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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 24-280C 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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