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BIOCHAR: A NOVEL TOOL TO ENHANCE WHEAT PRODUCTIVITY AND SOIL FERTILITY ON SUSTAINABLE BASIS UNDER WHEAT-MAIZE-WHEAT CROPPING PATTERN

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Abstract

The application of organic matter is an important element for preserving long-term soil fertility because it is the reservoir of metabolic energy, which drives soil biological processes involved in nutrient availability. Two years field experiments were conducted for the assessment of the interactive effect of biochar with synthetic fertilizer and farmyard manure. Biochar application at the rate of 25 t ha^{-1} increased spikes m^{-2} by 6.64%, grains $spike^{-1}$ by 5.6%, thousand grain weight by 3.73, grain yield by 9.96%, biological yield by 15.36%, phosphorus use efficiency by 29.03% and grain phosphorus uptake by 19.67% in comparison with no biochar treated plots. Likewise, biochar application significantly increased soil carbon(C), phosphorus (P) and potassium (K) by 54.02, 61.39 and 18.41%, respectively. Similarly, farmyard manure at the rate of 10 t ha^{-1} resulted in significantly higher yield components, grain yield, soil C, P and K than 5 t ha^{-1} . Likewise, mineral nitrogen application at the rate of 120 kg ha^{-1} improved wheat yield and yield components with no significant effect on soil C, P and K contents. It is concluded that application biochar either alone or in combination with FYM or mineral nitrogen improved yield and yield components of wheat and soil quality in wheat-maize cropping pattern.

Key words: Biochar, Nitrogen, Grain yield, Phosphorus use efficiency.

Introduction

Wheat is an important member of family Poacea among cereal crops and has a high importance worldwide, measured either by cultivated area or production (Jagshoran *et al*., 2004). According to the Pakistan Bureau of Statistics annual report for 2012-2013, the country produced 25285 t of wheat grains from an area of 9039 ha. Wheat has got an evolutionary history parallel to the history of human civilization; as it decides the feast or famine for millions of people even today. Wheat contributes more than 10% of the total agricultural products and 15% of agricultural employment in Pakistan, over 50% share of which comes from small landholding farmers (Anon., 2011). It is highly nutritious as its per acre amino acid yield is far exceeding that of animal products (Zong *et al*., 2008). It attained its premier position due to its unique protein called gluten, responsible for bread making property of wheat flour (Asp *et al*., 1986). Soil fertility degradation and rapid nutrients losses are the major constraints for crop production and food security of the third world country (Jones *et al*., 2012). The application of synthetic fertilizer is higher as compared to organic sources due to the lower availability of crop nutrients (Nicholson *et al*., 1999). The use of inorganic fertilizer was considered unavoidable factor for enhancing crop production since green revolution due to the spectacular performance that doubled and in some cases tripled the grain yield of crops than organic manures (Widowati *et al*., 2011). On the other hand, the rate of fertilizer slowly increases from year to year for the same yield due to the decrease in soil quality. The inorganic fertilizer is not only reducing the increase in yield but also causes soil deterioration and several ecological problems (Liu *et al*., 2010). To cope with this scenario, the common practices for enhancing yield and nutrient use efficiency not on the expense of soil health is the integrated crop management, the use of organic manure and other organic materials like biochar along with chemical fertilizers (Fageria & Baligar, 2005). Developing sustainable fertilizer management practices such as synchronizing the type and quantity of organic sources of nutrients such as FYM can improve soil fertility and ecosystem (microbial population) (Manqiang *et al*., 2009) and that application of FYM should be as an alternative to synthetic fertilizer (Ali *et al*., 2011) because it not only provides nutrients but also helps restore the degraded soils (Sanchez-Monedero *et al*., 2004). It improves soil N and organic matter status which in turn enhances crop yield (Lampkin, 2002). The FYM application occupies a key position in farming system of Pakistan as it supplies 1.5 m t of nutrients annually (Bari, 2003). Previous research on the use of biochar had shown to improve soil properties such as soil pH and CEC (Chan *et al*., 2007), soil aggregation, soil water holding capacity and soil microbial activity (Rondon *et al*., 2007). Similarly, long-term use of biochar enhances availability of plant nutrient and soil productivity (Steiner *et al*., 2007).

The use of biochar increases the content of available P, exchangeable K, Mg and Ca compared to no biochar (Sukartono *et al*., 2011). Integrated use of biochar with FYM and N improves wheat nutrients uptake and soil N content (Ali *et al*., 2015). Likewise, it also enhances cation exchange capacity which then also increases nutrient retention capacity (Castaldi *et al*., 2011). Application of biochar accelerates nutrients uptake (Ali *et al*., 2015). Similarly, soil pH, organic carbon and total nitrogen also was improve with biochar amendment (Zhang *et al*., 1998). Lehmann *et al*. (2003) and Steiner *et al*. (2007) reported an improved nitrogen use efficiency on biochar containing soils. The influence of biochar is vital for enhancing soil biology that affect the microbial biomass and composition (Steiner *et al.*, 2004). Rondon *et al*. (2007) reported improvement in biological nitrogen fixation through biochar application.

Application of mineral N depends on the need of the crop its availability in soil and the N use efficiency (Kindred *et al*., 2014). The continuous application of N from synthetic fertilizer enhances the cost on the production of wheat and maize consequently reduction of farm income therefore alternative approaches are required to reduce reliance on chemical fertilizers and increase the use of organic materials as source of nutrients (Gandah *et al*., 2003, Schlecht *et al.*, 2006). Nitrogen improves wheat yield by 37% with application of 196 kg N ha^{-1} (Powlson *et al.*, 1986).

The ultimate motivation behind this instant study was thus to determine empirically the effectiveness of biochar, FYM and mineral nitrogen alone, in particular, and in various combinations on aspects of wheat yield and soil fertility in maize-wheat cropping systems, in general.

Materials and Methods

Site description and experimental details: The experiments were undertaken in Rabi season during 2012-13 and 2013-14 at the Agricultural Research Farm of the University of Agriculture, Peshawar (34.1°'21" N and 71°28'5"E). The climate of the site is semi-arid and sub-tropical, having an annual rainfall of about 360 mm during summer with an average maximum temperature of 40°C and minimum temperature of 25°C whereas during winter the average minimum temperature is 4°C and maximum of 18.4°C. Higher precipitation occurs in Rabi Season as compared to Kharif Season. The soil is deficient in N, P and Zn however soil K is adequate.

The treatments were comprised on biochar (0, 25 and 50 t ha^{-1}), FYM (5 and 10 t ha^{-1}) and nitrogen (60 and 120 kg ha^{-1}) along with a control (no biochar, FYM or N) for comparison however biochar was applied only once during 2012 to wheat crop whereas its residual effect was studied during 2nd year 2013-2014. The detail of different treatments combinations are shown in Table 1. Farmyard manure and biochar were applied at sowing while nitrogen was applied in two splits, half at sowing and the remaining at tillering stage. Biochar was applied in first year of the experiment while its residual effect was studied in the second year. Phosphorous in the form of single super phosphate (SSP) was applied at sowing as basal dose at the rate of 90 kg ha^{-1}.

The experiment was carried out in RCB design having three replications. The area of each experimental unit was 4.0 m x 4.5 m having row to row distance of 30 cm and separated from other plots by formation of big ridges for the blocking of runoff of biochar and FYM particles. The soil was thoroughly prepared by ploughing two times 15 cm deep using cultivator followed by planking for leveling and removal of clods. Wheat cultivar Siran was grown on 1st and 7th November during winter 2012 and 2013, respectively at seed rate of 100 kg ha^{-1}. Irrigation was done from canal water as per requirements of the crop. For the control of grassy weeds, Puma Super was sprayed one month after sowing. The physico-chemical properties of the experimental site before the conduction of experiments are given in Table 2.

Table 1. The treatment combinations of biochar, FYM and mineral nitrogen were as fallow.

Treatment	Biochar (t ha^{-1})	FYM (t ha^{-1})	Nitrogen (kg ha^{-1})
T1	0	0	0
T2	0	5	60
T3	0	5	120
T4	0	10	60
T5	0	10	120
T6	25	5	60
T7	25	5	120
T8	25	10	60
T9	25	10	120
T10	50	5	60
T11	50	5	120
T12	50	10	60
T13	50	10	120

Table 2. Physico-chemical properties of the experimental site before conduction of experiment.

Soil physical properties	Unit	Value at the depth of (0-15cm)
Sand	%	24.39 ± 0.03
Silt	%	67.20 ± 0.05
Clay	%	8.44 ± 0.05
Soil texture Class	-	Silt loam
Soil bulk density	-	0.27 ± 0.001
Soil chemical properties		
pH	-	7.8 ± 0.002
EC	d Sm^{-1}	0.56 ± 0.001
Soil P	mg kg^{-1}	2.18 ± 0.07
Sol total N	%	0.045 ± 0.004
Sol K	mg kg^{-1}	73.25 ± 0.04
Organic matter	%	0.67 ± 0.02

Observations recorded (crop related): Data on number of spike m^{-2} were recorded by counting total number of spikes in one meter row length in four central rows in each plot and were converted into number of spikes m^{-2}. Grains from five randomly selected spikes of each treatment were threshed, counted and converted into average number of grains spike^{-1}. Hundred grains were counted at random from sample of each plot, weighed and were converted into thousand grain weight. Biological yield data were recorded by harvesting six central rows in each plot. The harvested crop was sun dried, weighed in kg and was then converted to kg ha^{-1}. Data regarding grain yield were recorded by weighing grains collected from the harvest of four rows in each plot and were then converted to kg ha^{-1}.

$$\text{Grain P-uptake (kg ha}^{-1}\text{)} = \frac{\text{Grain P content (g kg}^{-1}\text{) x Grain yield (kg ha}^{-1}\text{)}}{1000}$$

Phosphorus use efficiency (PUE) was calculated by the following formula (Fageria *et al*., 1997):

$$\text{PUE (\%)} = \frac{\text{(Total P uptake (kg ha}^{-1}\text{) in fertilized plot) - (Total P uptake (kg ha}^{-1}\text{) in control plot)}}{\text{Total applied P (kg ha}^{-1}\text{)}}$$

Laboratory analysis: After the harvest of the crop, soil samples were taken from each plot at 15cm depth. The samples were air dried and then grinded and passed through sieve of 2 mm. Soil carbon content was determined by the procedure outlined by Walkely-Black (Nelson & Sommers, 1996). The available P and K were determined in the AB-DTPA extract (Soltanpour & Schwab, 1977). Soil P content was determined by spectrophotometer and soil K_2O by flame photometer.

Statistical analysis of the data: The data recorded were subjected to statistical analysis according to the procedure described by Jan *et al.* (2009) recommended for RCB design. Least significant difference test ($LSD_{(0.05)}$) was performed for treatment means comparison.

Results

Number of spikes m^{-2}: The data regarding individual and integrated influence of biochar (BC), farmyard manure (FYM) and nitrogen fertilizer (N) averaged over two growing seasons are presented in Tables 3-5 and Fig. 1, respectively. Application of BC at 25 t ha^{-1} produced higher spikes m^{-2} than 50 t BC and no BC plots. Likewise, FYM and N applied at 10 t ha^{-1} and 120 kg N ha^{-1} resulted in higher spike m^{-2} as compared to 5 t FYM and 60 kg N ha^{-1}, respectively (Table 1). Generally, BC applied either at 50 or 25 t ha^{-1} improved spike m^{-2} at both levels of N and FYM (Fig. 1) as compared to plots with no application of BC. In addition, the performance of 25 t ha^{-1} BC treated plots was superior than 50 t ha^{-1} BC plots at 60 kg N ha^{-1} treated plots under both levels of FYM. Overall, all treatments combination resulted in higher spike m^{-2} as compared to control plots.

Number of grain spike^{-1}: The effect of various organic and inorganic amendments on grains spike^{-1} of wheat are shown in Fig. 2 (Interactive effect) and Tables 3-5 (Main effect). Application of BC at the rate of 25 t ha^{-1} significantly increased grains spike^{-1} by 12% as compared to no BC plots (Table 1). FYM and N had non significant effect on grains spike^{-1} ($p<0.05$). The combined effects of all treatments (BC, FYM and N) are shown in Fig. 4. Overall, application of 25 t BC had increased grain spike^{-1} regardless of FYM and N application rate. At 5 t FYM the effect of 50 t BC was at par with no BC plots, however, under 10 t FYM negative effect of 50 t BC was found and reduction in grain spike^{-1} was noted in comparison with no BC plots irrespective of N application rate (Fig. 5). The figure further illustrated that control plots resulted in lower number of grain spike^{-1}.

Thousand grain weight: Thousand grain weight is an important yield contributing parameter. The data on thousand grain weight averaged over two years are reported in Tables 3-5 and Fig. 3. All the treatments significantly affected thousand grain weight ($p<0.05$). Thousand grain weight increased with increase in BC rate from 0 to 25 but further increase in BC rate from 25 to 50 t ha^{-1} declined thousand grain weight (Table 3). Likewise, FYM and N application at higher rate (10 t and 120 kg N ha^{-1}) resulted in heavier grains than their lower levels (5 ton FYM and 60 kg N ha^{-1}) (Tables 4-5). At 5 t FYM ha^{-1} application of BC at the rate of 50 t ha^{-1} resulted in higher grain weight while at 10 t FYM ha^{-1}, higher grain weight was produced by 25 t BC ha^{-1} irrespective of N application rate (Fig. 3).

Biological yield: Biological yield was significantly affected by different biochar, FYM and N levels (Tables 3-5, $P< 0.05$). All treatments accelerated wheat biological yield over control (Fig. 5). Higher biological yield (15.36%) was recorded in plots treated with 25 t BC ha^{-1} as compared to no BC plots or 50 t ha^{-1} BC plots (Table 3). Likewise, application of 10 t FYM ha^{-1} and 120 kg N ha^{-1} resulted in higher soil N after wheat harvest than control (Table 4). Moreover, Application of 25 t BC ha^{-1} resulted in higher biological yield at all level of FYM and N (Fig. 4). Unexpectedly, 50 t BC drastically reduced wheat biological yield than no BC plots and this decrease was much dominant when 50 t BC was applied in 10 t FYM ha^{-1} treated plots as compared to application of 5 t FYM ha^{-1} (Fig. 4).

Grain yield: Grain yield of wheat is the most important economical part in wheat production system. The data regarding grain yield are presented in Tables 3-5 and Fig. 5 (interactive effect of treatments). The application of BC at the rate of 25 t ha^{-1}, FYM at the rate of 10 t ha^{-1} and N at the rate of 120 kg ha^{-1} improved wheat grain yield by 9.96, 7 and 11% as compared to no BC, 5 t FYM ha^{-1} and 60 kg N ha^{-1}, respectively (Tables 3-5). The combined effect of treatments indicated that application of BC either at the rate of 25 or 50 t ha^{-1} resulted in higher grain yield than no BC plots irrespective of FYM and N (Fig. 5). Application of BC at the rate of 25 t ha^{-1} resulted in higher grain yield when applied in combination with 60 kg N and 10 t FYM ha^{-1} while at 120 kg N and 5 t FYM higher grain yield was produced in plots treated with 50 t BC ha^{-1} (Fig. 5). In general, the performance of BC was superior when applied with 120 kg N ha^{-1} over 60 kg N ha^{-1}.

Grain phosphorus uptake: Plant phosphorus uptake largely depends on the addition of P through organic and inorganic sources. Continuous cereal (wheat-maize-wheat) cropping pattern degrade soil P content. The effect of various biochar, FYM and N levels on plant P uptake content averaged over two years are presented in Table 3, 4 and 5 (individual effect) and Fig. 6 (interactive effect). All the treatment significantly affected grain P uptake except N ($p<0.05$). Biochar application at the rate of 25 t ha^{-1} and FYM at the rate of 10 t ha^{-1} enhanced grain P uptake by 19.96 and 9%, respectively over 0 t BC ha^{-1} and 5 t FYM ha^{-1} (Tables 3 and 4). This increase was much dominant in comparison to control than their respective lower levels (Fig. 6). The Fig. 6 revealed that overall BC application increased grain P uptake at either rate than no BC plots or control plots. However, the performance of 25 t BC was better than 50 t BC irrespective of FYM and N levels (Fig. 6).

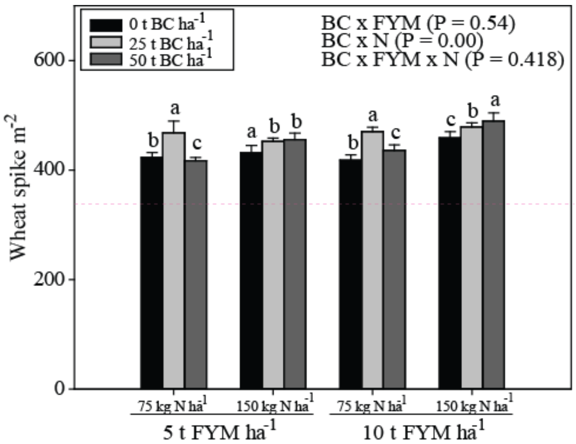

Fig. 1. Interactive effect of BC, FYM and N on wheat spikes m^{-2} averaged over two growing seasons. Vertical bars indicate SE of three replications.
Dotted line represents value of control plots (all treatments at nil level)

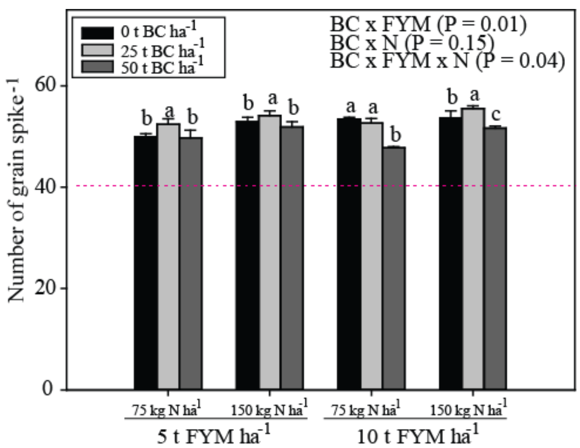

Fig. 2. Interactive effect of BC, FYM and N on wheat grain spike^{-1} averaged over two growing seasons. Vertical bars indicates SE of three replications. Dotted line represents value of control plots.

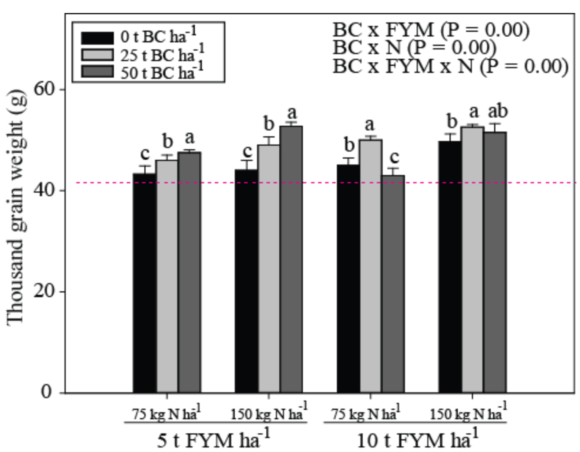

Fig. 3. Interactive effect of BC, FYM and N on wheat thousand grain weight averaged over two growing seasons. Vertical bars indicates SE of three replications.
Dotted line represents value of control plots (all treatments at nil level)

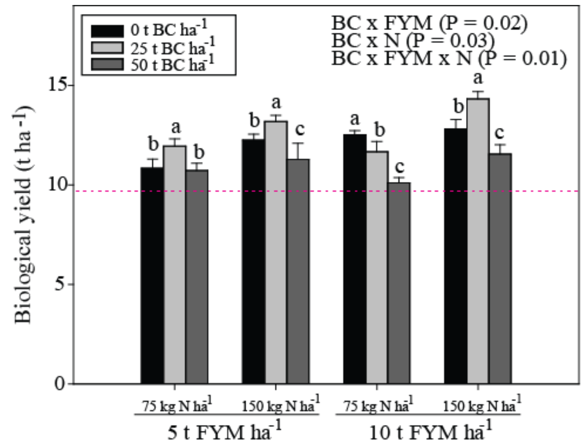

Fig. 4. Interactive effect of BC, FYM and N on wheat biological yield averaged over two growing seasons. Vertical bars indicates SE of three replications.
Dotted line represents value of control plots (all treatments at nil level)

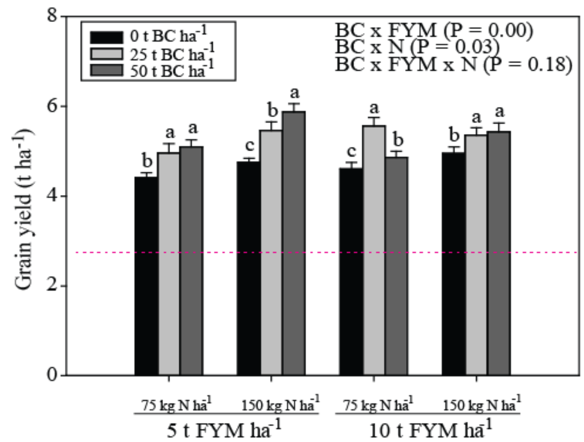

Fig. 5. Interactive effect of BC, FYM and N on wheat grain yield averaged over two growing seasons. Vertical bars indicates SE of three replications.
Dotted line represents value of control plots (all treatments at nil level)

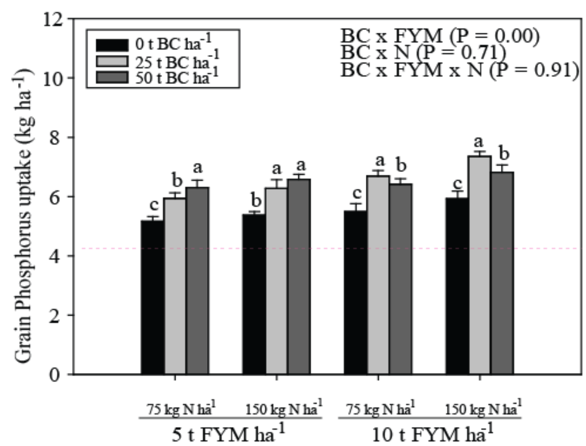

Fig. 6. Interactive effect of BC, FYM and N on wheat grain Phosphorus uptake averaged over two growing seasons. Vertical bars indicates SE of three replications.
Dotted line represents value of control plots (all treatments at nil level)

Table 3. Effect of biochar on soil properties, yield and yield components of wheat.

Parameters	Biochar levels (t ha^{-1})			LSD $_{(0.05)}$
	0	25	50	
Number of spikes m^{-2}	434 c	463 a	447 b	7.4
Number of grains $spike^{-1}$	53.05 a	53.48 a	50.64 b	0.63
Thousand grain weight (g)	47.64 b	49.42 a	49.58 a	0.90
Grain yield (t ha^{-1})	4.52 c	5.01 a	4.74 b	0.116
Biological yield (t ha^{-1})	13.30 a	13.97 a	12.11 b	0.259
Wheat Phosphorus use efficiency	7.37 c	9.07 b	9.51 a	0.17
Grain Phosphorus uptake	5.49 b	6.57 a	6.53 a	0.13
AB-DTPA extractible P (mg kg^{-1})	4.74 c	7.65 b	7.95 a	0.18
Soil Carbon (%)	0.72 c	0.93 b	1.11 a	0.03
Soil Potassium content	74.38 b	88.44 a	87.50 a	1.82

Means followed by different letter(s) in the same rows are significantly different from one another at 5% level of probability
NS = Non-significant

Table 4. Effect of FYM levels on soil properties, yield and yield components of wheat.

Parameters	FYM levels (t ha^{-1})		Significance Level
	5	**10**	
Number of spikes m^{-2}	439	458	*
Number of grains $spike^{-1}$	51.88	52.89	*
Thousand grain weight (g)	48.06	49.69	*
Grain yield (t ha^{-1})	4.919	4.985	ns
Biological yield (t ha^{-1})	12.9	13.36	*
Wheat Phosphorus use efficiency	8.13	9.19	*
Grain Phosphorus uptake	5.49	6.45	*
AB-DTPA extractible P (mg kg^{-1})	6.01	7.55	*
Soil Carbon (%)	0.82	1.03	*
Soil Potassium content	79.68	87.19	*

*,** = Significant at 5 and 1% level of probability, respectively
NS = Non-significant

Wheat phosphorus use efficiency: Wheat P use efficiency as affected by biochar, FYM and N levels are reported in Table 3, 4 and 5 (Individual effect) and in Fig. 7 (interactive effect). Biochar application at the rate of 25 t ha^{-1} improved wheat P use efficiency over no BC plots, however there was no significant difference between 25 and 50 t BC ha^{-1} (Table 3). Likewise, 10 t FYM ha^{-1} resulted in higher P use efficiency as compared to 5 t FYM ha^{-1} (Table 4). The combined effect of BC, FYM and N averaged over two years are reported in Fig. 7. Overall BC application improved P use efficiency irrespective of FYM and N levels however, at 10 t FYM the effect of BC was better as compared at 5 t FYM ha^{-1} regardless of BC application rate and N fertilization (Fig. 7).

Soil carbon: Soil carbon is the driving agent of soil organic matter content in particular and soil quality in general. The effect of biochar, FYM and N levels on soil C are shown in Tables 3-5 (individual treatment effect) and in Fig. 8 (interactive effect). Soil C was increased by 54.16 and 18% as a result of BC and FYM application over control (Tables 3 and 4). Expectedly, N fertilizer had non significant effect on soil C content ($p>0.05$). The combined effect of BC, FYM and N averaged over two years are presented in Fig. 8. Overall, BC application at either rate improved soil C content in comparison with no BC regardless of FYM and N. Under different level of FYM (5 and 10 t ha^{-1}) BC application behaved in different manner and at 5 t FYM both level of BC had similar effect on soil C irrespective of N application rate. However, at 10 t FYM application of 50 t BC resulted in higher soil C as compared to 25 t BC ha^{-1} at both levels of N (Fig. 8).

Soil phosphorus: Availability of soil phosphorus play an important role in increasing crop yield. Pakistani soils are deficient in P and wheat growers largely depend on application of higher rate of synthetic fertilizer. The results indicated that application of BC increased soil P content by 61.39% and FYM by 21% as compared to no BC and control plots, respectively (Tables 3 and 4). The Interactive effects of all treatments averaged over 2 years are presented in Fig. 9. Overall, BC application at either rate promoted soil P content in comparison with no BC plots regardless of FYM and N. However, in plots treated with 10 t FYM ha^{-1} the performance of BC was more superior than 5 t FYM treated plots irrespective of BC application rate and N application (Fig. 9).

Soil potassium: Soil Potassium (K) is an important macro plant nutrient that regulates various plant physiological functions. In the current experiments the effects of biochar, FYM and N levels were significant on soil K ($p<0.05$; all values were averaged over two years). Biochar application enhanced soil K content by 18.41 and FYM by 09% over control (Tables 3 and 4). The interactive effect of BC, FYM and N are reported in Fig. 10. Overall, BC application had positive effect on soil K irrespective of application rate. However, both level of BC (25 and 50 t ha^{-1}) had variation in their response to FYM. At 5 t FYM application of 50 t BC had higher soil K while at 10 t FYM ha^{-1} application of 25 t BC ha^{-1} had higher soil K regardless of N application rate (Fig. 10). Higher soil K was recorded in samples collected from 10 t FYM and 25 t BC treated plots at either level of N.

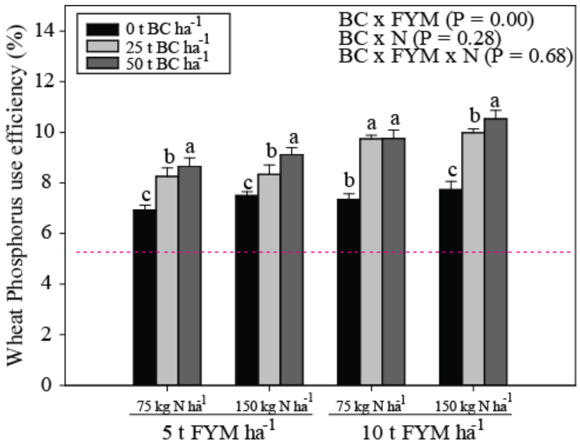

Fig. 7. Interactive effect of BC, FYM and N on wheat Phosphorus use efficiency averaged over two growing seasons. Vertical bars indicates SE of three replications.
Dotted line represents value of control plots (all treatments at nil level)

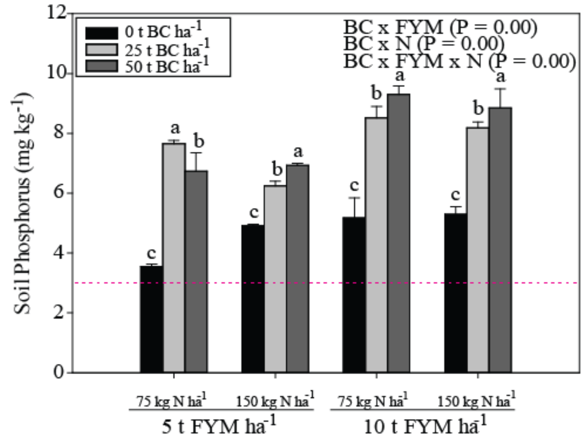

Fig. 9. Interactive effect of BC, FYM and N on soil Phosphorus content after wheat harvest averaged over two growing seasons. Error bars indicates SE of three replicates.
Dotted line represents value of control plots (all treatments at nil level).

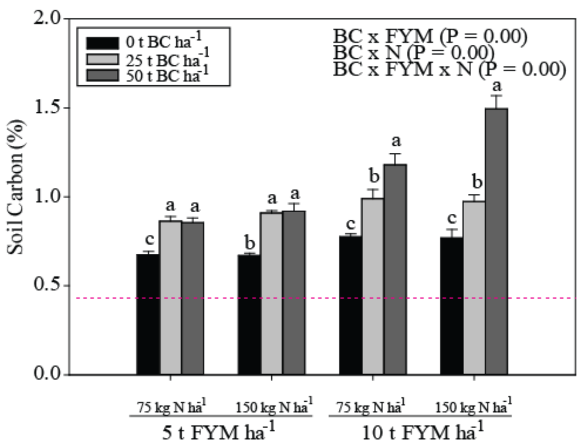

Fig. 8. Interactive effect of BC, FYM and N on soil Carbon content (%) averaged over two growing seasons. Error bars indicates SE of three replicates.
Dotted line represents value of control plots (all treatments at nil level).

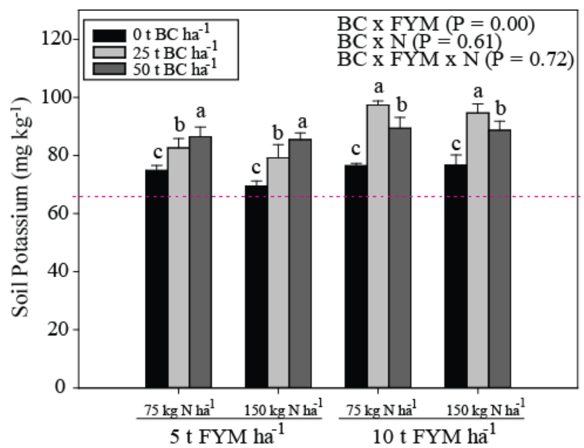

Fig. 10. Interactive effect of BC, FYM and N on soil Potassium after wheat harvest averaged over two growing seasons. Error bars indicates SE of three replicates.
Dotted line represents value of control plots (all treatments at nil level)

Table 5. Effect of nitrogen levels on soil properties, yield and yield components of wheat.

Parameters	Nitrogen (kg ha^{-1})		Significance level
	60	120	
Number of spikes m^{-2}	438	459	*
Number of grains spike^{-1}	51.45	53.33	*
Thousand grain weight (g)	47.43	50.33	*
Grain yield (t ha^{-1})	4.82	5.08	*
Biological yield **(**t ha^{-1})	12.49	13.76	*
Wheat Phosphorus use efficiency	8.45	8.87	ns
Grain Phosphorus uptake	6.00	6.39	ns
AB-DTPA extractible P (mg kg^{-1})	6.82	6.74	n
Soil Carbon (%)	0.89	0.96	ns
Soil Potassium content	84.52	82.36	ns

** = Significant at 1% level of probability
NS = Non-significant

Discussion

Nitrogen application radically enhanced thousand grain weight of wheat over control during both years. This increase was due to the fact that nitrogen application promotes vigorous growth resulted in more photosynthates which were transported to grain later at maturity consequently produced heavier grains. Hussain & Shah (2002) also reported marked increase in grain weight of wheat under higher N application. The increase in 100 grain weight of maize under higher rates of N fertilizer was also reported by Akmal *et al*. (2010). The findings are in consonance with Bazitov (2000) and Bhagat *et al.* (2001) that reported more number of tillers plant^{-1}, lengthy spikes, more spikelets spike^{-1} and more fertile florets and higher number of grain filled attributed to increased grain yields higher 1000-grain weight under increased application rate of nitrogen fertilizer (Maqsood & Shehzad, 2013).

Wheat grain weight was increased with FYM in comparison with the control. The higher grain weight from FYM plots and sole N applied may be due to rapid mineralization and timely release of nutrients to the soil. Chan *et al*. (2007) also reported an increase in grain weight with application of organic manures at different rates. The results are also in line with Kumar & Puri (2001) who found that FYM in integration with mineral N was best possible option for enhancing maize yield. Integrated N management enhanced biological yield of maize and this might be due to the slower and timely release of N from organic sources with least losses than mineral N. Similarly, Uzoma *et al*. (2011) reported significant increase in maize yield due to integrated N management production. It also increased maize yield by 32% as compared to control. Wheat produced more tillers when it was planted in high FYM incorporated plots. This increase can be attributed to the beneficial effect of nutrients released from the decomposition of FYM especially nitrogen. The minimum tillers in control plots probably may be due to the exhaustive effects of wheat in terms of nutrient absorption that led to nutrient deficiency and poor crop performance (Ali *et al.,* 2011).

Biochar application increase grain yield of maize by 16% over no biochar. This increase could be attributed to nutritional value of biochar that enhances soil fertility. Biochar increases crop productivity by improving soil fertility and productivity and enhances fertilizer use efficiency especially nitrogenous fertilizer by reducing leaching of N (Day *et al.,* 2005). Other reasons might be due to its potential to improve organic matter mineralization and improved crop yield and growth (Chan *et al.,* 2007). Technically, biochar acts as a buffer and contains some essential plant nutrients which significantly increase crop yield. A progressive increase in the beneficial effect of biochar was also observed by Steiner *et al.* (2007) who found that biochar application to soil can provide increasing benefits over time and improve crop yield. Yield increases with biochar application have been documented in controlled environments as well as in the field (Blackwell *et al.,* 2009). Biochar efficiently absorbs ammonia (NH_3) and acts as a binder for NH_3 in soil, therefore, having the potential to decrease NH_3 volatilization from soil surfaces and increase nitrogen use efficiency which increased crop stover yield and biomass (Oya & Iu 2002). Application of mineral N, FYM and biochar significantly improved grain yield of wheat over control. The increase in wheat grain yield could be attributed to N fertilization and mineralization of organic sources such as biochar and FYM throughout the growing period that kept the plant safe from nutrient stress at any stage resulted in higher grain yield (Singh & Agarwal 2001, Iqbal *et al.,* 2002). Surely, the strong affinity of biochar for ammonium and nitrate had already investigated (Atkinson *et al*., 2010; Lehmann *et al*., 2003) and thus reduced nutrient losses by leaching (Chan *et al*., 2007; Lehmann *et al*., 2003).

Soil organic matter plays key role in soil fertility sustainability and soil quality (Ali *et al*., 2015) and thus considers as potential factor in determination of soil structure, nutrient and water use efficiency, infiltration rate, aeration and porosity of the soil. In other words, if only one soil trait of productivity is to be chosen then it might be organic matter content (Selvakumari *et al*., 2000). It was observed in the exploration of this study that soil carbon and organic matter content improved under both levels of biochar application. The status of organic matter in the soil had a relationship with the quantity applied (Pattanayak *et al*., 2001, Sarwar *et al*., 2003). Soil P content was significantly improved by biochar and FYM application. Biochar addition to soil can improve soil nutrient retention and availability to plants such as soil P due to its high cation exchange capacity (Krull *et al*., 2003). Therefore, biochar can improve soil fertility and production capacity while maintaining high levels of soil nutrient such as P (Major *et al*., 2009). Soil amended with high C:N ratio plant materials, generally have a greater incidence of fungal feeding nematodes, therefore the addition of biochar with high C:N ratio to soil could lead to a shift in decomposition to a more fungal based channel. Therefore, biochar has the potential to promote soil P availability by improving michorizal association in which P is made available by fungi (Matsubara *et al*., 2002). Mycorrhizal fungi play key role in P availability and it is clear that mycorrhizal fungi can use biochar as a habitat. This will highly depend on the biochar properties and the biochar addition rates. Nevertheless, the finer parts of the mycelium, generally the absorptive hyphae, are more vulnerable to fungal grazers (Klironomos & Kendrick, 1996), and it is primarily these architectural elements that could be effectively protected within biochar particles and enhanced soil P content. In addition to chemical signals, biochar may also adsorb compounds toxic to mycorrhizal fungi. For example, Wallstedt *et al*. (2002) determined decrease in amount of water-soluble phenols under the application of biochar to soil that might enhanced the fungal capacity for P availability in soil.

Conclusion

Biochar application significantly improved wheat grain yield and post harvest soil NPK status in alkaline soil of Peshawar, Pakistan under wheat-maize-wheat cropping pattern. Application of either half (60 kg ha^{-1}) of full level of N (120 kg ha^{-1}) in combination with 25 t ha^{-1} biochar produced similar wheat grain yield. Application of FYM at the rate of 5 or 10 t ha^{-1} improved yield and yield components of wheat and also soil C, K and P as compared to control. In nutshell, biochar at the rate of 25 t ha^{-1} with 60 kg N ha^{-1} is sufficient to produce consistently higher yield as compared with 50 t ha^{-1} with 120 kg N ha^{-1} without adverse effect on soil properties.

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