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ORIGINAL RESEARCH ARTICLE

Impact of biochar and plastic mulch on soil properties in a maize field in Nepal

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ABSTRACT

Biochar is a carbon rich product obtained from organic material by a process called pyrolysis. Similarly, plastic mulch protects soil from erosion, conserve water, suppress weed, and makes soil condition favorable for crop growth. The use of biochar and mulch has the potential to boost soil fertility by raising soil pH, increasing water and nutrient holding capacity, improving cation exchange capacity, and increasing microbial population. A field experiment was conducted to evaluate the effects of biochar application and plastic mulch on soil properties applied in maize fields with sandy loam soil at Rampur, Chitwan, Nepal from 31 March to 6 July 2018. The experiment was carried out in a split-plot design having plastic mulch as a main factor and biochar doses as a sub factor with three replications. The main plot is comprised of plastic mulch and no mulch. Similarly, the subplot consisted of four biochar doses i.e., 0 t/ha, 5 t/ha, 15 t/ha, and 25 t/ha. To know the effect of treatments the soil samples were collected at random points in the middle of each plot (to avoid edge effect) from 30 cm depth with the help of a screw auger. Dried, and grounded soil samples were analyzed in the lab. The results indicated that the Bulk density of soil relatively decreased with the plastic mulch but it was significantly higher in plots with biochar. 0 t/ha biochar showed the highest (1.22 gm/cm^3) bulk density and the lowest was obtained from 25 t/ha (1.09 gm/cm^3). However, soil parameters such as soil pH, Cation Exchange Capacity, Nitrogen, Phosphorus, Potassium, and Organic Carbon were relatively higher under plastic mulch over no mulch. In the same way, the potassium content of the soil was significantly influenced by biochar doses, it was the highest at 25 t/ha (741.47 Kg/ha) and the lowest at 0 t/ha (351.60 Kg/ha). However, soil pH, CEC, N, P, and OC were relatively increased with increasing rates of biochar application. Therefore, application rate of 25 t ha^{-1} biochar and use of plastic mulch in soil is considered as suitable because these efficiently increase soil moisture. In addition to that biochar increase Potassium content, decrease bulk density, and also improves Soil pH, Cation Exchange Capacity, Nitrogen, Phosphorus, Potassium, and Organic Carbon of soil.

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INTRODUCTION

Soil is the foundation of agriculture; good soil denotes the productivity of any agricultural field. Intensive cultivation, fault agricultural practices, and an increase in climate variability are posing an enormous threat to the soil that ultimately affects agricultural production. Degradation in physical-chemical properties of soil results through loss of soil organic matter (SOM) and soil organic carbon (SOC), loss of N and other nutrients, decreased porosity, infiltration, and water holding capacity, increased pH, and increase in bulk density (Karim *et al.*, 2020). The application of biochar and the use of plastic mulch in crop fields can improve these soil properties. Biochar is a carbon rich product obtained by pyrolysis in which biomass such as wood, manure, or leaves are heated at relatively low temperatures (<700°C) in a closed container with little or no available air (Lehmann and Joseph, 2009; Babalola *et al.*, 2020). According to the purpose of use; biochar is also named bio-char, pyrochar, charcoal or biomass derived black carbon (Hossain et *al.*, 2020). The use of biochar as a soil amendment has been growing, as it has the potential to boost soil fertility by increasing water and nutrient holding capacity, improving cation exchange capacity, maintaining soil pH, and making soil a more suitable habitat for soil microorganisms (Lehmann *et al.*, 2006). In addition to that, it can sequestrate carbon from the atmosphere and transfer it to soil (Joseph, 2021). Sequestration of carbon in soil is one of the ways to enrich the soil with organic matter; which is the source of major plant nutrients, promote favorable soil condition, increases soil microbial population, and regulate nutrient recycling in soil (Jakhar, 2017).

Mulching is the practice of covering the soil to make favorable conditions for plant growth, through moisture conservation, erosion control, suppressing weeds, and raising the soil temperature (Kader *et al.*, 2019). Straws, husks, grasses, cover crops, sawdust, compost, and manures are the most often used organic mulches, whereas polyethylene plastic mulch is the most commonly used inorganic mulch worldwide (Iqbal *et al.*, 2020). Plastic mulches are completely impermeable to water; therefore, it prevents direct evaporation of moisture from the soil and thus limits the water losses. Similarly, it is reported that mulch can effectively minimize water vapor loss, soil erosion, weed problems, and nutrient loss (Bahadur, 2018). The objective of this study is to assess the effect of plastic mulch and biochar on important soil properties i.e., Soil pH, Cation Exchange Capacity, Nitrogen, Phosphorus, Potassium, soil moisture and Organic Carbon.

MATERIALS AND METHODS

The experiment was conducted at the research block of Agriculture and Forestry University, Rampur, Chitwan, Nepal from 31 March 2018 to 6 July 2018 to know the effects of biochar and plastic mulch on soil properties in the field of spring maize. The geographical location of the experimental site is at 27°37' N latitude and 84°25' E with an elevation of 228 meters above sea level. The experimental field was fallow before experimenting. The crop used for the experiment was spring maize and the variety was "Arun-2". The soil was sandy loam in texture and acidic in reaction (pH 5.89) with low organic matter content (0.85%). The total nitrogen, available phosphorus, and exchangeable potassium were 0.13%, 54.25 kg ha^{-1}, 460.06 kg ha^{-1} soil. The total rainfall during the crop season was 122.16 mm and the relative humidity ranged from 75.0% to 80.0%. The mean maximum temperature during the experimental period ranged from 30.84°C to 23.73°C. The experiment was carried out in a split-plot design (SPD) with three replications. The main plot is comprised of plastic mulch and no mulch. Similarly, the subplot consisted of four biochar doses i.e., 0 t/ha, 5 t/ha, 15 t/ha, and 25 t/ha. In each replication, main plot treatments were first randomly assigned followed by a random assignment of the subplot treatments within each main plot. There were twenty-four plots have with dimension of 4.8 m ×1.5 m each and contains forty-eight plants in each plot. Before seed sowing land was prepared to make it pulverized and friable. The well-ground biochar passed through a 1 mm sieve was applied in the plots before two weeks of seed sowing. The soil was sampled before seed sowing and at the time of harvest. The samples were collected at random points from the middle portion of each plot (to avoid edge effect) at 30 cm depth with the help of a screw auger. Samples were ground in mortar and pestle and passed through a 2 mm sieve after air drying at room temperature. The physicochemical properties of soil and biochar were analyzed by the following methods (Table 1). The data were first tabulated in Microsoft Excel and analyzed using R-studio. Means were separated using Duncan's Multiple Range Test (DMRT) at 1 % and 5% levels of significance (Gomez and Gomez, 1984).

Table 1. Analysis methods for various soil parameters.

Parameters	Analysis methods	
	Soil	Biochar
pH	Beckmann electrode pH meter in 1:2 soil and water ratio (Cottenie *et al.*, 1982)	Beckman electrode pH meter in 1:4 biochar and water ratio (Cotteni *et al.*, 1982)
Soil texture	Hydrometer method (Gee, Bauder and Klute, 1986)	
Soil bulk density	Core ring method	
Organic matter content	Degtjareff or chromic acid titration method (Walkley and Black, 1934)	Elemental analyzer (Matejovic, 1993)
Cation exchange capacity	Sodium acetate method (Chapman, 1965)	Sodium acetate method (Chapman, 1965)
Nitrogen content	Kjeldhal distillation (Bremner and Mulvaney, 1982)	Elemental analyzer (Matejovic, 1993)
Phosphorus content	Modified Olsen's method (Watanabe and Olsen, 1965) using spectrophotometry	Modified Olsen's method (Watanabe and Olsen, 1965) using spectrophotometry
Potassium content	Ammonium acetate extraction method using flame photometry (Simard, 1993)	Ammonium acetate extraction method using flame photometry (Simard, 1993)

RESULTS AND DISCUSSION

Soil moisture content

Soil moisture content was significantly affected at silking (11.45%) and harvesting stage (15.23%) due to different doses of biochar (Table 3). It was reported that 15 % more moisture was retained by biochar treated plots over no treatment (Laird *et al.*, 2010). Tryon (1948) stated that the application of biochar increased the water retention capacity of the soil, but it was soil texture-dependent. Similarly, in the case of mulching, it was significantly higher in the mulched plot at the harvesting time (Table 3). Restriction of evaporation by plastic mulch increased the soil moisture as compared to non-mulch plots. Bandopadhyay *et al.* (2018), found that under-plastic mulch helps in moisture conservation as it acts as a barrier on the soil surface thus reducing evaporation.

Soil Bulk density

The mean bulk density of soil due to mulching and different doses of biochar was 1.16 gm/cm^3 (Table 2). The results showed significant effects due to different doses of biochar but was found non-significant effect due to mulching. In the case of mulching, soil bulk density was 1.71 % higher from non-mulch than that of plastic mulch. Soil bulk density being significantly highest from 0 t/ha (1.22 gm/cm^3) and significantly the least from 25 t/ha (1.09 gm/cm^3). It was observed that the bulk density of soil from 0 t/ha was 10.66 %, 4.09 %, and 2.46 % higher than 25 t/ha, 15 t/ha, and 5 t/ha, respectively. The bulk density of soil was relatively higher in non-mulch plots compared to plastic mulch plots. Similar results were also recorded by Mehmood *et al.* (2015). The application of biochar on soil significantly decreased the soil bulk density as the rates of biochar application increased. This decrease in soil bulk density might be due to the lower bulk density of biochar (Alburquerque *et al.*, 2014) and an increase in pore volume as biochar is highly porous (Mukherjee and Lal, 2013).

Soil chemical properties

Soil available potassium was significantly influenced by the application of biochar but other parameters such as soil pH, CEC, total N, available P, and OC were statistically non-significant but showed a relative increase with the increase in biochar rate (Table 4). Available potassium was higher in plot containing biochar 25 t/ha (741.47 Kg/ha) which was at par with 15t/ha (719.13 t/ha), followed by 5 t/ha (6.75t/ha) and the least from 0 t/ha (351.60 Kg/ha). Similarly, other soil parameters such as soil pH, CEC, total N, available P and OC were relatively higher from biochar dose of 25 t/ha i.e., 6.81, 14.72 Cmol/Kg, 0.13 %, 62.85 Kg/ha and 0.94 %, and the least from 0 t/ha i.e., 6.66, 11.62 Cmol/Kg, 0.12 %, 54.25 Kg/ha and 0.83 %, respectively. Lehmann *et al.* (2009) stated that higher nutrients contained in the plot with biochar might be the nutrient content of biochar itself. In addition to that, the increase in nutrient contents of soil with biochar could be due to the high porosity and surface area of biochar, which facilitated the adherence of nutrients to the exchange site on biochar particles (Nystrom, 2015). Ogawa and Okimori (2010) observed that nutrient availability was increased (particularly potassium) when biochar alone was applied to rice fields. The soil pH was increased with the increase in application rates of biochar. This increase in soil pH might be due to the alkaline nature of biochar (Major *et al.*, 2010). Biochar application to soil improves NH_4^+ immobilization and subsequently decreases nitrification which in turn conquers the discharge of H^+ concentration to the soil and relieves soil acidification (Nelissen *et al.*, 2015). CEC of soil was increased as the application rate increased, this might be due to high surface area, high porous, possess organic materials of variable charge that had the potential to increase soil CEC and base saturation (Glaser *et al.*, 2002).

Table 2. Biochar and mulching effects on soil bulk density at Rampur, Chitwan, Nepal, 2018.

Treatments	Bulk density (gm/cm^3)
Mulching	
Plastic mulch	1.15
No mulch	1.17
LSD (0.01)	0.05 (NS)
Sem (±)	0.02
C.V. (%)	2.2
Biochar	
0 t/ha	1.22^a
5 t/ha	1.19^a
15 t/ha	1.17^a
25 t/ha	1.09^b
LSD (0.01)	0.05 **
Sem (±)	0.04
C.V. (%)	4.5
Grand mean	1.16

Treatment means in columns followed by common letters (s) are not significantly different from each other based on DMRT at 1 % level of significance.

Table 3. Biochar and mulching effects on soil moisture content during crop growing periods at Rampur, Chitwan, Nepal, 2018.

Treatments	Soil moisture content (%)	
	Silking time	Harvesting time
Mulching		
Plastic mulch	12.10	17.47[a]
No mulch	10.79	12.98[b]
LSD (0.01)	2.18 (NS)	1.86 **
Sem (±)	0.28	1.33
C.V. (%)	3	10.7
Biochar		
0 t/ha	9.33[c]	13.33[b]
5 t/ha	10.28[bc]	14.61[ab]
15 t/ha	11.69[b]	15.61[ab]
25 t/ha	14.48[a]	17.37[a]
LSD (0.05)	2.14 *	3.56 *
Sem (±)	1.06	1.25
C.V. (%)	11.4	10.1
Grand mean	11.45	15.23

Treatment means in columns followed by common letters (s) are not significantly different from each other based on DMRT at 1 % and 5 % level of significance.

Table 4. Biochar and mulching effects on soil chemical properties after crop harvest at Rampur, Chitwan, Nepal, 2018.

Treatments	pH	CEC (cmol/Kg)	Nitrogen (%)	Phosphorus (Kg/ha)	Potassium (Kg/ha)	OC (%)
Mulching						
Plastic mulch	6.76	13.88	0.13	59.06	588.48	0.92
No mulch	6.72	12.52	0.12	58.89	518.62	0.89
LSD (0.05)	0.24 (NS)	2.76 (NS)	0.01 (NS)	10.51 (NS)	199.41 (NS)	0.09 (NS)
Sem (±)	0.25	1.07	0.02	11.31	60.92	0.24
C.V. (%)	4.6	10	17.7	23.5	13.5	32.4
Biochar						
0 t/ha	6.66	11.62	0.12	54.25	351.60[b]	0.83
5 t/ha	6.75	12.37	0.12	56.65	402.00[b]	0.91
15 t/ha	6.76	14.11	0.13	62.14	719.13[a]	0.93
25 t/ha	6.81	14.72	0.13	62.85	741.47[a]	0.94
LSD (0.05)	0.36 (NS)	3.87 (NS)	0.02 (NS)	14.92 (NS)	188.66 **	0.17 (NS)
Sem (±)	0.22	1.98	0.02	10.69	147.16	0.10
C.V. (%)	4	18.4	16.3	22.2	32.6	14.2
Grand mean	6.75	13.20	0.13	58.97	553.55	0.91

Treatment means in columns followed by common letters (s) are not significantly different from each other based on DMRT at 1 % level of significance.

In the case of plastic mulching all the soil properties i.e., pH, CEC, Nitrogen, Phosphorous, potassium, and OC were found non-significant (Table 4). However, all the properties were found better in plots with plastic mulch i.e., CEC (13.88 cmol/Kg), Nitrogen (0.13%), and Phosphorus (59.06 Kg/ha), Potassium (588.48 Kg/ha), OC (0.92%). Under plastic mulch decomposition of organic matter occurred at a slow rate due to more moisture conservation and moderating temperature, so more soil organic carbon was found high in the case of plastic mulch (Mehmood *et al.*, 2015). Similarly, it has been found that change in microclimate under plastic mulch results indirect increase in nutrient availability due to a reduction in nitrate leaching, an increase in moisture availability (Qin *et al.*, 2015; Bandopadhyay *et.al.*, 2018).

Conclusion

The application of biochar and plastic mulch positively affected the soil properties, but the effect varied with the dose of biochar. Soil moisture content was found higher in plots with mulching and biochar doses of 5 t/ha, 15 t/ha, and 25t/ha. Among biochar doses, relatively higher moisture was at 25t/ha. Similarly, Bulk density was significantly lower and Potassium was significantly higher in plots with biochar of 25t/ha. Besides these all-other soil properties i.e., Soil pH, CEC, N, P, and OC were found relatively higher as the dose of biochar got increased with the application of plastic mulch. Based on the results of the study it can be concluded that the application of biochar and plastic mulch in crop fields would have a positive effect on soil properties that may contribute to higher soil productivity.

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