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FORMULATION OF BIOCHAR BASED FERTILIZER FOR IMPROVING MAIZE PRODUCTIVITY AND SOIL FERTILITY

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Abstract

Incorporation of biochar to agriculture field has the potential to be a primary factor in maintaining soil fertility and productivity particularly in nitrogen and organic matter limiting environments. Clear experimental evidences to support this view, however, are still lacking. Keeping in view the significance of biochar and limited information on its role in crop production, the current experiments were designed to evaluate the potential use of biochar in crop production for 2 years. The experiment consisted of three factors namely: (1) Biochar (0, 25 and 50 ton ha^{-1}), (2) FYM (5 and 10 ton ha^{-1}) and (3) nitrogen (75 and 150 kg ha^{-1}). A control treatment (all at nil level) was included in the experiment for comparison. All the treatments were replicated three time in RCB design at New Developmental Farm of the University of Agriculture Peshawar Pakistan. As per expectation inorganic N and FYM application increased maize yield in comparison to control. Furthermore, BC treatments increased maize grain ear^{-1} and grain yield by 21 and 11% over no BC treatments (where FYM and N was applied but no biochar) while caused 29 and 35% in comparison to control respectively. Similarly, maize biological yield was increased by 14 and 39% over no BC and control treatments respectively. Beside crop yield, soil properties like carbon content, N status, Phosphorus, crop N uptake and crop P uptake was significantly increased by BC treatment over no BC treatment. Overall, application of BC showed convincing results as compared to sole application of N and FYM, however, problems associated with BC production in Pakistan are needed to be addressed in future research.

Key words: Biochar, C: N ratio, Carbon sequestration and Crop production.

Introduction

Nitrogen is believed to be the primary nutrient that regulates and generates plant growth and development in agriculture environment. Mineral N application augmented plant growth swiftly and presented credible result that led to increase farmers' interest in the use of nitrogenous fertilizer (Jones *et al.,* 2012). On the other hand, Nitrogen (N) losses by percolation or invigoration from coarse-textured soils often lead to reduced production and negative environmental repercussions (Lehmann *et al.,* 2006). Consequently not only demand of N application per unit area increased but it also brought degradation in soil quality and increased production cost (Arif *et al.,* 2012). Some tentative evidence proposes that plant may take nitrogen in organic form or as amino acids (Jones *et al.,* 2009). Likewise, inorganic N production in soil is controlled by many factors, among them the rate of above and below ground plant residue decomposition, their content of soluble materials and the interaction with decomposer communities and environmental conditions appear to be the most significant (Lehmann *et al.,* 2003; Stenier *et al.,* 2007). Soil is the most important natural resource on which human existence and prosperity depends, but soil quality and fertility mainly depends on soil organic matter status. Organic matter content is less than 1% in Pakistani soil (Sharif *et al.,* 2002). Due to population density and extensive cereal cropping, farmers use more commercial fertilizer which further degrade soil health and fertility. In the early 1970s, most of the wheat and maize farmers were using organic matter but their interest declined with the surge in cropping intensity and availability of high yielding commercial fertilizers (Khaliq *et al.,* 2009). Constant use of inorganic manure had disturbed the natural equilibrium of soil fertility and caused high imbalances among various nutrient content in the soil (Ali *et al.,* 2011). Use of organic manure not only lessen production cost but also ameliorate soil health and increase production per unit area on sustainable basis (Arif *et al.,* 2012). FYM as a source of organic manure is well tested in Pakistan. It provides nutrients to crop and acts as a source of energy for soil microbes. Consequently, crop yield and soil physiochemical and biological properties are enhanced as a result of higher microbial population and activities (Arif *et al.,* 2013; Sharif *et al.,* 2002; Ali *et al.,* 2015). Improvement in soil properties such as soil structure, soil organic matter status, soil carbon, etc. has been reported as a result of FYM application to soil (Ali *et al.,* 2012). Several scientists are of the view that FYM positively affect soil structural quality, by reducing bulk density, increasing porosity, water infiltration rate and saturated hydraulic conductivity (Khan *et al.,* 2008). The importance of FYM is paramount in the current circumstances of high soil degradation. However, growers are reluctant to use FYM either because of its availability at large scale in Pakistan or because of rapid decomposition under high temperature (Ali *et al.,* 2011b). In such cases FYM is required to be applied regularly which is impossible for poor farmers. For the eradication of this problem farmers need to apply the more decomposition resistant organic material to soil that can sustain in soil for long time (Rondon *et al.,* 2007). Historically, clay amendment has been used on coarse-textured soils to decrease water repellence and nutrient leaching (Sohi *et al.,* 2009). Currently, biochar has been proposed as an alternative soil amendment to decrease N leaching whereas simultaneously storing carbon (Varela *et al.,* 2013). Biochar is believed to have greater nutrient-retention capacity and is highly resistant to decomposition. The beneficial effects of biochar are determined primarily by some of its properties: high porosity, responsible for its high water retention capacity; high cat-ion exchange capacity which favours the retention of nutrients and prevent their loss; direct nutrient supply depending on the type of bio-char; and the capacity of being a habitat for beneficial microorganisms, which can promote the release and uptake of nutrients by plants (Widowati *et al.,* 2011). Thus, the chemical and biological stability of bio-char have a high potential interest for agronomic systems in Mediterranean soils because they are generally poor in organic matter, which limits their fertility (Atkinson *et al.,* 2010).

In the present study, wheat-maize-wheat cropping cycle was followed for 2 years under different treatments (bio-char, FYM and mineral fertilization) in New Developmental Farm of the University of Agriculture Peshawar Pakistan. Both of these crops are highly exhaustive and degrade soil fertility (Arif & Ali, 2013). Farmers mainly rely on the use of inorganic fertilizer for increasing the yield of these crops. Due to population pressure we cannot ignore the importance of these crops, and also we cannot compromise on soil fertility and quality at the same time. We hypothesized that biochar in combination with other manures and commercial fertilizer may increase crop yield without degrading the soil quality. Therefore, in order to deal with this situation, the current study was designed to evaluate the integrative effect of bio-char, FYM and mineral fertilizer on wheat and maize yield and soil fertility and productivity. This paper investigates the potential use of biochar for agriculture production and soil improvement, and to find out how farmers and commercial growers can utilise it in order to achieve these goals.

Material and Methods

In this experiment we have studied the integrated use of biochar, FYM and mineral nitrogen for improving maize yield and soil fertility. These experiments were based on the hypothesis (1), Biochar could be used as tool for improving crop productivity and soil fertility (2) Biochar did not effect maize yield and soil properties. Two level of FYM and N were used in the experiment to insure timely availability of all essential nutrients and mineralization of added biochar with the help of soil microbes.

Experimental site: The trial site was located at the New Developmental Farm of the University of Agriculture, Peshawar (34°1'21"N, 71°28'5"E) and the experiments were carried out during the summer of 2013 and 2014. The site has a warm to hot, semi-arid, sub-tropical, continental climate with mean annual rainfall of 360 mm. Summer (May–September) has a mean maximum temperature of 40°C and mean minimum temperature of 25°C. Winter (December to the end of March) has mean minimum temperature of 4°C and a maximum of 18.4°C. The average winter rainfall is higher than that of the summer. The highest winter rainfall has been recorded in March, while the highest summer rainfall is in August.

Soil characteristics: Soil was collected from the top layer (0-10 cm depth) of the New Developmental Farm of the University of Agriculture, Peshawar located at 34.1°'21"N, 71°28'5"E. The soil has a clay loam texture. Immediately after collection, the soil was transferred to the laboratory in gas permeable bags where it was sieved to pass 2 mm to remove stones, plant roots and earthworms. The basic properties of the soil are presented in Table 1.

Table 1. Physio-chemical properties of soil used in these experiments are given below. Values represent means ± Standard error mean (n = 3).

Soil character	Measured quantity
Water content (%)	20.48 ± 0.29
pH (1:2 H_2O)	7.21 ± 0.01
EC (1:2 H_2O µScm^{-1})	15.93 ± 0.53
Available NO_3^- (mg N l^{-1} soil solution)	4.51 ± 0.07
Available NH_4^+ (mg N l^{-1} soil solution)	0.1 ± 0.01
Organic matter (%)	0.65 ± 0.03

Table 2. Chemical characteristics of biochar and FYM used in experiments. Values represent means ± Standard error mean (n = 3).

Parameters	Biochar	FYM
Total N (%)	0.08 ± 0.002	0.7 ± 0.003
Total C (%)	57 ± 0.08	13 ± 0.02
Ca (mg l^{-1})	15 ± 0.04	19 ± 0.04
K (mg l^{-1})	27 ± 0.01	15 ± 0.03
P (mg l^{-1})	1.2 ± 0.07	2.4 ± 0.04
Na (mg l^{-1})	12 ± 0.02	07 ± 0.01
Mg (mg l^{-1})	09 ± 0.05	04 ± 0.02
EC (mS)	0.02 ± 0.001	0.05 ± 0.01
pH	7.2 ± 0.06	4.5 ± 0.02

Nutrients analysis of biochar and FYM: The biochar and FYM samples were ground to a fine powder for subsequent C and N determination using a TruSpec® CN Analyzer (Leco Corp., St Joseph MI, USA). Water content was measured by sub sampling 10 g of biochar and FYM, dried over night at 105°C and calculated on the basis of weight loss. Samples pH and EC were measured by sub sampling 5g of sieved sample and 10ml of deionised water (1:2 w/v) was added, followed by shaking for 1 hour using orbital shaker (250 rev min^{-1}). The available P and K were determined in the AB-DTPA extract (Soltanpour & Schwab, 1977). Phosphorus was read as Spectrophotometer after colour development and potash on Flame Photometer. For Ca and Mg, solution was directly read on Atomic Absorption Spectrophotometer (Perkin Elmer Model 2380, USA).

Experimental design: The study consisted of three levels of biochar (0, 25 and 50 t ha^{-1}), two levels of FYM (5 and 10 t ha^{-1}) and two levels of fertilizer-N (urea) (75 and 150 kg ha^{-1}) together with a control treatment (no biochar, FYM or fertilizer-N). Biochar and FYM were applied at the time of sowing and reflected typical FYM doses for the region. Half of the fertilizer-N was applied at sowing and the remaining half applied at the 8 leaf stage (V7). Single super phosphate (SSP)was applied at the rate of 90 kg ha^{-1} as a basal dose. The FYM was obtained from the Peshawar University of Agriculture dairy farm and the biochar was produced from Acacia (e.g. *A. nilotica* (Linn.) Delile) using traditional methods employed in the region (Amur and Bhattacharya, 1999). Characteristics of the FYM and biochar are shown in Table 2.

The experiment had three replicates per treatment, and was laid out in a randomized complete block design. The treatment plots were 4.0 m x 4.5 m in size with strong ridges placed around each plot for delineation and to prevent biochar migration. Row-to-row and plant-to-plant distance was 75 cm and 20 cm, respectively. The field was ploughed twice down to a depth of 30 cm with the help of cultivator followed by planking to break the clods and level the field taking care not to disturb the ridges and to facilitate biochar movement from one plot to another. Maize (*Zea mays* L. cv. Azam) was sown at a rate of 30 kg ha^{-1} on July 21^{st}, 2013 and 25th June 2014. Locally recommended irrigation schedules were followed, with modifications according to the prevailing weather condition as and when needed. Weeds were controlled manually by hoeing. All other standard agronomic practices were applied uniformly to each experimental unit.

Crop harvest: At harvest (Oct 9th, 2013 and 13th October 2014), the following maize yield components were recorded: total aboveground biomass, grain yield, number of ear^{-1} and the thousand grain weight. To determine total above-ground yield (kg ha^{-1}), the plants from the four central rows in each plot were harvested, dried and weighed. The ears from these harvested plants were then removed, threshed and grain yield (kg ha^{-1}) calculated. Ears were counted in the four central rows of the standing maize crop in each plot. Thousand grain weight was calculated from a sub-sample from of each plot.

Soil parameters: Soil samples from depth of 15cm were collected from each experimental plot at physiological maturity of wheat crop and crushed, passed through 2mm sieve and stored for analysis in polythene bages after air drying. Soil carbon was determined by the Walkely-Black procedure (Nelson & Sommers, 1996). Total N in soil samples was determined by the steam distillation method as described by Mulvaney (1996). The available P was determined in the AB-DTPA extract (Soltanpour & Schwab, 1977). Phosphorus was read as Spectrophotometer after color development and potash on Flame Photometer.

Results

Number of grains ear^{-1}: Maize number of grains ear^{-1} averaged over two cropping seasons are presented in figure 1. As expected, inorganic nitrogen (N) and FYM significantly increased grains ear^{-1} over control ($p<0.005$; Table 1). Overall, biochar (BC) application at the rate of 25 t ha^{-1} performed better in comparison to 50 t BC ha^{-1} at level of N and FYM except in treatments of 75 kg N and 5 t FYM ha^{-1}. However, in comparison to no BC treatments (receiving FYM and N but no BC), 50 t ha^{-1} BC increased grains ear^{-1} ($p<0.05$). Biochar application at the rate of 25 t ha^{-1} increased grains ear^{-1} by 21%.

Thousand grain weight (g): Thousand grain of maize is important yield contributing parameter. Figure 2 represent thousand grain weight of maize as affected by BC, FYM and N over two cropping seasons. Nitrogen fertilization and FYM improved thousand grain weight ($p<0.05$) in comparison to control (all treatments at nil level). Generally BC application resulted in higher grain yield over no BC treatments irrespective of FYM and N levels ($p<0.05$). As a result of BC treatments 1000 grain weight was increased by 17% (two field seasons average).

Grain yield (kg ha^{-1}): The effect of organic and inorganic treatments (BC, FYM and N) on maize grain yield of two cropping season are presented in figure 3. Significant increase in grain yield of maize was noticed in FYM and N treatments as compared to control ($p<0.05$). In general, BC treatments increased grain yield of maize in comparison to control and no BC treatments ($p<0.05$). The performance of 25 t BC ha^{-1} were superior than 50 t BC under 10 t FYM ha^{-1} treatments regardless N level. Biochar treatments increased maize grain yield by 35 and 11% over control and no BC treatment respectively.

Biological yield (kg ha^{-1}): Response of maize biological yield to BC, FYM and N are shown in figure 4. Expectedly N application significantly affected maize biological yield ($p<0.05$). Though the two levels of BC (25 and 50 t ha^{-1}) had variable effect on biological yield, however, overall BC treatment increased biological yield in comparison to no BC treatments ($p<0.05$). At 75 kg N ha^{-1} both levels of BC had similar biological yield irrespective of FYM levels, however at application rate of 150 kg N ha^{-1}, the performance of 50 t BC treatments were superior than 25 t BC regardless of FYM levels. BC treatments increased maize biological yield by 14% in comparison to no BC treatments while this increase was much visible than control (39%).

Maize total N-uptake: Maize total N-uptake in response to organic and inorganic treatments averaged over two field seasons are reported in figure 5. All treatments (BC, FYM and N) performed better than control treatment. Likewise, FYM and N significantly increased maize N uptake and expectedly their higher levels (150 kg N and 10 t FYM ha^{-1}) were better than respective lower levels (75 kg h and 5 t FYM ha^{-1}; $p<0.05$). Overall, BC treatment increased total N uptake in comparison to no BC treatments. In general, 25 and 50 t BC had at par effect on total N uptake in combination with 5 t FYM treatments however; under 10 t FYM the effect of 25 t BC treatments were much impressive than 50 t BC, irrespective of N fertilization.

Maize phosphorus uptake: The effect of BC, FYM and N on maize phosphorus (P) uptake averaged over two field seasons are presented in figure 6. Though FYM and N resulted in higher P uptake over control ($p<0.05$) however, both levels of FYM and N were at par ($p>0.05$). On the whole, BC treatments improved maize P uptake in comparison to no BC treatments. The performance of 50 t BC was superior than 25 t BC treatment regardless of FYM and N levels. Overall, BC treatments resulted in 36 and 22% increase in P-uptake over control and no BC treatments.

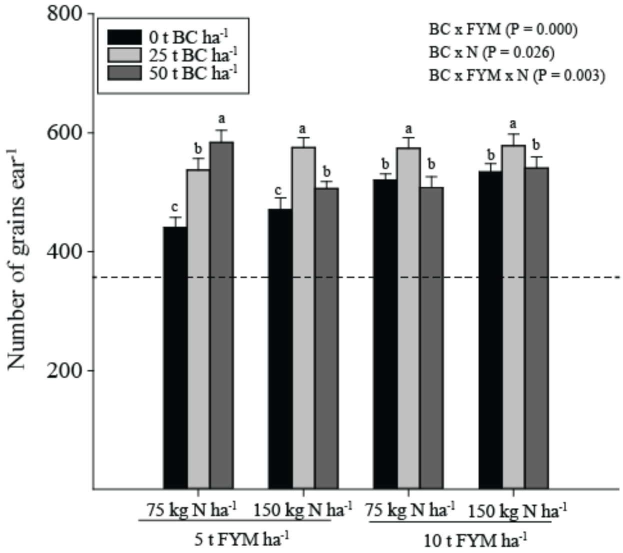

Fig. 1. Response of maize grain ear^{-1} to biochar, FYM and N. Dotted line presents value of control treatment.

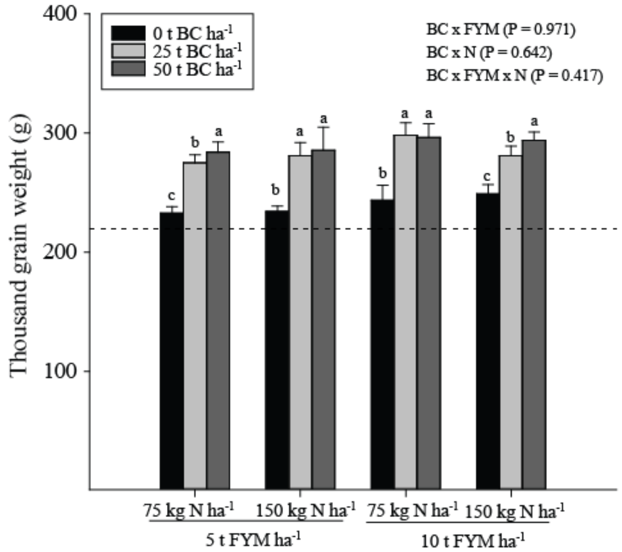

Fig. 2. Response of maize thousand grain weight to biochar, FYM and N. Dotted line presents value of control treatment.

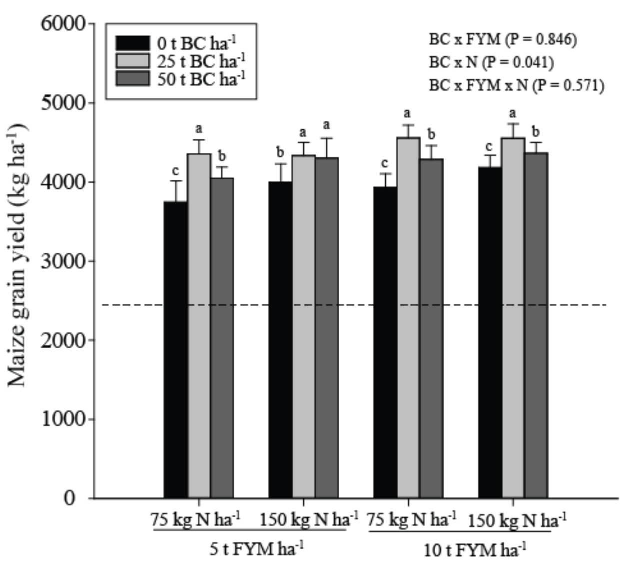

Fig. 3. Response of maize grain yield (kg ha-1) to biochar, FYM and N. Dotted line presents value of control treatment.

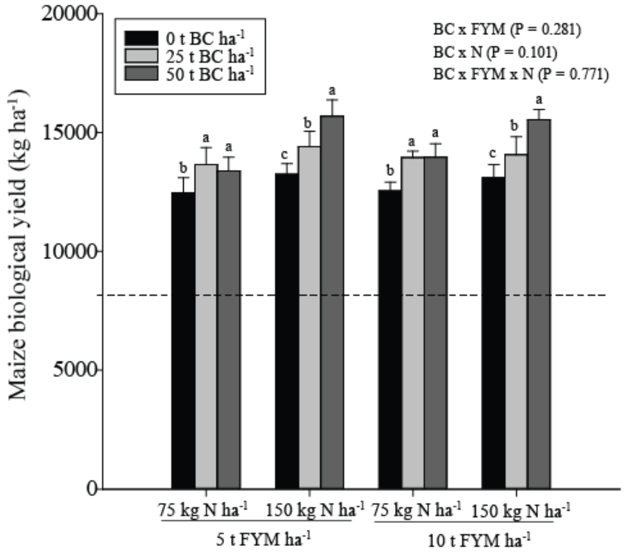

Fig. 4. Response of maize biological yield (kg ha-1) to biochar, FYM and N. Dotted line presents value of control treatment.

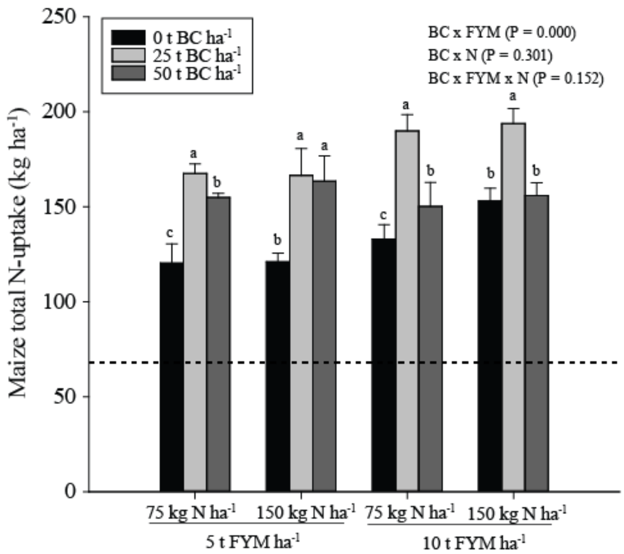

Fig. 5. Response of maize N-uptake to biochar, FYM and N. Dotted line presents value of control treatment.

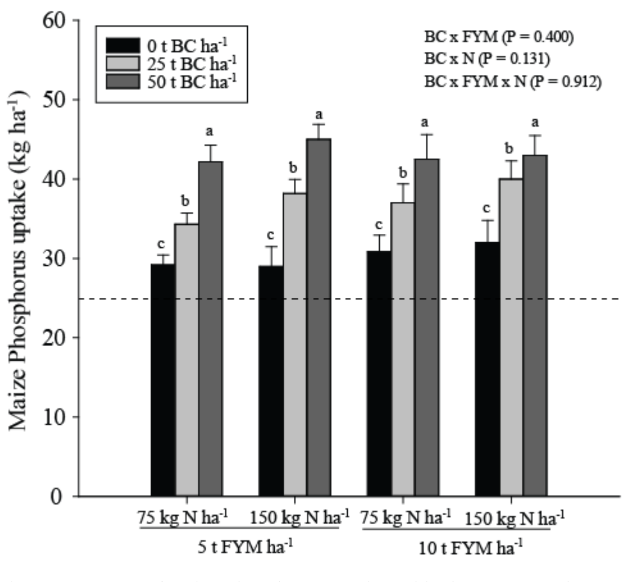

Fig. 6. Response of maize Phosphorus uptake to biochar, FYM and N. Dotted line presents value of control treatment.

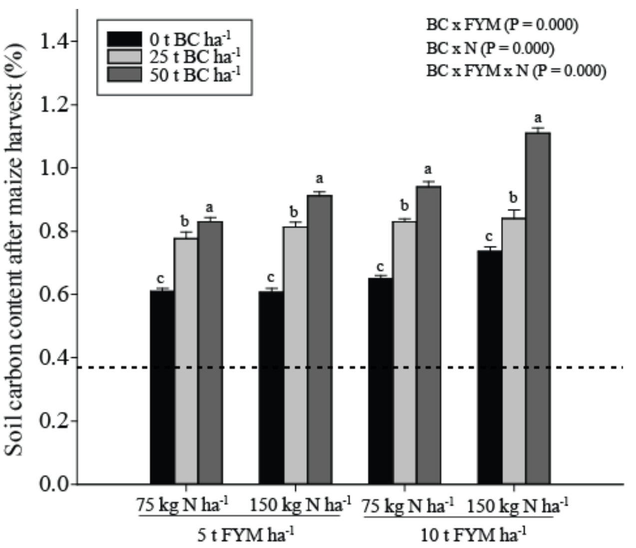

Fig. 7. Response of soil carbon content to biochar, FYM and N. Dotted line presents value of control treatment.

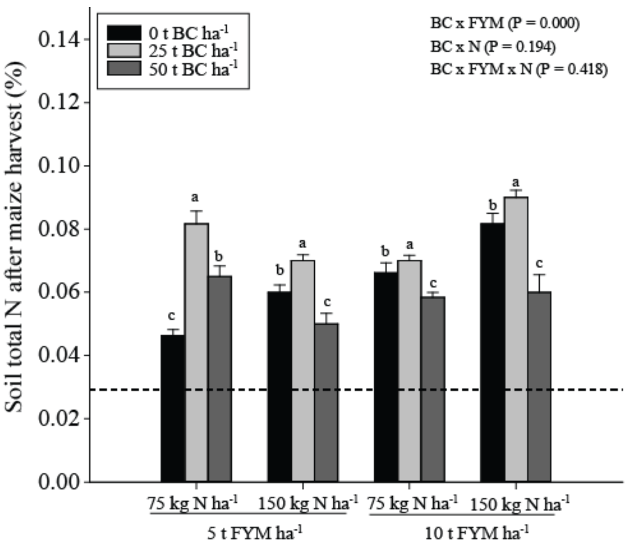

Fig. 8. Response of soil total N to biochar, FYM and N. Dotted line presents value of control treatment.

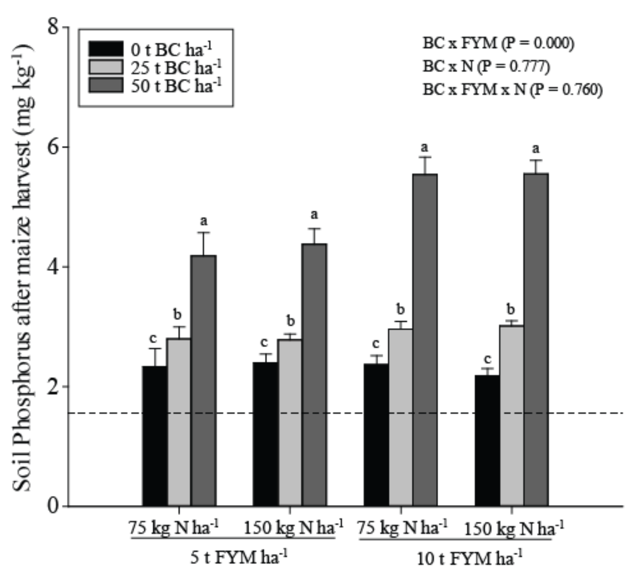

Fig. 9. Response of soil Phosphorus to biochar, FYM and N. Dotted line presents value of control treatment.

Soil carbon after maize harvest (%): Soil carbon is important soil chemical property that directly affect soil organic matter status. Changes in soil carbon as a result of BC, FYM and N over two field season are presented in figure 7. The effect of FYM and N was found significant on soil C content after maize harvest over two years ($p<0.05$). Soil carbon increased in linear manner as BC application rate was increased from 0 to 50 t ha-1 ($p<0.05$). Overall, application of 50 t BC resulted in higher soil C as compared to 25 t BC regardless of FYM and N, however; this increase was higher in combination with 10 t FYM in comparison to 5 t FYM ha-1 treatments.

Soil total nitrogen (%): Nitrogen is the most limiting crop nutrient in crop production. The effect of organic and inorganic soil amendments on total N content of soil after maize harvest are presented in figure 8 (two field season average). As expected, inorganic N and FYM treatments increased soil total N content after maize harvest in comparison to control ($p<0.05$). Generally, 25 t BC treatments increased soil total N at all level of FYM and N while 50 t BC treatments showed decreasing trend in soil total N.

Soil prosperous after maize harvest (mg kg^{-1}): The effect of BC, FYM and N on soil phosphorus after maize harvest are shown in figure 9 (averaged over two years). Both levels of FYM and N were at par however, both of them resulted in higher soil P as compared control. Overall, BC treatments increased soil P after maize harvest over control ($p<0.05$). The 50 t BC treatment performed better than 25 t BC treatments under all level of FYM and N. Soil P was increased by 120% over control and 92% over no BC treatments as a result of BC application.

Discussion

The beneficial effects of biochar on crop performance and yield gain have been reasonably well addressed for dry croplands though there has been wide variation in the field trials undertaken (e.g. type of biochar, soil conditions and crop types) and, frequently, lack of detailed information (Yamato *et al.,* 2006; Asai *et al.,* 2009; Zwieten *et al.,* 2010). In a field trial, Azeem (2014 unpublished) applied 0, 0.25 and 0.50% sugar cane bagasse biochar with and without NPK fertilizer to calcareous arid soils of Pakistan and found that 0.5% biochar +NPK fertilizer significantly increased grain yield of mash bean and subsequent wheat crop. Moreover, wheat-biochar (10%) + N-fertilizer increased by the number of grains per plant by 220% and the 1000 grain weight of mungbean by 55% in arid alkaline soil of Pakistan compared to control (Hameed, 2014 unpublished). In a pot trial with mungbean, Ahmad (2013 unpublished) found that biochar derived from *Populous euphratica* leaves , biochar + N and biochar +P increased 96%, 82% and 84% pods per pot relative to control in arid calcareous soil of Pakistan. Nutrient responses have been observed for various biochar arid soil combinations. When biochar was mixed into an Australian Aridisol at 10 Mg biochar ha^{-1}, no change in extractable soil nutrients was observed (Zwieten *et al.*, 2010). When a

Mollisol was amended with an equivalent of 12 Mg ha^{-1} biochar, soil-extractable P, as well as K and Fe, increased as compared with unamended soil (Brewer *et al.,* 2012). Laird *et al.* (2010a) amended a Mollisol with an equivalent of up to 20 Mg biochar ha^{-1}, noting an increase in soil-extractable P, K, Mg, and Ca. Ippolito *et al.* (2012a) added approximately 40 Mg biochar ha^{-1} to two Aridisols and observed a decrease in P leaching, suggesting that P retention was a function of surface functional groups, the presence of Fe and Al oxides, and precipitation with Ca and Mg. Biochar application to temperate and aridic soils can also affect the soil NO_3–N status. In a column study, Laird *et al.* (2010b) incubated a Mollisol containing up to 20 Mg biochar ha^{-1}. After 45 weeks of weekly leaching, the 20 Mg ha^{-1} biochar treatment lost 26% more NO_3–N than control columns. The authors attributed the increased NO_3–N loss to enhanced organic N mineralization stimulated by the high biochar application rate (Laird *et al.,* 2010b). In contrast, Streubel *et al.* (2011) showed a decrease in N mineralization in several soils amended with various types of biochars (up to 39 Mg ha^{-1}). Kameyama *et al.* (2012) studied NO_3–N retention by calcareous Japanese soils amended with biochar. The authors showed that biochar NO_3–N sorption was related to base functional groups present and that increased retention of NO_3–N in biochar micro pores decreased NO_3 leaching. Ippolito *et al.* (2012b) studied biochar application to two Aridisols, showing that NO_3–N leaching decreased with biochar addition to both soils at a rate equivalent to approximately 40 Mg ha^{-1}. Biochar-borne unstable C likely stimulated microbial growth and thus increased N immobilization (Ippolito *et al.,* 2012b).

Moreover, in a laboratory incubation study by Ippolito *et al.* (2014), wood derived biochar application to calcareous soil enhanced the plant available Fe and Mn and 10% biochar amendment caused a huge decline in soil NO_3–N concentration relative to other biochar application rates (1 & 2%). Arif *et al.* (2012) investigated the effect of biochar on growth and yield performance of maize and wheat in alkaline soil of Pakistan. The control plot resulted in lower yield than both the full fertilizer application without biochar and full fertilizer application with biochar. This might have been caused by high levels of nitrogen in the full fertilizer with biochar treatment. Furthermore, Ali *et al.* (2012) elaborated through experiments that biochar application significantly improved wheat leaf by 8%, stem, straw and grain N content by 4%, 7% and 13% respectively; grain and total N-uptake was enhanced by 21 and 29% and grain protein content by 6% of wheat crop compared with control or no biochar treated plots. This increase in N uptake and quality parameters of wheat through biochar application indicates the potential of biochar to improve fertilizer use efficiency, especially in soils where N loss is a major environmental and agronomic concern. Likewise, biochar application significantly increased maize N-uptake but did not induce significant variation in grain protein content and grain size and weight. Wheat yield and quality was positively improved by biochar application at the rate of 25 t ha^{-1} under the agro climatic conditions of Pakistan (Ali *et al.*, 2015).

Conclusion

Our findings of the 2-year maize experiments concluded that the integration of biochar with organic and inorganic N sources could improve maize productivity and soil quality under field conditions. Biochar application convincingly increased maize yield and soil fertility in comparison to no biochar treated plots. It also improved soil properties such as soil total N and soil phosphorus content after maize harvest. Moreover, application of FYM improved maize yield and yield components. Nitrogen alone at the rate of 150 kg ha^{-1} resulted in higher maize yield and yield components. However, nitrogen application of 75 kg N ha^{-1} in integration with 25 t BC ha^{-1} had higher yield and yield components of maize as compared to sole application of 120 kg N ha^{-1} or 50 t BC ha^{-1}. However, to quantify the long-term effect of biochar on crop production and soul fertility, time-scale for benefits of biochar under field conditions is a critical factor needs to be taken into consideration before recommendation.

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