Pak. J. Bot., 54(6): 2303-2309, 2022. DOI: http://dx.doi.org/10.30848/PJB2022-6(30)

COMPARATIVE ROLE OF DWARF CAVENDISH BANANA LEAF FORMULATED BIOCHAR AND COMPOST IN CORN - NUTRIENT UPTAKE AND ITS RELATIONSHIP WITH YIELD

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Abstract

Research shows a mixed outcome on the use of compost, biochar, or a mixture of both along with chemical fertilizer application on crops. This study evaluated the use of banana-leaf biochar and compost. The latter additionally had 25% farm manure rather than the compost of the main material. Trials were carried out with 5 tons of compost, and 20 and 40 tons of biochar, each integrated with nitrogenous and phosphatic fertilizer rates of 0-0, 120-0 and 120-90 kg of N and P_2O_5 on a hectare basis. On average, the N and P contents of biochar were respectively 53% and 43% of the compost contents. The average K contents of compost (97%) were close to the biochar content. While the organic C contents of compost were 79% of the biochar contents. Available P and K contents of the soil were inadequate. The highest uptake was obtained when 120 kg N and 90 kg of P_2O_5 ha^{-1} were coupled with 5 tons of compost, which gave equivalent nutrient uptake with 20 tons of biochar under both experiments. Additional 20 tons of biochar (40 tons ha^{-1}) was not beneficial. The nutrient uptake regressed with corn yield gave a positive and linear relationship, which reflected the impact of existing nutrient contents in corn. Same products may be tested under long-term trials using different soil textures.

Key words: Compost, Biochar, Farm manure, Uptake, Yield, Regression.

Introduction

After wheat and rice, corn stands third among cereal crops in Pakistan. It is a great source of potassium, which lowers blood pressure. The antioxidants and carotenoids are good for the health of the eyes. Corn oil, flour, starch, and animal feed are some of the common products in use. Corn production in Pakistan has increased from 0.381 million tons in 1950-51 to 7.83 million tons in 2019-20. This trend will continue in the coming years as the usage of corn in wet-milling and feed is increasing rapidly. It has recently gained more importance as many people have added this cereal to their diet plans. The average yield of Pakistan as of 2019-2020 was 5679 kg ha^{-1}, which is more or less half of the yield reported in New Zealand (1089 kg ha^{-1}) for the same year. In order to keep up with the increasing demand, the corn yields need to be further enhanced as specified by the Government of Pakistan for sustainable socio-economic transformation.

Soil quality is one of the key factors. Organic matter is the elementary constituent that not only safeguards the environment and health of the soil (Bloem *et al*., 2005), but is an essential reservoir of carbon, nutrients, and energy that last longer. Fertilizer management strategies are implemented in such a way that there is an increase in the carbon storage in the soil (Lal, 2004). In diversified ecological zones, globally, more than 50% loss of soil carbon has been reported during the last decade which poses a great challenge to crop productivity (Lemenih *et al.*, 2005).

Possible ways to add organic carbon to soil is by addition of farm manure and residues in the form of compost (Memon *et al.*, 2012) or as such. Banana compost integrated with inorganic fertilizer, increased the yield and quality of bananas (Eman *et al*., 2008 and Ei-Naby, 2002). One other way would be to add it in the form of biochar (pyrolyzed biomass), prepared from farm manure or organic residues. It is estimated that approximately 4.10 million tons of banana residue are produced in Pakistan with 3.79 million tons in Sindh (Anon., 2010). Combustion of organic material in the presence of little oxygen forms extremely resistant carbon-rich charcoal (Thies & Rillig, 2009), which persists in soil for extended periods and has great potential to improve crop production (Downie *et al.*, 2011; Laird *et al.*, 2010). During pyrolysis, labile carbon is converted into a relatively stable aromatized carbon, and basic cations are transferred from the fresh biomass to biochar. When applied to soil, these cations become available to the soil by occupying the soil exchange sites (Krull *et al.*, 2009).

Nutrient uptake and corn yields are of significant importance. Studies highlighted the beneficial effects of wood-biochar on the growth and uptake of corn in controlled (Pandit *et al*., 2018) and natural (Brantley *et al*., 2015; Medynska-Juraszek *et al*., 2021) environments. Compost prepared from banana clones and that prepared from farm manure were not different in nutrient contents of banana leaves. However, the farm-manure compost was reported to be economical (Doran *et al*., 2003). Greenhouse studies, as a counterpart to field tests, allow the testing of corn under precise settings with no distracting effects of heterogeneity in the environment. Pot studies are much cheaper and easy to deal with but depend on the environment and the material under experimentation. Many studies have focused on the properties of biochar prepared from plant residues (Gaskin *et al*., 2008). Relatively little information is available regarding the application of biochar and yet the comparative role of biochar and compost mainly prepared from banana leaves. Feeding the ever-growing population of the country from limited resources necessitates that the local wastes of organic nature be utilized in a sustainable manner to uplift the agriculture sector.

Materials and Methods

Nutrient uptake and yield of corn were tested in a pot and field environment (48° 65′ 91.12″ E 31° 30′ 53.82″ N) using nitrogenous and phosphatic (0-0, 120-0 and 120-90 kg N and P_2O_5 ha^{-1}) sources of fertilizers with banana-leaf amendments (BL-A) i.e. compost (5 tons ha^{-1}) and biochar (20 and 40 tons ha^{-1}) along with control (0 BL-A). The treatments were arranged in a complete randomized design under the pot and a randomized complete block design under the field with four replications. As per treatment details, compost and biochar were thoroughly mixed in each pot (19 kg soil) and in experimental land (0-30 cm soil depth) and watered. As soil reached field capacity, it was leveled. The required quantity of P was added at once along with the $3/4^{th}$ portion of N in the form of urea in both experiments. The leftover two portions of N were applied at the tasseling and silking stage of corn growth. Ten corn seeds were sown in potting soil (0-20 cm) collected from the same area under field experimentation and later, only one healthy plant was left in pots for further growth. The corn seeds (30 kg ha^{-1}) were sown on leveled field plots with rows 70 cm apart and 30 cm spacing between the plants. The mature corn plants from each pot/plot were carefully cleaned, dried and the grains were separated from the cobs and dried. The corn grain weight was recorded as g pot^{-1}, and kg $plot^{-1}$, correspondingly and the latter was converted to kg ha^{-1}.

Preserved corn grains were dried in an oven (65-68°C), ground (20-mesh) and tested for N, P and K concentration. Nitric and perchloric (5 and 1 ml) acid mixture was used to digest the fine corn grain powder using a hot plate. Wet oxidation is preferred for specific nutrient analysis as the acid oxidizes organic substances. The P and K content in the digested material were respectively quantified as detailed by Cottenie (1980) and Knudsen *et al*., (1982). While N was separately determined as detailed by Jones (1991). The N, P, and K uptakes were calculated as a product of corn/straw yield and nutrient contents, further fractioned into 100. The data from pot and field experiments were analyzed separately using complete randomized and randomized complete block design and a comparison of means was done by running the least significance difference test. The yield data under each experiment was separately regressed with associated nutrient uptakes.

The soil in use was tested for particle size, electrical conductivity, pH, organic C, and available P and K as per details covered by Ryan *et al*., (2001). Total P and K in compost, biochar, corn and grain were also determined. A 0.25 g quantity of the material, along with 10 ml of 5:1 acid mixture (HNO_3:$HClO_4$) was left for 10-12 hours and later digested (80°C) on a hot plate set in a digestion block (Zarcinas *et al*., 1987). The digested material was diluted to 50 ml and tested for P on a spectrophotometer (ANA-75) and K on a flame photometer (Jenway PFP7). While N in soil (1 g), compost, biochar and grain (0.2 g) were determined as given by Bremner & Mulvaney (1982).

Results and Discussion

General characteristics of soil and amendments: The sandy clay loam soil possessed electricity conductivity in the range of 0.59-0.63 dS m^{-1}, pH 8.19-8.25, organic C 3.0-3.4 g kg^{-1}, available P 2.28-2.33 mg kg^{-1} soil, and available K 64-70 mg kg^{-1} soil. The nutrient composition of compost and biochar varied to some extent. The N content of the compost was in the range of 2.30-2.35%, while the biochar had about half (1.23-1.25%) of that in compost. Phosphorus content followed the same trend with relatively lower contents than N, both in compost (1.20-1.26%) and biochar (0.5-0.6%). However, K contents were more or less similar, both in compost (1.50-1.52%) and biochar (1.53-1.56%). As for organic C, it was higher in biochar (50.0-55%) than that obtained in compost (40.0-42%).

Nutrient uptake: The BL-A showed significant improvement in leaf N uptake from 1.33 g pot^{-1} for unamended soil to a maximum value of 2.79 kg pot^{-1} N with compost, followed by 2.48 kg pot^{-1} N with biochar at 20 tons ha^{-1} and 2.41 kg pot^{-1} N with biochar at 40 tons ha^{-1}. The effect of fertilizer N was significant and prominent. The N uptake was enhanced from 1.73 kg pot^{-1} in control (0 N-P) to a maximum value of 2.60 kg pot^{-1} with N-P, respectively at 120 and 90 kg N and P_2O_5 ha^{-1}. The combination of BL-A and N-P fertilizer was also significant (Table 1) and increased the NPK uptake (Fig. 1). The N uptake increased from 1.06 kg pot^{-1} in control (0 N-P and 0 BL-A) to the highest N uptake value of 3.37. kg N ha^{-1} when 120 kg N, and 90 kg P_2O_5 ha^{-1} were applied with compost (5 tons ha^{-1}). The N uptake (2.9 kg pot^{-1}) obtained with biochar (20 tons ha^{-1}) and compost at 5 tons ha^{-1} at the same fertilizer rate (120 kg N, and 90 kg P_2O_5 ha^{-1}) did not statistically differ. Phosphorus uptake followed a somewhat similar trend. The effect of N-P fertilizer and BL-A was significant on P uptake. The values increased from 0.023 kg pot^{-1} in control to 0.157 kg pot^{-1} with N-P (120+90 kg ha^{-1}) and compost (5 tons ha^{-1}), which was equal to the P uptake (0.136) obtained with N-P (120+90 kg ha^{-1}) and biochar (20 tons ha^{-1}). The BL-A also showed significant enhancement in K uptake with a little different scenario. The values increased from 0.52 kg pot^{-1} in control to 2.1 kg pot^{-1} with the highest rate of N-P (120+90 kg ha^{-1}) and compost (5 tons ha^{-1}), however, the K uptake obtained at the same fertilizer rate with a biochar rate of 20 or 40 tons ha^{-1}, and 120 kg N with 5 tons of compost gave equivalent values.

Table 1. F values along and significance for nutrient uptake with amendments and fertilizer.

Uptake of nutrients	Amendments BL-A	Fertilizer N-P	Bl-A x N-P
	Field		
Nitrogen (kg ha^{-1})	53.54**	37.21**	2.88*
Phosphorus (kg ha^{-1})	83.72**	76.28**	2.55*
Potassium (kg ha^{-1})	20.57**	5.60*	2.03NS
	Pot		
Nitrogen (g pot^{-1})	128.34**	90.06**	6.27**
Phosphorus (g pot^{-1})	94.75**	206.43**	2.56**
Potassium (g pot^{-1})	60.51**	164.65**	6.70**

BL-A, banana-leaf amendments; ** significant at1% probability level; * significant at 5% probability level, NS, non-significant

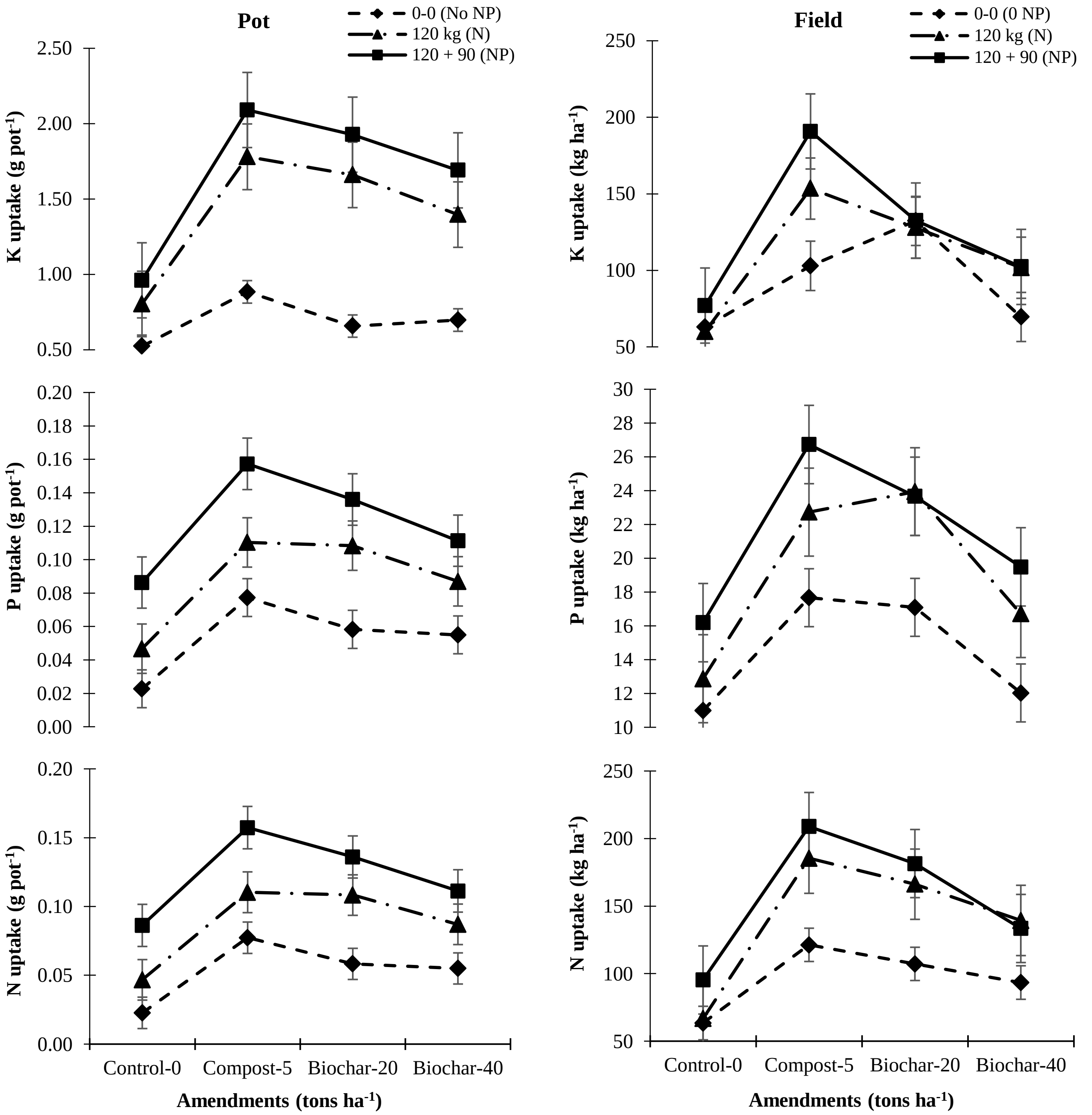

Fig. 1. Nutrient uptake of corn under pot and field environment with amendments and fertilizer.

The BL-A under field conditions also gave a significant effect on N, P, and K uptake (Table 1). The N uptake was enhanced from 75.22 kg ha^{-1} in control to a maximum value of 208.94 kg ha^{-1} with compost and equivalent uptake was obtained with 20 tons of biochar. The P uptake improved from 13.35 kg ha^{-1} in control to 22.38 kg ha^{-1} with compost and an equal and significant uptake of 21.57 kg ha^{-1} with 20 tons of biochar. The potassium uptake also increased in a similar manner. The values increased from 66.64 kg ha^{-1} in control to 149.05 kg ha^{-1} with compost, which was at par with the uptake obtained with 20 tons of biochar (Fig. 1). The fertilizer application data showed an increase in N, P, and K uptake, respectively from 96.39, 14.44, and 91.94 kg ha^{-1} in control to 154.82, 21.52, and 125.65 kg ha^{-1} with N-P (120+90 kg ha^{-1}), which were equivalent to the uptakes obtained with 120 kg N, except in case of P. The interactive effect of BL-A and N-P fertilizers was significant, except in case of K (Fig. 1). The respective uptakes increased from 63.48, 10.99, and 62.93 kg ha^{-1} in control to 208.94, 26.73, and 190.75 kg ha^{-1} with N-P (120+90 kg ha^{-1}) and 5 tons of compost. The N uptake (208.94 kg ha^{-1}) with N-P (120+90 kg ha^{-1}) and 5 tons of compost was equivalent to the uptake (181.44 kg ha^{-1}) when compost was replaced with 20 tons of biochar. Likewise, the N fertilizer (120 kg ha^{-1}) without P either with 5 tons of compost (185.39 kg ha^{-1}) or 20 tons of biochar (166.21 kg ha^{-1}) gave equal N uptake. Phosphorus uptake followed a similar trend. The N-P (120 +90 kg ha^{-1}) or N (120 kg ha^{-1}) fertilizer, with either 5 tons of compost (26.73 and 22.73 kg ha^{-1}) or 20 tons of biochar (23.67 and 23.94 kg ha^{-1}) gave equivalent P uptakes, correspondingly.

Inorganic fertilizers increase basic crop production, but the use efficiency has overall declined with no or little use of organic sources (Arif *et al*., 2017). Based on the variability of organic sources, soil organic carbon stocks are strengthened, ultimately the availability, uptake of nutrients, and yield (Xu *et al*., 2019). Biochar application under both setups can fetch similarities and dissimilarities and an improved understanding. The use of banana-based biochar (Ismail (2015) and compost (Doran *et al*., 2003) have proved to be beneficial in terms of the nutrient contents of plants. Very few studies taken up under field set-up also include pot experimentation (Fidel *et al*., 2019). In this study, both the biochar and compost were tested on corn. The deep roots of corn plants make it most exhaustive, and the nutrient uptake is much more and quicker. It can be easily managed in a natural and controlled environment by using similar soils. The crop has wide economic importance all over the world (Anon., 2019).

The compost application of 5 tons gave the highest N, P, and K uptake, which was similar to the uptakes obtained with 20 tons of biochar, revealing that in both the experiments the environment was suitable for corn. The reason for compost being at the upper edge was that it contained banana leaves along with 25% of farm manure, which created a balance in nutrients (Virk *et al*., 2021). In both environments, the N, P and K uptake did not experience any increase with additional 20 tons of biochar (i.e., 40 tons of biochar). This is because compost application directly alters the microbiological activity pertaining to available N. The same is not true for biochar, it enhances only the soil C pools (Sanchez-Garcia *et al*., 2016). The N uptake in pots increased highest by108% when N-P (120-90 kg ha N and P_2O_5) was coupled with 5 tons of compost, and it equally increased the N uptake by 77% with 20 tons of biochar. In natural conditions, the same treatments had an increase in N uptake by 119% (5 tons compost) and 90% (20 tons biochar), which were equivalent to the increase in N uptake when only N (120 kg N ha^{-1}) was combined with 5 tons of compost or 20 tons of biochar. This was not true in a potted environment. The N mineralization process was boosted in the compost applied treatments due to its high C (easily convertible) stocks which support the transformation of microbial N (Darby *et al*., 2016). Improved N uptake and corn production with the combined use of compost and inorganic fertilizers have been reported even in a potted environment (Nigussie *et al*., 2021). However, the rates of compost were double the rates used in this study. The P uptake in a controlled environment increased by 82% when N-P (120+90 kg N-P_2O_5 ha^{-1}) was coupled with 5 tons of compost, and by 58% with 20 tons of biochar. On the other side, the natural environment achieved a 65% and 46% increase in P uptake when N-P was coupled with the same rates of compost and biochar. The P uptakes obtained with the same rates of compost and biochar but no P (120 kg N ha^{-1}) were equally beneficial in increasing the P uptakes in these treatments. This also conveys that in the absence of fertilizer applied P, there was enough P coming from the BL-A. This was supported by the research findings of the pot study with a P uptake increase of 2.71-3.71 folds (Sulemana *et al*., 2021). The. Organic sources of nutrients in soil release organic acids that minimize the P sorption process and P availability is enhanced (Mashori *et al*., 2013; Memon *et al*., 2011). The understanding of organic sources i.e. biochar or compost on K dynamics is still a myth and the K responses may vary according to the mineralogical makeup of the soil Wang *et al*., (2018). The highest K uptake increase was with the compost, followed by biochar (20 tons). On the other hand, K uptake increase in a controlled environment was highest (118%) when N-P was coupled with compost. Equivalent uptakes were obtained when N-P was coupled with 20 or 40 tons of biochar. This was true even when only N was applied with 5 tons of compost. Many studies have highlighted the potential of biochar in enhancing the available nutrients (i.e. P and K), which facilitated the nutrient uptake, and more of K (Oram *et al*., 2014). This was further confirmed by Mia *et al*., (2014) and Abu-Zied Amin, (2016). The uptake of nutrients in lettuce was also enhanced with biochar application (Nigussie *et al*., 2012). Our results regarding the uptake of NPK with biochar or compost were further supported by Liu *et al*., (2021).

Nutrient uptake associated with grain weight of corn: The relationship between nutrient uptake (i.e. N, P, and K) and grain yield of corn has been presented in (Fig. 2). While the contribution of each nutrient uptake in the yield of corn with BL-A has been covered in Table 2. The nutrient uptake of each N (r = 0.89 and 81), P (r = 0.88 and 83), and K (r = 0.94 and 71) regressed against the yield of corn in a controlled and natural environment correspondingly gave a linear, positive, and significant (p<0.01) relationship. The findings of a pot study by Nigussie *et al*., (2021) showed that the dry weight of corn was positively correlated (r = 0.89 and 0.82) with N uptake and other properties when corn was grown on two different soils with a combined application of compost (10 tons ha^{-1}) and N fertilizer. In this study, the compost application of 5 tons ha^{-1} achieved similar results. The biochar prepared from corn stalks used on lettuce in a pot study also showed that Bray-I P was correlated with P uptake in corn plants (Nigussie *et al*., 2012). Likewise, the shoot biomass was significantly correlated with K uptake (r = 0.79) in the polybag growing medium (Radin *et al*., 2018). These results were further in line with the correlations given by Agegnehu & Amede (2017). The coefficients of correlation (r) were stronger under a potted environment compared to those in the field. These findings were in line with the findings given by Spoor & Simmond (1993). Yields of pot trials have been found to be correlated with the yields obtained under field trials. Coefficients of correlation under potted plants were high and about 15-30% higher than those under field (Spoor and Simmond, 1993). The coefficient of determination (R^2) increased in a similar manner. The regression equations (Table 2) depicted that 79%, 78%, and 88% variability, respectively in the corn yield was explained by the variation in N, P, and K uptakes under potted corn. when corn was grown in a field environment, the variability in the yield and N, P, and K uptakes was explained by 65%, 69%, and 50% variation.

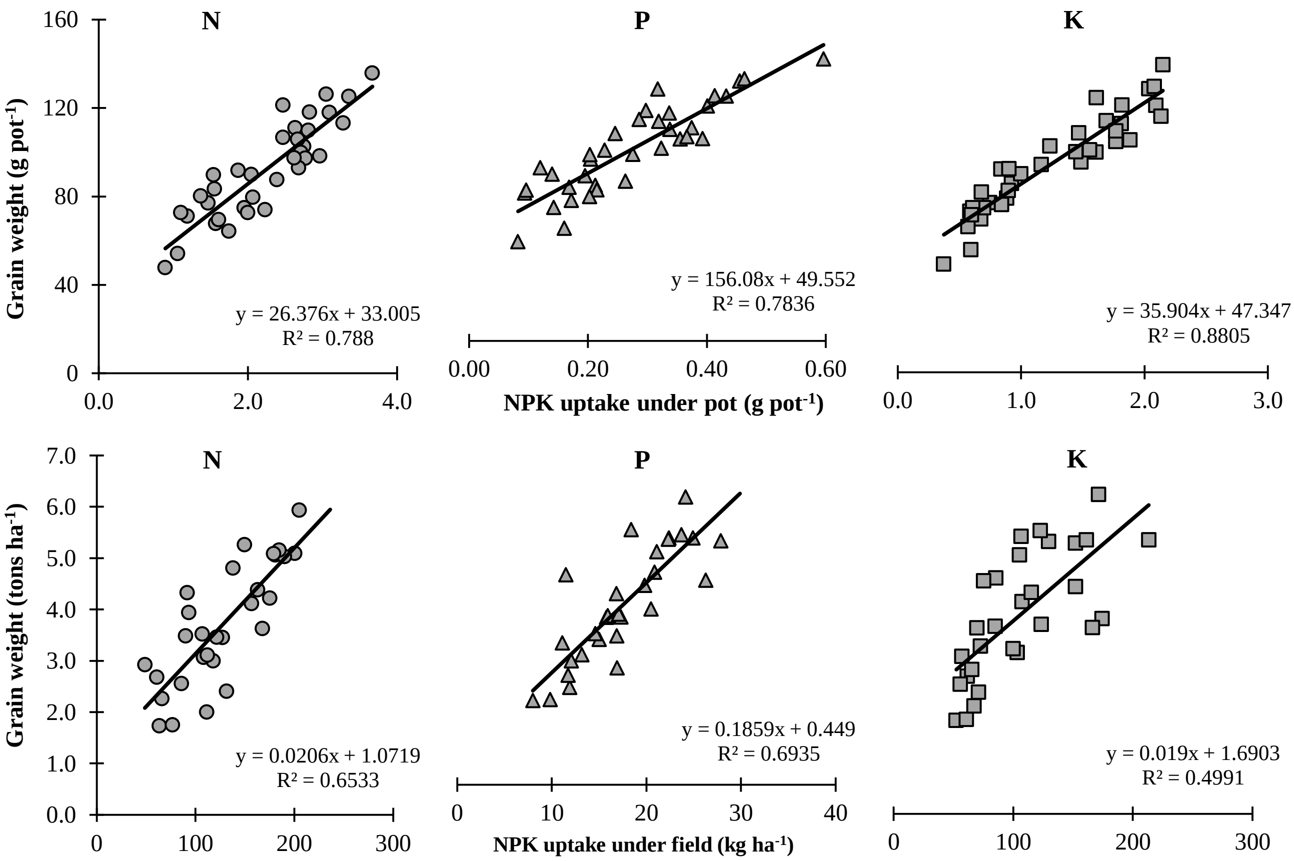

Fig. 2. Relationship between nutrient uptake and grain weight of corn under pot and field environment.

Table 2. Contribution of nutrients in corn yield with amendments.

Uptake of nutrients	Coefficient of correlation (r)	Coefficient of determination (R^2)	Regression equation
		Pot	
Nitrogen (g pot^{-1})	0.89**	0.79**	y = 26.376x + 33.005
Phosphorus (g pot^{-1})	0.88**	0.78**	y = 156.08x + 49.552
Potassium (g pot^{-1})	0.94**	0.88**	y = 35.904x + 47.347
		Field	
Nitrogen (kg ha^{-1})	0.81**	0.65**	y = 0.0206x + 1.0719
Phosphorus (kg ha^{-1})	0.83**	0.69**	y = 0.1859x + 0.449
Potassium (kg ha^{-1})	0.71**	0.50**	y = 0.019x + 1.6903

** Significant at1% probability level

Conclusion

The soils under experimentation were low in organic C (3.0-3.4 g kg^{-1}), and AB-DTPA P (2.28-2.33 mg kg^{-1}), and marginal in K (64-70 mg kg^{-1}). The banana-leaf compost with 25% farm manure had a relatively better nutrient composition than banana-leaf biochar, except that, the K contents of biochar were slightly higher. The corn crop experienced a significant effect of banana-leaf formulated amendments on N, P and K uptake in pot and field environments. The results of the experiments suggested that 5 tons of banana-leaf compost (+25% farm manure) or 20 tons of banana-leaf biochar with inorganic N and P fertilizer (120 and 90 kg N and P_2O_5 ha^{-1}) application gave similar NPK uptake of corn. Corn yield was directly associated with nutrient uptake. This study suggested that the combined application of biochar and compost, prepared banana waste and farm manure may be tested under long-term experiments.

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(Received for publication 2 September 2021)