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Effect of biochar and crop residue application on physico-chemical properties of soil

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Abstract
A field experiment was carried out in Rabi, 2017-18 and continued to Rabi 2018-19 at research farm, College of Agriculture and Research Station, Raigarh (C.G.). The experiment was laid out in randomized block design with three replications and consisted eleven treatments namely (T_1) Control, (T_2) GRD, (T_3) 75% GRD+RB@2.5 t/ha, (T_4) 75% GRD+RR@5 t/ha, (T_5) 75% GRD+RR@5 t/ha+FYM @2.5 t/ha, (T_6) 75% GRD+ RB@2.5 t/ha+FYM @2.5 t/ha, (T_7) T_3+*Trichoderma*+FYM @2.5 t/ha, (T_8) T_4 + *Trichoderma* + FYM @ 2.5 t/ha, (T_9) 75% GRD+RR@5 t/ha+6%ureaspray, (T_{10}) 75% GRD+RR@ 5 t/ha RB @2.5 t/ha, (T_{11}) T_{10}+6% urea spray. The bulk density was recorded maximum with 100% GRD (1.47Mgm^{-3}) during both the years. The particle density of soil recorded 2.62 Mg m^{-3} and 2.63 Mgm^{-3} respectively during both the years. Porosity ranged from 43.86 (100% GRD) to 47.04 (75% GRD + rice residue @ 5t/ha+ rice biochar @2.5t/ha) and 44.31 (100% GRD) to 47.89 (75% GRD + rice residue @ 5t/ha+ rice biochar @2.5t/ha+ 6% urea spray) % after rice-groundnut cropping system of 2017-18 and 2018-19, respectively. The lowest mean pH value was recorded (6.73) in control and the highest pH (6.95) in treatment 75% GRD + rice residue @ 5 t/ha+rice biochar @2.5t/ha+6% urea spray. The electrical conductivity of the soil ranged from 0.22 to 0.27 dSm^{-1} where minimum value was observed with control and maximum with the treatments of 75% GRD + rice residue @ 5t/ha+ rice biochar @ 2.5 t/ha+6% urea spray. The CEC values ranged from 13.52 to 20.19 cmol (p+) kg^{-1}and 13.66 to 20.42 cmol (p+) kg^{-1} was recorded after rice-groundnut cropping system of 2017-18 and 2018-19 respectively.

Keywords: RR**(**Rice residues), RB(Rice Biochar), electrical conductivity, *Trichoderma*, CEC

Introduction
Biochar application had improved some physical soil properties, such as increased soil aggregation, water holding capacity, and decreased soil strength. An increase in saturated hydraulic conductivity of upland rice soil with biochar application has been reported by Asai *et al*., (2009) [2]. Furthermore, Chan *et al*., (2007) [4, 5] also showed that the application of biochar could increase soil organic carbon, soil pH, and CEC. However India is a lack of other effective information on the potential of biochar produced by various important crop residues, physical and spectral characterization, optimal biochar application rate to improve the efficiency of nutrient use by crops and soil health.

Materials and Methods
A field experiment entitled "Effect of crop residue management on soil health and productivity of groundnut in Inceptisol under rice- groundnut cropping system" "was conducted at research farm, College of Agriculture and Research Station, Raigarh, Chhattisgarh. Field experiment was started in Rabi, 2017-18 and continued to Rabi 2018-19 on the inceptisol. The entire study was subdivided into two major parts. Firstly collection of agricultural residues followed by preparation of biochar from these residues. Secondly, a field experiment was carried out with biochars produced from rice residue along with rice residue and chemical fertilizers with their effects on yield and nutrient use efficiency by groundnut crop.

Preparation of Biochar
Rice straw biochars were made in a small pyrolysis chamber at temperatures ranging from 450 ºC to 500 ºC (drum method). The remnants were broken into little pieces, weighed, and deposited into the drum after drying in the sun. The metal pole was carefully removed before starting the conversion process, leaving a central vent through the loaded residue to guarantee efficient flow of hot gases from bottom to top for continuous heat transmission through the residues.

To raise the temperature, dry twigs can be employed as a combustible source near the firing point of the kiln base vents. Exposed residues were flamed for 3-4 minutes at concentric base vents. The ultimate step of bio-carbonization was identified by thin blue hot vapours with a puff of flame. At this point, the kiln was ready to be sealed with a clay and sand sealing mixture to restrict carrier media flow and achieve significant production. The metal cap was placed over the top vent to prevent hot exhaust gases from rising. The kiln was then moved on a leveled surface to ensure that there was no significant primary air ingress, effectively shutting down the partial combustion process. To raise the temperature, dry twigs can be employed as a combustible source near the firing point of the kiln base vents residues exposed circumferential edges of the drum, as well as the edges of the metal lid used to cover the top hole for the formation of gas pressure in the enclosed region of the kiln, can be sealed with a clay sealing mixture. During the cooling stage, all feasible air-entry points should be sealed to guarantee that no volatiles leave the kiln. Heat loss by natural convection and radiation should be allowed to cool biochar samples in the kiln for 3-4 hours. The biochar was extracted after cooling and weighed to determine the conversion factor.
Percent of biochar = 100 (dry mass of biochar/dry mass of feed stocks) is the yield of biochar provided by a kiln (Antal and Gronli 2003) [1].

Land Preparation
The experimental field was ploughed once after the harvest of previous crop followed by two harrowing at the time of sowing the plots were laid out as per plan of the experiment.

Application of Biochar and fertilizers
Biochar crop residues and inorganic fertilizers were applied to the field according to the treatments one week before sowing. Inorganic nitrogen (urea) was applied at different levels as per treatments in two splits (as basal dose and at 30 DAS) Groundnut crop total amount of P and K were applied to all the plots as basal dose through SSP and MOP respectively.

Fig A: Material used for biochar production

Fig B: Produced biochar from

Fig C: Marking the points and prepare the field

Fig D: Urea treatment with rice residues

Fig E: Farm yard manure and biochar

Fig F: Groundnut K-6 variety used for sowing

Physical characterization
Bulk density
The bulk density of biochar was determined using Veihmeyer and Hendrickson's core method (Veihmeyer and Hendrickson, 1948) [17]. A metallic core was used to determine bulk density. A hard piece of paper was stuck to one of the core's opening sides. The core was filled with biochar and gently tapped to ensure that it was entirely filled. The weight of both the empty and biochar-filled cores was measured. The following method was used to compute biochar bulk density from the weight of biochar in the core and core inner volume (m^3).

$$\text{Bulk Density (Mg m}^{-3}) = \frac{\text{Wt of oven dry sample (Mg)}}{\text{Volume of ring (m}^3)}$$

Particle Density
A soil sample's particle density was determined using two measurable quantities: the mass of the soil solid and its volume. The method is known as the "Pycnometer method" given by Gupta and Dakshinamurti (1981) [8]. The following formula was used to compute particle density.

$$\text{Particle density (Mg m}^{-3}) = \frac{\text{Mass of solid (Mg)}}{\text{Volume of solids (m}^3)}$$

Total porosity
Total porosity was estimated from the bulk and particle density of the soil by using the relationship between them:

$$\text{Total porosity (\%)} = \left(1 - \frac{\text{Bulk density}}{\text{Particle density}}\right) \times 100$$

Water holding capacity
The saturated water holding capacity of biochar was measured using the Keen Rackzowski box method provided by Keen and Raczkowski (1921) [9]. Before and after filling with biochar, the boxes were weighed. The biochar-filled boxes were then placed in a tray with enough water to saturate the biochar over night. The boxes were removed from the water when the capillary passage of water through the biochar matrix was completed, and any excess water adhering to the boxes was wiped away with tissue paper. The boxes containing moist biochar were weighed again to determine the biochar's weight growth and saturated water holding capacity.

Chemical Analysis
pH, electrical conductivity and cation exchange capacity
Biochar pH in water and EC was determined at 1:20 (W/V) ratio after continuous shaking over one hour (Cheng *et al*., 2006) [6]. After filtration electrical conductivity was determined. The CEC of biochar was determined using Yuan *et al*., method's (2011) [19]. "To eliminate the ash and salts found in biochar, 5g biochar samples were first treated to vigorous leaching with double distilled water." The system was carefully monitored during the leaching phase to ensure that no biochar" particles were lost. Leaching was carried out until the leachate had an EC of less than 0.05 dSm^{-1}. The moist biochar samples were then oven dried for two days at 70 °C, cooled in desiccators, and stored in an airtight small sample holding bottle. The CEC of biochar was then measured using the ammonium acetate obligatory displacement method. 1N sodium acetate, pH 7.0, was used to leach 200 mg of biochar samples. To remove the extra sodium, the biochar samples were washed in 95 per cent ethanol. The sodium was then displaced with neutral normal ammonium acetate. A flame photometer was used to calculate the sodium concentration in the leachate. (Bower and colleagues, 1952) [3]

Observation of total organic carbon, total nitrogen, total phosphorus, total potassium, total manganese and zink
Total carbon was measured using a total organic carbon analyzer and a dry combustion method (Laird *et al*., 2010) [10]. The total nitrogen content of biochar and crop residues was determined using Chapman and Pratt's (1961) [20] method of fine grinding and digestion in concentrated sulphuric acid. After wet digestion in Jackson's diacid process (1967), total phosphorus in biochars and crop residues was evaluated using the molybdovanadate phosphoric acid yellow colour method. After calibrating the flame photometer with a known potassium concentration, the total potassium content in the di-acid digestion material was assessed using a flame photometer (Chapman and Pratt, 1961) [20].

Result and Discussions
Physical properties
In both years, a higher bulk density (1.47Mgm^{-3}) was observed with 100% GRD. According to the pooled data, applying biochar and RR along with 75% GRD of chemical fertilizers resulted in a decrease in bulk density compared to applying fertilizer alone. The highest bulk density was found with 100% GRD, whereas the lowest was under 75% GRD + RR @5 t/ha + RB @2.5 t/ha (1.41Mgm^{-3}) (1.40 Mgm^{-3}). In the long run, this effect may prove to be beneficial. The particle density of the soil did not differ significantly amongst the treatments when biochar was applied. It was measured between 2.58 and 2.66 Mgm^{-3} in the rice-groundnut cropping system of 2017-18 and between 2.59 and 2.66 Mgm^{-3} in 2018-19. Particle density for the various treatments ranged from 2.58 to 2.66 Mgm^{-3}, with a total average value of 2.62 Mgm^{-3}, according to the pooled mean data. The bulk and particle densities of the soil are directly correlated with porosity. The rice-groundnut cropping systems of 2017-18 and 2018-19, respectively, porosity varied from 43.86 (100% GRD) to 47.04 (75% GRD + RR @5t/ha+ RB @2.5t/ha+ 6% urea spray on rice residues) and 43.97 (control) to 47.89 (T_{11}). The control condition had the lowest mean data on water holding capacity (38.34%) and the treatment condition T_{11} had the greatest after rice-groundnut cropping system.

Chemical Properties
Soil pH
Soil available nutrient status in connection to the application of biochar and rice residues with combinations of GRD are shown in Table. 1 and 2 for two consecutive cropping years. The control had the lowest mean pH (6.73) whereas the treatment T_{11} had the highest mean pH (6.95). All of the treatments showed a small rise in soil pH when compared to the control. This could be owing to an increase in alkaline metal concentration in biochar soil (Ca^{2+}, Mg^{2+}, and K^+).

Soil electrical conductivity
After both years of rice-groundnut farming, the patterns of variance in soil's electrical conductivity among the treatments were statistically equal. When looking at trends, it is clear that soils treated with biochar and 75% GRD of fertilizers have increased electrical conductivity. The soil's electrical conductivity ranged from 0.22 to 0.27 dSm^{-1}, with the control treatment having the lowest value and the T_{11} treatment having the highest value. The application of biochars and RR along with 75% GRD of chemical fertilizers has led to higher EC values; however, chemical fertilizer use alone did not result in these modifications.

Cation exchange capacity
The rice-groundnut cropping systems of 2017-18 and 2018-19, the CEC values were measured and ranged from 13.52 to 20.19 cmol (p+) kg^{-1} and 13.66 to 20.42 cmol (p+) kg-1, respectively. Under the treatment of 75% GRD + RR @ 5t/ha + RB 2.5t/ha + 6% urea spray on rice residues (T_{11}), the

maximum cation exchange capacity in soil was reported, with the minimal under control (T_1). According to the pooled data, different treatments had a significant impact on cation exchange capacity, with the T_{11} treatment having the highest pooled cation exchange capacity that was comparable to treatment T_{10}. The average value of cation exchange capacity across all treatments was 16.70 cmol (p+) $kg^{-1.}$

Soil available nitrogen
These findings showed that there was a significant difference between the control and fertilizer and biochar applications that were combined. In the years 2017-18 and 2018-19, it varied between 176.83-209.33 and 178.18-212.55 kg ha^{-1}, respectively, and the highest amount of nitrogen was found in T_{11}, T_{10}, T_7, T_6, T_8, and T_9 come next, with the minimum under control (T_1). Additionally, it was found that during 2018-19, the average soil available nitrogen (197.11 $kgha^{-1}$) was a little bit higher than the previous (195.04 kg ha^{-1}) year 2017-18. In all treatments, there was more nitrogen available in the soil than in the control. The combined average of the two years revealed comparable trends in the state of the soil's available nitrogen, with the lowest level (177.50 kg ha^{-1}) being recorded under control and the maximum level under 75% GRD + RR @5t/ha + RB @2.5 t/ha + 6% urea spray on rice residues (T_{11}) (210.94 kg ha^{-1}).

Soil available phosphorus
After the rice-groundnut cropping systems in 2017-18 and 2018-19, the results showed that different treatments had a significant impact on the amount of phosphorus in the soil. In comparison to other treatments, the amount of available phosphorus was found to be significantly higher under the T_{11} treatment (17.41 kg ha^{-1}). Although P was available, T_{10}, T_7, T_8, T_2, T_9, T_8, and T_3 were statistically equivalent among these treatments. In comparison to applications of 100% GRD, 75% GRD, and combined applications of rice biochar and RR with 75% of GRD, the control plot showed lower phosphorus availability. Additionally, it was noted that the available phosphorus marginally improved in 2018-19 compared to 2017-18, especially with the T_{10} and T_{11} treatments.

Soil available potassium
When biochar and rice residues were applied with 75% GRD of fertilizer as compared to control plot, available K was higher. After the rice-groundnut cropping systems of 2017-18 and 2018-19, it varied between 278.24 and 302.48 kg ha^{-1} and 278.98 and 309.16 kg ha^{-1}, respectively. The 75% GRD + rice residue @5t/ha + rice biochar 2.5t/ha + 6% urea spray on rice residues (T_{11}) had the highest pooled mean of available potassium (305.82 kg ha^{-1}) and the lowest in the control (278.61 $kgha^{-1}$). Because of the direct supply of mineral potassium by MOP in 75% GRD with combination of biochar and rice residues applied treatments; available potassium was higher than control and 100% GRD. Because biochar contains some potassium-rich ash, the amount of available potassium in the soil increased as the rate of application of biochar increased.

Available sulphur
The 2017-18 rice-groundnut cropping system demonstrated that the application of 75% GRD + rice residue @5t/ha + rice biochar @2.5t/ha + 6% urea spray on rice residues T_{11} (15.16 mg kg^{-1}) resulted in the maximum available sulphur, whereas the lowest equivalent values were obtained in the control (13.32 mg kg^{-1}).During second year of rice-groundnut cropping system (2018-19), highest soil available sulphar (15.22 mg kg^{-1}) was recorded with the application of 75% GRD + rice residue @5t/ha+ rice biochar @2.5t/ha+ 6% urea spray on rice residues (T_{11}) and lowest available sulphur status of soil (13.34 mg kg^{-1}) was recorded in the control (T_1). T_{11} had about 15.19 mg kg^{-1} available sulphur (pooled mean) and showed higher values over respective treatments combination of biochar and rice residues with GRD of fertilizers.

Available copper
The amount of soil copper that was available had no significantly influence from the various treatments. Under T_1 (control) for the years 2017-18 and 2018-19, respectively, the lowest soil available copper status (3.08 and 3.03 mg kg^{-1}) was noted. The highest available copper in soil was recorded with T_{11} on rice residues (3.23 mg kg^{-1}) and with T_{10} (3.18 mg kg^{-1}) during rice-groundnut cropping system 2017-18 and 2018-19 respectively. The highest pooled mean of available copper content (3.21 mg kg^{-1}) was recorded under the treatment of T_{11} as compared to GRD of fertilizer (T_2). Lowest pooled mean of available copper was observed in control (3.05 mg kg^{-1}).

Available iron
During rice-groundnut 2017-18 and 2018-19, the highest available iron (28.48 and 28.74 mg kg^{-1}) value were recorded by T_{11} and lowest value (26.45 and 26.10 mg kg^{-1}) found in T_1 (control). It was also observed that the available iron was almost similar during 2017-18 and 2018-19 and a minimal increment in the iron status were also observed in the soils treated with biochar and GRD as compared to control. The pooled mean of available iron content was found higher by the application of T_{11} (28.61 mg ka^{-1}) followed by T_2 (28.49 mg kg^{-1}) over control (26.28 mg kg^{-1}).

Available manganese
When biochar and rice residue were treated with 75% GRD of fertilizer as opposed to 100% GRD of fertilizer and the control plot, there was more available manganese. It ranged from 15.33 to 16.35 mg kg^{-1} and from 15.39 to 16.40 mg kg^{-1} was recorded after 2017-18 and 2018-19 of rice-groundnut cropping system, respectively. Maximum values of available manganese was observed in T_{11} on rice residues followed by T_{10} and 100% GRD (T_2) during both the years. The fact that soil manganese status improved after adding biochar may be related to the mineralization process. T_{11} has the highest observed manganese status, and it is greater than all other remaining treatments.

Available zinc
After rice-groundnut cropping systems in 2017-18 and 2018-19, soil Zn availability was non-significant and varied from 2.44 to 2.64 ($mgkg^{-1}$) and 2.44 to 2.67 ($mgkg^{-1}$), respectively. Maximum value of available Zn was observed in treatment T_{11} after rice-groundnut 2017-18 and T_{11} (75% GRD + RR @5t/ha+ RB @2.5t/ha+ 6% urea spray on rice residues) and T_{10} were recorded after rice-groundnut 2018-19. Due to the modest application rate compared to findings from multiple other sources, biochar application may not have had a major impact on nutrients.

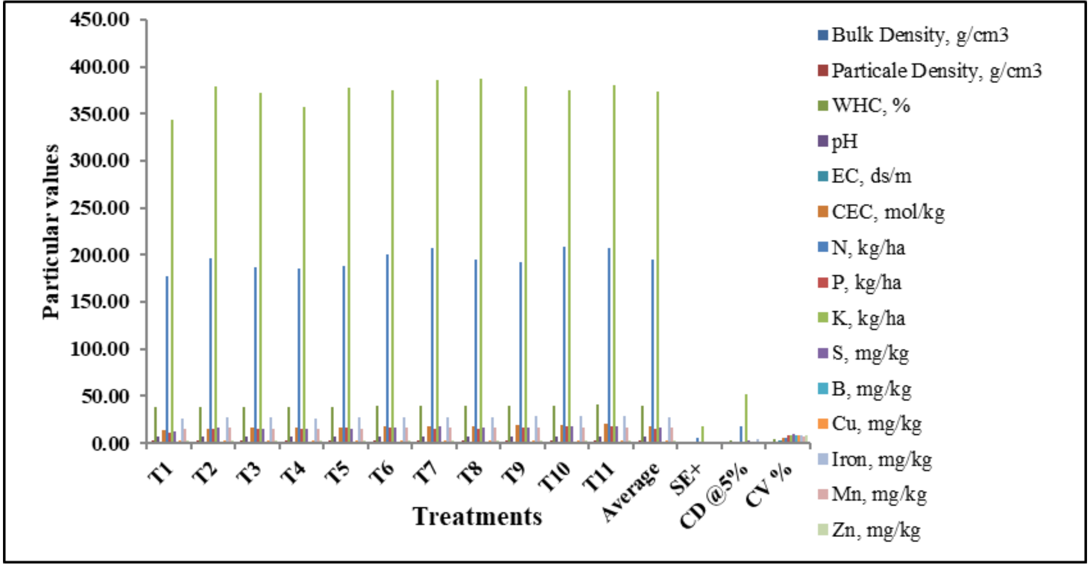

Fig 1: Soil Physico-chemical properties in the year 2017-18

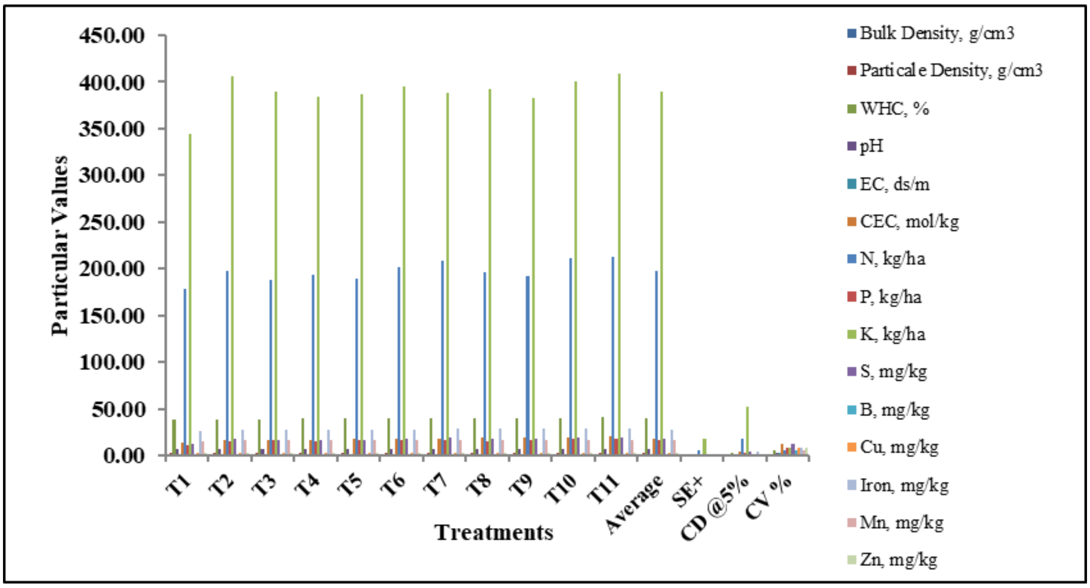

Fig 2: Soil Physico-chemical properties in the year 2018-19

Table 1: Soil properties 2017-18

Particulars	Treatments												SE±	CD @5%	CV%
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	Mean			
Bulk Density, g/cm^3	1.56	1.57	1.52	1.53	1.54	1.53	1.52	1.54	1.54	1.51	1.51	1.53	0.01	0.04	1.55
Particle Density, g/cm^3	2.56	2.55	2.56	2.56	2.55	2.54	2.56	2.56	2.56	2.55	2.54	2.55	0.01	0.03	0.79
WHC,%	38.27	38.54	38.43	38.94	38.35	39.48	39.71	39.53	39.75	40.03	40.69	39.25	1.09	3.21	4.80
pH	6.73	6.75	6.90	6.78	6.76	6.71	6.87	6.79	6.77	6.82	6.92	6.80	0.08	0.24	2.07
EC, dS/m	0.22	0.26	0.25	0.25	0.25	0.26	0.25	0.25	0.26	0.27	0.26	0.25	0.00	0.01	3.41
CEC, mol/kg	13.52	15.02	16.92	16.36	16.52	17.84	18.09	18.37	19.21	19.78	20.19	17.44	0.64	1.89	6.36
N, kg/ha	176.83	196.59	187.12	185.56	188.24	201.04	207.05	194.79	191.83	209.37	207.05	195.04	5.92	17.46	5.26
P, kg/ha	11.61	15.54	15.50	15.24	15.94	16.19	15.67	14.65	16.58	17.30	17.41	15.60	0.75	2.23	8.38
K, kg/ha	343.34	379.71	371.70	357.58	378.20	375.29	386.28	386.81	379.57	374.40	380.60	373.95	17.57	51.83	8.14
S, mg/kg	11.94	16.75	14.72	14.58	15.04	17.25	17.48	16.69	16.41	17.56	17.78	16.02	0.89	2.61	9.58
Cu, mg/kg	2.50	3.20	3.08	2.90	2.74	3.11	3.13	3.33	3.00	3.47	3.41	3.08	0.15	0.44	8.41
Fe, mg/kg	26.45	27.15	27.37	26.47	27.43	27.50	28.12	28.15	28.19	28.25	28.48	27.60	1.33	3.91	8.33
Mn, mg/kg	15.33	15.98	15.83	15.80	15.87	16.01	16.23	15.93	15.90	16.30	16.35	15.96	0.70	2.05	7.56
Zn, mg/kg	2.46	2.48	2.44	2.56	2.47	2.55	2.56	2.57	2.62	2.62	2.63	2.54	0.12	0.36	8.32

Table 2: Soil properties 2018-19

Particulars	Treatments												SE±	CD @5%	CV%
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	Mean			
Bulk Density, g/cm^3	1.57	1.56	1.53	1.53	1.54	1.54	1.54	1.54	1.53	1.52	1.52	1.54	0.02	0.05	1.82
Particle Density, g/cm^3	2.58	2.56	2.56	2.55	2.55	2.55	2.56	2.57	2.55	2.55	2.54	2.56	0.02	0.05	1.06
WHC,%	38.40	38.49	38.53	39.32	39.60	39.63	39.51	39.75	39.81	40.21	40.75	39.46	1.11	3.26	4.85
pH	6.74	6.77	6.99	6.79	6.83	6.83	6.86	6.89	6.87	6.94	6.97	6.86	0.09	0.27	2.35
EC, dS/m	0.21	0.25	0.25	0.26	0.26	0.27	0.26	0.25	0.26	0.26	0.26	0.25	0.00	0.01	2.41
CEC, mol/kg	13.66	15.88	16.98	15.76	17.39	17.90	18.17	18.60	19.34	19.82	20.42	17.63	1.29	3.80	12.64
N, kg/ha	178.18	196.91	188.05	193.52	189.43	201.40	209.01	195.74	191.78	211.69	212.55	197.11	6.07	17.89	5.33
P, kg/ha	11.60	15.53	15.83	15.74	16.22	16.09	16.21	14.95	16.71	17.51	17.65	15.82	0.81	2.39	8.86
K, kg/ha	344.36	406.47	389.92	383.82	386.22	395.07	387.70	392.29	382.03	400.28	409.26	388.86	17.76	52.38	7.91
S, mg/kg	11.95	18.26	16.39	15.91	16.31	17.74	18.81	18.09	17.83	18.86	19.66	17.26	1.24	3.67	12.49
B, mg/kg	0.56	0.59	0.62	0.63	0.60	0.62	0.63	0.66	0.66	0.67	0.69	0.63	0.02	0.06	5.63
Cu, mg/kg	2.45	3.20	3.12	2.85	3.00	3.04	3.11	3.14	2.95	3.26	3.35	3.04	0.13	0.40	7.64
Fe, mg/kg	26.10	27.42	27.66	27.07	27.69	27.43	28.39	28.45	28.48	28.74	28.73	27.83	1.37	4.05	8.55
Mn, mg/kg	15.39	15.87	15.93	15.83	15.97	15.95	15.99	16.20	16.27	16.34	16.40	16.01	0.54	1.59	5.81
Zn, mg/kg	2.44	2.43	2.48	2.45	2.55	2.48	2.50	2.51	2.53	2.57	2.57	2.50	0.11	0.33	7.72

Conclusion

The integration of rice biochar with different doses of fertilizers (100%, 75% and 50% GRD) is beneficial and "can enhance the natural rates of carbon in the soil and can reduce farm waste and improve soil quality" and nutrient use efficiency. Application of biochars with and without combinations of different doses of GRD had no significant variations on soil physical properties (BD, PD, porosity and WHC) and chemical properties (pH, EC, available N, K, and micronutrients.

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