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Full Length Article

Peanut-Waste Biochar and Buffalo Manure Decreased Nitrogen and Phosphorus Requirement of Maize Grown in an Alkaline Calcareous Soil

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Abstract

A calcareous soil was used in a pot study to evaluate the effect of peanut-waste biochar (PB) and buffalo manure (BM) on maize nitrogen (N) and phosphorus (P) demand. Three nitrogen-phosphorus fertilizer doses (NPDs) [0, 66 and 100%] were used along with organic amendments *i.e.*, control, 1.50% PB, 1.50% BM and 0.75% PB + 0.75% BM (on w/w basis of soil). At 66 and 100% NPD, statistically maximum dry biomass yield (40.0 and 38.3 g pot^{-1}, respectively) at vegetative growth stage was achieved with 1.50% PB. Maximum ammonical-N (31.3 mg kg^{-1}), mineral-N (45.8 mg kg^{-1}) and available P (20.6 mg kg^{-1}) contents were found in the soil amended with 1.50% PB at 100% NPD. For grain yield at crop maturity, comparative statistical results were obtained with 1.50% PB and 1.50% BM at both 66 or 100% NPDs. Maximum harvest index (40%) was with BM at 66% NPD. Overall, maximum N uptake (*i.e.*, 1.31 g pot^{-1}) was with 1.50% PB at 66% NPD. Maximum P uptake was with PB at 100% NPD. At 66 and 100% NPDs, mineral-N and available P contents were significantly greater with organic amendments than respective controls, but, statistically comparable with each other. Conclusively, at vegetative stage, statistically maximum dry biomass yield was achieved at 66% NPD along with 1.50% PB addition. At maturity, grain yield achieved with 66% NPD was statistically similar at 1.50% PB and 1.50% BM. Therefore, addition of either 1.50% PB or BM can decrease requirement of mineral N and P fertilizers by about 34%.

Keywords: Fertilizer requirement; Maize; Nitrogen; Organic amendments; Phosphorus; Grain yield

Introduction

Alkaline soils are located in arid to semiarid regions of Pakistan, United Kingdom, central Saudi Arabia, Jorden, central Sudan, Syria, Ireland, Lebanon, Yemen, Iraq, Iran, Afghanistan and some other countries (FAO, 2011, 2015). Soils of arid and semi-arid regions are poor in nitrogen (N) and extractable phosphorus (P), and often very low in organic matter (<1%). Plants can use only half or even less of the applied N due to heavy losses from soil system through the volatilization and denitrification (Khan *et al*., 2014). Such soils have high total P content, however, P fertilizers cannot fulfill nutrient demands of crop plants because of precipitation with calcium (Ca) (Khan and Joergensen, 2006; Muhammad *et al.*, 2008). Moreover, continuous deep tillage, indiscriminate use of agro-chemicals, excessive use of marginal lands and reduction of the fallow period, have improved annual yields, but, at the expense of soil quality. In this way, the agricultural practices are continuously deteriorating soil fertility (Kibblewhite *et al*., 2008; Lal, 2008). Organic fertilizers and amendments may improve soil nutrient cycling and availability (Bruhn *et al*., 2012; Kamara *et al*., 2015). Organic soil amendments can be combined with mineral fertilizers, which ultimately help to overcome the ill-effects of the decades-long use of artificial nutrient sources (Jama *et al*., 1997).

To maintain soil quality, organic soil amendments (*i.e*., compost and manures) have already been used successfully (Scotti *et al*., 2013; Shah and Shah, 2017). Due to higher decomposition rates and unstable carbon content, the benefits of above mentioned organic soil amendments are just for a short period of time (Jenkinson and Ayanaba, 1977). Within few cropping seasons, added organic soil amendments are usually completely mineralized (Bol, 2000). To sustain soil productivity, these organic amendments are, therefore, to be applied repeatedly after every year. According to Jenkinson *et al*. (1991), along with higher cost of

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applied organic soil amendments, the mineralization and rapid decomposition of organic soil materials significantly contribute towards the global warming.

Just like other amendments, biochar may play a constructive role as an organic soil amendment (Woolf, 2008; Hamdani *et al.*, 2017; Zhang *et al.*, 2016; Naeem *et al.*, 2017). Unlike some common organic amendments, however, biochar does not easily decompose in soils as its carbon is highly resistant against the microbial attack (Granatstein *et al*., 2009; Hussain *et al*., 2017). Biochar may significantly improve plant growth and yield by improving the efficiency of applied N fertilizers (Steiner *et al*., 2008). Synergistic effect of biochar along with compost and NPK fertilizer has been observed by Schulz and Glaser (2012) for better plant growth and soil health.

Biochar addition at 1.5% (w/w) to alkaline soil significantly improved plant growth (Aon, 2015; Aon *et al*., 2015). Our previous results also showed that 100% recommended nitrogen-phosphorus dose (NPD) and 66% NDP + 1.50% peanut-waste biochar (PB) were comparable to get maximum statistical results at an early growth stage. However, at full vegetative and reproductive stages of maize, such comparison is still lacking for sole or combined response of PB and BM. Therefore, this study was planned to compare the sole and combined application effects of PB and BM for reducing N and P inorganic fertilizer demand of maize at vegetative and reproductive stages under nutrient deficient alkaline calcareous soil condition. Soil N and P dynamics were also studied to relate the effects of treatments with maize growth at vegetative stage and grain yield at reproductive stage.

Materials and Methods

Site Description and Collection of Experimental Material

A pot experiment was conducted in a rain-protected wire-house, situated at research area of Institute of Soil and Environmental Sciences, University of Agriculture-Faisalabad (UAF), Pakistan. For a pot experiment, soil was first air-dried, then passed through a sieve of 2 mm mesh size. Sieved soil was analyzed for various physico-chemical properties (Table 1).

From a peanut-factory located on Rajbah Road, Faisalabad (Pakistan), peanut-waste was collected to produce biochar. After oven-drying, peanut-factory waste was slowly pyrolyzed at low temperature, using a muffle furnace (Gallonhop, England) (Aon *et al*., 2015). For this purpose, the adjustment of the reaction chamber temperature (per unit time) was at 8–9°C per min. A peak temperature of 300°C was maintained for 20 min. Buffalo manure (BM) was collected from livestock shed of UAF. Characteristics of PB and BM are mentioned in Table 2.

Experimental Setup

Two-factorial completely randomized design was followed for three NPDs (0, 66 and 100% of recommended inorganic N and P fertilizer) in all possible combinations with four levels of organic soil amendments (control, 1.50% PB, 1.50% BM and 0.75% PB + 0.75% BM). Organic soil amendments were used on dry weight (w/w) basis of soil used in this experiment. Fifteen kg soil was taken in each pot (pot depth and diameter were 65 and 45 cm, respectively) and all the treatments were replicated six times. Before seed sowing, 60 kg K ha^{-1} soil (450 mg pot^{-1}) as sulfate of potash was applied uniformly to all the pots. As a recommended N and P fertilizer dose (100% NPD), 240 kg N ha^{-1} (1800 mg N pot^{-1}) and 90 kg P ha^{-1} (675 mg P pot^{-1}) were applied as urea and single super phosphate, respectively. According to the treatment plan, full rate P fertilizer was added in pots. However, the mentioned rates of N fertilizer were applied in two equal splits *i.e*., before seed sowing and one week after seed germination.

Three seeds of a maize hybrid (cv. Syngenta-6621) were sown in each pot. Thinning was done up to a single healthy plant per pot, after seven days of germination. Throughout the experimental period, all the pots were irrigated with tap water to maintain soil moisture content at field capacity. Weeds were removed manually.

Sampling and Yield

At vegetative growth stage (55 days after sowing); three random replicates of each treatment were selected for growth, physiological and nutrient measurements. Remaining three replications were harvested at full maturity (115 days after sowing). Immediately after first and second harvesting, soil samples were collected and preserved in air-tight zip-bags in an ultra-low temperature freezer (Robus Technologies) at 4°C.

At vegetable stage, fresh and dry weights were measured. Right from the germination time of each treatment, days were counted for tassel and silk initiation. Plant samples of both harvestings were first dried in the air and then in a forced air-driven oven (Eyela WFO-600ND, Tokyo, Japan) at 65°C, until constant weight of samples was achieved. Then, the weight of oven-dried plant samples was recorded.

Physiological Parameters

After 55 days of sowing, fully opened top second leaf of each maize plant was taken for chlorophyll and gaseous exchange measurements. Physiological parameters of maize were recorded in the morning between 09 to 11 a.m. Chlorophyll meter, SPAD-502 (Konica-Minolta, Japan) was used to check the chlorophyll content of maize leaves. By using portable photosynthesis system (CIRAS-3, PP Systems-Hitchin, United Kingdom), rate of transpiration (E) and photosynthesis (A) were measured. Response of gas exchange to CO_2 was measured at 1.50 mmol m^{-2} s^{-1} PPF which was provided by a LED source at 0.06-2.00 μmol mol^{-1} CO_2 (Long and Hallgreen, 1985).

Table 1: Physico-chemical properties of surface layer of Lyallpur soil series in the study

Parameter	Unit	Value	Procedure
Soil organic matter	%	0.78	Nelson and Sommers (1982)
pH (1:1)	--	8.23	McLean (1982)
Electrical conductivity	dS m^{-1}	1.13	Richards (1954)
Textural class	--	Sandy clay loam	USDA classification (Bouyoucos, 1962)
Sand	%	56.3	Gee and Bauder (1986)
Silt	%	22.5	
Clay	%	21.2	
Cation exchange capacity	$cmol_c\ kg^{-1}$	6.75	Sumner and Miller (1996)
Nitrogen	g kg^{-1}	0.74	Jackson (1962)
Phosphorus	mg kg^{-1}	4.36	Olsen and Sommers (1982)
Potassium	mg kg^{-1}	127	Richards (1954)
Calcium carbonate	g kg^{-1}	46.2	Leoppert *et al.* (1984)
Zinc	mg kg^{-1}	2.12	Soltanpour and Schwab (1977)
Copper	mg kg^{-1}	3.53	
Iron	mg kg^{-1}	13.4	
Manganese	mg kg^{-1}	64.7	

Table 2: Chemical, physical and elemental/nutritional ratio characteristics of peanut-waste biochar and buffalo manure used in the study

Characteristic	Unit	Peanut-waste biochar	Buffalo manure
Physical/chemical			
Ash Content	%	13.8	18.1
Moisture Content	%	0.72	11.4
Conversion efficiency	%	64.2	
pH (1:20)		6.91	8.16
Electrical conductivity (1:20)	dS m^{-1}	1.62	4.18
Cation exchange capacity	$cmol_c\ kg^{-1}$	49.1	13.2
Nutritional/elemental composition			
Carbon	%	55.1	32.7
Hydrogen	%	5.03	4.35
Oxygen	%	23.5	ND
Nitrogen	g kg^{-1}	26.1	15.2
Phosphorus	g kg^{-1}	6.73	7.62
Potassium	g kg^{-1}	12.3	11.7
Calcium	g kg^{-1}	20.6	11.3
Magnesium	g kg^{-1}	14.3	14.8
Sulfur	g kg^{-1}	5.95	0.30
Zinc	mg kg^{-1}	261	473
Copper	mg kg^{-1}	051	121
Iron	mg kg^{-1}	418	178
Manganese	mg kg^{-1}	442	383
Elemental ratio			
Carbon : Nitrogen		21.1	21.5
Carbon : Phosphorus		81.9	43.1
Carbon : Sulfur		92.6	109
Molar ratio			
H:C		1.09	ND
O:C		0.32	ND
(O+N):C		0.34	ND

*ND represents not determined

Nutrient Measurements

Grain and shoot samples were finely ground in Wiley-mill fitted with a chamber and stainless-steel blades. A known weight of ground shoot and grain samples was taken for digestion in H_2SO_4 and H_2O_2 (Wolf, 1982). For the determination of N content in shoot and grain samples, Kjeldahl method was used (Jackson, 1962). Phosphorus contents in shoot and grain samples were determined on a spectrophotometer (UV-visible) after developing yellow color by vanadate-molybdate method (Chapman and Pratt, 1961).

Post-harvest soil analysis

Soil ammonium-nitrogen (NH_4^+-N) was extracted by potassium sulfate method followed by determination on a spectrophotometer (Clare and Stevenson, 1964). Soil NO_3^--N was extracted by ammonium bicarbonate-DTPA (Soltanpour and Schwab, 1977) followed by the hydrazine-reduction before measuring the absorbance on a spectrophotometer at 540 nm (Kamphake *et al.*, 1967). By adding soil NO_3^--N and NH_4^+-N content, total mineral-N contents were calculated. Labile soil P was also extracted by AB-DTPA method and determined through the procedure proposed by Olsen and Sommers (1982).

Statistical Analysis

Microsoft Excel-2013® (Microsoft Corporation, Redmond, USA) was used for data computations. Significance of treatments was confirmed by running ANOVA test on Statistix 8.1® (Analytical Software, USA). Tukey's multiple comparison test ($P \leq 0.05$) was followed to compare the significance of different treatment means.

Results

Agronomical Traits

At vegetative stage, 66% NPD + 1.50% PB resulted a significant ($P \leq 0.05$) increase of 41 and 40% in fresh and dry biomass over respective control treatments (Fig. 1a, b). Maximum shoot dry biomass (40 g pot^{-1}) was observed with 1.50% PB + 100% NPD; however, this was statistically comparable with 1.50% PB + 66% NPD.

Addition of 66% NPD + 1.50% PB significantly ($P \leq 0.05$) decreased (16%) the days to tasseling over the respective control (Fig. 2a). At 66% NPD, 1.50% PB and 0.75% PB + 0.75% BM significantly ($P \leq 0.05$) decreased (14 and 13%, respectively) the days required for silking than respective control (Fig. 2b).

At 66% NPDs, 1.50% PB was most effective for improving dry biomass yield of maize plants by up to 2.0 folds as compared to its control (Fig. 3a). Regarding grain yield, at 66% NPD, both 1.50% PB and 1.50% BM amended treatments were statistically similar with each other, but significantly ($P \leq 0.05$) better than the respective control (Fig. 3b). Overall, maximum harvest index (39%) was obtained with 1.50% BM + 66% NPD (Fig. 3c).

Physiological Traits

As compared to control, 66% NPD + 1.50% PB resulted maximum statistical increase (14%) in chlorophyll contents.

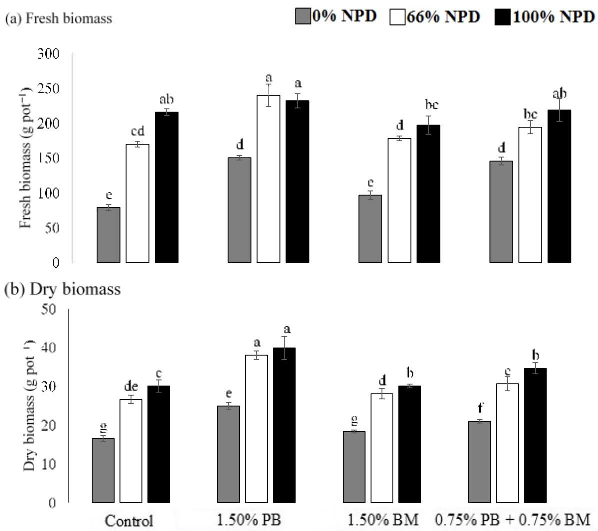

Fig. 1: Effect of peanut-waste biochar (PB) and buffalo manure (BM) on fresh and dry biomass (fifty five days after sowing) of maize supplied with different nitrogen-phosphorus fertilizer doses (NPDs). Recommended 100% NPD was 240 kg N ha^{-1} + 90 kg P ha^{-1}. Values are means of 3 replications ± error bars of standard deviation (SD). Treatment sharing the similar letter(s) with each other do not had significant difference at $P \leq 0.05$ based on Tukey-HSD test

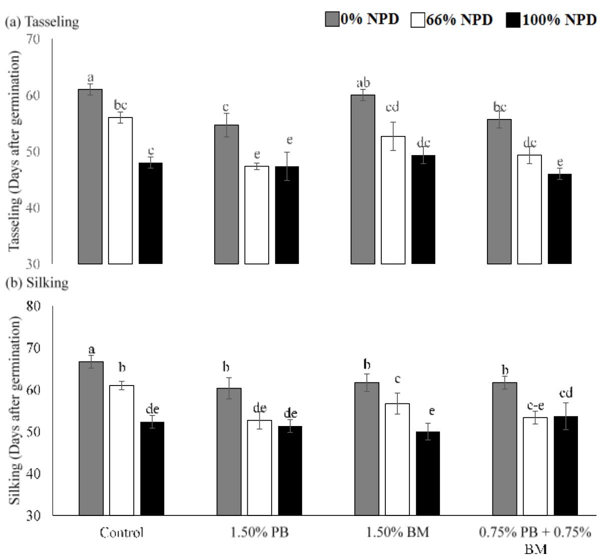

Fig. 2: Effect of peanut-waste biochar (PB) and buffalo manure (BM) on days to (a) silking and (b) tasseling of maize supplied with different nitrogen-phosphorus fertilizer doses (NPDs). Recommended 100% NPD was 240 kg N ha^{-1} + 90 kg P ha^{-1}. Values are means of 3 replications ± error bars of standard deviation (SD). Treatment sharing the similar letter(s) with each other do not had significant difference at $P \leq 0.05$ on Tukey-HSD test

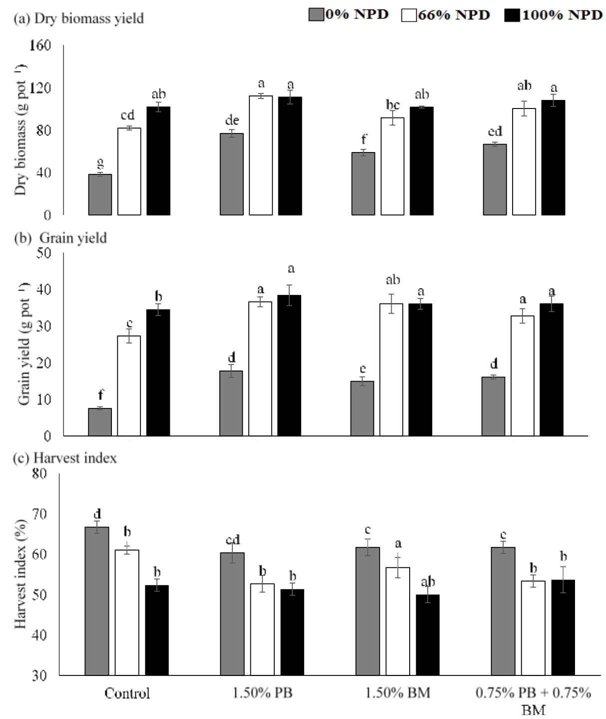

Fig. 3: Effect of peanut-waste biochar (PB) and buffalo manure (BM) on (a) dry biomass, (b) grain yield and (c) harvest index of maize supplied with different nitrogen-phosphorus fertilizer doses (NPDs). Recommended 100% NPD was 240 kg N ha^{-1} + 90 kg P ha^{-1}. Values are means of 3 replications ± error bars of standard deviation (SD). Treatment sharing the similar letter(s) with each other do not had significant difference at $P \leq 0.05$ based on Tukey-HSD test

With same treatment combination, photosynthetic rate was increased by 21% than respective control (Table 3). Addition of 0.75% PB + 0.75% BM at 66% NPD increased transpiration rate to a maximum value in the experiment (4.62 mmol H_2O m^{-2} s^{-1}).

Nitrogen and Phosphorus in Plant Tissues

At vegetative growth stage, comparing the different treatments at 66% NPD, only 0.75% PB + 0.75% BM significantly ($P \leq 0.05$) increased shoot N concentration than respective control (Table 4). At 1.50% PB, maximum increase in shoot N concentration (59%) was at 66% NPD over 0% NPD. Maximum shoot N concentration (7.97 g kg^{-1}) at maturity was with 66% NPD + 1.50% PB. At both vegetative and reproductive stages, shoot P concentration was statistically comparable at different organic treatments at 66 and 100% NPDs. At 0% NPD, shoot P concentration at vegetative stage was maximum with 1.50% PB.

At both 66 and 100% NPDs, there was a non-significant effect of different organic amendments on grain N or P concentration (Table 5).

Table 3: Effect of peanut-waste biochar (PB) and buffalo manure (BM), applied at three mineral fertilizer doses, on chlorophyll content, photosynthetic rate and transpiration rate at vegetative stage of maize

Organic amendments	Nitrogen and phosphorus fertilizer doses (% of recommended)		
	0	66	100
Chlorophyll content			
Control	19±1 f	32±1 c	35±1 ab
1.50% PB	26±2 d	36±1 a	36±1 a
1.50% BM	22±1 e	32±1 c	34±1 abc
0.75% PB + 0.75% BM	24±1 e	33±2 bc	36±1 ab
Photosynthetic rate (μmol CO_2 m^{-2} s^{-1})			
Control	14±0 f	21±1 cd	25±1 ab
1.50% PB	18±0 de	25±1 ab	25±2 ab
1.50% BM	17±1 ef	23±1 abc	26±1 a
0.75% PB + 0.75% BM	18±2 de	24±1 abc	22±1 bc
Rate of transpiration (mmol H_2O m^{-2} s^{-1})			
Control	2.4±0.0 d	4.0±0.3 abc	3.9±0.3 abc
1.50% PB	3.2±0.2 bcd	3.8±0.3 abc	4.0±0.2 abc
1.50% BM	2.6±0.2 d	3.6±0.3 bc	3.9±0.3 abc
0.75% PB + 0.75% BM	3.2±0.2 cd	4.6±0.4 a	4.1±0.5 ab

Values are means of 3 replications ± standard deviation (SD); 100% NPD was 240 kg N ha^{-1} + 90 kg P ha^{-1}; For each parameter, treatment sharing the similar letter(s) with each other do not had significant difference at $P \leq 0.05$ based on Tukey-HSD test

Table 4: Effect of peanut-waste biochar (PB) and buffalo manure (BM), applied at three mineral fertilizer doses, on nitrogen and phosphorus concentration in maize shoot

Organic amendments	Nitrogen and phosphorus fertilizer doses (% of recommended)		
	0	66	100
Shoot nitrogen concentration (g kg^{-1}) at vegetative stage			
Control	7.7±0.4 d	14.4±0.4 b	15.7±0.8 ab
1.50% PB	10.2±0.6 c	16.2±0.7 ab	15.6±1.1 ab
1.50% BM	9.7±0.4 cd	15.5±0.6 ab	16.3±0.8 ab
0.75% PB + 0.75% BM	10.6±0.6 c	16.7±1.3 a	15.6±0.9 ab
Shoot nitrogen concentration (g kg^{-1}) at maturity			
Control	5.5±0.3^{NS}	7.3±0.2	7.0±0.3
1.50% PB	6.9±0.4	7.4±0.7	7.5±0.5
1.50% BM	7.2±0.3	7.1±0.4	7.8±0.6
0.75% PB + 0.75% BM	8.0±0.4	8.0±0.4	7.8±0.5
Shoot phosphorus concentration (g kg^{-1}) at vegetative stage			
Control	2.4±0.0 d	1.8±0.2 e	2.7±0.3 abc
1.50% PB	3.2±0.2 bcd	2.5±0.2 b-d	3.3±0.2 a
1.50% BM	2.6±0.2 d	2.0±0.1 de	2.8±0.3 abc
0.75% PB + 0.75% BM	3.2±0.2 cd	2.4±0.2 c-e	3.1±0.3 ab
Shoot phosphorus concentration (g kg^{-1}) at maturity			
Control	1.4±0.1 e	1.8±0.2 a-d	1.9± 0.1 abc
1.50% PB	1.6±0.1 b-e	2.0±0.1 a	2.0± 0.1 a
1.50% BM	1.5±0.1 c-e	1.9±0.1 abc	2.0± 0.1 a
0.75% PB + 0.75% BM	1.5±0.2 de	1.9±0.1 ab	1.9± 0.2 abc

Values are means of 3 replications ± standard deviation (SD); 100% NPD was 240 kg N ha^{-1} + 90 kg P ha^{-1}; For each parameter, treatment sharing the similar letter(s) with each other do not had significant difference at $P \leq 0.05$ based on Tukey-HSD test; ^{NS}non-significant interaction effect

At 0% NPD, however, grain N and P concentration were increased respectively by 51 and 40% with 0.75% PB+ 0.75% BM than respective control. At maturity stage, maximum total N (88% greater than respective control) and P (49% greater than respective control) uptake were observed with 66% NPD + 1.50% PB (Fig. 4).

Soil Nutrient Dynamics

At vegetative stage, statistically maximum (25% more than the respective control) soil NO_3^--N contents (15.4 mg kg^{-1} soil) were at 66% NPD + 0.75% PB + 0.75% BM (Table 6). At maturity, addition of 1.50% BM with 0 and 66% NPDs increased soil NO_3^--N contents by 2.8 and 1.5 folds, respectively, over their respective control treatments.

At vegetative stage, 1.50% PB + 66% NPD significantly increased (14%) soil NH_4^+-N contents than respective control (Table 6). Maximum soil NH_4^+-N contents (31.3 mg kg^{-1} soil) were at 100% NPD + 1.50% PB. At maturity, 66% NPD + 1.50% PB increased soil NH_4^+-N contents by 2.4 folds over respective control treatment.

At vegetative growth stage, comparing the different treatments with 1.50% PB, 100% NPD increased soil mineral-N contents by 3.1 folds than 0% NPD (Table 6). At maturity stage, comparing the different treatments at 0% NPD, 1.50% BM amended treatment increased mineral-N contents by 2.1 folds than the respective control treatment. At 66% NPD, 1.50% PB amended soil showed 1.9 folds greater mineral-N content over the respective control.

At vegetative growth stage, 1.50% PB amended treatments increased available P contents by 44 and 32% respectively at 66 and 100% NPD than respective control treatments (Table 6). With addition of 1.50% PB, a significant ($P \leq 0.05$) increase in soil available P contents were observed with 66 and 100% NPDs (up to 2.3 and 2.5 folds, respectively) than 0% NPD. At maturity stage, at 0 and 66% NPDs, addition of 0.75% PB + 0.75% BM resulted increase in available P contents by 2.8 and 2.0 folds than their respective control treatments. However, maximum increase of 2.0 folds was observed with at 100% NPD + 1.50% BM than respective control.

Discussion

Combine application of animal manures, crop residues and other organic amendments with inorganic fertilizers may be more productive than the sole application of inorganic fertilizers or organic amendments (Uzoma *et al*., 2011; Naeem *et al.*, 2018). At vegetative growth stage, with different NPDs, 1.50% PB amended treatments performed better for improving maize growth (Fig. 1), and shoot N and P concentration (Table 4). Due to greater N content in biochars derived from animal manures, a significant increase in plant available N was observed (Wang *et al*., 2012). At higher pyrolysis temperature, N becomes progressively embodied in heterocyclic and aromatic structures as formation of these structures relate with pyrolysis temperature (Almendrosa *et al*., 2003). As a result, labile forms of N, *i.e.*, proteins decrease at high pyrolysis temperature and vice versa (Wang *et al*., 2012).

Table 5: Effect of peanut-waste biochar (PB) and buffalo manure (BM), applied at three mineral fertilizer doses, on nitrogen and phosphorus concentration in maize grain

Organic amendments	Nitrogen and phosphorus mineral fertilizer doses (% of recommended)		
	0	66	100
Grain nitrogen concentration (g kg^{-1})			
Control	11±1 e	19±2 a-d	18±1 a-d
1.50% PB	16±2 d	21±1 ab	20±1 a-d
1.50% BM	17±1 cd	21±1 ab	20±2 abc
0.75% PB + 0.75% BM	17±1 b-d	22±2 a	20±1 a-d
Grain phosphorus concentration (g kg^{-1})			
Control	3.2±0.2 d	5.2±0.2 ab	5.2±0.2 ab
1.50% PB	4.4±0.2 bc	5.7±0.4 a	5.5±0.4 a
1.50% BM	3.9±0.2 cd	5.4±0.2 a	5.9±0.3 a
0.75% PB + 0.75% BM	4.4±0.3 bc	5.6±0.3 a	5.4±0.5 a

Values are means of 3 replications ± standard deviation (SD); 100% NPD was 240 kg N ha^{-1} + 90 kg P ha^{-1}; For each parameter, treatment sharing the similar letter(s) with each other do not had significant difference at $P \leq 0.05$ based on Tukey-HSD test

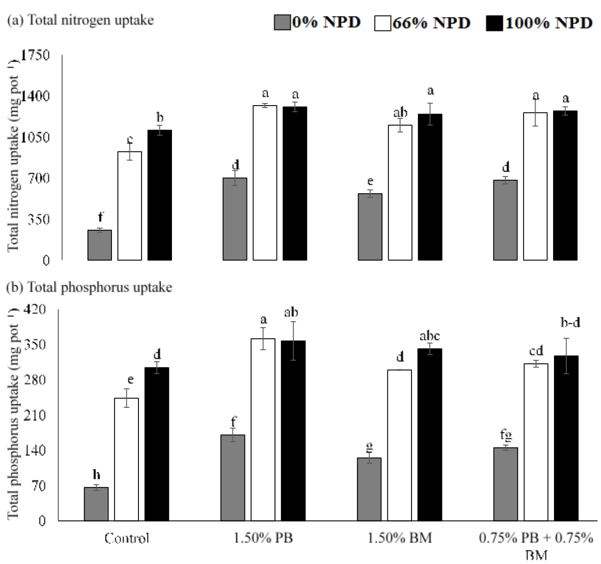

Fig. 4: Effect of peanut-waste biochar (PB) and buffalo manure (BM) on (A) total N and P (B) uptake of maize supplied with different nitrogen-phosphorus fertilizer doses (NPDs). Recommended 100% NPD was 240 kg N ha^{-1} + 90 kg P ha^{-1}. Values are means of 3 replications ± error bars of standard deviation (SD). Treatment sharing the similar letter(s) with each other do not had significant difference at $P \leq 0.05$ based on Tukey-HSD test

In the current study, we used a low pyrolysis temperature (300°C) for PB production and that had a total of 2.61% N (Table 2). A significant improvement in growth (Fig. 1–3) and plant physiological attributes (Table 3) proved the effectiveness of low temperature produced PB.

At vegetative growth stage, highest soil mineral N contents were also obtained with 1.50% PB (Table 6). In low temperature produced biochar, the mineralization of organic N provides inorganic N in the soil (Schimel and Bennett, 2004); that may relate with growth and yield response (Figs. 1–3) and shoot N concentration (Table 4). Soil application of high CEC containing biochar, improves NH_4^+-N retention capacity of soil (Zheng *et al.*, 2013). At maturity stage, better soil NH_4^+-N status in PB treatments could be due high CEC (49.1 $cmol_c$ kg^{-1}) of PB along with its nutrient status (Table 2 and 6).

Only at vegetative stage, sole BM addition did not enhance maize growth (Fig. 1) or nutrient concentration in plant tissue (Table 4). This was possible as application of non-stabilized or semi-decomposed organic wastes to soil may initially lead to nutrient immobilization in soils (Butler *et al.*, 2001).

In 1.50% PB amended soil, improved P availability (Table 6) may be due to higher extractable P in biochars (Doan *et al*., 2015). During feedstock pyrolysis, organic C starts to volatilize, but not P unless the temperature of pyrolysis reaches up to 700°C. Thus, pyrolysis of organic wastes may considerably enhance inorganic P by breaking organic P bonds with disproportionately volatilizing C portion (Knoepp *et al.*, 2005). At 0 and 66% NPDs, tasseling and silking were initiated earlier in 1.50% PB amended treatments, over the respective control and 1.50% BM amended treatments (Fig. 2). This may relate with improved P availability from soil (Table 6) as nutrient availability influences onset of crop growth stages (Jan *et al.*, 2018).

At vegetative growth stage, with 100% NPD, 1.50% BM amended treatment showed comparatively lower NH_4^+-N, NO_3^--N and available P contents than 1.50% PB amended treatment (Table 6). A temporary reduction in plant available N was might be due to the immobilization of mineral N in the soil (Butler *et al*., 2001; Lamb *et al*., 2014) and rapid N uptake by plants. Moreover, losses of ammonia, as high as 50%, have been reported for soils applied with animal manures (Terman, 1979). However, during the whole growing season, there is often a net gain of mineral-N in the animal residues amended soil after microbial bloom (Lamb *et al*., 2014). This may be a possible reason of improved nutrient status in 1.50% BM and 0.75% PB + 0.75% BM amended treatments at later growth stage (Table 6).

In BM amended treatments, improved soil mineral N and P content at later growth stage confirmed mineralization by microbes. Moreover, maximum harvest index (Fig. 4) achieved as a result of 66% NPD with 1.50% BM addition was the indication towards improved soil nutrient availability at later growth stage. Growth, yield, and grain and shoot nutrient parameters at maturity were comparable at different organic treatments at respective 100 and 66% NPDs (Fig. 3; Tables 5, 6). We could not find any further significant increase in the growth, yield and nutrient uptake of maize, with combined 0.75% PB + 0.75% BM addition over their respective sole applications of 1.50% PB or 1.50% BM. However, effects of PB may be long lasting as it has more stabilized organic C than BM.

Table 6: Effect of peanut-waste biochar (PB) and buffalo manure (BM), applied at three mineral fertilizer doses, on soil nitrate-nitrogen, ammonium-nitrogen, mineral-nitrogen and available phosphorus content

Treatment	Nitrogen and phosphorus mineral fertilizer doses (% of recommended)					
	0	66	100	0	66	100
	At vegetative stage			At maturity		
Nitrate-nitrogen (mg kg^{-1} soil)						
Control	2.8±0.4 f	12.3±0.9 cd	12.8±0.8 b-d	2.2±0.2 g	3.76±0.3 f	3.7±0.2 f
1.50% PB	5.2± 0.4 e	12.1±0.8 cd	14.5±0.8 ab	4.8±0.3 e	4.81±0.3 e	6.7±0.3 ab
1.50% BM	3.7± 0.3 ef	11.9±0.6 cd	11.5±1.0 d	6.2±0.5 bc	5.59±0.5 cd	6.3±0.2 b
0.75% PB + 0.75% BM	5.1±0.4 f	15.4±1.8 a	13.4±0.8 bc	5.3±0.5 de	5.54±0.4 cd	7.3±0.5 a
Ammonical-nitrogen (mg kg^{-1} soil)						
Control	4.1±0.3 e	24.8±2.1 bc	25.6±1.6 bc	4.6±0.3 g	4.9±0.3 fg	5.9±0.1 ef
1.50% PB	9.4±0.6 d	28.2±2.2 ab	31.3±1.6 a	7.3±0.8 cd	11.7±1.2 a	11.4±0.9 a
1.50% BM	8.9±0.5 de	23.8±1.7 bc	25.1±2.1 bc	7.8±0.7 c	10.6±0.8 ab	11.6±0.5 a
0.75% PB + 0.75% BM	8.2±0.5 de	21.9±1.3 c	27.2±2.6 ab	6.2±0.4 de	10.6±0.6 ab	9.5±0.5 b
Mineral-nitrogen (mg kg^{-1} soil)						
Control	6.9±0.1 d	37.1±1.3 b	38.4±2.2 b	6.8±0.5 g	8.7±0.2 f	9.6±0.2 f
1.50% PB	14.6±0.3 c	40.2±1.7 b	45.8±2.4 a	12.1±0.9 e	16.5±1.6 bc	18.1±1.1 a
1.50% BM	12.6±0.5 c	35.7±2.2 b	36.6±3.1 b	14.0±1.2 d	16.2±1.2 c	17.9±0.7 ab
0.75% PB + 0.75% BM	13.3±0.4 c	37.3±2.6 b	40.6±3.2 ab	11.5±0.9 e	16.2±0.6 c	16.9±0.9 abc
Available phosphorus content (mg kg^{-1} soil)						
Control	5.5±0.2 f	14.8±0.5 cd	14.3±0.8 d	3.1±0.2 f	5.3±0.4 e	5.5±0.5 e
1.50% PB	8.2±0.4 e	19.6±1.4 a	20.6±1.3 a	7.2±0.4 d	9.3±0.5 bc	9.7±0.5 abc
1.50% BM	6.1±0.5 ef	15.4±1.3 b-d	17.3±1.2 b	8.2±0.5 cd	9.7±0.6 abc	11.2±0.8 a
0.75% PB + 0.75% BM	7.6±0.4 ef	13.5±0.8 d	16.5±0.6 bc	8.6±0.4 cd	10.8±0.4 ab	10.6±0.9 ab

Values are means of 3 replications ± standard deviation (SD); 100% NPD was 240 kg N ha^{-1} + 90 kg P ha^{-1}; For each parameter, treatment sharing the similar letter(s) with each other do not had significant difference at $P \leq 0.05$ based on Tukey-HSD test

Conclusion

At vegetative stage, 1.50% PB with 66 or 100% NPDs increased dry matter yield than respective control, 1.50% BM and 0.75% PB + 0.75% BM. This was related with greater availability of soil N and P with with low temperature (300°C) produced PB than with other treatments. At maturity, however, 1.50% PB and 1.50% BM amended treatments likewise improved dry biomass and grain yield at both 66 and 100% NPDs. Moreover, mineral-N and available P contents with either PB or BM were statistically at par at 66 and 100% NPDs, but, statistically more than respective controls. Conclusively, additions of 1.50% PB and BM similarly improved grain yield, and decreased N and P fertilizer demand of maize by about 34%. Long-term comparison of biochar and animal manures is, however, required to test sustainable response of applied treatments.

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