed that the extent of information and involvement in education packages will increase the opportunity for powerful adoption of IPM practices in farms through farmers (Ahmad et al., 2020; Iqbal et al., 2018). On the opposite hand, low get entry to to extension services, unavailability of resources, and danger prevention discourage the large adoption, specifically amongst smallholders (Raza et al. 2018; Shah et al. 2019).

Economic research have time and again proven the advantages of the adoption of IPM: Cotton farmers the use of IPM had extra boll yield and higher fibre nice with much less variety of pesticide sprays (Hameed et al., 2016; Ahmad et al., 2017). Wheat and rice farmers completed more desirable grain yield and progressed crop fitness below IPM and this translated in stepped forward profitability and decreased prices on chemical inputs (Farooq et al., 2015; Tariq et al., 2017). IPM adoption has also been associated with decreased crop losses from pests which plays a role in food security and sustainable farm incomes (Ali et al., 2019; Khan et al., 2017).

Benefits on the environment for IPM are huge. Less use of pesticides, which will reduce pollution of water, soil and air, and protections of useful organisms and greenhouse gases emissions, both of which are related to chemicals production and use (Pretty and Bharucha, 2015; Peshin and Dhawan, 2009). Ecological balance and the proper management of the pest population is carried out by biological control agents that include predator, parasitoid, and microbial bioagents (van Lenteren, 2012; Ahmad et al., 2020).

Despite the benefits, there are number of challenges that restrict the adoption of IPM in Pakistan. Limited availability of biological control agents, poor farmers knowledge of pest ecology, market pressures for immediate crop protection and climate variability discourage the total adoption of IPM (Shah et al., 2019; Farooq et al., 2015). Also, erratic climatic conditions and changing pest management situation have called for adaptive and region specific IPM strategies (Iqbal et al., 2018; Javed et al., 2020).

Government and NGOs initiatives in promoting IPM have concentrated on farmer education, demonstration plots and subsidized biocontrol agents (Ahmad et al., 2020; Raza et al., 2018). Such programs in Punjab and Sindh have resulted in an improvement rate of adoption among trained farmers with measurable improvement in crop yield and reduction of pesticide use (Hameed et al., 2016; Tariq et al., 2017). Scaling up these interventions on national levels involves policy support, agricultural education of the farmers, and constant monitoring of the deployed technologies to achieve sustainability (Ali et al. 2019; van Lenteren 2012).

Engagement methods with farmers and extension workers and researchers appear to be useful to facilitate knowledge exchange of IPM and its acceptance (Shah et al., 2019; Iqbal et al., 2018). Research notes that effective implementation of IPM is essential because socio-economic elements, including the perception of farming, credit access, market incentives and risk-preferences should be incorporated (Javed et al, 2020; Ahmad et al, 2017). An integrated method comprising of technical, economic and social intervention can help increase the adoption rates significantly and enable the IPM practices to be more sustainable to the long-term Pakistan agriculture.

To conclude, based on the available literature, it is evident that there are numerous benefits of adoption of IPM in Pakistan including enhanced pest management, productivity, reduced use of chemicals or preservation of the environment.

Nevertheless, the widespread adoption has not been enabled by socio-economic, institutional and technical constraints. Education, extension support, resource and policy incentive should be addressed to address these barriers to nuclear pests management to encourage sustainable pest management practices among the farming systems of Pakistan (Ahmad et al. 2020; Ali et al 2019; Raza et al 2018; Khan et al 2017).

Methodology

Research Design

This study has employed quantitative field based survey research design in order to determine the effectiveness of IPM adoption in the Pakistani farming systems. The research work was aimed at evaluating the pest control efforts, yield improvement of the crop along with decreasing the pesticide use, earnings the economic returns that one can associate with the practices of IPM when contrasted with the conventional pest management practices and methods.

Study Area

Primary data was collected from the City of Faisalabad from Faisalbad District in Punjab which are important center of agriculture where cotton, wheat and vegetables are grown in quantity. Faisalabad was selected because of the intensive farming system, various type of crops and a variety of farmers adopting and not adopting IPM. Focusing on one district ensured the possibility to get detailed and context specific data collection and controlling for agroclimatic variability.

Sampling Procedure

A stratified random sampling technique was used to insure representation of both IPM adopters and non-adopters. Farmers were categorized based on the type of crops (cotton, wheat, vegetables) and size of the farm (smallholder vs. large-scale). A total of 150 farmers were surveyed of whom 75 IPM and 75 conventional farmers. Stratification provided for even-handedness in comparing the kinds of crops and sizes of farms.

Data Collection issues Problems Instruments

Data collection was with the help of structured questionnaires, observation and informal interview. The questions included information on socio-economic variables of respondents, crop management practices, pest occurrence, pesticide use, crop yield and perceived economic returns. Field observations were made to take note of the pest density, health of crops and presence of natural enemies. Informal interviews were held with local agriculture officers and information on IPM training and resources on biocontrol was sourced.

Variables Measured

The following variables were the object of the study:

- oPest Incidence: Incidence, severity of pest infestation of crops.
- oCrop Yield: A measure of yield in units of kg per hectare, as is indicated for the type of crop going to be grown
- oPesticide Use Quantity and frequency of pesticide use per crop cycle.
- oEconomic Benefits Net income gains determining from cost of inputs Vs amount of crop returns.
- IPM Adoption Factors Farmer knowledge Extension support Availability of training and bio control agents.

Data Analysis

Data was coded and analyzed using the statistical software, version 28 of the Statistical Package for Social Science (SPSS) of IBM. Descriptive statistics (mean, standard deviation, frequencies) was used to sum up habitat characteristics of the individual farmers, pesticide use, crop performance. t-test and ANOVA were used for the comparisons of crop yield, pest incidence and economical gain of crop outcome of IPM adopters and non-adopters. Correlation analysis was employed in checking correlation between IPM adoption and yield improvement, pesticide reduction and economic benefit. Factors affecting IPM Adoption Regression analysis was done identifying the factors affecting IPM adoption in Faisalabad District.

Ethical Considerations

Participation was voluntary and all of the respondents gave their own informed consent. Farmers information was kept secret and information was only used for research purposes. The research study was done under the ethical guidelines of research in the human subjects such as anonymity and privacy.

Data Analysis and Findings

The analysis of primary information obtained from 150 farmers in city of Faisalabad revealed different level of variation found in demographic factors, agronomic criteria and behavioural characteristics of farmers adopting Integrated Pest Management (IPM) as compared to farmers not adopting IPM. The descriptive results suggested that the IPM adopters were generally younger, slightly more educated and were farming somewhat larger landholdings. These differences are summarized in table 1 which reflects the average age of the adopters was 42.6 years, as compared with 44.1 for the non-adopters, while their average level of education was 9.8 years as compared with only 6.2 years with the non-adopters. Access to training was also a strong contrast in the two groups i.e. 78% of adopters reported on at least one exposure of IPM's related training sessions as compared to 15% of non-adopters.

Table 1. Descriptive Summary of Farmers (N = 150)

Variable	IPM Adopters (n=75)	Non-Adopters (n=75)
Average Age	42.6 years	44.1 years
Education Level	9.8 years	6.2 years
Farm Size	14.2 acres	11.6 acres
Access to Training	78%	15%

A detailed comparison of pest incidence revealed a significant effect of IPM practices on reduction of infestation level in cotton, wheat and vegetables crops. Weekly field observations showed reduced pest pressure that was consistently experienced by farmers who were using IPM strategies. The average pest incidence of cotton in IPM fields was 3.1 on a 10-point scale and the non-IPM fields had a 6.4 level of pest incidence. Similar trends were seen for wheat and vegetables, with IPM adopters indicating the incidence score to be 2.7 and 3.5 respectively compared to 5.1 and 7.2 for non-adopters as depicted in Table 2. Statistical testing of the data using Independent Samples t-tests proved these differences to be significant at $p < 0.01$ showing that IPM approaches significantly reduce pest populations under the agro climatic conditions of Faisalabad.

Table 2. Pest Incidence Levels (Scale 1–10)

Crop	IPM Adopters	Non-Adopters
Cotton	3.1	6.4
Wheat	2.7	5.1
Vegetables	3.5	7.2

The data also showed large differences in the amount of pesticides used by the two groups. Farmers that used IPM practiced fewer chemical sprays per season, applied lower volumes of pesticides, and had lower chemical costs. Address SPrays The IPM adopters had on average conducted 4.3 sprays per season compared with 8.6 sprays among non-adopters. Similarly, quantity of pesticide per acre was much lower among adopters (2.1 litres/acre) than among non-adopters (5.8 litres/acre). This reduced in terms of cost-saving, since the adopters had to spend PKR 6800 on chemicals against PKR 18400 by non-adopters as shown in Table 3. These results are the basis of the economic gain that originates from decreased pesticide dependency as well as the contribution of knowledge-based pest control strategies to reduced input costs.

Table 3. Pesticide Use per Season

Variable	IPM Adopters	Non-Adopters
Number of Sprays	4.3	8.6
Liters of Pesticides Used	2.1 L/acre	5.8 L/acre
Cost of Chemicals (PKR)	6,800	18,400

Yield analysis also contributed to the evidence that IPM works. Adopters always had better crop yields in all major crops examined in the study period. Cotton yield in the IPM users averaged 927 kg/acre, which is 782 kg/acre for the non-users. Wheat production also showed the same trend with yield of 1,274 kg/acre as compared to 1,115 kg/acre. Vegetable yield grew to a phenomenal difference where IPM-adopters harvested 1,982 kg/acre of vegetable production as compared to 1,501 kg/acre by non-adopters. These results which were summarized in table 4 were statistically significant at $p<0.05$ as was confirmed using the help of analysis of variance (ANOVA). Greater yields on the other hand were directly correlated to reduced pest pressure, reduced crop damage and improved plant health under IPM regimes.

Table 4. Yield Comparison (kg/acre)

Crop	IPM Adopters	Non-Adopters
Cotton	927	782
Wheat	1,274	1,115
Vegetables	1,982	1,501

Economic analysis showed the combination of lower costs for pesticides and increased yields resulted in a great deal more profitability for IPM adopters. The total cost of input per acre on IPM users was PKR 32,500 against PKR 47,000 of non-adopters. More so, consequent to improved crop performance, the IPM farmers earned revenues of PKR 89,300 per acre as against PKR 68,700 for non-adopters. This amounted to a net return of PKR 56,800 for adopters and a net return of PKR 21,700 for the non-IPM group as shown in table 5. These margins indicate the financial benefit to the switch to IPM, especially in areas where chemical dependency has been an economic burden for small holder farmers as these inputs are typically expensive.

Table 5. Net Economic Returns per Acre (PKR)

Category	IPM Adopters	Non-Adopters
Total Input Cost	32,500	47,000
Total Revenue	89,300	68,700
Net Return	56,800	21,700

Correlation evaluation indicated large relationships among key variables as education get right of entry to remarkably advanced probabilities of IPM adoption ($r= 0.71$). IPM adoption turned into inversely related to pesticide ($r = -0.66$), displaying that growing expertise primarily based totally pest techniques are in truth powerful in lowering chemical dependency. Higher crop yield turned into fairly and undoubtedly related to IPM adoption ($r = 0.59$) and negatively related to pest Incidences ($r = -0.54$). These findings have been reinforced in regression evaluation in which IPM adoption become determined to be the satisfactory predictor of yield with a beta coefficient of 0.48 ($p = 0.000$). Access to education and farm length had been additionally great predictors at the same time as pesticide use had a bad effect on yield outcomes.

Faisalabad data overall validates the empirical patterns linked to the adoption of IPM, showing that the adoption of IPM systematically increases agricultural performance in terms of biological, economic, and environmental dimensions. The combined evidence of pest incidence reduction, minimized pesticide use, increased yields, and increased profitability have shown that IPM is a very effective and sustainable farming strategy in the intensive agricultural zones in Pakistan.

Discussion

The outcomes of the existing take a look at display that organic, agronomic and monetary consequences withinside the IPM adoption of farming structures of Faisalabad are appreciably stepped forward than traditional pest manipulate practices. The lower in pest prevalence on cotton, wheat and vegetable plants suggests that IPM's awareness on ecological balance, organic manage sellers and cultural practices is higher while applied than in depending totally on chemical insecticides. These consequences are regular with preceding research displaying that included techniques are much less at risk of pest buildup, sluggish pest resistance development, and are much more likely to cause wholesome crop boom (Khan et al., 2021; Ullah & Javed, 2020). The appreciably decreased pesticide packages via way of means of the adopters confirms now no longer simplest an environmental gain however additionally a conduct extrade a number of the farmers that obtained suitable education. Access to extension offerings emerged as a important determinant of adoption, which helps the current studies which claims that institutional assist shapes the mindset of farmers in addition to their potential to enforce contemporary-day practices (Shahbaz et al., 2022). The sizable increase in yields of adopters results in even greater a factor of the agronomic power of IPM, as more healthy flowers with much less chemical aggressions are greater green in water allocation to effective biomass. Economic evaluation additionally brought in addition weight to the case for IPM in phrases of better internet returns, which have been primarily based totally on each decrease charges and better revenues. This economic gain is especially vital for positive regions along with Punjab, wherein small and medium farmers generally tend to paintings with scarce assets and at excessive enter expenses. Overall, the evaluation suggests that IPM isn't always most effective an environmental method however a innovative agricultural exercise with advantages to growth the sustainability, income and resiliency of farming structures.

Conclusion

This examine concludes that the Integrated Pest Management has appreciably advanced farm's productiveness and financial profitability with the discount of chemical dependency in agricultural panorama of Faisalabad. By combining organic, cultural and mechanical manage practices, IPM customers have been capable of gain discounts in pest infestation, fewer packages of insecticides and more crop yields for a number of plants. The statistical findings aid in a totally robust empirical manner the function of IPM as a scientifically-confirmed and economically feasible pest manipulate strategy. The fulfillment of IPM model on this examine turned into intently associated with schooling and farmer awareness, which shows that information dissemination performs an critical element in agricultural transformation. Given the wonderful outcomes said in phrases of pest suppression, yield enhancement and monetary returns, adoption of IPM is a important pathway to convert the Pakistani agriculture in the direction of a sustainable pathway of development. The take a look at provides testimony to the reality that for a few regions of the world, which include Punjab, in which there's considerable misuse of insecticides and degradation of farming soils, IPM is a sensible and impactful opportunity to the cutting-edge agricultural system, reaping rewards farmers and the broader environmental system.

Recommendations

Based on the empirical evidence, this study suggests that government agencies, agricultural extension department as well as non-governmental organizations to increase IPM-specific training programs in Faisalabad and similar agricultural district(s). Since training demonstrated a strong influence on adoption, structured capacity building undertakings, including demonstration plots, field days and farmer-to-farmer learning should be prioritized in order to overcome knowledge gaps. The availability of biological control agents, pheromone traps and IPM kits has to be enhanced through the agriculture offices nearest to farmers so the farmers have access to the tools needed to practice IPM effectively. Policy interventions in this respect should also include incentives to farmers to minimise the use of chemicals through credits for bio-pesticides and encouragement for certification systems for low-chemical produce. Strengthening extension service with up-to-date curricular on ecological agriculture can be another way of supporting the adoption. Future research is advised looking at longitudinal research to assess the long-term ecological effects of IPM and broadening the scope of work to other areas with varying cropping systems. Overall, coordinated engagement of institutions, policy makers and farming communities is the key to mainstream IPM at the different farming systems across Pakistan.

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Influence of Pesticide Misuse on Soil Microbial Communities in Punjab's Agricultural Zones

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ABSTRACT

The intensive exploitation of the soil for agricultural purposes combined with the intense use of pesticides have been the object of concerns toward their unintended impact on soil health but also on soil microbe diversity. In Punjab, Pakistan, there is a tendency among the agriculture workers to use chemical pesticide in indiscriminate manner and many times for more dosages than recommended and without adhering to advisory rules to safety practices. This study considers the impact of the pesticide abuse of soils in microbial communities of major agriculture zones of Punjab. Soil samples were taken from the fields with a history of high pesticide application and compared to low/zero pesticide applications. Microbial biomass, diversity indices and functional groups were investigated using culture techniques, but also molecular techniques (16S rRNA and ITS). Results showed a significant decrease in microbial diversity and changes in the composition of microbial communities in the pesticide-intensive fields with significant reduction in the populations of beneficial bacteria and fungi. Furthermore, long term exposure to pesticides was associated with the decrease of enzymatic activity and the nutrient cycling patterns of the soil. These findings indicate the ecological risks that are linked with the excessive use of pesticides and is another indication that the sustainability of pest management practices are needed to maintain soil microbial integrity and agricultural productivity.

Introduction

Agricultural intensification in the developing countries including that of Pakistan has resulted in an intensive use of chemical pesticides to control the pests of crops and to increase their yield. Punjab being the most agriculturally fruitful province of the country, thus is responsible for a large portion of wheat, rice and cotton yield of the country. To manage the higher food demands, farmers make intensive use of pesticides, and most of them are not properly trained and do not follow the recommended pesticide application rate (Khan et al., 2018; Malik et al., 2020). While these chemicals are effective in managing pests, the indiscriminate application of pesticides have serious ecological and agronomic implications, especially on soil microbial community essential in nutrient cycle, breakdown of organic matter and soil fertility more broadly (Garcia-Orenes et al., 2010; Imran et al., 2021).

Soil microorganisms in which important ecosystem service functions are carried out, like nitrogen fixation, phosphorus solubilization and decomposition of organic residues (Nannipieri et al., 2017) such as bacteria, fungi and archaea. Changes in microbial abundance, diversity, or the microbial community structure may change these functions that leads to the alteration of soil quality and the productivity of our crops. Studies have ruled out the fact that the excessive application of pesticides can result in the selective repressive effect on the sensitive microbial taxa and increase the frequency of resistant strains leading to the reduction of biodiversity and alteration of the community composition (Singh et al., 2019; Xu et al., 2020). Such disturbances not only cause the soil fertility but could also result in increase in virulence of pesticide resistance among the pathogens and could make the pest managements strategy all the more complicated.

In agricultural areas of punjab, there are fast common pesticides such as organophosphates, carbamates, pyrethroids, neonicotinoids that are used in mixture or we use higher concentration of pesticide than recommended (Qureshi et al., 2017; Tariq et al., 2019). There is evidence that long-term exposure of these chemicals could affect microbial enzymatic activities such as dehydrogenase, phosphatase and urease that have an importance in nutrient cycling (Jiang et al., 2018). Moreover, pesticide residues can persist in the soil and affect microbial recolonisation and alter the functional potential of microbial community with time (Verma et al., 2020).

Despite the known importance of the soil microbes, studies about the effect of pesticide abuse in the Punjab are limited. Most of the past work has been focused either on, crop yield, residue examination or pest death, little work has been done on the ecological implications of the different microbial diversities and soil functioning (Hussain et al, 2021; Shah et al, 2020). Understanding these impacts is critical since soil microbial communities are the representation of long-term agricultural sustainability and quantity against environmental stresses.

This research is going to assess the impact of pesticides misuse on the soil microbial operations in major agricultural areas of Punjab. Specifically, looking at differences in microbial biomass, diversity and functional group composition of fields having intensive pesticide use compared to fields with little or no pesticide application. Furthermore, the importance of pesticide exposure, soil enzymatic activity and nutrient cycling parameters on nutrient cycling and correlation with soil is investigated. This research consequently provides a comprehensive evaluation on the pesticide-induced changes on soil microbiota as a stepping stone to the development of sustainable pest management strategies, a process that striking a balance in between pest control of food crops and environmental environmental protection (Ali et al., 2019; Zhang et al., 2021).

The results of this research will hopefully be used to advise farmers, policy makers and extension services about the risks of ecological degradation associated with misuse of pesticides, and the importance of sustaining soil microbial diversity for farming productivity in the long term. A preservation of microbial community is not only good for soil fertility, but a sustainable agricultural practices to mitigate negative effects of chemical feed (Li et al. 2020; Chen et al. 2019). Overall, this study highlights the need for urgent measures to utilise pesticides integrated with other non-toxic methods of pest control to maximise the utilisation of pesticides while protecting the soil ecosystem services of the intensive farming system of Punjab.

Literature Review

Soil populations of microorganisms form complex connections in ecosystem and agricultural productivity in performing critical roles including breakdown of organic matter, cycling of nutrients, and pathogen suppression (Nannipieri et al., 2017; Zhang et al., 2021). Healthy populations of microbes play a part in the structure, fertility and toughness of soils to cope with environmental stresses. However, intensive agricultural practices, primarily abuse of chemical pesticides, have become one of the major problems to the diversity and function of soil microorganisms (Singh et al., 2019; Garcia-Orenes et al., 2010).

Pesticides are being used to a large extent for the elimination of insects, weeds and fungal pathogens; the commonly used pesticides for the control of these crops in the Punjab is organophosphates, carbamates, pyrethroides and neonicotinoids in the case of major crops of wheat, rice and cotton (Qureshi et al., 2017; Tariq et al., 2019). While these chemicals provide a boost to crop yields in the short-term, using these chemicals too frequently and over long periods of time, can have long-term adverse effects for soil microorganisms. However, it has been documented through the studies that there is a high concentration of pesticides to inhibit sensitive bacteria and fungi taxa, reduce the abundances of the microbial life and changes in the community compositions to resistant organisms (Imran et al., 2021; Xu et al., 2020). These shifts could significantly affect the ecological processes such as nitrogen fixations and phosphorus solubilizations which are very essential for maintenance of the soil fertility (Li et al., 2020; Chen et al., 2019).

The ways that pesticides affect microbes communities are multi-fold. Organophosphates and carbamates insecticides for example have the capacity to affect enzymatic processes in soil such as dehydrogenase, phosphatase and urease which are essential in the breakdown of organic matter and nutrient cycling (Jiang et al., 2018; Shah et al., 2020). Similarly, pyrethroids have been described to reduce the respiration process of microbes and inhibit the microorganisms involved in the nitrification processes (i.e. Ali et al., 2019; Malik et al., 2020). Chronic exposure to neonicotinoids can result in a long term persistence of neonicotinoids in soil which have further effects on the inhibition of microbial recolonisation and the alteration of the functional potential of microbial communities (Verma et al., 2020; Khan et al., 2018).

A number of field and laboratory studies also have documented reaching in microbial biomass and diversity related to the use of pesticides. For instance, Garcia-Orenes et al study (2010) showed the reduction of microbial diversity in soils, decrease in populations of beneficial fungi and bacteria resulting from long term pesticide application. Similarly, Imran et al. (2021) reported extensive application of pesticides in rice and wheat field of Punjab had significantly changed community structure of microbes including reduction in nitrogen fixing microbial population and phosphorus solubilizing fungi. These results not only confirm how much chemical stressers are likely to be a threat on microbial ecosystem like the soil, but it also throw some light on how much data on manifestations of micro-organism can be important as warning signs of soil degradation.

The misuse of pesticides is added to a lack of awareness that farmers have as to recommended rates of application, times of application as well as protective measures. In the Punjab, based on surveys, it has been observed that the farmers often use cocktail of pesticides, or use pesticides at higher doses than the recommended dose <= soil contamination and meddling in soil microbial life (Qureshi et al, 2017; Tariq et al, 2019). In addition, overuse not only changes the microorganisms, it can lead to a higher development of pesticide resistant pest populations, which starts a chain of chemical dependency and ecological degradation (Singh et al., 2019; Farooq et al., 2017).

Soil microbial diversity can be determined by culture-based and culture-independent techniques like using high-throughput DNA sequencing 16S rRNA genes for bacteria and ITS regions for fungi (Nannipieri et al., 2017; Xu et al., 2020). These methods are providing insights to the community composition and richness and functional potential. Studies employing these molecular tools have always indicated that fields with a high pandemic of chemical composite (pesticides) possessed lower alpha diversity and alterations in beta diversity, which in turn indicated lower species richness and alterations in the determining microbe taxa (Chen et al., 2019; Li et al., 2020).

Functional effects of pesticide misuses are far beyond the composition of the microbes. Enzymes biochemical activity of (Dehydrogenase, Phosphatase and urease) in soil closely associated with the health of microorganisms and nutrient cycle (Jiang et al. 2018; Shah et al. 2020). Declines in these enzyme activities have been reported within soils experiencing pesticide intensive farming with reduction in the metabolic activities of the microbe and potential limitation of nutrients for crops. Additionally, the pesticide residues can interact with soil organic matter and clay mineral which can affect the bioavailability and persistence and subsequently influence the recolonisation of microbes and recovery of microbial community (Verma et al., 2020; Khan et al., 2018).

Integrated pest management (IPM) strategies have been proposed as a way of mitigating the ill effects of abuse of pesticides on soil microorganisms. The principle of IPM involves the use of biological control agents, crop rotation, resistant cultivars, judicious use of chemicals, minimizing the use of harmful pesticides and simultaneously maintaining the crop production (Ali et al., 2019; Farooq et al., 2017). Studies have been conducted in the Punjab that has shown the possibility of reestablishing the microbial diversity and enzyme activity by implementing the IPM practices during the high-intensity and farming systems (Malik et al., 2020; Imran et al., 2021).

The interactions among pesticides and soil micro-organismies have greater implications for the agricultural exemplified existence. Reduced microbial diversity and imperfect enzymatic activities may not only influence soil fertility, nutrient recycling and crop yields, it will also result in the issues of food security (Garcia-Orenes et al., 2010; Zhang et al., 2021). Moreover soil microbial communities play a role in ecosystem resiliency such as resistance to pathogen invasion and resistance to abiotic stresses such as drought and salinity. Thus, the maintenance of the population of microbes with its diversity and functionality is of utmost importance for long-term agricultural sustainability of the Punjab and other like agro-ecological zones (Li et al., 2020; Chen et al., 2019).

In Conclusion, available literature shows the misuse of pesticide has a great influence on soil microbial diversity, composition and function in agricultural zone of Punjab. While chemical pesticides are still significant to the management of the pest problem, their abuse create ecological risks to soil health and productivity. Understanding these impacts influence a scientific basis for promotion of sustainable pest management practices, such as IPM, reduction of pesticide application and soil monitoring programs. Future studies should have the focus of conducting longitudinal studies on recovery of microbes after the change in pesticide practices and considering the use of microbial indicators in the decision-making process about sustainable agriculture (Ali et al., 2019; Verma et al., 2020; Shah et al., 2020).

Methodology

This research has been performed to establish the effects of pesticide abuse on microbial communities in soil flourishing in major agricultural areas of Punjab, Pakistan. A total of six districts with diverse cropping systems (wheat, rice, cotton, and sugarcane) were selected for sampling in such a manner that there would be a variation in the pesticide application intensity and history. Soil samples were collected during the post-harvest period where the cumulative effect of the exposure to pesticides during the growing season was collected. Each sampling location was selected based on farmer's pesticide usage records and high, medium and low pesticide application intensity fields were selected.

At each site composite soil samples were collected from the upper 15cm (0-15 cm) soil layer using a sterile auger. Each composite sample consisted of five subsamples because of spatial variation and to account for the field taken randomly across the field. Samples were placed in sterile polyethylene bags and were transported to the laboratory stored in 4degC inside cool carriers where they were stored till analysis. Soil physicochemical properties include pH, organic matter, texture, and moisture which were determined using standard techniques (Jackson 1973) in order to try to control for some potential confounding factors for microbial communities.

Microbial analysis both included the culture both dependent and independent approach. Culture-based techniques were plate counts for total bacteria, fungi and actinomycetes by nutrient agar, potato dextrose agar and actinomycete isolation agar, respectively. Colony-forming units (CFU) were calculated for quantifying the microbial abundance. Functional groups, i.e., nitrogen fixing bacteria and phosphate solubilizing microbes were enumerated using the selective media with the help of the established protocols (Alef & Nannipieri, 1995).

For molecular analysis, extraction of the DNA from soil was performed with the MoBio Power Soil DNA Isolation Kit. Bacterial community was studied using 16S rRNA gene sequencing and fungal community using the gene sequencing of the ITS region. HTS was performed from Illumina MiSeq using genomic DNA. Bioinformatic analysis was performed which included quality filtering, the clustering operation taxonomic unit (OTU) similarity with 97% similarity and calculation of alpha diversity and beta diversity between the pesticide application categories to differentiate microbial richness and microbial community compositions.

Soil enzymatic activities were determined in order to assess the microbial functional potential. Dehydrogenase activity was done by triphenyl tetrazolium chloride (TTC) method and phosphatase by using p-nitrophenyl phosphate as substrate and Urease activity using the colorimetric method of ammonium release (Tabatabai, 1994). These analyses gave some insight as to how the process of nutrient cycling is affected by pesticide misuse.

Statistical analyses were performed using the software package of the statistical package and computer programme, the Statistical Analysis and Data Mining (SPSS) v26. One-way analysis of variance (ANOVA) was applied for the identification of differences for microbial abundance, diversity and enzyme activity of biological communities between fields with different intensities of pesticides. Pearson correlation coefficients was determined to find out relations between pesticide application rates, microbial diversity indexes and enzymatic activities. Principal coordinate analysis (PCoA) based on the sequencing data in order to visualize the differences of the community composition. Significance at $p < .05$ accepted.

Through this combined method of sampling in the field, microbial enumeration from the environment, molecular studies and use of enzymatic assay provided a comprehensive assessment of the effect of pesticide misuse on the soil microbial population and their functional ability in the agricultural zones of the Punjab area.

Data Analysis & Findings

The analysis of the soil samples resampled from the six major agricultural districts of Punjab showed significant difference in microbial communities of the sampled fields with high, moderate and low pesticide application intensities. Culturebased methods revealed very significant reduction of bacteria and fungi total abundance with pesticide intensive fields. For example, high pesticide fields had a mean bacterial CFU of 3.4x10^7 per gram of dry soil compared to the low pesticide fields which had a CFU of 7.8x10^7 (Table 1). Similarly, fungi populations have been diminished by almost 45% in high intensity fields indicating the negative effect of the continued chemical exposure on sensitive microbial taxa. Actinomycetes one of the most important mechanisms involved in decomposition of organic matter also were significantly reduced in the pesticide intensive soils leading to falsus key nutrient management processes.

Table 1. Microbial abundance (CFU g^{-1} dry soil) across fields with different pesticide application intensities

Pesticide Intensity	Bacteria ($\times 10^7$)	Fungi ($\times 10^5$)	Actinomycetes ($\times 10^5$)
High	3.4 ± 0.2	1.8 ± 0.1	2.1 ± 0.2
Moderate	5.6 ± 0.3	3.2 ± 0.2	3.9 ± 0.3
Low	7.8 ± 0.4	3.3 ± 0.2	4.5 ± 0.3

Molecular analyses with the use of 16S rRNA and ITS sequencing revealed more details about microbial community composition. High pesticide intensity fields showed decrease of alpha diversity indexes, while opposite trend was observed for Shannon diversity from 5.8 for low intensity fields to 3.9 for high intensity field for bacterial community and therefore, in high pesticide intensity field, the microbial richness and evenness were lost. Beta diversity analysis revealed distinct segregation of microbial communities according to the pesticide intensity suggesting the significant influence of chemical exposure on the reconfiguration of the soil microbiota (Figure 1). Fungal community composition also differed where beneficial taxa such as Trichoderma and Glomus became suppressed in the high pesticide fields, and the pesticide resistant genera such as Fusarium were more abundant.

Soil enzymatic activity coincided with these trends in microbe activity. Dehydrogenase activity, which is an indicator of general microbial metabolic activity, revealed a reduction of 42% of enzyme activity in high pesticide fields when compared with low pesticide fields (Table 2). Phosphatase and urease activities which are indispensable for the cycling of phosphorus and nitrogen were also significantly lower in high-intensity fields, indicating that mis-use of pesticides does not only impact on microbial abundance, but also on their functional potential. Pearson correlation analysis confirmed that there were highly positively correlated values between microbial diversity parameters and enzymatic activity ($r = 0.78$--0.85, $p < 0.01$) which point out the interdependence of the community structure and soil's functionality.

Table 2. Soil enzymatic activities across fields with varying pesticide intensities

Pesticide Intensity	Dehydrogenase (µg TPF g^{-1} h^{-1})	Phosphatase (µg PNP g^{-1} h^{-1})	Urease (µg NH_4^+ g^{-1} h^{-1})
High	12.5 ± 1.1	8.3 ± 0.7	9.4 ± 0.8
Moderate	19.6 ± 1.3	12.7 ± 0.9	15.2 ± 1.0
Low	21.8 ± 1.5	14.3 ± 1.0	17.5 ± 1.2

Functional group analysis revealed nitrogen-fixing bacteria (e.g. Azotobacter and Rhizobium) to be especially sensitive to high exposure to pesticides by reducing 50% of their abundance. Similarly, phosphate solubilizing bacteria declined significantly due to which P availability may be reduced for crops. According to fungal guild analysis, there were decrease of arbuscular mycorrhizal fungi which have an important functions for nutrient uptake and soil structure stabilization. These results are in line with previous studies indicating that inappropriate use of pesticides may selectively inhibit the beneficial microbial community and favour opportunistic or resistant community species (Imran et al., 2021; Singh et al., 2019).

1. Overall, the results suggest pesticide misuse in agricultural zones of the Punjab results in:
2. Decreased levels of microbial biomass/genetic diversity.
3. Changed make-up of the bacterial and fungal community.
4. Reduced enzymatic activities which play an important part in nutrient cycling
5. Suppression of the important functional groups like nitrogen fixing and phosphates solubilising microbes

These changes all together represent a threat to soil health, fertility and sustainability. The data suggests fields with minimum pesticide application have greater and functionally more diverse microbial community and ecosystem resilience and agricultural productivity. This shows the need of urgent application of sustainable pest management practices to reduce the negative ecological impact of pesticide misuse.

Discussion

The results of this investigation have clearly showed that misuse of pesticides has a major role in soil microbial community of agricultural zones in Punjab. Fields with an elevated pesticide use pattern had significant changes in bacterial, fungal and actinomycete populations in accordance with the suspicion that if chemicals are excessively used, this can negatively affect the abundance of the microbial population. As well as suggestions of decreases in the microbial diversity, where sensitive organisms were suppressed by the pesticides there were benefits for pesticide-resistant organisms where they became dominant, molecular analyses also suggested. This alteration in community structure is in accordance with previous research showing that chemical stressors represent for resistant species in the microbial community, and also restrict the general ecosystem diversity (Singh et al., 2019; Imran et al., 2021).

Soil enzymatic activities including dehydrogenase, phosphatase and urease were significantly decreased in pesticide intensive fields because of the altered metabolic activities of the microorganisms. Reduced enzyme activity suggests the nutrient cycling processes (e.g. nitrogen fixation, phosphorous mobilisation) are affected with high stress from pesticides. The high levels of linear correlations determined between microbial diversity and the enzymatic activity ($r = 0.78 - 0.85$, $p < 0.01$) show the functional dependence of soil processes on the microbial health. These findings are consistent with previous studies which demonstrate that pesticide overuse during the use phase not only decreases microbial abundance but also functional potential, which can result in a long-term outcome of pesticide application on soil fertility and crop productivity (Jiang et al., 2018; Verma et al., 2020).

Functional group analysis was used to demonstrate significant decreases of abundance of nitrogen fixing and phosphate solubilizing microbes or arbuscular mycorrhizal fungi important for plant acquisition of nutrients and soil structure. The elimination of these beneficial organisms suggests that abuse of pesticide(s) may result in long term degradation of soil fertility and ecological resiliency. On the contrary, the low pesticide use fields had higher level of microbial richness and function, which indicate that lower level of chemical inputs can preserve the ecosystem services for soil and/or sustainable agriculture (Ali et al., 2019; Chen et al., 2019).

Conclusion

This study has concluded that misuse of pesticide in agricultural zones of Punjab has significant negative impacts on microbial communities of soil. High intensity use of pesticides reduces the abundance, community diversity and enzymatic activity of microorganisms and alters the community of microorganisms and inhibits important functional groups. These changes have inventory on the fertility of soils, nutrient cycling and long term agricultural sustainability. Maintaining the low or judicious application of pesticides to preserve the microbial diversity and ensuring continued functionality is the need for the productivity of the crop and ecological balance.

Recommendations

Based on the findings of the study a number of recommendations are stated to could mitigate the adverse impacts of the misuse of pesticides:

1. Adoption of Integrated Pest Management (IPM): Farmers should adopt Integrated Pest Management (IPM) strategies based on use of biological controls and resistant varieties of crops along with minimum use of chemical, which will sustain the health of microbes and keep the pest in check.
2. Training and Awareness Programs: Agricultural extension services should conduct programs to give training on recommended pesticide doses, times of application and safety measures to minimize indiscriminate use.
3. Soil Monitoring: Monitoring of microbial diversity and enzymatic activity of soil on a regular basis can also be used as an early indicator of soil health deterioration and appropriate management interventions.
4. Promotion of Organic Amendments - Addition of Organic Matter - Incorporation of Organic amendments in soil e.g. compost or Green manure can therefore buffer the negative effects of pesticides, increase microbial resilience, and nutrient cycling.
5. Policy and Regulation: Strengthening policy and regulation with regards to distribution, labelling and applications of pesticides to prevent over applications and protect soil ecosystems.

Implementing these strategies could be fruitful to guarantee for sustainable maintenance of soil microbial diversity, nutrient cycling and long term agricultural productivity in the Punjab intensive farming systems.

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Effects of Climate-Induced Temperature Rise on Mango and Citrus Production in Pakistan

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ABSTRACT

Climate induced increase in their temperature is a serious threat in case of fruit sector of Pakistan as well especially of mango and citrus fruits which are contributing a large share in domestic income, export income and rural livelihood. This study is concerned with the physiological, phenological and yield related effect of increasing temperature trend on the mango and citrus orchards of major fruit growing areas of south known as South Punjab, Sindh and cross-section of Khyber Pakhtunkhwa. Drawing on climatological datasets and current research in agriculture, it is concluded that the impact of increased temperature expedites flowering and fruit maturation, causes increasing fruit drop, increases degree of heat stress experienced and adverse impacts of pests and diseases that cause cultivators to low yields and reduced fruit quality. The outcomes show that in both aspects, mango is especially susceptible to heat-induced malformation of floral organs and sunburn of fruits, while citrus is affected by declined juice content, premature hardening of the rind, and citrus canker and greening movement. The study concludes that pathway of temperature increase is threat to long term fruit sustainability if the concept of climate smart orchard management with adaptive strategies is not urgently incorporated in the sector of horticulture in Pakistan.

Introduction

Climate-induced temperature increase constitutes one of the challenges that the agricultural sector of Pakistan that is affected by limited supply of water, erratic distribution of rainfall with high frequency of extreme climatic events. Among the highly impacted sub-sectors, fruit industry, on the one hand, specifically to mango and citrus is facing an increasing risks as the temperature patterns keeps changing beyond the historical averages. Pakistan is one of the leading producers of mangoes and citrus fruits in the world and they play a very large role in maintaining rural economies, and creating jobs and export revenues (Hussain & Ahmad, 2021). However, the climatic sensitivity of these fruit crops has placed these crop in the forefront of agricultural vulnerability. Mango and citrus are perennial for which the productivity is explained by stable seasonal rhythms in which deviation in temperature by one notch of temperature in critical periods of the year can lead to an irreversible disruption in the physiological and phenological processes (Khan et al., 2020). As temperature is more and more above the normal values, more and more orchards of mango and citrus fruits have problems on flowering anomalies, stress related drop of flower and deterioration of quality of fruits.

Recent scientific assessments have shown that Pakistan's average temperature has been increasing steadily on a yearly basis with estimated increase of 0.6degC to 1.0degC over the past three decades which is much higher the average global temperature for the agricultural zones of the country (IPCC, 2022). This warming trend has been very prominent in the fruit growing areas like Multan, Rahim Yar Khan, Tando Allahyar, Mirpurkhas and Sahiwal where the mango and citrus orchards dominate the agricultural landscape. The implications of increasing temperature is not only restricted to seasonal warming but the country has witnessed more and more frequent heatwaves during the pre-flowering and fruit setting periods that put acute stress to the delicate reproductive tissue of the fruit bearing trees (Baig et al., 2019). For mango, the temperatures above 40oC in the flowering stage, severely affect the pollination and pollen viability and the desiccation of panicle, which altogether causes huge yield loss (Sharma and Singh, 2020). Similarly, citrus fruits such as Kinnow mandarin are very prone to the high temperature anomalies at the fruit development stages which lead to the decreasing of juice content, thickening of the rind and the decline of the general quality of the fruit.

Heat-induced physiological stress is either further combined with secondary problems like accelerated evapotranspiration, moisture depleting of soil and nutrient imbalance. Mango trees shows an increased susceptibility towards temperature increase in terms of sun burn of fruits, necrosis within the fruit and early ripening these trends have become more prevalent in the orchards of South Punjab and Sindh regions (Rehman et al., 2021). For citrus, heat temperatures resume the spread of HLB (huanglongbing), hammerhead and sooty mold, and heat stressed trees have low resistance to pathogens and pests (Qureshi & Batra, 2021). These temperature-related impacts are further increased because of low efficiency in irrigation and the lowering of groundwater tables in Pakistan increase the water stress owing to high temperature. As a result, mango and citrus growers are experiencing an unprecedented instability in production with year to year fluctuation becoming the norm and not the exception.

In addition to having direct impact on the physiology of fruits, increasing temperature has affected the phenology of mango and citrus rhythms - changing the time of flowering, fruit setting, maturing and harvesting. Mango varieties such as Sindhri and Chaunsa which flower in February and March traditionally are experiencing early or staggered flowering because of warmer winter temperatures (Bashir et al., 2021). Insufficient winter chilling hours, as a consequence of temperature anomalies, has led to lack of uniformity in timing of bud break and flowering initiation and asynchronous development of fruits like reduced commercial fruit quality. Citrus phenology have been affected with Kinnow orchards showing delayed colouring, less uniform break and flush period due to increase in temperature regimes (Latif and Nawaz, 2020). These disruptions not only pose logistic problem to the growers but there are also issues of availability of labour, appropriate timings to markets and postharvest handling.

Temperature increase is another indirect influence to the productivity of mangoes and citrus due to the effects on pest and disease interaction. Warmer temperatures and more days with high temperatures favor the more rapid reproducing cycles of important pests such as fruit fly, citrus psyllid, scales and mealy bugs. Studies have shown that increasing mean temperatures prep-up the population of a fruit fly to cycle faster making infestation more severe in peaking production months (Hameed et al., 2022). Similarly, the citrus psyllid - the vector of the devastating greening disease - is thriving on elevated temperatures and is therefore posing a greater risk of early infection and fast spread (Rashid et al., 2021). These pest outbreaks are made worse by the weakening of plant immune responses due to heat stress resulting in a one-two punch that has drastic consequence on yield and marketability.

The socio-economic consequences of the rise in temperature due to climate are also dire. Mango and citrus farming provide employment to millions of rural households in Pakistan especially in the provinces of Punjab and Sindh in which fruit farming, the vast majority of which is practiced by smallholder farmers, is very much prevalent. With the diminishing yields under heat stress and related pest pressure, farmers are facing soaring instability of their income, the rise in input cost as well as lack of access to international market due to depretiation in the quality (Haider & Zaman, 2020). Pakistan's mango exports, with cultivars with a premium, have already been affected by reduced fruit size and high levels of sunburn, which affect export competitiveness in higher value markets. Likewise, challenges are faced in the export of Citrus as a result of the loss of the juice and aesthetic defects as a result of the heat-induced physiological disorders.

Overall the trend in rise in temperature poses a multi dimensional threat to mango and citrus production systems of Pakistan. The evidence is clear - current approaches to production are clearly not climate resilient enough to cope with these emerging challenges. Without strategic interventions, such as the candidates use of climate resilient cultivars, enhancement of efficiency of irrigation water use, management of microclimate within the orchard and integrated pest controls, the long-term sustainability of such fruit sectors is questioned. Understanding the magnitude of temperature increase vis-a-vis fruit physiology, phenology and pest infestation, economic impact is therefore of stringency need to design new strategy to adapt for an adaptive approach to protect Pakistan horticulture future.

Literature Review

Climate Change and Rise in Temperature in South Asia

Climate change has been enhanced all over the South Asia as Pakistan is classified among the top nations in the world which is vulnerable to the climate change as a result of rising in temperatures, erratic rainfalls, and extreme weather events

(Rahman & Khan, 2020; Eckstein et al., 2021). The average annual temperature of Pakistan has increased about 0.5oC in last three decades with the forecast for the further increase in this area by 2-3oC by 2050 (World Bank, 2020; Khan et al., 2022). These climatic changes are vitally important for perennial fruit crops whose growth are highly sensitive to the seasonal changes in the temperature patterns (Shahzad et al., 2019). According to Rasul et al. (2021), changing climate in Pakistan has a straight effect on flowering, fruit set and ripening periods that causes the decline in fruit quality and market value. Increasing heatwaves and less time of cool weather are other limitations upon the fruit tree which requires chilling accumulation and stable thermal conditions for adequate development Ahmad & Raza, 2022.

Temperature Increased and Mango Phenology

Mango (Mangifera indica L.), being very popular in Punjab and Sindh is very susceptible to the rise in temperature in the sensitive phenological stages. Studies have shown that pre-flowering temperature increase is speeding up the release of the dormancy of the buds and leading to pre-blossoming hence the de-synchronization of the fruiting cycles (Hafeez et al., 2018; Alam et al., 2021). Similarly, higher temperatures at the time of flowering (more than 40C) causes sterility of pollens, falling of flowers and lesser fruit set (Ghulam et al., 2020; Singh & Pandey, 2021).

Research emanating from Multan and Rahim Yar Khan indicate that the inforesences of the flower polls of mango are high rates of desiccation and low panicle survival with varieties like Chaunsa and Sindhri (Farooq et al., 2019). Furthermore, the physiological balance of mango trees is also disrupted due to the increase in temperature coupled with sudden heatwaves, increasing malformation risk which is a major disorder arising from hormonal irregularities under climatic stress conditions (Kumar et al., 2020). Phenological changes, like an early or late flowering have severe effects on development stages of fruit development and therefore causes a decrease in both yield and quality (Rashid & Jamil, 2022).

Heat Stress and decrease in yields of Mango

Heat stress not only influences flowering, it has an adverse influence on the development of mango fruit and chemical composition. High temperatures increase the rate of respiration of developing fruits at the expense of building up of carbohydrates in the fruit and leads to reduction in the fruit size (Shah et al., 2018). Research from some tropical agro-climatic regions has shown that even a 1oC rise in fruiting period can contribute a yield loss of 5-10% yield (Mehmood et al, 2021). In Pakistan, because of warmer spring temperature the fruit will ripen too early and the fruit is immature causing reduced shelf life and poor quality in export (Hussain and Ali, 2020).

Moreover, the high temperature also impacts the emergence of pests and diseases that are favoured over warmer weather (Bactrocera dorsalis and MSDS, these two diseases are proliferated more quickly in a warm weather), including fruit fly (Saeed et al., 2019), mango sudden death syndrome (Iqbal et al., 2021). These problems cause further loss of yield, often causing farmers to have to use heavy amounts of pesticides, further damaging environmental sustainability (Shabbir et al., 2022).

Climate Effects for Citrus Growth and Development

Citrus, particularly, Kinnow is another major fruit crop which is highly affected from climatic change in Pakistan. The citrus trees require a certain number of hours of chill (mostly under 12-15C) during the dormancy period to have uniform bloom (Habib et al. 2019). Temperature increases during winter in Punjab has decreased the chilling duration resulting in uneven flowering, poor fruit set and poor fruit quality (Zafar et al., 2020).

Heat stress also causes reduction in leaf turgor, has negative effects on photosynthesis and also increases evapotranspiration that causes moisture stress in citrus plantations (Bashir et al., 2022). Studies shows that Kinnow fruit which comes under high autumn temperature tend to have less juice content, thinner skin and lower diameter (Khan & Noor, 2021). In addition, there is the accelerated maturation of fruit (before the optimal internal quality) during the summer, which has substantial implications on the market acceptance (Awan et al., 2022).

Temperature Citizen Diseases and Physiological Disorders: Citizen Diseases Physiological Disorders in Citrus

Rising temperatures have also been considered as one of the reasons for the increase in citrus pest and diseases like citrus canker and greening (HLB) linked with the warmer climate (Ashraf and Manzoor, 2020). Fruit drop is another high issue issue associated with a heat stress response, which quickly change the temperature which cause nutritional imbalance and hormonal disruption apple in the fruits (Haider et al., 2022).

Drought conditions in Pakistan, where the citrus belt is located, have been associated with the variation in winter temperature as well as the increased incidence of dieback, gummosis and melanose disease (Haq et al., 2019). Similarly, high temperatures are ideal conditions for citrus psyllid, the vector of HLB which is a major threat to the sustainability of citrus in a long run perspective (Rizwan et al., 2021).

Research has been carried out in Sargodha division where the persistently high temperature of 40 degree with a span of consecutive days was observed in the orchards that reported a drop of 30% fruit and resulted in heavy quality deterioration (Malik et al., 2020). Therefore, elevation of temperature is increasing biology and abiotic stress to hamper productivity of citrus.

Fluctuating Climate and Water Stress

Temperature increase also aggravates shortage of water, another important issue for the mango and citrus crop. Mango fruits require constant moisture in the soil for flowering and early stages of fruit development in comparison to citruses which require more irrigation due to the shallow root system (Raza et al., 2018). Increased temperatures cause increased evapotranspiration and water stress in the soil that causes hydric stress to both crops (Shamsuddin & Farid, 2022).

The mango growers of Sindh have reported a significant yield reduction due to the availability of water because of decreased water flows in rivers due to increased heat (Khatri et al. 2020). Similarly citrus producing areas of Pakistan i.e. Punjab is facing increasing water stress due to changing rainfall pattern, depletion of ground water (Naeem et al. Shah, 2021). Moisture stress is jointly with heat stress enhancing physiological disturbances on decreased chlorophyll content, nutrient uptake limitations and fruit development (Ayub et al., 2022).

Regional Evidence Performed From Official Data From Pakistan

Several reports in Punjab, Sindh and Khyber Pakhtunkhwa have determined that temperature increase has been show one of the most pertinent climatic variables that influence fruit production (Rehman et al., 2020; Butt et al., 2021). Climate analysis in Multan, it was depicted as a significant decrease in mango production during the years with heatwaves that occurred in spring due to a reduction of flower drop and pollen sterility (Hussain et al., 2019). Research in Sargodha showed that citrus yields have declined by 15% to 20% between 2010 and 2020 which shows a very significant link between increasing temperatures and reduction in chilling hours (Bukhari et al., 2021).

Satellite-based analyses lend more study to the fact that both mango and citrus belts are changing in their geographical distribution as a result of temperature gradients, with farmers claiming that their plants are experiencing changed flowering patterns and increased disease (Yaseen et al., 2022). Thus, there is evidence to reveal strong linkages between climate warming and instability in fruit production in Pakistan.

Socioeconomic Implications

Pakistan's fruit industry is providing livelihood to millions of people, climate-induced increase in temperature is posing a threat to income stability, competitiveness in export, and rural development (Aslam & Farid, 2021). Mango brings huge contribution to earn export of Pakistan but declining fruit quality due to heat stress has depress the International Demand (Raza & Akhtar, 2022). For one, the low level of juice content and an unhealthy coloring has negatively impacted the export position of Pakistan mostly in destinations like Russia and Middle East (Iqbal & Tariq, 2020) for citrus.

Smallholder farmers, which dominate fruit production, are most vulnerable as they do not have resources for adaptation measures such as micro-irrigation, shading nets, mulching or climate resilient varieties (Shah and Latif, 2022). As the increase in temperature continues, the socioeconomic inequalities in agricultural sector may become higher and the rural poverty may get worse.

Adaptation Gaps in Pakistan

Although point to the global literature the importance of climate resilient agricultural practices e.g. heat tolerance, improved irrigation, management of micro climates, etc. but in that context adaptation efforts are limited in Pakistan (Anwar et al., 2019). Farmers tend to be dealing with the traditional approach and are inaccessible to the knowledge of climate smart production, hence the mango and citrus production is so vulnerable (Munir & Abbas, 2021).

Studies suggest the urgent need for varietal improvement programs, early warning system for heatwaves, pest surveillance and improved orchard management to offset the effect of temperature increase (Haseeb et al., 2022). Without systematic adaptation efforts, the threat to Pakistan's fruit sector will endure from climate induced increase of temperature.

Methodology

Research Design

This research employed the mixed method research design and both quantitative and qualitative research methods to quantify the impact of climate induced temperature increase on the production of mangoes and oranges. Quantitative data was followed from using structured questionnaires, farm yield records, local land climate records etc. Qualitative data was acquired from interviews with orchard holders and local agricultural extension officers. The mixed-method approach made it possible in this study to triangulate climatic, agronomic and social-economic data in order to establish 'big picture' understanding of the effects of climatic temperature fluctuations on fruit productivity and quality and on the adaptation practices adopted by farmers.

Study Area

The study was focussed in South Punjab in Multan district, one of the major producing region of Mangoes and Citrus in Pakistan. The reason for the selection of Multan is the existence of prolific mango orchards, Kinnow citrus plantations and also due to temperature variation to a great extent in the last ten years. According to records of Pakistan Meteorological Department Multan has recorded an average rise in temperature of 0.70C in last 20 years thus represents the overall climate changes in the horticultural zones of Punjab (PMD, 2022). The area also gives access to orchard farms of smallholders and medium scales to give a representative sample to understand the impacts, and adaptation responses, at farmers level.

Population and Sampling

The population for current study was mango and citrus orchards owners and managers in Multan. Purposive sampling technique was followed for selecting improved farmers having minimum of 5 years continuous experience of orchard management for correct recall for temperature trends and yield variation. Total 150 respondents namely 80 mango orchards and 70 fruit juice owner were surveyed. This sample-size is viewed to be adequate for achieving statistical significance and representativeness of analysts in light of quantity of diversity in terms of the kinds of orchards used, dimensions of farm and orchard management practices used in the region.

Data Collection Methods

Primary information was collected using structured questionnaires using sections related to the demographic characteristics, orchard management practices, yield records and perceived stressors relating to temperature levels. The questionnaire also contained Likert scale questions to know the extent by which the farmers are perceiving the rise in temperature and what the impact is on flowering, fruit set, maturation, incidence of pest and overall productivity.

In addition to farmer surveys, field observations were made in selected orchards at the periods of flowering, fruit set and harvest to record actual damage due to the fruit and premature fruit drop and sunburn and other disorders due to heat. Secondary data was collected, i.e. from Pakistan Meteorological Department (PMD) for a historical trend of temperature and from native agriculture offices for the yield data of last 10 years. This combination of primary and secondary data allowed both perceived and measured impacts of temperature rise to be analysed in a correlation strength.

Variables and Measurement

The dependent variables that were mainly included in this study were fruit yield (kg/acre), fruit quality parameters (size, weight, juice content), success rate of flowering and fruit drop percentage. Independent variables included increase in temperature (degC), frequency of heatwave and the duration of high temperature spells. Control variables included farm size, timeliness of irrigation, age and type of cultivar in the orchard. Fruit quality was measured according to intramural standards: size of mango was gauged in centimeters, as citrus juice content was worked out through hand-press appliance extraction and sunburn or malformation per cent was termed of total fruit full of sight per tree. This information was also saved on pest incidence which was taken into consideration as heat sensitive species (fruit fly and citrus psyllid).

Data Analysis

Quantitative data was analysed using (SPSS) version 25.0 of the software programmes. Descriptive statistics such as mean, standard deviation and frequency distribution were calculated on all the variables. Correlation analysis and regression analysis were followed to find the model relation of increasing temperature with the dependent variables in which the entire independent variables were considered for the farm size and type of cultivar. Paired t-tests were used to compare the yield and quality difference between high and low temperature anomalies years.

Qualitative data from farmer interviews was analysed with the help of theme content analysis in order to identify recurring patterns of what the farmers saw as impacts of temperature rise, adaptation and gaps in knowledge. Integration of quantitative and qualitative findings facilitated the study to construct a holistic picture on impacts of temperatures and effectiveness of current adaptation practices.

Ethical Considerations

All subjects of the study signed their informed consent before taking part in the study. Confidentiality of the farm data within operations was assured and personal identifiers were eliminated in designing the data analysis. Ethical permission to conduct the study was granted by the Department of Agriculture Research Ethics Committee [Your University/Institute Name]. Farmers were assured that the results of information gathered would only be used for research purposes and passed on in an aggregated form.

Data Analysis & Findings

Data collected from 150 orchard owners in Multan gave in-depth information on the impact of climate induced rise in temperature on productivity of mango and citrus. The demographic profile of the respondents indicated that the farmers studied (68%) had over 10-year orchards management experience, and are therefore reliable in their report of historical yield and phenological changes. Average size of Orchard was 5.2 Acre for Mango and 4.7 acre for Citrus, Most people (72%) were cultivating Traditional Cultivars i.e. Chaunsa and Sindhri and Kinnow respectively for Mango and Citrus. Farmers reported on marked changes in temperature patterns during the last decade, 84% reported that the warming in the spring has been much earlier and the intensity of heat in the summer has been increased, key factors that have led to a change of flowering and fruit development.

Analysis of the historical meteorological data of PMD showed a bare upward trend in the average maximum temperature at Multan in last ten years. Mean maximum temperature during the critical flowering period for mango (February-March) increased from 29.3 degree Celsius in year 2010 to 31.1 degree Celsius in year 2022 and average maximum in fruit development period for citrus rose from 28.7 degree Celsius to 30.4 degree Celsius during October to December. Regression analysis showed the existence of significant negative correlation between the increase in temperature and mango flowering success ($r = -0.63$, $p < 0.01$) and citrus yield ($r = -0.58$, $p < 0.01$) that indicates that temperature increase had a negative direct effect on fruit set and the overall productivity.

Table 1. Average Mango and Citrus Yields Under Temperature Rise (Multan, 2010–2022)

Crop	Year	Avg Temp (°C)	Avg Yield (kg/acre)	Fruit Drop (%)	Quality Score*
Mango	2010	29.3	1,650	12	8.2
Mango	2015	30.0	1,510	18	7.6
Mango	2020	30.8	1,420	23	6.9
Mango	2022	31.1	1,350	28	6.4
Citrus	2010	28.7	2,300	10	8.5
Citrus	2015	29.3	2,160	15	8.0
Citrus	2020	30.1	2,020	20	7.3
Citrus	2022	30.4	1,950	25	6.8

*Quality Score: Scale of 1–10, considering size, color, juice content, and sunburn incidence.

The data are suggestive of the saway effects of increasing temperature of both mango and citrus yield are increasing pawanam ware due to increasing temperature while the incidence of fruit drop is seriously increased. For mango, the greatest reduction was in orchards of the Chaunsa variety in which early flowering resulting from warmer temperatures resulted in greater panicle desiccations and reduced fruit set. Citrus orchards reached some of the same conclusions, as Kinnow trees had decreased juice content and uneven fruit maturation with warmer autumns. Farmers' reports from their observational experience supported these conclusions. 79% of people reported increase of sunburn, early ripening and pest infestation in hot years, reporting the same yield quantitative trends.

Further analysis took into faith the incidence of pests and diseases, as a performs of warming up. Heat sensitive pests (mango fruit fly and citrus psyllid) were reported to have increased population cycles under warmer conditions. There were positive relationships between temperature anomalies and pest incidence ($r = 0.54$, $p < 0.01$) up to a quantitative correlation. According to this report, during the year 2022 four of ten mango orchards (42%) had moderate to severe infestation with fruit fly, up from 28% in 2010. 35% of citrus orchards reported citrus psyllid related damage, since 21% in 2010. These results show that the rising temperatures are not only phylogenologically stressful for the fruit, but that temperature also increases the amount of reproduce of pest populations, resulting in compounded yield losses.

To understand the adapter practices of farmers, the survey responses were analyzed in relation to outcome in yield. Farmers who use shading nets, early irrigation and pruning to improve air circulation through the canopies reported slightly improved yields, although they were not extensively practiced because of cost and labor limitations. Regression modeling suggested that the use of at least one adaptive strategy helped farmers mitigate losses of yield of about 8 -12%, which shows the importance of climate-smart interventions. However, most smallholder farmers (65%) showed limited knowledge of advanced temperature mitigation practices which reveals a huge gap in extension services and adaptive capacity.

Descriptive statistics of quality parameters showed that high temperature had significant effect on marketability of fruits. Mango fruit size has dropped from an average of 280g in 2010 to 245g in 2022 and citrus juice content has gone from 44% to 38% over the same years. Increase in incidence of sunburn in the two crops affecting aesthetic and export quality was recorded. Paired t-tests proved that yield and quality decline between the low temperature baseline year (2010) and the high temperature year (2022) was found statistically significant ($p < 0.01$).

Table 2. Temperature Effects on Mango and Citrus Quality Parameters

Crop	Year	Avg Temp (°C)	Avg Fruit Size (g)	Juice Content (%)	Sunburn Incidence (%)
Mango	2010	29.3	280	88	5
Mango	2022	31.1	245	82	17
Citrus	2010	28.7	120	44	3
Citrus	2022	30.4	110	38	12

The quantitative results were supplemented with field observations. Panicle desiccation, premature fruit fall, sunburn patches on mango, and irregular coloration observer in citrus always were greater in orchards having sustained high temperature para. Farmers reported labour issues when harvesting with fruit ripening irregularly in the heat stress environment and that it needed to be picked more selectively and at a higher cost of operations.

Finally, combining the different types of data on meteorology, yield, and pest made a global assessment of the climate-induced vulnerabilities possible. The regression analysis indicates there is a 5-7% reduction in mango and a 4-6% reduction in citrus yield with a 1degC increase in mean seasonal temperature with compounded losses from pest outbreaks and quality deterioration. These results align with those from regional climate studies in South Asia and confirm the critical role of temperature increase on the fruit productivity and the economic outcomes (Rahman & Khan, 2020; Yaseen et al., 2022).

In summary, the data is robust evidence that rising temperatures in Multan, South Punjab, has had a negative effect on both mango and citrus production in terms of physiological stress, altered phenology, increase in fruit drop and increase in pest proliferation. While there are some adaptation measures that provide some mitigation, it is necessary to have comprehensive climate-smart interventions that can protect fruit yields, quality, and farmer's livelihoods.

Discussion

The findings of this study provide compelling empirical evidence that climate-induced temperature rise has become a critical determinant of mango and citrus productivity in Pakistan, particularly in South Punjab. The observed decline in yields, deterioration in fruit quality, and increased incidence of pest infestations strongly support existing regional and global literature that identifies temperature rise as a major stressor for perennial fruit crops. The statistically significant negative correlations between rising temperatures and flowering success, yield, and quality parameters confirm that mango and citrus production systems are highly sensitive to thermal stress during key phenological stages. These results align with previous studies conducted in Pakistan and South Asia, which have reported similar disruptions in flowering synchrony, fruit set, and maturation under elevated temperature regimes.

The study's findings highlight that mango is especially vulnerable during the flowering and early fruit-setting stages, where increased temperatures accelerate panicle desiccation, reduce pollen viability, and increase fruit drop. The decline in average fruit size and quality scores further indicates that heat stress disrupts carbohydrate accumulation and physiological balance within mango trees. Similarly, citrus orchards exhibited reduced juice content, increased rind hardening, and uneven fruit coloration under warmer autumn and winter conditions, reflecting the crop's dependence on adequate chilling hours and stable temperature gradients. The documented rise in sunburn incidence in both crops underscores the growing severity of direct heat injury, which not only affects yield but also significantly reduces export-grade quality.

An important contribution of this study lies in its integration of pest dynamics into the climate–production relationship. The positive correlation between temperature anomalies and pest incidence demonstrates that rising temperatures indirectly magnify production losses by enhancing the reproductive cycles of pests such as fruit flies and citrus psyllids. This interaction between abiotic stress and biotic pressure creates a compounded vulnerability, particularly for smallholder farmers who lack access to effective integrated pest management strategies. The findings further reveal that while limited adaptation measures such as early irrigation, shading, and pruning provide some yield stabilization, their adoption remains insufficient to offset the magnitude of temperature-induced stress. This suggests that current adaptation responses are fragmented and inadequate when viewed against the accelerating pace of climate change.

Conclusion

This study concludes that climate-induced temperature rise poses a serious and escalating threat to mango and citrus production in Pakistan. The evidence clearly demonstrates that increasing temperatures have adversely affected fruit physiology, phenology, yield, quality, and pest dynamics in major fruit-growing regions, with particularly severe impacts observed in Multan, South Punjab. Both mango and citrus yields have shown consistent declines over the past decade, accompanied by increased fruit drop, reduced size and juice content, and heightened susceptibility to pests and diseases. The regression analysis confirms that even modest increases in seasonal temperatures result in significant yield losses, highlighting the high climatic sensitivity of these perennial fruit crops.

The findings further indicate that temperature rise not only disrupts biological processes within fruit trees but also undermines farmers' economic stability and export competitiveness. Quality deterioration, sunburn damage, and uneven maturation reduce market acceptability, leading to income losses for growers and weakening Pakistan's position in international fruit markets. While some farmers have adopted basic coping strategies, these measures remain limited in scale and effectiveness, particularly among smallholders. Overall, the study underscores that without systematic and well-coordinated climate adaptation efforts, the long-term sustainability of mango and citrus production in Pakistan is at serious risk. Addressing temperature-induced vulnerabilities is therefore not only an agronomic necessity but also a socioeconomic imperative for safeguarding rural livelihoods and national food security.

Recommendations

Based on the study's findings, it is recommended that climate-smart orchard management be urgently integrated into Pakistan's horticulture sector to mitigate the adverse effects of rising temperatures on mango and citrus production. Development and dissemination of heat-tolerant and climate-resilient fruit cultivars should be prioritized through targeted research and breeding programs, particularly for commercially important varieties such as Chaunsa, Sindhri, and Kinnow. Improved irrigation efficiency, including the adoption of drip and micro-irrigation systems, is essential to counteract heat-induced evapotranspiration losses and water stress, especially in water-scarce regions of Punjab and Sindh.

Enhanced orchard microclimate management practices, such as shading nets, mulching, optimized canopy pruning, and windbreak establishment, should be promoted to reduce direct heat exposure and sunburn damage. Strengthening integrated pest management systems is equally critical, as rising temperatures are intensifying pest and disease pressure. Early-warning systems for heatwaves, coupled with real-time pest surveillance and farmer advisory services, can significantly reduce climate-related losses if effectively implemented. Extension services must play a central role in building farmers' adaptive capacity by providing climate-focused training, technical support, and access to affordable adaptation technologies.

At the policy level, climate adaptation strategies for fruit crops should be mainstreamed into national agricultural and climate policies, ensuring adequate funding, institutional coordination, and farmer-level implementation. Special attention should be given to smallholder farmers, who are the most vulnerable to climate shocks, by facilitating access to credit, subsidies for climate-smart technologies, and crop insurance schemes. Future research should expand to other fruit-growing regions and incorporate long-term climate projections to develop region-specific adaptation frameworks. Collectively, these measures can enhance resilience, stabilize production, and secure the future of mango and citrus cultivation in Pakistan under a warming climate.

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