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Response of maize to integrated use of organic and inorganic sources of phosphorous with biochar

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Abstract
Soil phosphorous (P) limitation is one of the most important constraint to food production in Pakistan. An experiment comprised of two biochar levels (0 and 10 tons ha^{-1}) and three P sources was designed with an objective to study the integration of organic and inorganic sources of P with biochar for improving maize yield. The P sources included two organic sources i.e. Farmyard manure (FYM) and poultry manure (PM) and an inorganic source i.e. diammonium phosphate (DAP). Experiment was conducted at Agronomy Research Farm of the University of Agriculture, Peshawar during summer 2015 by using randomized complete block design with three replications. FYM, PM and DAP were applied in different ratios of organic and inorganic fertilizers i.e. 100, 75 and 50% of P was obtained from the organic sources and the rest was compensated from the inorganic source to provide a total of 100 kg P ha^{-1}. A control treatment was also included in the experiment for comparison. Statistical analysis of the data showed that more number of days to 75% tasseling and silking with maximum plant height, grains ear^{-1}, grain yield, biological yield, and harvest index were recorded in plots treated with 10 tons ha^{-1} biochar along with application of 50% organic fertilizer of P and 50% inorganic fertilizer regardless of source of organic fertilizer. It can be concluded that application of P @ 100 kg ha^{-1} in such a combination that 50% P is applied from organic source (FYM/PM) and 50% P from inorganic source along with biochar (10 tons ha^{-1}) improved yield of maize.

Keywords: farmyard manure, poultry manure, diammonium phosphate, grain yield

1. Introduction

Maize (*Zea mays* L.) is the third most important cereal crop in the world. In Pakistan, maize is the fourth largest grown crop after wheat, cotton and rice. While in the farming system of Khyber Pakhtunkhwa it ranges 2nd after wheat in its importance. Maize is an exhaustive cereal crop having higher potential than other cereals and absorbs large quantity of nutrients from the soil during different growth stages. In most of the cropping system all over the world the least available mineral nutrient is phosphorous (P) (Shenoy and Kalagudi, 2005) [29]. Agriculture is impossible without P (Osava, 2007) [18]. Adequate phosphorous results in higher grain production, improved crop quality, greater stalk strength and increased root growth (Bugbee and Khera, 1999) [8]. Phosphorous fertilizer application to maize is more effective and profitable at sowing than late application (Rehman *et al.*, 2007) [26]. Several options are currently considered by researchers in order to overcome challenges like increasing yield, decreasing production cost and maintaining soil health, these include organic farming, integrated nutrient management and efficient weeds control methods (Rasool *et al.*, 2007) [23]. Ninety percent of Pakistan soils suffer from moderate to severe phosphorus deficiency (Alam *et al.*, 1994) [1]. Phosphorus fertilization is essential for exploiting maximum yield potentials of different crop plants (Rashid *et al.*, 1994) [22]. In Pakistan, the increasing cost of phosphatic fertilizers emphasized the need to find some methodology for improving the efficiency of added fertilizers (Twyford, 1994) [35].

Paul and Mannan (2006) [19] suggested that integrated nutrient management through combined use of organic wastes and chemical fertilizers can be an effective approach to combat nutrient depletion and promote sustainable crop productivity. Integrated use of organic matter and chemical fertilizers is beneficial in improving crop yield, soil pH, organic carbon and available N, P and K in soil (Rautaray *et al.*, 2003) [25]. To achieve sustainability in high production systems, only the integrated use of organic and inorganic fertilizers can play a vital role in improving crop productivity (Gosh *et al.*, 2004). Organic fertilizers have equivalent or even better effect on crop yield than P from mineral sources. Sole use of Farm yard manure (FYM) and/or in combination with chemical fertilizers can be efficiently utilized for nutrient supplementation (Rasheed *et al.*, 2003) [21].

Application of FYM adds nutrients to the soil and thus reduces the total dependence on chemical fertilizers. Application of inorganic P fertilizers in combination with FYM was found effective in enhancing the effectiveness of inorganic P fertilizers (Whalen and Chang, 2001) [37]. According to Brady and Weil (1999) [7] poultry manure mineralizes faster than other animal manures such as cattle or pig dung; hence it releases its nutrients for plant uptake and utilization rapidly. Poultry manure is an excellent organic fertilizer as it contains high N, P, K and other essential nutrients (Farhad *et al.*, 2009) [11]. It has been reported to supply P more readily to plants than other organic sources (Garg and Bahla, 2008) [12].

Biochar (BC) is the porous carbonaceous solid produced by thermo chemical conversion of organic materials in oxygen depleted atmosphere which has physiochemical properties suitable for safe and long-term storage of carbon in the environment and potentially soil improvement (Steinbeiss *et al.*, 2009) [32]. Biochar improves soil water holding capacity (Laird *et al.*, 2008) [15] and facilitating seedling biomass gain (Kammann *et al.*, 2012) [14]. Plant growth responses can be altered by biochar induced changes in soil nutrient conditions, particularly the cycling of P and K (Taghizadeh-Toosi *et al.*, 2012) [33]. Biochar improves the physical conditions around the crop-root zone and enhanced crop production (Shinogi *et al.*, 2003) [30]. Therefore, keeping in view the importance of integrated use of organic and inorganic fertilizers the present study was initiated with aim to sort out the best combination of organic and inorganic sources of phosphorous along with biochar to get maximum maize yield under the climatic conditions of Peshawar.

2. Materials and methods

To study the integrated use of organic and inorganic sources of phosphorous (P) with biochar (BC) on maize productivity, an experiment was conducted at Agronomy Research Farm, the University of Agriculture, Peshawar during summer 2015. The experimental farm is located at 34.01º N latitude, 71.35º E longitude and at an altitude of 350 m above sea level in Peshawar valley. Peshawar is located about 1600 km north of the Indian Ocean and has continental type of climate. The research farm is irrigated by Warsak canal from river Kabul. Soil is clay, low in organic matter (0.87%), alkaline (pH 8.2) and is calcareous in nature. The experiment was laid out according to randomized complete block design with three replications. A plot size of 18 m^2 having 6 rows, 4 m long and 75 cm apart was used. Strong bunds around each plot were made to avoid the dispersal of biochar and organic manure among the plots. Maize variety Azam was sown at a seed rate of 30 kg ha^{-1}. The treatments comprised of two levels of biochar (0 and 10 tons ha^{-1}) and P sources included two organic sources i.e. Farmyard manure (FYM) and poultry manure (PM) and an inorganic source i.e. diammonium phosphate (DAP). The P sources were applied to field in such a combination that 100, 75 and 50% of P was obtained from the organic sources (Table 1) and the rest was compensated from the inorganic source and vice versa for making a total of 100 kg P ha^{-1}. A control treatment was also included in the experiment. The organic sources of P were applied ten days before sowing and inorganic P source was applied at the time of seedbed preparation. The nitrogen was applied in two equal splits i.e. half at sowing and half at V5 stage. The N from organic manures was compensated from inorganic fertilizer (urea), ensuring that each plot receive equal amount of the nitrogen (150 kg ha^{-1}). Field was ploughed twice at field capacity level before sowing with cultivator and rotavator. Irrigations were given according to crop water requirement and weather conditions (rainfall). Weeding was done manually with the help of hoe one after 20 days of emergence and second after 40 days of emergence for complete weeds eradication. The crop was sown with maize planter and thinning was done manually after 20 days of emergence keeping a uniform plant population of 65000 plants ha^{-1}.

Procedure for recording data

Data on days to emergence were taken by counting the number of days form sowing up to 75% emergence of the seedlings in each subplot. Days to tasseling and silking were recorded by counting the number of days from sowing to date when 75% plants produced tassels/silks in each subplot. Plant height was recorded at physiological maturity stage. Ten representative plants from each subplot were selected randomly and measured from base to the tip of tassel with meter rod and their average was worked out. Data on number of grains ear $^{-1}$ was recorded by counting the number of grains in five ears randomly selected in each subplot and averaged. Four central rows in each subplot were harvested, sun dried and weighed for recording biological yield data then converted into kg ha^{-1}. Ears from four rows harvested for biological yield were threshed and weighed to determine grain yield in kg per subplot and converted into kg ha^{-1}. Harvest index (%) was calculated as the ratio of grain yield to biological yield and multiplied with hundred. The recorded data were statistically analyzed according to analysis of variance techniques used for randomized complete block design and least significant difference (LSD) test was used at 5% level of significance ($P \leq 0.05$) upon significant F-test through the procedure described by Jan *et al.* (2009) [13].

Table 1: Treatments structure

Treatment	Biochar (t ha^{-1})	Organic (%)	Inorganic (%)	Desired P (kg ha^{-1})
T1	10	0 (Control)	0	0
T2	10	100 FYM	0	100
T3	10	100 PM	0	100
T4	10	75 FYM	25	100
T5	10	75 PM	25	100
T6	10	50 FYM	50	100
T7	10	50 PM	50	100
T8	10	0	100	100
T9	0	0	0	0
T10	0	100 FYM	0	100
T11	0	100 PM	0	100
T12	0	75 FYM	25	100
T13	0	75 PM	25	100

T14	0	50 FYM	50	100
T15	0	50 PM	50	100
T16	0	0	100	100

3. Results

Days to emergence

Data on days to emergence as affected by different ratios of phosphorous (P) and biochar (BC) are reported in Table 2. Statistical analysis of the data revealed that phosphorous sources i.e. Farmyard manure (FYM), poultry manure (PM), and diammonium phosphate (DAP) had non-significant effect on days to emergence. The control versus (vs) rest and biochar vs no biochar contrasts were also found non-significant.

Days to 75% Tasseling

Data on days to tasseling are presented in Table 2. Analysis of the data revealed that Phosphorous sources had significantly affected days to tasseling. The control vs rest and biochar vs no biochar contrasts were also found significant for days to tasseling. Minimum days (49 and 50 days) to tasseling were observed in control and no biochar plots, respectively. Mean values of the ratios indicated that delayed tasseling (53 days) were recorded in plots which received 50% P from organic sources and 50% P from inorganic source, followed by plots which received 75% P from organic sources and 25% from inorganic source. Earlier tasseling (51 days) was observed in plots which received 100% P from inorganic source.

Days to 75% Silking

Data on days to 75 % silking are given in Table 2. Analysis of the data indicated that phosphorous sources had significantly affected days to silking. The control vs rest and biochar vs no biochar contrast was also found significant for days to silking. Minimum days (52 and 54 days) to silking were recorded in control and no biochar plots, respectively. Mean values of the ratios revealed that delay in days to silking (59 days) were recorded in plots which received 50% P from organic sources and 50% from inorganic source, followed by plots which received 75% P from organic sources and 25% P from inorganic source. Earlier silking (54 days) was observed in plots which received 100% P from inorganic source.

Plant height (cm)

Data concerning plant height are shown in Table 3. Analysis of the data revealed that phosphorous sources significantly affected plant height of maize. The control vs rest and biochar vs no biochar contrasts were also found significant for plant height and indicated that control and no biochar plots produced short statured plants (182 cm and 186 cm) as compared with the means of the fertilized treatments and biochar (196 cm and 194 cm), respectively. Mean values of the ratios indicated that plants which received 50% P from organic sources and 50% form inorganic source attained maximum height (204 cm) followed by plants (199 cm) which received 75% P from organic source and 25% from inorganic source while shorter plants were noted in plots which received 100% P from inorganic source or organic source alone.

Table 2: Days to emergence, tasseling and silking of maize as affected by different ratios of P sources and biochar.

P-Sources	Days to emergence	Days to tasseling	Days to silking
100% FYM	6	51 b	55 b
75% FYM	6	52 ab	57 ab
50% FYM	7	53 a	58 a
100% PM	7	51 b	54 b
75% PM	7	52 ab	57 ab
50% PM	8	53 a	59 a
100% DAP	7	50 b	55 b
LSD (0.05)	NS	1	3
Control vs rest	NS	**	**
Control	7	49	52
Rest	7	52	56
Biochar vs no biochar	NS	*	*
Biochar	7	51	56
No biochar	7	50	54

Means of same categories followed by different letters are statistically different at 5% level of probability.
NS = Non significant
* = Statistical significance at 5% level of probability
** = Statistical significance at 1% level of probability
FYM = Farmyard manure, PM = Poultry manure
DAP = Di ammonium phosphate

Number of grains ear^{-1}

Data related to number of grains ear^{-1} are given in Table 3. Analysis of the data showed that P sources significantly affected number of grains ear^{-1}. The control vs rest and biochar vs no biochar contrasts were also found significant for number of grains ear^{-1} and indicated that control and no biochar plots produced lower number of grains ear^{-1} (365 and 401) as compared with the means of the fertilized treatments and biochar (430 and 401), respectively. Ratios indicated that lower number of grains ear^{-1} were counted in plots which received 100% P from organic and inorganic sources. Higher number of grains ear^{-1} (474) were counted in plots which received 50% P from organic sources and 50% from inorganic source followed by plots which received 75% P from organic sources and 25% from inorganic source.

Biological yield (kg ha^{-1})

Data regarding biological yield are given in Table 4. Analysis of the data showed significant effect of P sources on biological yield of maize. The control vs rest and biochar vs no biochar contrasts were also found significant for biological yield. Lower biological yield (8166 and 10457 kg ha^{-1}) was obtained from control and no biochar plots, respectively. Ratios indicated that plots which received total of P from organic or inorganic sources resulted in lower biological yield (11347 kg ha^{-1}) while higher biological yield (12819 kg ha^{-1}) was obtained from the plots which received 50% P from organic sources and 50% from inorganic source followed by plots which received 75% P from organic sources and 25% from inorganic source.

Table 3: Plant height and number of grains ear^{-1} of maize as affected by different ratios of P sources and biochar.

P-Sources	Plant height (cm)	Grains ear^{-1}
100% FYM	188 b	404 b
75% FYM	199 a	431 a
50% FYM	204 a	458 a
100% PM	192 b	411 b
75% PM	203 a	436 a
50% PM	200 a	474 a
100% DAP	189 b	398 b
LSD (0.05)	12	27
Control vs rest	**	**
Control	182	365
Rest	196	430
Biochar vs no biochar	*	*
Biochar	194	422
No biochar	186	401

Means of same categories followed by different letters are statistically different at 5% level of probability.
NS = Non significant
* = Statistical significance at 5% level of probability
** = Statistical significance at 1% level of probability

Grain yield (kg ha^{-1})

Data regarding grain yield are shown in Table 4. Analysis of the data revealed that P sources significantly affected grain yield. The control vs rest and biochar vs no biochar contrasts were also found significant for grain yield and showed that control and no biochar plots produced lower grain yield (2057 and 2996 kg ha^{-1}) as compared to fertilized and biochar treatment (3453 and 3279 kg ha^{-1}) respectively. Mean values for P sources revealed that higher grain yield (4029 kg ha^{-1}) was obtained in the plots which received 50% P from organic sources and 50% from inorganic source followed by plots which received 75% P from organic sources and 25% from inorganic source while lower grain yield (2867 kg ha^{-1}) was obtained in plots which received 100% P from organic or inorganic sources alone.

Harvest index (%)

Data regarding harvest index (HI) of maize are given in Table 4. Analysis of the data indicated that P sources significantly affected harvest index. The control vs rest contrast was found significant while biochar vs no biochar contrast was found non significant. Control plots resulted in lower HI (25.3%) as compared to fertilized plots (28.7%). Different ratios of P sources indicated that highest HI (31.3%) was calculated for the plots which received 50% P from organic sources and 50% from inorganic source, which was statistically at par with harvest index obtained from plots received P 75% from PM and 25% from DAP while lowest HI (25.1%) was recorded in plots which received 100% P from FYM which was statistically similar with Plots received 100% P from DAP.

Table 4: Biological yield, grain yield and harvest index of maize as affected by different ratios of P sources and biochar.

P-Sources	Biological yield (Kg ha^{-1})	Grain yield (Kg ha^{-1})	Harvest index (%)
100% FYM	11347 b	2842 c	25.1 b
75% FYM	12841 a	3607 b	28.1 ab
50% FYM	12819 a	3948 ab	30.9 a
100% PM	10647 b	3024 c	28.7 ab
75% PM	12332 ab	3856 ab	31.3 a
50% PM	12908 a	4029 a	31.3 a
100% DAP	11199 b	2867 c	25.7 b
LSD (0.05)	1310	349	3.5
Control vs rest	**	**	*
Control	8166	2057	25.3
Rest	12013	3453	28.7
Biochar vs No biochar	*	*	NS
Biochar	11532	3279	28.3
No biochar	10457	2996	28.5

Means of same categories followed by different letters are statistically different at 5% level of probability.
NS = Non significant
* = Statistical significance at 5% level of probability
** = Statistical significance at 1% level of probability

4. Discussion

Crop phenology is a vital phenomenon and can affect the maize productivity. Phenological parameters like days to emergence, tasseling and silking play a significant role in crop yield. Days to emergence was not significantly affected by phosphorous (P) sources i.e. Farmyard manure (FYM), poultry manure (PM) and diammonium phosphate (DAP). The control versus (vs) rest and biochar vs no biochar contrasts were also found non significant. The possible reason for non significant effect of P sources on days to emergence might be the available food reserves of seed and there was no need of external food source. Theodora *et al.* (2003) [34] stated that addition of organic manures had no effect on seed germination. Phosphorous sources, control vs rest and biochar vs no biochar contrasts significantly affected days to 75% tasseling and silking. Earlier tasseling and silking were recorded in plots which received 100% P from organic or inorganic sources while delayed in tasseling and silking was recorded in plots which received 50% P from organic source and 50% P from inorganic source. The possible reason for delayed in tasseling and silking might be the availability of timely and balanced nutrients which helped the plant to enhanced its vegetative growth and thus resulted in late tasseling and silking. Our results are in agreement with those of Faisal *et al.* (2015) [10] who reported that tasseling and silking was delayed in those plots where inorganic P was used at the rate of 120 kg ha^{-1}. Makinde and Ayoola (2010) [16] also reported that combined use of oraganic and inorganic fertilizers enhanced plant growth and resulted in delayed phenology. Biochar enhanced soil fertility and ensure availability of all essential nutrients that enhanced vegetative growth duration and resulted in delayed tasseling and silking. Our findings are in line with the results of Ali *et al*. (2017) [2].

Taller plants were recorded in plots which received 50% P from organic sources and 50% P from inorganic source while shorter plants were observed in the plots which received 100% P from organic or inorganic source. The reason for shorter plants could be that organic manures have the characteristics of slow releasing nutrients and timely availability of nutrients to the plants is not fulfilled which stunted the plant growth and resulted in lower plant height. The possible reason for taller plants from both organic and inorganic phosphorous sources might be the timely availability of nutrients. Our results are in line with the findings of Makinde and Ayoola (2010) [16] and Ayoola and Makinde (2007) [16] who documented that with the application of inorganic and organic fertilizers plant height of maize was significantly greater than those from sole fertilizer application. These consequences also verify the verdicts of Pirdashi *et al.* (2010) [20] who stated that integrated use of 50% inorganic P fertilizer and 50% organic source of P considerably improved plant height. Increased in plant height under biochar amendments have been reported by Varela *et al*. (2013) [36]. It is well known that biochar improves soil fertility (Schulz *et al*., 2013) [28] acting as a good source of C, K and, to a lesser extent, of P for crop nutrition, thus increased plant height.

More grains ear^{-1} were recorded in plots where required P was applied through the integration of organic and inorganic sources (50: 50) and less number of grains ear^{-1} were counted in plots where required P was applied from organic or inorganic sources alone. The increased in the number of grains ear^{-1} might be due to the synergistic effect of organic and inorganic phosphorous fertilizers while less number of grains ear^{-1} observed in organic sources might be due to the low mineralization of nutrients and high leaching and fixation of P in case of inorganic source. Our findings are in agreement with those of Ayoola and Adeniyan (2006) [5] who reported that integrated use of NP and K fertilizers with poultry manure performed better than inorganic and organic sources alone for achieving higher grains per ear in maize. Higher grain yield was obtained with the integration of organic and inorganic P sources (50:50). The possible reason for higher grain yield may be the result of balanced supply of nutrients form organic and inorganic P sources. Our results are in line with the findings of Zafar *et al.* (2011) [38] who stated that use of 50% mineral phosphorous in combination with 50% poultry manure outcome in superior maize grain yield when compared to 100% inorganic phosphorous. This is also in agreement with the results of Rasool *et al.* (2008) [24] who recorded higher maize grain yield when manure + mineral fertilizers were practiced. Our result is also supported by Antonio *et al*. (2013) [3] who reported that appliance of biochar improved the yield of crops due to better supply of water to plants.

The higher biological yield obtained from 50% organic and 50% inorganic P sources might be due to the synergistic effect of organic and inorganic fertilizers which resulted in enhanced crop growth and thus produced more biological yield. Our outcomes are in line with results of Munir *et al.* (2007) [17] who reported that incorporation of combined inorganic and organic fertilizers resulted in higher biological yield of sunflower and it might be due to the availability of supplementary nutrients and enhanced nutrients uptake which led to higher biological yield. Boateng *et al.* (2006) [6] reported that no fertilizer application resulted in lower biomass while poultry manure in combination with chemical fertilizer had the highest biomass probably due to synergy.

Phosphorous sources significantly affected harvest index (HI). Higher HI was calculated in plots where P was applied through the integration of organic and inorganic sources (50:50). The possible reason for higher HI could be the balanced supply of nutrients form combination of organic and inorganic sources of P. Our results are in line with those of Cheema *et al.* (2010) [9] who reported that addition of 50% organic and 50% inorganic mineral fertilizers to maize crop resulted in higher harvest index (%). Our findings are similar to those of Sara *et al*. (2018) [27] who documented that biological and harvest index increased with the addition of biochar.

5. Conclusion and Recommendation

It is concluded that combined use of organic and inorganic P produced 29.46%, 28.84% and 24.94% higher maize yield as compared to sole application of farmyard manure (FYM), poultry manure (PM) and diammonium phosphate (DAP), respectively. Maize yield was 48.9% higher with addition of 50% organic (PM, FYM) and 50% inorganic (DAP) P fertilizer than control. Addition of biochar in combination with organic and inorganic P fertilizer improved maize yield by 9% than no biochar. Thus, application of 50% P from organic source (FYM, PM) and 50% P from inorganic source (DAP) at the rate of 100 kg ha^{-1} along with 10 tons ha $^{-1}$ biochar is recommended for obtaining higher yield of maize in Peshawar region.

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