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Optimizing Maize Growth and Soil Health Using Integrated Nutrient Management

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ABSTRACT

The incorporation of organic and inorganic fertilizers in maize production has gained increasing attention due to its potential to enhance crop yield and soil fertility. Maize being important cereal requires a balanced supply of nutrients for optimal growth and productivity. Inorganic fertilizers improve maize performance and soil properties i.e. pH, nutrient content and availability, their continuous use may lead to nutrient imbalances, soil acidification and excessive nitrate leaching. Contrariwise, organic fertilizers offer sustainable benefits but face challenges related to nutrient release, availability and transportation. This investigation highlights the significance of integrating organic and inorganic fertilizers as a sustainable approach to maize production. Results suggest that sole reliance on either fertilizer type is insufficient for long-term productivity. The collective application of organic and inorganic fertilizers enhances maize yield, improves soil health and supports sustainable agricultural practices. This study recommends integrated nutrient management as a viable strategy for improving maize productivity and ensuring food security.

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INTRODUCTION

Soil fertility management is critical factor in sustaining agricultural productivity, particularly in Asia. The traditional farming practices have relied on the crop-fallow system which allows arable land to remain fallow after cultivation to restore soil fertility. However, increasing population pressure and socio-economic constraints have significantly reduced fallow period, often eliminating it altogether [1]. This has led to a decline in soil fertility, necessitating adoption of alternative soil fertility management strategies.

The usage of both organic and inorganic fertilizers has been identified as a viable approach to improving crop yield and sustaining soil productivity [2]. Research indicates that organic fertilizers i.e. cow dung, poultry manure and farmyard manure are effective in enhancing soil health and increasing crop productivity, particularly for smallholder farmers [3]. Fertilizer application is crucial to replenishing soil nutrients depleted by the continuous cropping, ensuring adequate nutrient availability for optimal plant growth [4]. While organic fertilizers contribute to the long-term soil health by improving soil structure and microbial activity, their slow nutrient release rate can result in temporary nutrient deficiencies. Additionally, large quantities of organic fertilizers are often required, which can not be readily available for small-scale farmers [5,6,7].

Inorganic fertilizers provide an immediate supply of nutrients essential for plant growth but have limited residual effects and can contribute to soil degradation when used excessively [8]. The continuous and unbalanced application of inorganic fertilizers can lead to soil acidification, nutrient imbalances and reduced crop yields. Furthermore, inorganic fertilizers are often very costly and may not be readily accessible to resource-poor farmers. Maize (*Zea mays* L.), a high nutrient-demanding cereal crop, requires an adequate and balanced nutrition for optimal performance [9]. However, soil degradation resulting from the intensive cultivation and continuous use of inorganic fertilizers can limit nutrient uptake and adversely affect maize productivity [10].

Several studies have demonstrated that maintaining a continuous crop production solely through inorganic fertilization has not been successful in many regions. Consequently, there is a growing need to adopt the integrated soil fertility management practices that combine organic and inorganic fertilizers to enhance soil productivity and maize yield. Countries i.e. Tanzania, India and the Central African Republic have successfully implemented integrated nutrient management strategies to sustain soil fertility and improve crop performance. Excessive reliance on chemical fertilizers must be avoided due to their adverse effects on long-term soil productivity [11].

The research conducted has recommended the combined application of farmyard manure and NPK fertilizers for both sole and intercropped maize production [12,13]. These previous studies emphasize that soil productivity cannot be sustained through fertilizers alone but requires appropriate soil management practices that enhance organic matter accumulation and nutrient cycling. Given limitations of both organic and inorganic fertilizers when used independently then an integrated fertilization approach is necessary to optimize maize productivity while ensuring long-term soil health.

This study aims to evaluate the effects of the complementary applications of organic and inorganic fertilizers on maize production in Pakistan. By analyzing various fertilization strategies, this

research seeks to provide insights into sustainable maize production practices that can improve yield and soil fertility while mitigating adverse effects of exclusive reliance on either organic or inorganic fertilizers.

Materials and Methods

Experimental Site

The study was conducted at Arid Zone Research Center, Dera Ismail Khan (DI Khan), which have an arid climate with short rainy seasons occurring between July and early September. The experimental soil had sandy loam texture, very low organic matter content and a deep clay profile, making it suitable site for evaluating soil fertility management practices.

Experimental Design and Treatments

The experiment was laid out in a randomized complete block design (RCBD) with three replications. Four fertilizer treatments were applied:

1. Control (no fertilizer application)
2. Inorganic fertilizer (NPK at 150-90-60 kg ha^{-1})
3. Farmyard manure (FM) at a recommended rate
4. Combined application of NPK (150-90-60 kg ha^{-1}) and FM

Each experimental plot measured **5 × 5 m²** with uniform spacing between plots and replications to minimize treatment interactions.

Crop Management and Fertilizer Application

Maize cultivar 'Shahenshaw' was used for the experiment. Farmyard manure was incorporated into the soil one week before sowing to allow for decomposition and nutrient mineralization. Phosphorus (P) and potassium (K) were applied as a basal dose at the time of planting, while nitrogen (N) was applied in three equal splits at the first, second and third irrigation stages through ring application around the maize plants to optimize nutrient uptake.

Chemical weed control was performed as required to prevent weed competition. Maize was harvested 120 days after planting and the grains were sun-dried to a moisture content of 15–18% before further analysis.

Data Collection and Analysis

Growth and yield parameters were recorded, including:

- Plant height (cm)
- Cob weight (g)
- Grain yield (kg ha^{-1})
- Soil nutrient content (N, P and K) post-harvest

Statistical analysis was conducted using Analysis of Variance (ANOVA) to determine the significance of treatment effects. Mean comparisons were performed using the Least Significant Difference (LSD) test at a 5% probability level to assess differences among treatments.

Table 1: Characteristics of soil and enriched fertilizers

Characteristic	Unit	Soil	Farm Manure
pH		7.6	6.81
Organic Carbon (%)	%	0.59	7.68
Total N (%)	%	0.21	0.73
Available P (ppm)	ppm	10.03	0.84
Available K (ppm)	ppm	98.64	0.96
CEC (cmol/kg)	cmol/kg	5.09	
Texture		Sandy Loam	

Results

Plant Height

Fertilization had a significant impact on maize growth and yield parameters. Among the treatments, the tallest plants (250.25 cm) were recorded in plots receiving the combined application of NPK and farmyard manure (FM). Plants treated with NPK alone exhibited a slightly shorter height (243.11 cm), while those in the FM-only plots were moderately shorter than the NPK treatment. In contrast, maize plants in the control plots (no fertilization) attained the shortest height, highlighting the essential role of nutrient application in promoting vegetative growth (Figure 1).

Cob Weight

Similarly, fertilization positively influenced cob weight. The highest average cob weight (165.3 g) was observed in the NPK + FM treatment, followed closely by NPK alone (146 g) and FM (130 g). In comparison, maize grown in the control plots produced significantly smaller cobs, averaging 110 g, further emphasizing the importance of fertilization in improving cob development (Figure 1).

Grain Yield

Grain yield followed a comparable trend, with the highest yield (3.79 t ha^{-1}) recorded in the NPK + FM treatment, followed by NPK alone (3.29 t ha^{-1}) and FM alone (3.11 t ha^{-1}). The control treatment produced the lowest yield (2.55 t ha^{-1}), demonstrating the necessity of external nutrient supplementation for optimal maize productivity (Figure 1).

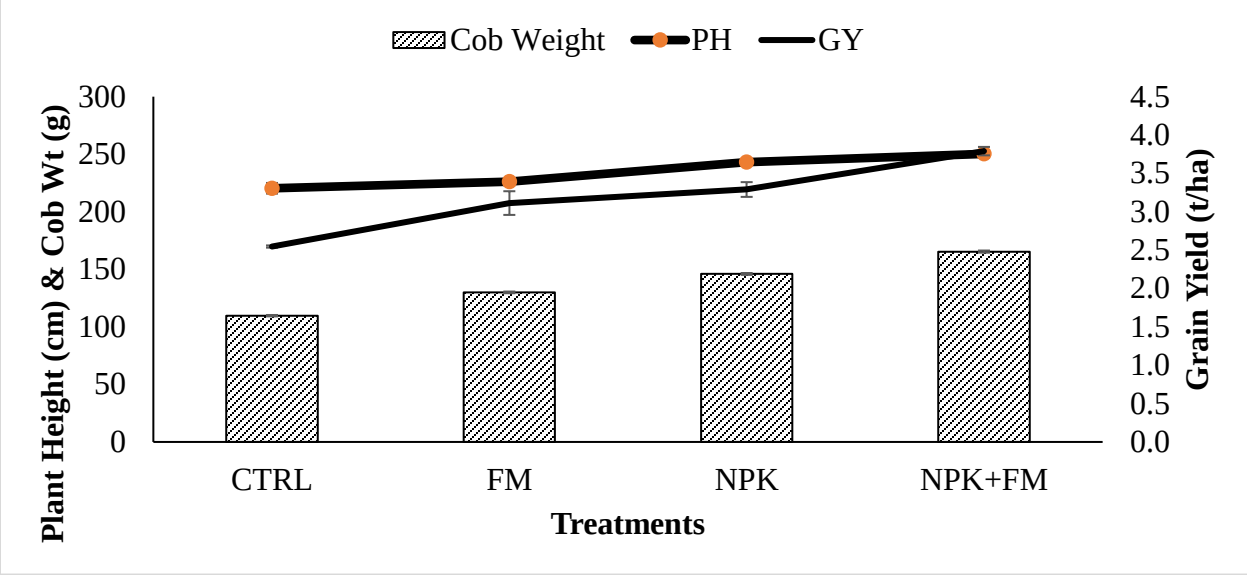

Figure 1. Effect of NPK and organic fertilizers on plant height, cob weight and grain yield of maize

The application of different fertilization treatments significantly influenced soil nitrogen (N), phosphorus (P) and potassium (K) content. Highest values for all the nutrients were observed in the combined NPK + FM treatment, followed by NPK and FM alone and the control (CTRL) treatment, which exhibited the lowest nutrient concentrations.

Soil Nitrogen (N) Content

Soil nitrogen (%) was markedly influenced by fertilization, with NPK + FM treatment recording the highest nitrogen content, exceeding 1.0%. NPK-only treatment also showed a substantial increase in soil nitrogen compared to the FM and control treatments. FM-only treatment exhibited moderate nitrogen enrichment, whereas the control plots had the lowest nitrogen levels, highlighting the importance of external nutrient inputs for maintaining soil fertility (Figure 2).

Soil Phosphorus (P) Content

The available phosphorus levels (ppm) followed similar trend across treatments. NPK + FM combination resulted in highest soil phosphorus concentration, indicating enhanced phosphorus retention when organic and inorganic fertilizers are integrated. The NPK-alone treatment also improved phosphorus availability, albeit to a lesser extent than NPK + FM. The FM-only plots showed minimal phosphorus enhancement, while the control treatment exhibited the lowest phosphorus content, emphasizing the need for fertilization to maintain adequate phosphorus levels for plant uptake (Figure 2).

Soil Potassium (K) Content

Soil potassium levels (ppm) increased progressively with the fertilizer application, with highest potassium content recorded in the NPK + FM treatment. The NPK treatment alone also contributed significantly to soil potassium improvement. Meanwhile, FM treatment demonstrated moderate potassium enhancement, reinforcing the role of organic amendments in nutrient retention. In contrast, control plots had the lowest soil potassium levels, indicating nutrient depletion in the absence of fertilization (Figure 2).

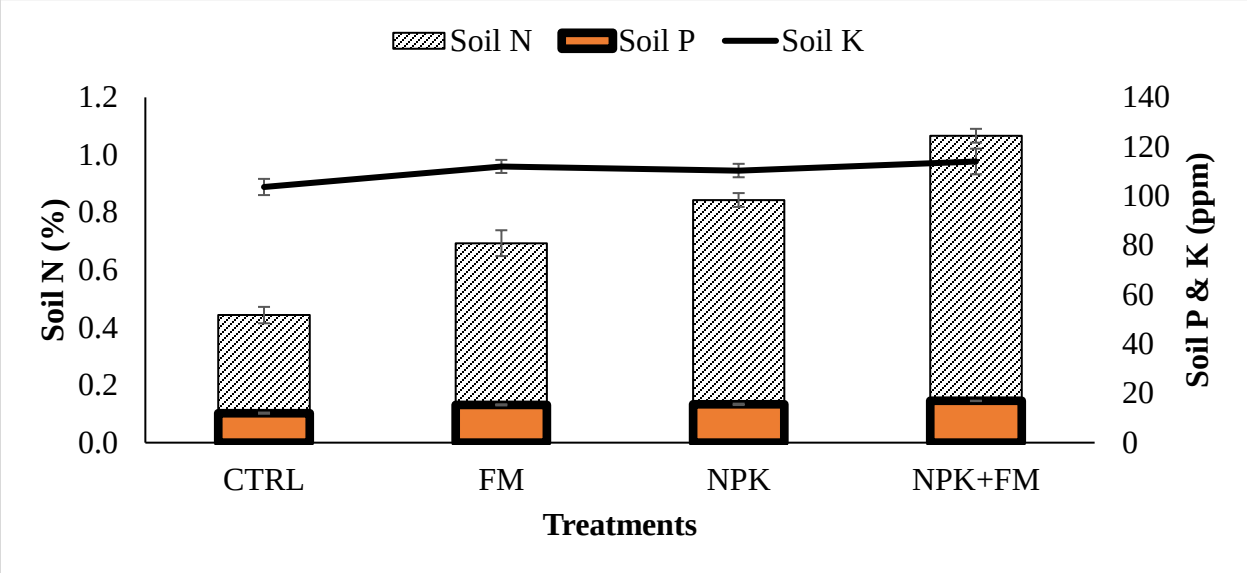

Figure 2. Effect of NPK and organic fertilizers on soil N, P and K contents

Discussion

The outcomes of the study indicate that maize growth, yield and soil fertility were significantly influenced by fertilization, with highest performance observed in combined NPK + FM treatment. The superior plant height, cob weight and grain yield in this treatment demonstrate benefits of integrating organic and inorganic nutrient sources for optimal maize production. These results align with the previous studies highlighting role of balanced fertilization in enhancing crop productivity and sustaining soil fertility [14,15].

Maize plant height was significantly improved by fertilization, with tallest plants (250.25 cm) recorded in NPK + FM treatment. This was followed by NPK alone (243.11 cm), while FM application alone resulted in moderately shorter plants. lowest plant height was observed in control plots, where nutrient deficiency restricted vegetative growth. These findings emphasize crucial role of balanced fertilization in improving maize growth and suggest that integration of organic and inorganic fertilizers provides more sustained nutrient supply for optimal plant development. Similar results have been reported by Mamuye et al. [16] who found that organic amendments, when supplemented with inorganic nutrients, significantly improve maize vegetative growth.

The observed differences in plant height among treatments can be attributed to variations in nutrient availability. NPK fertilizers provide an immediate nutrient boost, promoting rapid vegetative growth, while organic manure improves soil structure, microbial activity and gradual nutrient release. comparable performance of NPK + FM and NPK alone suggests that enriched organic fertilizers can effectively supplement synthetic fertilizers while ensuring sustained nutrient supply.

Fertilization significantly influenced cob weight, with heaviest cobs (165.3 g) observed in NPK + FM treatment. This was closely followed by NPK alone (146 g) and FM alone (130 g), while control treatment resulted in significantly lighter cobs (110 g). enhanced cob weight in fertilized treatments indicates that adequate nutrient supply supports better grain filling and kernel development. comparable performance of NPK + FM and NPK alone suggests that organic amendments can enhance cob formation when used alongside inorganic fertilizers. These findings align with studies by Gezahegn et al. [16] which reported that combination of organic and inorganic fertilizers improved maize ear weight due to better nutrient availability.

Grain yield followed similar trend, with highest yield (3.79 t ha^{-1}) recorded in NPK + FM treatment, followed by NPK alone (3.29 t ha^{-1}) and FM alone (3.11 t ha^{-1}). lowest yield (2.55 t ha^{-1}) was recorded in control plots, demonstrating necessity of external nutrient supplementation for optimal maize productivity. improved grain yield in NPK + FM plots suggests that organic amendments enhance nutrient retention and uptake efficiency, leading to better crop performance. results align with previous findings by Ejigu et al. [18] who observed that integrated fertilization strategies resulted in significantly higher maize yields than sole organic or inorganic fertilization.

The improvements in soil nitrogen, phosphorus and potassium levels following fertilization highlight role of organic and inorganic nutrient integration in soil fertility management. highest nutrient concentrations were observed in NPK + FM treatment, reinforcing benefits of organic amendments in improving nutrient retention and microbial activity. gradual release of nitrogen from organic sources ensures sustained availability, reducing risks of nitrogen volatilization and leaching commonly associated with inorganic fertilizers [10].

The positive impact of fertilization on soil nutrient status aligns with findings from previous studies. Hossain et al. [12] and Tayagi et al. [13] reported that combined applications of farmyard manure and NPK fertilizers improved soil organic matter content and nutrient availability, leading to enhanced crop performance. results of present study suggest that organic amendments not only supplement nutrient supply but also improve soil structure and microbial activity, contributing to long-term agricultural sustainability.

Conclusion

The findings of this study support adoption of integrated fertilization strategies for sustainable maize production in arid regions. ability of enriched organic fertilizers to provide comparable yields to inorganic fertilizers alone suggests that farmers can reduce reliance on chemical inputs while maintaining high productivity. This approach not only mitigates environmental risks associated with excessive chemical fertilizer use but also enhances soil resilience against degradation.

Furthermore, study underscores importance of optimizing fertilization strategies based on nutrient composition and application frequency. superior performance of NPK + FM compared to FM alone indicates that organic manure requires proper enrichment and fortification to achieve maximum effectiveness. Future research should focus on determining optimal application rates and timing for different organic amendments to further enhance nutrient use efficiency and crop productivity.

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