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Effect Of Different Levels Of Phosphorus Applied With Biochar And Poultry Manure On Maize Yield And Phosphorus Use Efficiency

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ABSTRACT

To investigate the effects of different rates of P application in the combination of biochar and poultry manure on growth, yield and nutrient uptake of maize (Zea mays L.) a field experiment was carried out. The treatments were arranged in a randomized complete block design with three replications with the following treatments: control and combinations of phosphorus (0, 60, 90 and 120 kg ha-1), biochar (10 t ha-1) and poultry manure (10 t ha-1). There was a significant difference between treatments and the best treatment was T8, which was 120 kg ha-1 Phosphorus, without any application of poultry manure, with 10 t ha-1 biochar. T8 recorded the highest plant height (205 cm), biological yield (11022 kg ha-1), grain yield (4552 kg ha-1) and cob weight (208.3 g). It also achieved the maximum thousand grain weight (297 g), nitrogen content in straw (0.87%) and grain (1.96%), total nitrogen uptake (145.45 kg ha-1), total Phosphorus uptake (51.59 kg ha-1) and total potassium uptake (105.82 kg ha-1). The highest Phosphorus use efficiency (51.44) was observed in treatment T8. The results indicate that the combined use of 120 kg ha-1 phosphorus and 10 t ha-1 biochar markedly boosts maize productivity and nutrients accumulation and should be recommended to enhance yield of maize under similar agro-ecological zones.

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Keywords: Biochar, Maize, Phosphorus, Poultry Manure, Nutrient Uptake, Phosphorus Use Efficiency

Introduction

Maize (Zea mays L.), the third most important cereal crop behind wheat and rice, is of great value. Maize is grown widely in Pakistan, however productivity levels of the crop in many regions are below due to low levels of efficient nutrient use and soil degradation. Plants require phosphorus (P) as a macronutrient for their growth and development, and only uptake orthophosphate ions in the soil solution which occur in low concentrations (Simpson et al., 2011; Ryan et al., 1985). Therefore, low P availability is considered one of the most important constraints for crop production (Balemi and Negisho, 2012).

Biochar is a carbon-based product generated by pyrolysing biomass in the absence of, or with minimal, oxygen, and has a very porous and high surface area structure. It can be used to improve the availability of P, because of its capacity to decrease adsorption as well as increase soil nutrient and water holding capacity (Lehmann and Joseph, 2009; Cui et al., 2011; Glaser et al., 2015). The other advantage of using poultry manure is that it contains nitrogen, Phosphorus and Potassium (P, K) and also gives better soil structure, nutrient holding capacity, aeration and moisture holding capacity (Deksissa et al., 2008; Garg and Bahl, 2008; Warren et al., 2006).

Phosphorus nutrition has been widely reported as an important factor controlling maize growth, yield development and nutrient-use efficiency. Ahmad Alias et al. (2003) and Masood et al. (2011) showed that maize yield and yield components responded significantly to different phosphorus levels, whereas Khan et al. (2014) reported improved maize phenology and yield under balanced nitrogen and phosphorus management. The importance of efficient phosphorus management for sustainable crop production has also been highlighted by Buresh et al. (1997), Smil (2000), Roberts and Johnston (2015) and Dhillon et al. (2017). Moreover, Gaume et al. (2001), Schaffert (2003) and Kochian et al. (2004) described the role of root growth, phosphorus acquisition and plant adaptation mechanisms under low-phosphorus or stress conditions. Organic amendments and biochar are also important for improving soil fertility and nutrient availability. Boateng et al. (2006) reported improved maize growth and yield with poultry manure, while Liu et al. (2013), Lehmann and Joseph (2015), Bashir et al. (2021), da Silva Carneiro et al. (2021) and Khan et al. (2025) reported that biochar, organic amendments and phosphate-solubilizing approaches can improve crop productivity and soil nutrient dynamics. Similarly, Christel et al. (2014), Dai et al. (2016), Dai et al. (2020), Parvage et al. (2013), Wang et al. (2015) and Zhu et al. (2018) showed that organic residues, biochar and phosphorus-based amendments can affect phosphorus release, recycling, availability and retention in agricultural soils.

Combined application of mineral P with organic amendments may thus be more effective in improving the plant growth, yield and uptake of maize than mineral P alone. The present study was conducted to find out the yield of maize under different rates of phosphorus application with biochar and poultry manure, the uptake of N, P and K under these treatments and to recommend maximum and economical production of maize under the condition of Peshawar for different rates of P

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application.

Materials and Methods

Towards this end, a field experiment was carried out at the University Research Farm, The University of Agriculture, Peshawar in 2024 growing season to elucidate the impact of various P rates incorporated with biochar and poultry manure on maize yield and P use efficiency. Jalal variety of maize was planted on 14 July 2024. The trial was laid out in randomized complete block design (RCBD) with three replications.

A total of twelve treatments were used in the experiment, which consisted of a control, four treatments with phosphorus at 0, 60, 90 and 120 kg per ha in the form of single superphosphate (SSP), four treatments with phosphorus plus biochar (at 10 t ha-1) and four treatments with phosphorus plus poultry manure (at 10 t ha-1). Poultry manure and biochar were applied 15 days prior to planting and bedded during land preparation. Same agronomic practices were applied in all plots (plane irrigation, weeding, pest control).

The observations were taken for plant height, biological yield, cob weight, straw yield, grain yield, thousand grain weight, nutrient content in straw and grain, nutrient uptake and Phosphorus use efficiency. Composite soil samples (0–15 cm) and plant samples were examined using standard laboratory procedures. Soil pH was determined according to McLean (1982), although electrical conductivity was measured following Richards (1954). Organic matter was determined using the technique called by Nelson and Sommer (1996). Nitrogen was analyzed following Bremner and Mulvaney (1982), and inorganic nitrogen forms were determined according to Mulvaney (1996). Available phosphorus and potassium were extracted and determined using the AB-DTPA method described by Soltanpour and Schwab (1977). Khan and Khan (2026) supported the use of pH and electrical conductivity (EC) as basic physicochemical indicators, with other physicochemical variables for assessing the environmental quality. Analysis of variance (ANOVA) and least significant difference (LSD) was used to compare treatment means according to Steel and Torrie (1981). All graphs in this paper have been created in Python using the means of the experimental results.

Results and Discussion

Initial soil properties

The experimental soil was a non-saline, alkaline and calcareous silty clay loam that had low organic matter and low AB-DTPA extractable Phosphorus. The first few physicochemical properties are listed here.

Table 1 Physico-chemical properties of the experimental soil.

Property	Unit	Value
Sand	%	15.24
Silt	%	51.51
Clay	%	33.25
Texture class		Silty clay loam

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pH		7.76
EC	dS m-1	0.28
Organic matter	%	0.69
Lime content	%	16.3
AB-DTPA extractable-P	mg kg-1	3.6

Growth and yield attributes

Maize growth and yield attributes were enhanced with Phosphorus application with biochar and poultry manure as compared to the control. Plant height grew from 151.6 cm to 205 cm for the control and T8 (120 kg P ha-1 + 10 t ha-1 biochar), respectively, and the biochar treatment T8 resulted in an increase in the biological yield from 8099 to 11022 kg ha-1. The pattern was repeated for cob weight, straw yield and grain yield and thousand grain weight. The maximum cob weight (208.3 g), straw yield (6470.6 kg ha-1), grain yield (4552 kg ha-1) and thousand grain weight (297 g) were recorded in T8. The biochar treatments also gave improved growth and yield over control, although generally not as much as the biochar treatments when applied at the highest P level, the poultry manure treatments also produced growth and yield improvements over control. The findings suggest that both Phosphorus fertilization and biochar significantly enhanced maize productivity, consistent with previous studies showing that organic amendments boost maize plant growth and yield (Gunes et al., 2014; Santos et al., 2019; Agbede, 2025).

The combined application of phosphorus and biochar resulted in the improvement of plant height, biological yield, cob weight, straw yield, grain yield and thousand grain weight, which could be explained by the increased nutrient retention, better soil physical properties and increased availability of phosphorus in the root zone. Biochar can rally soil porosity, moisture retention and nutrient-holding capacity, even though phosphorus ropes root development, energy transfer and reproductive growth in maize. Therefore, the grander concert of T8 indicates that biochar helped the useful phosphorus persist more obtainable for plant uptake, resulting in healthier growth and yield formation. Comparable positive effects of biochar, phosphorus and organic amendments on crop growth and yield have also been reported by Inal et al. (2015), Santos et al. (2019), Hu et al. (2023) and Agbede (2025).

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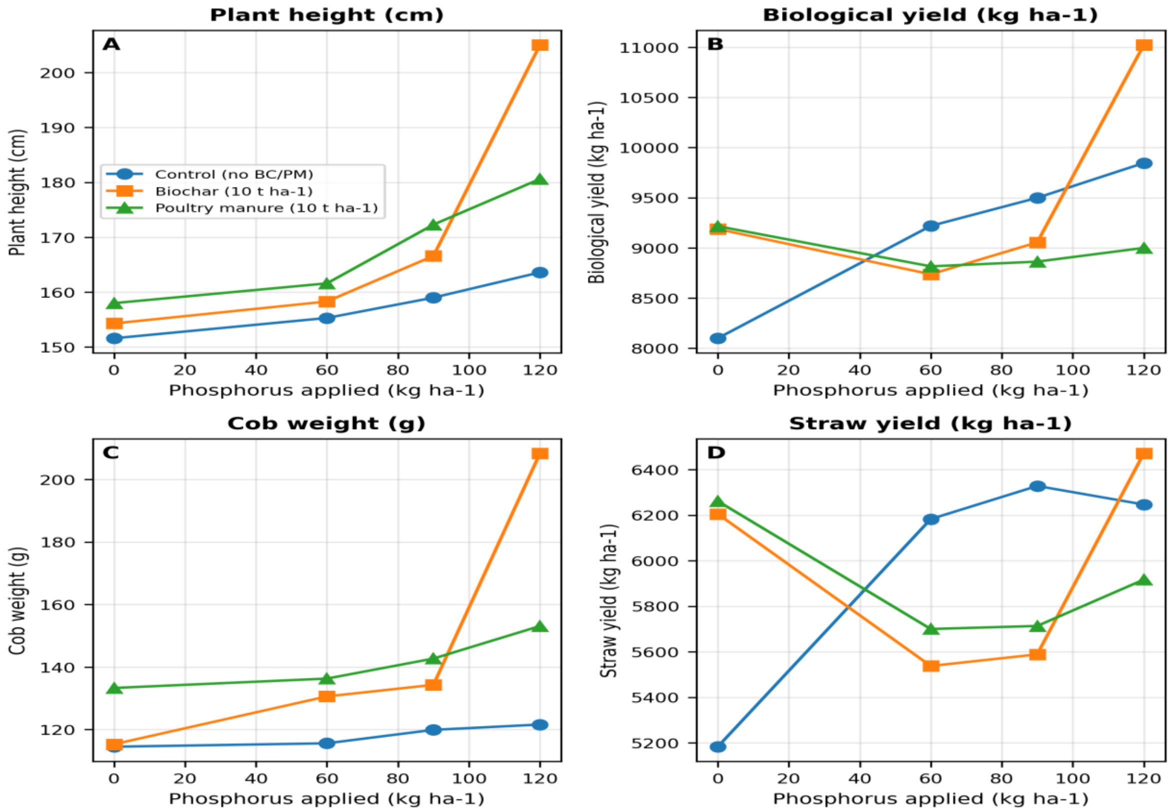

Figure 1 Growth and yield attributes of maize.

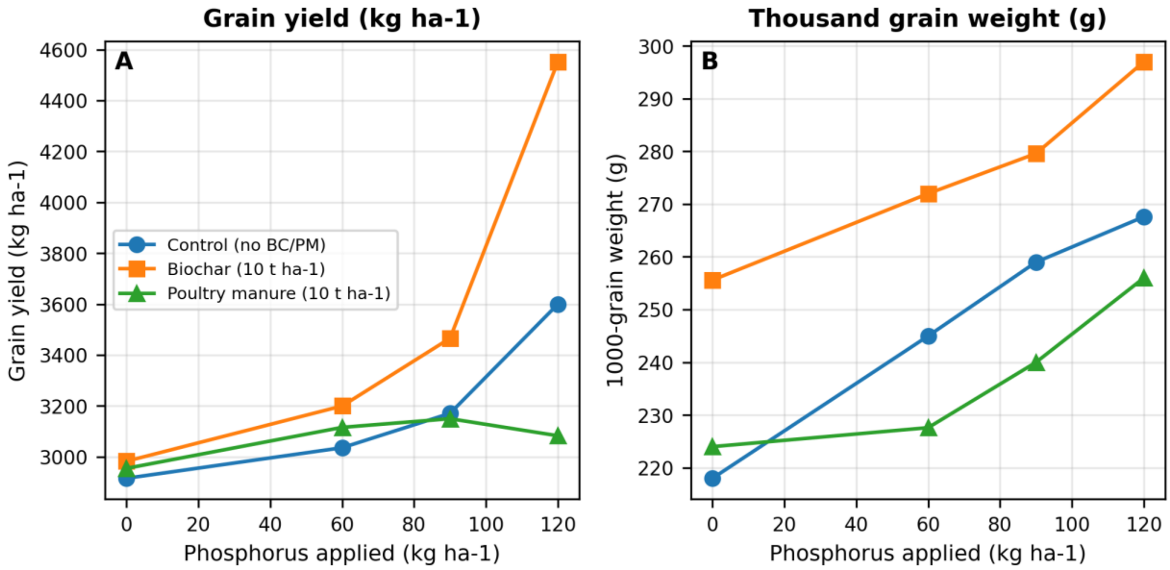

Figure 2 Grain yield and thousand grain weight of maize.

Nutrient concentration in straw and grain

The treatments significantly affected the nutrient content of maize straw and grain. The highest N level was seen in T8 with straw N being 0.87% and grain N being 1.96%. Similarly, the highest amounts of Phosphorus in straw and grain were 0.43%

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and 0.52%, respectively, and the highest amounts of Potassium in straw and grain were 1.13% and 0.72%, respectively, under the same treatment. Application of Phosphorus generally improved nutrient concentration, which increased with higher rates, particularly when combined with biochar application. Poultry manure also enhanced nutrient concentration when compared with the control confirming the benefits of integrated nutrient management in crop nutrition (Ahmed et al., 2021; Hu et al., 2023; Yasir et al., 2025).

The higher nitrogen, phosphorus and potassium levels in straw and grain could be attributed to the better nutrient availability and nutrient uptake under the integrated application of phosphorus and biochar. The nutrient holding capacity and the change in cation exchange capacity and favourable physical conditions for microbial activity may also enable better uptake of nutrients by maize roots, leading to improved nutrient transformation and uptake. This increased nutrient concentration in T8 indicates that application of both phosphorus and biochar was beneficial, especially on the vegetative and reproductive growth of maize. Similar enhancements in nutrient content and mineral profile of plants with biochar, poultry manure and phosphorus based amendments were also experienced by Gunes et al. (2014), Inal et al. (2015), Ahmed et al. (2021) and Hu et al. (2023).

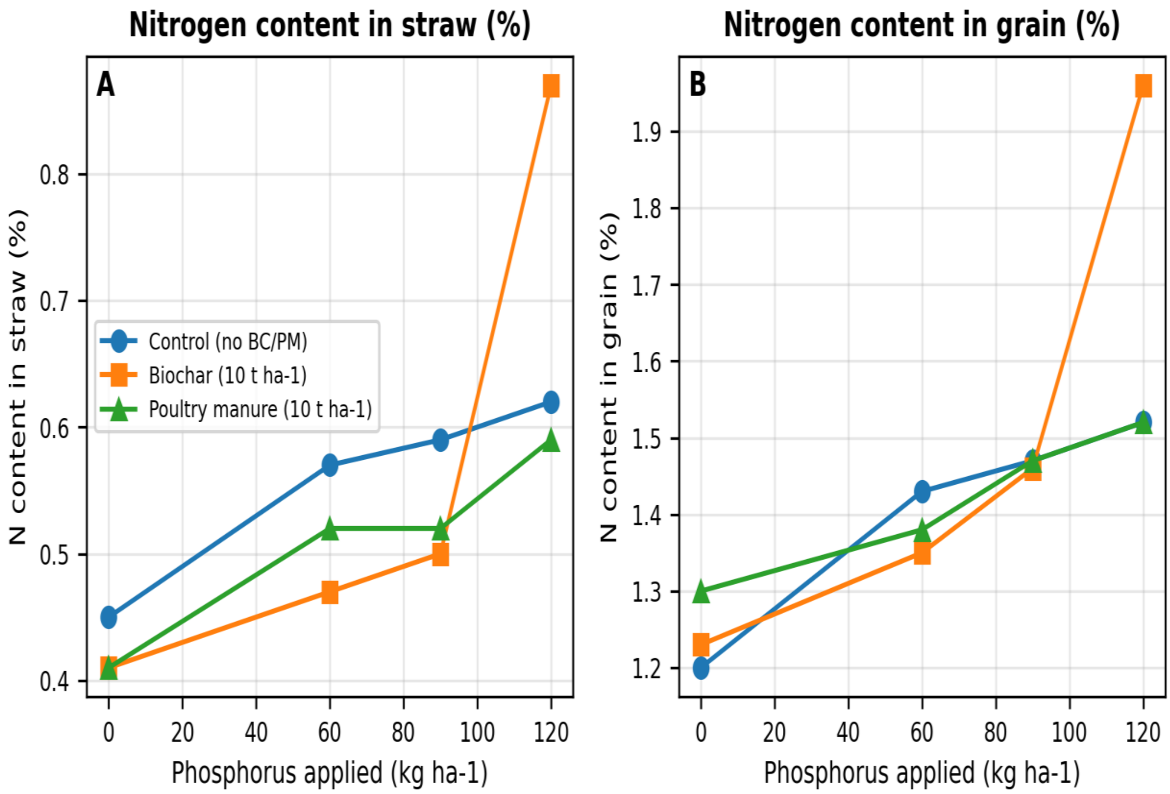

Figure 3 Nitrogen content in maize straw and grain.

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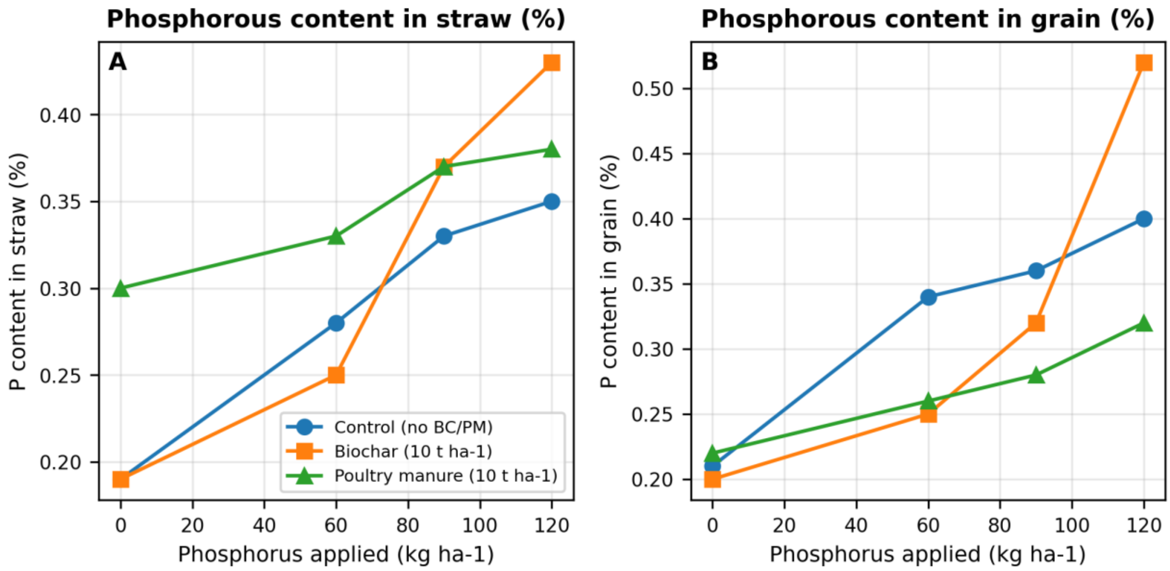

Figure 4 Phosphorus content in maize straw and grain.

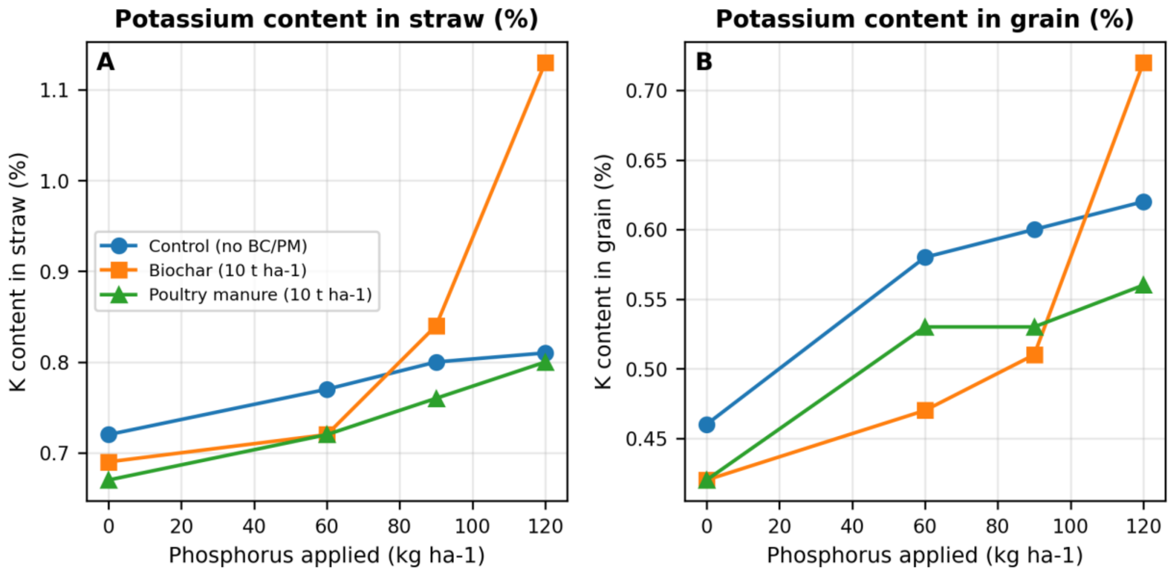

Figure 5 Potassium content in maize straw and grain.

Nutrient uptake and Phosphorus use efficiency

The integrated application of P and organic amendments had a significant effect on the uptake of N, P and K in maize. The nitrogen uptake in straw (56.22 kg ha-1), in grain (89.23 kg ha-1) and total uptake (145.45 kg ha-1) showed the highest uptake by T8. Likewise, the highest Phosphorus uptake in straw (27.91 kg ha-1) and grain (23.68 kg ha-1) and total Phosphorus uptake (51.59 kg ha-1) was obtained in the same treatment. The uptake of K was also highest in T8, with 73.0 kg ha-1 in straw, 32.78 kg ha-1 in grain and 105.82 kg ha-1 as total. Use efficiency of phosphorus was optimum for T8 (51.44 %), suggesting that biochar resulted in high % of applied Phosphorus stabilization and high availability for crop uptake. Overall, the results

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indicate that the biochar application with higher levels of Phosphorus application was more effective than the sole Phosphorus application and application of Phosphorus plus poultry manure, corroborating previous studies regarding the role of biochar in enhancing nutrient retention and utilization (Li et al., 2020; Yang et al., 2021; Ma et al., 2024).

The increased N, P and K uptake in T8 was primarily attributed to increased plant biomass, increased root activity and increased soil nutrient availability. Application of phosphorus, along with biochar may have resulted in decreased nutrient leaching, increased nutrient retention around the root zone, and improved energy transfer and nutrient movement within the plant. The biochar-based treatment had a higher efficiency in the use of phosphorus by maize plants, shown by the higher increase in efficiency. Our findings are consistent with Li et al. (2020), Yang et al. (2021), Hu et al. (2023) and Ma et al. (2024) which reported that biochar-based amendments are beneficial for enhancing the use of phosphates, nutrient uptake, and fertilizer use efficiency in crop production systems.

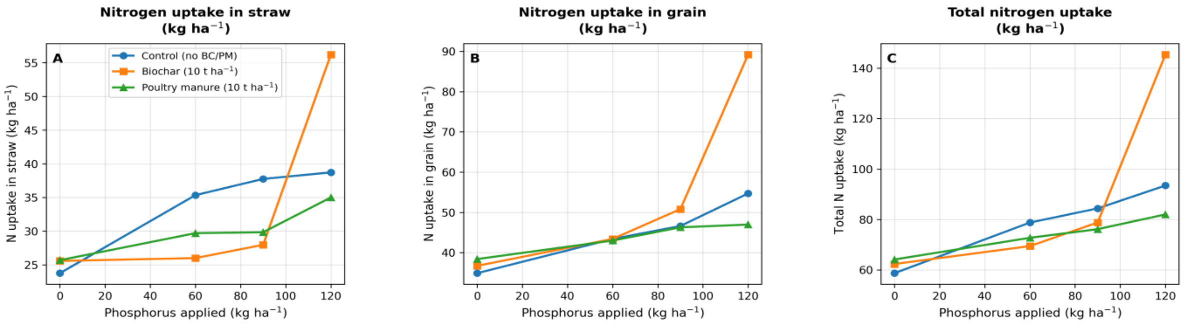

Figure 6 Nitrogen uptake by maize.

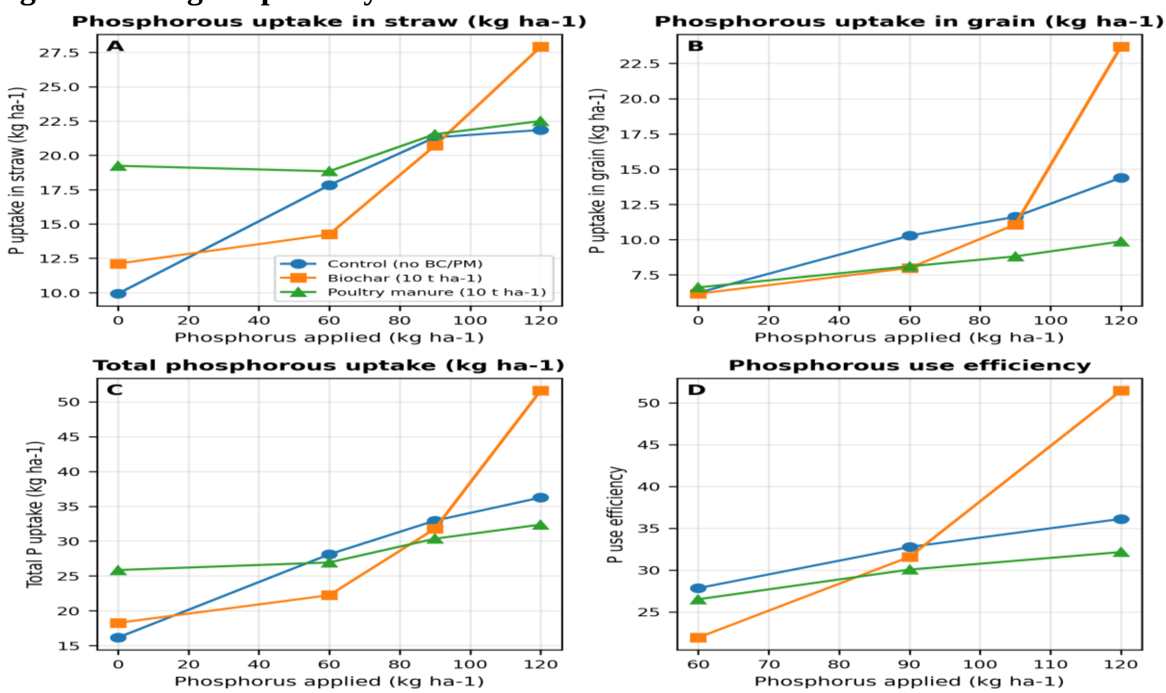

Figure 7 Phosphorus uptake and Phosphorus use efficiency of maize.

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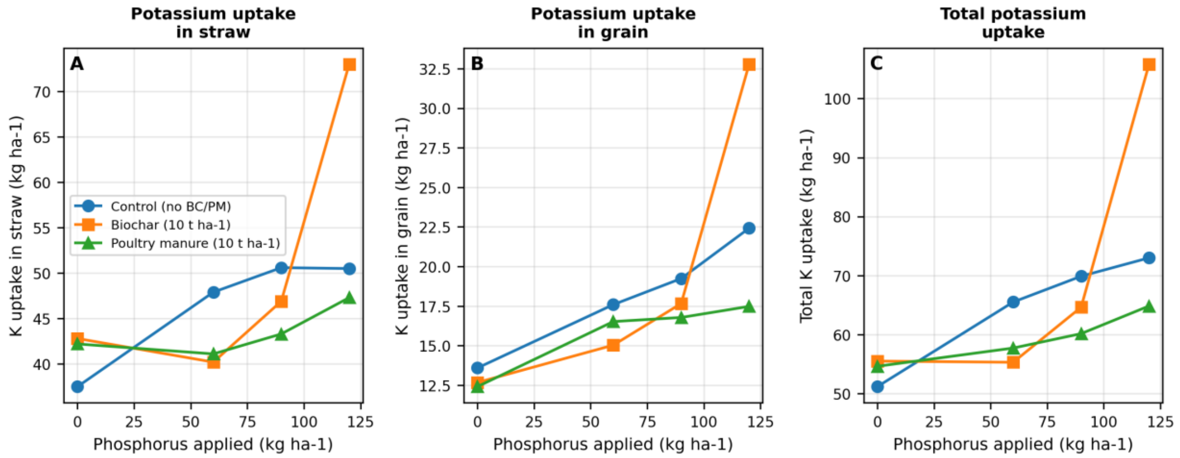

Figure 8 Potassium uptake by maize.

Conclusion

The results of the study revealed that the application of single super phosphate, biochar and poultry manure significantly affected the yield of maize, the nutrient concentration, nutrient uptake and Phosphorus use efficiency. The increase in yield was found to be more with the increase in Phosphorus application and the integrated treatments performed better than the mineral Phosphorus treatment alone. In general, 120 kg P ha-1 along with 10 t ha-1 biochar without poultry manure (T8) was the most effective treatment for most of the measured parameters of the experiment. This method can be suggested to enhance yield of maize plants and maintain sustainable Phosphorus management in soil with low availability of P similar to Peshawar condition.

Based on the results, the application of 120 kg P ha^{-1} combined with 10 t ha^{-1} biochar is recommended for improving maize yield, nutrient uptake and phosphorus use efficiency under soil and climatic conditions similar to Peshawar. However, further multi-location and multi-season field trials are suggested to confirm the long-term effects of this treatment on soil fertility, phosphorus availability and economic return.

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