Effects of Phosphogypsum and Biochar Addition on Soil Physical Properties and Nutrients Uptake by Maize yield in Vertic Torrifluvents

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Abstract: The aim of present study was to investigate phosphogypsum (PG) and biochar (B), applied individually and their mixture at rates of 5 and 10 Mg ha-1 with recommended nitrogen fertilizer for maize plants, on soil physical properties in Vertic Torrifluvents and on nutrients uptake. The results revealed that the aggregate stable index (AgS), hydraulic conductivity (Ks), cumulative infiltration rate (IR) significantly increased as a result of the plots treated with B and PG when compared to recommended nitrogen fertilizer (CN), however, combined application of PG and B was more effective than B or PG only. The application of biochar and PG at rate10 Mg ha-1 for each and N fertilizers at 285 kg N/ ha gave the highest significant increase in the uptake of NPK and yield of maize plants compared other treatments. The combination of biochar and phosphogypsum could be considered as an ameliorating material to reclaim compacted soils and to improve the yield of maize plants. Moreover, it can be used as an economical and simple alternative for disposal methods of phosphogypsum and organic wastes.

Keywords: Biochar; Phosphogypsum; hydraulic conductivity; Cumulative infiltration rate; Aggregate stable index; Maize yield

Introduction

Soil degradation is a genuine danger for an expanding number of areas everywhere throughout the world (Lal *et al.*, 1989; Qadir *et al.*, 2006). Soil degradation is bringing on a decrease in harvest efficiency and tremendous financial misfortunes, food security situation and farmers' occupations at hazard (Young, 1998). Soil degradation is really an applicable question since it influences the productivity of the soil directly, by decreasing crops, and indirectly by implication by expanding administration costs (Gomier6, 2001). The soil compaction is the physical type of soil degradation that progressions the soil structure and impacts the soil productivity (Mueller, *et al*. 2010). Compaction of rural soils is a worry for some rural soil researchers and agriculturists since soil compaction, because of overwhelming field movement, has brought about yield decrease of most agronomic products all through the world (Nawaz *et al*., 2013). Lal (1997) reports that soil compaction is an overall issue and can decrease crop yield by 20%–55%. Soil compaction is one of the primary issues of the clay soil in the Nile Delta, Egypt (El Kassas, 1999). The Nile Delta, as well as arid land, is undermined by, soil compaction, water logging, salinization and alkalinization (El Gabaly, 1972; Gad and Abel Samei, 1998; El Kassas, 1999). Soil Compaction reduces soil porosity and soil infiltration rate, can cause redistribution of water and nutrients, and decreases soil productivity and environmental quality. This decreases leads to increased penetration resistance and a degradation of soil structure (EEA, 1995; Duiker 2016). Reductions of soil permeability and loss of soil structure are often due to high sodium concentrations on the soil exchange complex. Soil texture, clay mineralogy, solution pH, soil aluminum and iron oxide content and salt concentration of irrigation water influence the sensitivity of soil structure to the adverse effect of Na ions (Barzegar *et al.*, 2002). Soil amendment with gypsum, manures, composts, municipal biosolids, biochar and other wastes has been found to improve the yield of barley plants and physical properties of soil. (Unagwu *et al.*, 2013; Ibrahim *et al* 2015; Oo *et al.*, 2015; Van Zwieten *et al.*,2010) found that compost and vermicompost application growth in saline and nonsaline were effective in mitigation salinity and improving maize growth.

Biocahr is a carbonaceous product obtained through the thermal decomposition of biomass without oxygen or little oxygen at high temperature. It has good physical properties i.e. high porosity, large surface area (Kolb *et al.*, 2007). The addition of biochar in high clay soils increased the infiltration rate, aeration and the permeability (Gokila and Baskar 2015). Gwenzi *et al*. (2015) showed that the application of biochar plus 100% recommended dose of NPK fertilizer recorded the higher grain yield (8100 kg ha^{-1}) and straw yield of maize plants (12,150 kg ha^{-1}) and crude protein content. Gwenzi *et al*. (2015) found that short-term application of sewage sludge biochar significantly improves soil chemical properties and enhances maize growth, biomass productivity, nutrient uptake (N, P, K, Ca^{2+} and Mg^{2+} and reduces heavy metal uptake in clay soil. The applications of biochar to degraded soils have been improved soil carbon sequestration and agronomic productivity (Kukal *et al*., 2016). Decrease in soil organic matter contrarily influences soil structure blocking soil aeration and water infiltration and restrains plant growth (Bai *et al*., 2009).

Phosphogypsum (PG) is a by-product produced during the process of manufacturing, especially the production of phosphoric acid from phosphate rock. PG is an acidic material that contains more than 90% gypsum. The acid content of PG is of direct advantage for decreasing aggregate dispersion through advancement of the soil particle flocculation and bonding by calcium, iron and aluminium released by disintegration of calcite and other soil minerals (Luther and Dudas, 1993). Marcano *et al*. (1997) they found that *the* application of PG in clay soil was improved soil bulk density, total porosity and hydraulic conductivity. Vicensi *et al*. (2016) studied the effect of PG on yield of corn plants and ammonia volatilization. They found that application of PG decreased ammonia volatilization, but increased yield of corn plants and improve N use efficiency. (Mullino and Mitchell 1990) have detailed utilization of PG to expand yield and quality of forages in Florida, USA. (Lee *et al.* 2009) observed a positive effect of the PG amendment on biological and chemical properties of soil and yield of cabbage in China. Heavy metal immobilization by PG application in polluted soils has been accounted for by (Mahmoud and Abd El-Kader 2014).

Maize (*Zea mays*, *L*.) is one of the essential grain edits on the planet's farming economy, both as food for men and encourage for animals **(**Chandrasekaran *et al*., 2010). The total area under cultivation of maize in Egypt is 888329 hectares which is about 25.17 % of the total cultivated agricultural land while average yield is 7.8 ton ha^{-1}. It is about 21.90 % of the total cereal production (FAO, 2011). Nitrogen is the most important nutrients required for all plants to obtain an improved yield and its quality (Rees *et al.*, 1995). Maize needs high rates of N-mineral application, achieved 714kg urea ha^{-1} in normal soils (non-salt affected soils) (Nofal and Hinar 2003). Moreover, organic source of bio-waste such as biochar are effective to reduce the need of N- mineral fertilizer due to bio-fortification and enhances soil microbial activity and population, resulting in more carbon storage in soil (Lashari *et al.*, 2016). The aim of the study is to determine the impact of phosphogypsum and biochar with recommended nitrogen fertilizer for maize plants, on soil physical properties in Vertic Torrifluvents and on plant nutrient uptake.

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Material and Methods

Phosphogypsum (PG) is an industrial by-product created by wet-acid generation of phosphoric acid from rock phosphate at Abu-Zaable district (El-Sharkia governorate). PG was obtained from Soil Improvement Station at Sakha. PG is an acidic waste material (pH= 3.8) and its main components are calcium sulfate of 93.0%, oxides of calcium of 19.6%, silicon of 10.7%, aluminum of 1.15% and iron of 3.0% and some impurities such as P_2O_5 (0.5-1.4%), F, sodium silicate and organic substances. The biochar used in this experiment made of different types of citrus trees (B) was produced using pyrolysis at a final temperature of 500 ˚C with a retention time of 2 h. Biochar samples were ground and sieved <0.5mm, prior to use and characterization. It's had high organic carbon (63.8%), characterized by electrical conductivity (EC) of 1.4 dS/ m (1:10 biochar water suspension), total N 2.55 %, total P 0.65 %, total K 1.18 % and cation exchange capacity (CEC) of 32.15 cmol/ kg biochar. A field experiment was conducted at the EL-Gemmieza Agriculture Research Station El Gharbiah Governorate, Egypt (Middle Delta region 30˚ 43¯ latitude and 31˚ 47¯ longitude) during season (2015). The soil is classified as *Vertic Torrifluvents*. The soil temperature regime of the studied area could be defined as *thermic*, and the soil moisture regime could be considered *torric*. Mean temperature and relative humidity of the studied area during the winter seasons of 2014/2015 were 18.34°C and 72.80%, respectively. The physico-chemical analyses according to (Page *et al.*, 1982) of the experimental soil are shown in (Table 1).

The field was plowed with moldboard plow to a depth of 20 cm. Maize (*Zea mays, L.*) was planted on 3 July, 2015 using maize cultivar (TWC 329 hybrid) at seed rate 33 kg/ ha. The experimental field was prepared and then divided into 18 plots (4.2m x 4.0m) for each one plot. Each plot contains five ridges 0.7 m apart with 6 m length. Six treatments were applied in a randomized complete block design with three replications. The treatments used in this experiment were: The treatments were (1) recommended nitrogen fertilizer only (285 kg N/ ha as a control (CN); (2) 5.0 Mg/ ha biochar + CN (B5); (3) 10 Mg/ ha biochar + CN (B10); (4) 10 Mg/ ha PG (PG10); (5) 5.0 Mg/ ha biochar+ 10 Mg/ ha PG mixed in the field +CN (B5+PG10), and (6) 10 Mg/ ha biochar+10 Mg/ ha PG + CN (B10+PG10).

The total amount of B and PG were added as broadcast during final land preparation and mixed into the soil by a small machine at depth 15cm during the tillage. All plots received a total of 476 kg Ca-Superphosphate ha^{-1} (15.5% P_2O_5) and 119 kg K-sulfate ha^{-1} (48% K_2O) during tillage operation. The Maize crop was harvested on 23th October in 2015. The grain yield was determined by harvesting four central rows in each plot. Maize grain samples were taken and dried at 70^{o}C, grounded with a mill, wet digested according to (Jackson 1967) and its total N content was determined using the micro Kjeldahl (Cottenie *et al*., 1982). This study will be complete after crop rotations.

Electrical conductivity (EC) and pH were determined in a saturated paste of soil and water using conductivity meters and pH, respectively. The soluble cations (Na^+ Mg^{2+}, Ca^{2+}, K^+) and anions (HCO_3^- and Cl^-) were determined in soil paste extract as described by (Rhoades, 1954). pH value was determined in 1:10 (biochar: water) suspension using glass electrode pH-meter according to (Jodic *et al*.1982). EC of biochar was determined in 1:10 biochar extract as described by (soil laboratory staff 1984)**.** The organic matter of biochar and soil were determined according to Walkely and Black rapid titration method, as outlined by (Kim 1996). Total nitrogen of biochar and soil determined using Micro- Kjeldahl as described by (Page *et al.*, 1982). Total phosphorus of biochar and the studied soil was determined by ascorbic acid using spectrophotometer according to (soil laboratory staff 1984). Total potassium of biochar and the studied soil was measured using the flame photometer as described by (Page *et al.*, 1982). Sample of biochar was 1 g weight and digested using a mixture of sulphuric acid and Perchloric acid at mixed rate of 3:1 then, the digested was diluted with distilled water to a volume of 100 ml. Aliquots from this digest was analyzed for the content of these nutrients, according to (Cottenie *et al*., 1982). Available nitrogen of soil was extracted by using 1 M KCL and determined according to (Cottenie *et al*., 1982). Available phosphorous of soil was extracted in soil with 0.5 N $NaHCO_3$ and determined using spectrophotometer at wavelength 770 as described by (Cottenie *et al*., 1982). Available potassium of soil was extracted with 1 N ammonium acetate and determined using flame photometer as described by (Cottenie *et al*., 1982).

Bulk density was determined using soil coremethod (soil laboratory staff 1984). Hydraulic conductivity saturated (K_s) was determined for each tested soil and calculated by Darcy's low (Klute and Dirksen, 1986) as follows:

K_s = QL/ATH (Equation 1)

Where: K_s = Hydraulic conductivity (Cm/h); Q= Volume of water (cm^3); L= length of sample (cm); A= Cross sectional area of sample (cm^2); T= time (hour); and H= Constant water head (cm)

Infiltration rate was determined by using double ring cylinder at each treatment by applying 15 cm depth of water in the field. Then, the infiltration time was recorded for each plot. After that, the average of these values was calculated for each treatment. Cumulative infiltration rate (I) was calculated using the Kostiakov infiltration equation as follows:

$I= KT^n$ (Equation 2)

Where: K=constant; T=time (h); and n=exponent

Stability index of soil aggregates was determined using wet sieving with vertical oscillation (30 oscillations per minutes), according to the method described by (Cavazza 1981).

All treatments were conducted with three replicates. Treatments means were compared by Duncan’s Multiple Range Test (Duncan 1955).

Results

Effects of Phosphogypsum and Biochar, on Soil Physical Properties and Nutrient Uptake of Maize Plants

The soil bulk density (BD) significantly decreased as a result of the plots treated with soil amendment additions compared with the control treatment (Table 2). BD decreased from 1.45 g/ cm in the control soil to 1.05 g/ cm in B10+PG10 treatment. The 10 Mg/ ha addition rate of B10 + PG10 resulted in the greatest decreasing of BD by 27.6%. No-significant difference was observed between the treatments of B10 and PG10.

The saturated hydraulic conductivity (Ks) was significantly increased with an increasing addition of biochar, PG and their mixtures (Table 2). Mean soil Ks of B5+PG10 and B10+PG10 treatments was 83.8 and 108.8 % higher than the control and 23.8 and 48.9 % higher than the PG10 treatment. With the B10+PG10 treatment, the Ks was significantly increased from 0.96 to 3.56 Cm/ h. No-significant difference was observed between the treatments of B10 and PG10.

The results clearly showed that the cumulative infiltration rate (IR) was significantly increased with soil amendment additions (Table 2). IR varied from 9.72 mm for the control treatment to 20.3 mm for B10+PG10 treatment. IR of soil was increased about 108.8% in the plots treated with mixing between N mineral and biochar and PG treatments at a rate of 10 Mg ha^{-1} for each above the N alone treatment. The IR of soil treated with B10 was 25 % higher than B5 treatment. No-significant difference was observed between the treatments of B10 and PG10.

Aggregate stable index (AgS) in relation to inorganic fertilizer and organic amendment are shown in (Table 2). The aggregate stable index (AgS) of the CN treatment was significantly lower than the other treatments. Compared with the CN treatment, both the CN+PG and CN+B treatments at different rates significantly improved the stability of soil aggregates; however, the combined application of PG and the biochar was more effective than biochar or PG only. The highest AgS was found in the B10+PG10; the AgS was 12.7%, 14.5%, and 20.3% higher than in the B10, B5+PG10, and B10+PG10 treatments, respectively. A significant difference was observed between the treatments of B5 and B10 treatment.

It has been observed that all combinations between N fertilizer and soil amendments increased significantly the grain yield of maize plants, except of B5 treatment when their compared to without N fertilization alone (Table 3). Application of PG at rate of 10 Mg/ ha increased grain and straw yield of maize plants by 24 and 3%, respectively. The application of biochar and PG at rate10 Mg/ ha for each and N fertilizers at 285 kg N/ ha gave the highest significant increase in the grain and straw yield of maize compared to other treatments. Grain and straw yield of maize plants growth was higher under the application of biochar than PG when it used with N fertilization at the same rate. Grain yield of maize was increased about 43% in the plots treated with interaction between N mineral and biochar and PG treatments at rate of 10 Mg/ ha for each above the N alone treatment.

N uptake in grain of maize plants was significantly increased with the B10 and B and PG mixture additions (Table 3). Increasing the biochar application rate from 5 and 10 Mg

/ha increased the N uptake by 20.7 and 55.4%, respectively, when compared to N fertilizer alone treatment. The highest increment in N uptake (86.3%) over the control was obtained from the combination of biochar and PG at 10 Mg/ ha for each. The N uptakes in the soil treated with the soil amendments were not significantly different between the treatments. The uptake amount of P and K in grain of maize plants significantly increased with PG and biochar and PG mixtures, but its application with B5 and B10 treatments did not show any significant differences in the uptake of these nutrients compared to the N alone treatment (Table 3). The application of PG at 10 Mg/ ha was greater in P and K uptakes than biochar applied at the same rate. P and K uptakes of PG at 10 Mg/ ha increased to 54% and 43 %, respectively.

The uptake of N, P and K measured in straw yield were showed significantly higher in the B and PG mixtures – amended soil than the N fertilizers alone treatment (Table 3). N, P and K uptakes of the (B10 +PG10) treatment increased to 38.2%, 30.2 % and 36.7%, respectively.

Discussion

A aggregate stable index was significantly increased with increasing application of biochar. This can be attributed to high soil organic matter, Ca^{++}, Mg^{++} and CEC in biochar, which led to forms a bridge between the soil particles, resulting in stable aggregates. Similarly, (Downie *et al*. 2009) studied the effect of biochar rates on soil aggregate stability. They found that soil aggregate stability significantly increased with increasing application of biochar. The organic matter is of major importance for the stabilization of aggregates (Six *et al*., 2004). Domingo-Olivé *et al* (2016) found that the high in SOC may contribute to aggregate stability. High CEC made biochar more compelling as a binding agent for minerals and OM to form macro-aggregates. Biochar influences soil aggregation due to interactions with minerals, soil organic matter and microorganisms (Verheijen *et al*., 2010). (Glaser *et al*.

2002) has reported that the improved soil aggregate stability with biochar addition may be the interactions between oxidized carboxylic acid groups on the surface of biochar particles. Increases in soil stability in phosphogypsum treated soils can be attributed to the addition of Ca^{2+} which promoted soil flocculation (Sparks, 1998). Bivalent Ca^{2+} and Mg^{2+} cations improve soil structure through cationic bridging with clay particles and SOC (Zhang and Norton, 2002). Nan *et al*. (2016) has shown that the soil AgS improved with the application of PG may be due to high Ca^{2+} in PG. Madeline and Fisher (2011) reported that PG or gypsum improves soil structure. Flocculation, or the aggregation or clumping together of the soil particles, depends largely on electrostatic repulsive forces between negatively charged soil mineral particles by divalent cations facilitates binding of soil particles and induces soil particle stability through flocculation (Amezketa 1999).

The soil hydraulic conductivity of B5+PG10 and B10+PG10 was 83.8 and 108.8 % higher than the CN treatment and 23.8 and 48.9 % higher than the PG10 treatment. This can be attributed to the application of the biochar with PG10 to the soil increases the organic matter in the soil relative to the same PG10 applied individually (Table 2), which led to increase soil porosity and aggregate stability, and therefore enhanced soil permeability. The addition of biochar was shown to significantly increase the soil hydraulic conductivity in other studies (Felton and Ali, 1992; Aggelides and Londra, 2000). Similar improvements in Ks of the soil were found by (Asai *et al*. 2009) when biochar was applied to the rice fields in northern Laos. Also in a more recent study in New Zealand, (Herath *et al*. 2013) showed a 50-139 % increase in soil Ks after corn stalk biochar was applied to silt loam soils and attributed this effect to increase soil porosity and aggregate stability. The addition of phosphogypsum was increased the electrolyte concentration in the soil solution by Ca^{2+} and Mg^{2+}, which led to the thinness of the layer of positive charge surrounding the clay particle, therefore enhanced soil permeability (McNeal and Coleman, 1966; Quirk and Schofield, 1955).

In this study, soil organic matter increased from 1.5 in CN treatment to 1.95% in B10+ PG10 treatment (Table 2), which leads to an increased soil porosity, water aggregate stability increased and decreased soil bulk density. Moreover, the generation of macropores and channels by root penetration through soil tends to form preferential flow paths, thus enhancing soil infiltration (Benegas *et al*., 2014).

The increase in grain and straw yield of maize plants was corresponded with improving in soil physical properties and organic matter (Table 2). In addition, with the application of PG and biochar the grain yield was increased. These increases were attributed the improving action of PG and biochar on the soil physical properties as well as nutrient status in the soil, which enhance plant growth (Aggag and Mahmoud, 2006). Biochar and PG provide Ca, S and macronutrients; and led to increase yield of maize plants. Shaimaa *et al* (2012) studied the effect of gypsum, farmyard manure and mix of them on yield of wheat plants grown on salt-affected soil irrigated with low quality water. They found that yield of wheat plants significantly increased with different treatments, especially with addition of farmyard manure mixed with gypsum.

The increase in the uptake of NPK of straw and grain of maize plants was corresponded with straw and grain weight of maize plants and organic matter (Table 2). Similarly, (Gunes *et al*. 2014) showed increased NPK concentrations in lettuce plant after the biochar application. Chan et al. (Chan *et al*. 2007) found an increase in the uptake of N at higher levels of biochar. The application of PG and biochar the uptake of NPK were increased. These increases were attributed to increase N fertilizer use efficiency of plants [66]. Gwenzi *et al* (2015) showed that the application of biochar significantly improves soil chemical properties and enhances maize growth, biomass productivity, and uptake of NPK in clay soil.

Conclusion

The results demonstrated that the effects of biochar and phosphogypsum contributed to improve physical soil properties and maize yield. Grain and straw yield of maize plant growth was higher under the application of biochar than phosphogypsum when it used with N fertilization at the same rate. The application of biochar and phosphogypsum at rate10 Mg ha^{-1} for each and N fertilizers at 285 kg N ha^{-1} gave the best uptake of NPK, grain and straw yield of maize plants compared other treatments. So, the results suggest that the combination of biochar and phosphogypsum at rate10 Mg ha^{-1} for each was an optimum and sustainable strategy to achieve higher yield and improve physical soil properties in Vertic Torrifluvents and also to recycle organic wastes.

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Table 1 Physicochemical properties of the soil

Properties	units	Soil profile		
		0-15 cm	15-30 cm	30-60 cm
pH (1:2.5) soil extracts	dS m^{-1}	7.97	8.02	8.08
EC (soil past extracts)		1.50	1.40	1.12
Ca^{2+}	meq L^{-1}	6.00	5.60	4.00
Mg^{2+}	meq L^{-1}	3.00	2.00	1.20
Na^{+}	meq L^{-1}	5.00	5.00	5.50
K^{+}	meq L^{-1}	0.75	0.75	0.40
Cl^{-}	meq L^{-1}	8.00	6.24	5.00
HCO_3^{-}	meq L^{-1}	4.00	4.72	2.94
SO_4^{--}	meq L^{-1}	2.64	2.63	3.16
SAR		2.36	2.58	3.42
NPK available				
N				

P	mg kg^{-1}	55.46	47.35	44.15
K	mg kg^{-1}	5.92	5.12	4.64
O.C	mg kg^{-1}	460	320	280
O.M	%	0.84	0.72	0.69
CEC	%	1.45	1.24	1.19
Particle size distribution	Coml Kg^{-1}	52.20	50.55	49.56
Clay				
Silt	%	60.15	62.07	66.15
Sand	%	26.55	29.22	27.02
Texture	%	13.30	8.71	6.83
		Clay	Clay	Clay

Table 2 Effects of biochar and phosphogypsum on some soil physical properties

Control (CN): recommended nitrogen fertilizer only ; B5: 5.0 Mg ha^{-1} biochar + CN; B10 : 10 Mg ha^{-1} biochar + CN; PG10 : 10 Mg ha^{-1} PG; B5+PG10 : 5.0 Mg ha^{-1} biochar+ 10 Mg ha^{-1} PG mixed in the field +CN and B10+PG10 : 10 Mg ha^{-1} biochar+10 Mg ha^{-1} PG + CN.

Treatments	Organic matter,%	Hydraulic conductivity cmH^{-1}	Bulk density gmcm^{-3}	Total water stable aggregates (%)	Cumulative Infiltration. mm
Control	1.50^{d}	0.96 ^{e}	1.45 ^{a}	58.16 ^{d}	9.72 ^{e}
B5	1.81^{bc}	1.58 ^{de}	1.31 ^{b}	61.76 ^{c}	11.62 ^{d}
B10	1.84^{abc}	2.5 ^{bc}	1.24 ^{b}	65.54 ^{b}	14.56 ^{c}
PG10	1.74^{c}	1.99 ^{cd}	1.20 ^{b}	60.63 ^{cd}	15.55 ^{c}
B5+PG10	1.90^{ab}	2.74 ^{b}	1.15 ^{c}	66.62 ^{b}	17.87 ^{b}
B10+PG10	1.95^{a}	3.56 ^{a}	1.05 ^{d}	69.96 ^{a}	20.3 ^{a}
L.S.D.$_{0.05}$	0.12	0.71	0.05	2.61	1.08

Table 3 Effects of biochar and phosphogypsum on plant nutrient uptake

Treatments	Straw yield Mg ha^{-1}	grain yield Mg ha^{-1}	NPK uptake in grain (Kg ha^{-1})			NPK uptake in straw (Kg ha^{-1})		
			N	P	K	N	P	K
Control	14.73^{b}	3.66^{a}	67.00^{c}	18.43^{c}	13.75^{c}	207.97^{c}	51.86^{b}	292.09^{abc}
B5	14.90^{b}	4.23^{ab}	80.92^{bc}	20.87^{bc}	14.69^{bc}	212.83^{c}	49.14^{b}	263.74^{bc}
B10	15.78^{b}	4.17^{a}	102.96^{ab}	20.76^{bc}	16.14^{abc}	248.42^{abc}	47.93^{b}	257.13^{c}
PG10	15.17^{b}	4.54^{a}	93.96^{abc}	28.01^{ab}	19.36^{ab}	228.32^{bc}	67.01^{a}	424.02^{ab}
B5+PG10	16.00^{b}	4.84^{a}	112.75^{ab}	28.39^{a}	19.66^{a}	258.48^{ab}	63.81^{a}	428.24^{a}
B10+PG10	17.53^{a}	4.91^{a}	124.81^{a}	27.43^{ab}	18.68^{ab}	287.41^{a}	67.53^{a}	399.40^{abc}
L.S.D.0.05	1.43	0.70	32.06	7.45	4.82	45.47	8.45	160.99

Control (CN): recommended nitrogen fertilizer only ; B5: 5.0 Mg ha^{-1} biochar + CN; B10 : 10 Mg ha^{-1} biochar + CN; PG10 : 10 Mg ha^{-1} PG; B5+PG10 : 5.0 Mg ha^{-1} biochar+ 10 Mg ha^{-1} PG mixed in the field +CN and B10+PG10 : 10 Mg ha^{-1} biochar+10 Mg