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Effect of Invasive Weed Biochar Mixed with Inorganic Fertilizer on Soil Physical and Chemical Properties in Semi-arid Region of India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The application of different forms of organic material is a traditional strategy used to sustain soil fertility by replenishing soil organic matter (SOM) and enhancing nutrient profile for crops. This study focuses on the comparative efficacy of biochar prepared from locally available invasive weed biomass (*Parthenium hysterophorus* L. and *Lantana camara* L.) with or without inorganic fertilization on soil properties and nutrient availability in post harvested soils. Results revealed that soil bulk density (BD) was significantly decreased with application of biochar @ 5 t ha^{-1} and 10 t ha^{-1} along with 75% RDF (Recommended dose of fertilizers) as compared to control while water holding capacity (WHC) significantly increased in the range of 18.40-32.78% as compared to RDF by the application of *Parthenium hysterophorus* L. and *Lantana camara* L. biochar @ 2.5 t ha^{-1}, 5.0 t ha^{-1} and 10.0 t ha^{-1} along with 75% RDF. It was also observed that *Parthenium hysterophorus* L. and *Lantana camara* L. biochar along with 75% RDF addition to soil increased SOC (5.17 g kg^{-1} to 7.99 g kg^{-1}) and cation exchange capacity (CEC) by 3.36-37.14% as compared with control, depending on the quantity of biochar application. Similar trends were also reported in case of available macro and micro nutrients in the post harvest soil. Therefore,

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application of invasive weed biochar with inorganic fertilization is considered as promising strategy for improve physical and chemical properties of soils and soil health in semi-arid ecosystem.

Keywords: Biochar; inorganic fertilization; available nutrients; micronutrients; semi-arid region.

1. INTRODUCTION

Application of biochar in agricultural soils is one promising strategy that can enhanced carbon sequestration in the soil, improve soil physico-chemical properties and soil quality [1]. Biochar is a porous, low-density, carbon-rich material prepared by the pyrolysis of vegetative biomass in an oxygen-limited or absent environment [2], having potential option to be used for enhancement of soil health and soil organic carbon (SOC) stock [3]. Due to the presence of condensed aromatic structure which make its stable form of carbon resistant against decomposition and store carbon in soils for long time. Application of biochar influences water holding capacity and soil bulk density [4]. Biochar is also effective in improving the microbial population in a degraded land [5] and improving the nutrient content of the soil [6]. The benefits of biochar application on SOC build-up, soil properties and crop yields in different studies varied greatly with the composition of biochars, soil types and environmental conditions. Looking at the beneficial effect of biochar application on soil quality and crop productivity, there is a need to evaluate the appropriateness of locally available biomass materials, which is not economically important for preparation of biochar. *Parthenium hysterophorus* L. and *Lantana camara* L. are harmful and hazardous invasive weeds in the world [7,8]. Direct addition of residues of these weeds to soil may show allelopathic effects, affecting adversely the germination and growth of crops [9]. Utilization of these weed biomass materials as valuable resource is a big challenge before the environmentalists, agriculturists and ecologists. Thus, using them as feedstock for preparing biochar would be an effective weed management approach. The biochar prepared from invasive weeds can be used as a competent sorbent for allelochemicals, Which is significantly decreased the inhibitory effect of allelochemicals on soil and crops [10]. Research work on preparation of biochar from different perennial weed biomass and its characterizations and benefits of its application to fodder crops and soil health indicators are limited. Keeping these points in view, the present study was undertaken to find out the comparative efficacy of biochar prepared from locally available weed biomass (*Parthenium hysterophorus* L. and *Lantana camara* L.) with or without inorganic fertilization on soil properties and nutrient availability. The overall objective of this study was to sustainable use of locally available weed biomass, as useful amendment material for improving soil quality and crop productivity in semi-arid regions.

2. MATERIALS AND METHODS

Weed biomass of *Parthenium hysterophorus* L. and *Lantana camara* L. were collected from Central Research Farm, ICAR-Indian Grassland and Fodder Research Institute (ICAR-IGFRI), Jhansi- 248 003 (U.P.), India. The biomass of both weeds was cut into small pieces (30-50 mm) and used for preparation of biochar. All biomass was heated at a temperature of ~ 400 ºC for 2 hours in a cylindrical low cost portable biochar kiln, using the methodology described by [11]. After cooling, the biochar was crush manually and ground to pass through a 2 mm sieve in order to have the uniform particle size as that of the soil. A pot experiment was conducted during two consecutive *rabi* season of 2020-21 and 2021-22 in net house at Technology Demonstration Block (TD Block), ICAR-IGFRI, Jhansi (U.P.) using oat (*Avena sativa* L.) as test crop in completely randomized design (CRD) with ten treatments and replicated trice. The site is situated in a semi-arid region that located at (25° 27' of Northern latitude, 78° 35' of Eastern longitude) in the Bundelkhand region of Uttar Pradesh, India which covered about 7.16 million ha area [12, 13]. The average precipitation of this region is 887.4 mm. The long-term average maximum and minimum temperatures were 32.95°C and 19.08°C, respectively. The soil for the pot experiment was collected from Institute's TD Block field. The soil used in the pot experiment was sandy clay loam (sand:50%; silt:22% and clay: 28%), with a pH 7.3, electrical conductivity 0.026 dSm^{-1}, available N, P, K and S were 201, 6, 226, and 13 kg ha^{-1}, respectively and 26% water holding capacity. The sieved biochar were applied before 15 days of oat (variety: JHO-822) sowing and mixed with the soil as per treatments.

The treatments were T_1: Control, T_2: Recommended dose of fertilizers (RDF 80 kg N+40 kg P+ 40 kg K ha^{-1}), T_3: 75% RDF+ 2.5 t ha^{-1} *Parthenium hysterophorus* boichar, T_4: 75% RDF+ 5.0 t ha^{-1} *Parthenium hysterophorus* boichar, T_5: 75% RDF+ 10.0 t ha^{-1} *Parthenium hysterophorus* boichar, T_6: 75% RDF+ 2.5 t ha^{-1} *Lantana camera* biochar, T_7: 75% RDF+ 5.0 t ha^{-1} *Lantana camera* biochar, T_8: 75% RDF+ 10.0 t ha^{-1} *Lantana camera* biochar, T_9: 10.0 t ha^{-1} *Parthenium hysterophorus* biochar and T_{10}: 10.0 t ha^{-1} *Lantana camera* biochar. Soil sampling was carried out in March, 2021 and 2022 after harvest of oat crop for fodder (at 50% flowering). Different observations on soil physical and chemical properties were taken in post harvest soils. The soil bulk density (BD), particle density (PD) (pycnometer bottle) and WHC (Keen-Rackzowski box) were determined using in laboratory in disturbed soil sample [14]. Soil chemical properties like pH and EC (electrical conductivity)[15]soil organic carbon (SOC) [16], available macro nutrients; Nitrogen (N, alkaline permanganate method), phosphorous (P, Olsen's method), potassium (K, Flame photometer method), sulphur (S), DTPA extractable micro nutrients; zinc (Zn), iron (Fe), manganese (Mn) and copper (Cu) were determined using standard procedures given by [17]. The data of the both year were pooled together. Statistical analysis of all the experimental data was performed by the analysis of variance (ANOVA) and the significance of treatment differences were tested by Duncan's Multiple Range Test (at p=0.05) using SAS v9.3 [18].

3. RESULTS AND DISCUSSION

3.1 Soil Physical Properties

The results revealed that soil BD and PD decreased with the application of biochar @ 5.0 t ha^{-1} and 10.0 t ha^{-1} along with 75% RDF. Lower dose of biochar (2.5 t ha^{-1} with 75% RDF) have no significant effect on BD and PD (Table1).

The soil BD and PD were decreased 9.65% and 10.08%, respectively in T_8 followed by T_5 and T_7 treatment as compared to T_1 treatment. Soil BD and PD observed in both biochar treatments along with 75% RDF were almost statistically at par with similar application rates. The significant decreased in BD and PD with the application of biochar might be caused by physical dilution effects and increased total carbon content in soils. Blanco-Canqui [19] also reported similar findings that changes in BD and PD after biochar application, which is directly influence soil porosity. The WHC increased in the range of 18.40-32.78%, with the highest increased being observed in T_5 (32.78%) and T_8 (31.77%) treatments as compared to T_2 by the application of biochars @ 2.5 t ha^{-1}, 5.0 t ha^{-1} and 10.0 t ha^{-1} along with 75% RDF. Das and Ghosh [20] also reported that application of maize stalk biochar @ 5 t ha^{-1}, 7.5 t ha^{-1} and 10.0 t ha^{-1} significantly increased (11.37 to 19.8 g cm^{-3}) the WHC of sandy loam.

3.2 Soil Chemical Properties

The results showed that biochar application significantly increased in soil pH and EC (Table 2). The highest increase in soil pH was recorded in T_8 treatment (8.20) followed by T_5 treatment (8.17). Similar trend was also observed in case of EC. *Lantana camera* biochar addition recorded higher pH and EC over *Parthenium hysterophorus* biochar. The increased in soil EC and pH with biochar applications could be due to the presence of salts in biochar and its alkaline nature, respectively. Similar results were also reported by [21] in green house pot experiment on sandy soil.

The available soil N, P, K and micronutrients (Fe, Cu, Zn and Mn) significantly influenced due to application of different types and quantity of biochar along with 75% RDF (Table 2 and Fig. 1). Among the different treatments, T_8 resulted 22.52% higher available N followed by and T_7 treatment as compared to T_1. The increase in available N under biochar treatment was mainly due to the enhanced the soil moisture retention and root growth and release of nitrogen from the biochar as it contains significant amount of nitrogen in its composition and biochar acts as binder for ammonia in soil [23].

Table 1. Effect of different levels of biochars along with inorganic fertilizer on soil bulk density (BD), particle density (PD) and water holding capacity (WHC)

Treatments	BD (Mg m^{-3})	PD(Mg m^{-3})	WHC (%)
T_1	1.45 ^{a}	2.48 ^{a}	26.60 ^{e}
T_2	1.44 ^{ab}	2.48 ^{a}	29.90 ^{de}
T_3	1.40 ^{bcd}	2.40 ^{a}	35.40 ^{abcd}
T_4	1.35 ^{de}	2.31 ^{b}	39.10 ^{ab}
T_5	1.34 ^{e}	2.23 ^{b}	39.70 ^{a}
T_6	1.36 ^{cde}	2.41 ^{a}	35.33 ^{abcd}
T_7	1.34 ^{e}	2.31 ^{b}	36.50 ^{abc}
T_8	1.31 ^{e}	2.23 ^{b}	39.37 ^{a}
T_9	1.41 ^{ab}	2.44 ^{a}	33.33 ^{bcd}
T_{10}	1.40 ^{abc}	2.24 ^{a}	33.10 ^{de}
S.Em ±	0.017	0.032	1.57
C.D. (0.05)	0.051	0.094	4.70

Values in each column followed by different lowercase letters are significant according to Duncan's Multiple Range Test at p=0.05., T_1: Control, T_2: Recommended dose of fertilizers (RDF i.e. 80:40:40 N, P and K kg ha^{-1}, respectively), T_3: 75% RDF+ 2.5 t ha^{-1} Parthenium hysterophorus boichar, T_4: 75% RDF+ 5.0 t ha^{-1} Parthenium hysterophorus boichar, T_5: 75% RDF+ 10.0 t ha^{-1} Parthenium hysterophorus boichar, T_6: 75% RDF+ 2.5 t ha^{-1} Lantana camera biochar, T_7: 75% RDF+ 5.0 t ha^{-1} Lantana camera biochar, T_8: 75% RDF+ 10.0 t ha^{-1} Lantana camera biochar, T_9: 10.0 t ha^{-1} Parthenium hysterophorus biochar and T_{10}: 10.0 t ha^{-1} Lantana camera biochar

Table 2. Effect of different levels of biochars along with inorganic fertilizer on soil reaction, electrical conductivity, organic carbon, cation exchange capacity

Treatments	pH	EC (dSm^{-1})	OC (g kg^{-1})	CEC (cmol (p+) kg^{-1})	Available N (kg ha^{-1})	Available P (kg ha^{-1})	Available K (kg ha^{-1})	Available S (kg ha^{-1})
T_1	7.37 ^{e}	0.030 ^{d}	5.17 ^{e}	18.44 ^{e}	206.67 ^{d}	6.86 ^{c}	227.56 ^{c}	14.95 ^{b}
T_2	7.48 ^{de}	0.055 ^{c}	6.48 ^{cd}	20.65 ^{d}	215.47 ^{cd}	10.33 ^{ab}	234.25 ^{c}	16.95 ^{b}
T_3	8.01 ^{abc}	0.065 ^{bc}	6.51 ^{cd}	20.87 ^{d}	225.10 ^{bcd}	10.52 ^{ab}	240.14 ^{bc}	18.88 ^{b}
T_4	8.02 ^{abc}	0.067 ^{bc}	7.33 ^{abcd}	23.19 ^{bc}	228.63 ^{bc}	10.95 ^{ab}	290.57 ^{ab}	20.57 ^{ab}
T_5	8.17 ^{ab}	0.081 ^{ab}	7.85 ^{ab}	25.00 ^{ab}	244.77 ^{ab}	12.00 ^{a}	294.78 ^{a}	28.84 ^{a}
T_6	8.04 ^{ab}	0.066 ^{bc}	6.85 ^{bcd}	22.97 ^{c}	225.27 ^{bcd}	10.58 ^{ab}	247.54 ^{abc}	18.94 ^{b}
T_7	8.03 ^{abc}	0.074 ^{abc}	7.56 ^{abc}	23.26 ^{bc}	229.63 ^{bc}	11.89 ^{a}	291.89 ^{ab}	23.20 ^{ab}
T_8	8.21 ^{a}	0.090 ^{a}	7.99 ^{a}	25.29 ^{a}	253.23 ^{a}	12.16 ^{a}	297.24 ^{a}	29.12 ^{a}
T_9	7.67 ^{cde}	0.056 ^{c}	6.21 ^{de}	19.06 ^{de}	212.93 ^{cd}	8.39 ^{bc}	232.37 ^{c}	15.95 ^{b}
T_{10}	7.81 ^{bcd}	0.063 ^{bc}	6.23 ^{de}	19.13 ^{de}	223.67 ^{bcd}	9.50 ^{abc}	234.20 ^{c}	16.92 ^{b}
S.Em ±	0.13	0.007	0.38	0.64	21.83	1.05	18.50	3.19
C.D. (0.05)	0.37	0.021	1.13	1.91	7.35	3.12	54.97	9.46

Values in each column followed by different lowercase letters are significant according to Duncan's Multiple Range Test at p=0.05.

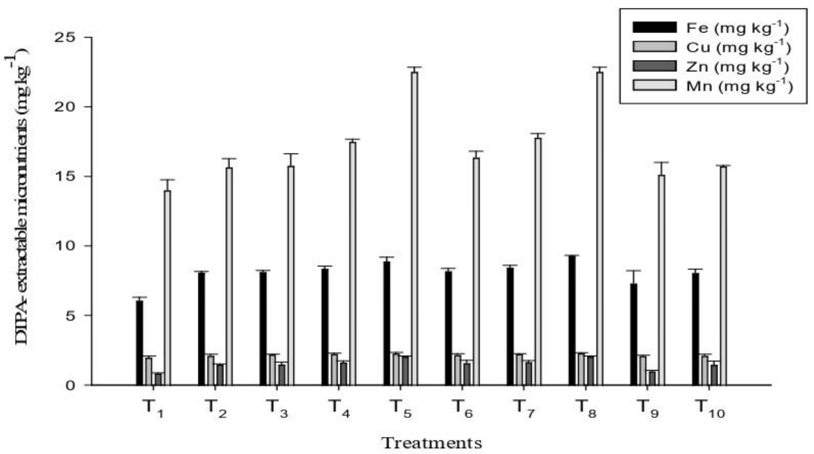

Fig. 1. Effect of different levels of boichars on DTPA-extractable micronutrients. Error bars represent standard error mean (S.Em ±)

There was a significant increase on SOC in T_8 (7.99 g kg^{-1}) and T_5 (7.85 g kg^{-1}) treatments followed by T_7 (7.56 g kg^{-1}) and T_4 (7.33 g kg^{-1}) treatments. Primary reason for these observations could be due to presence of stable carbon in the biochar that is difficult to decompose in soil environments, thus contributing to the soil carbon pool [22]. Almost similar results were also observed in case of CEC. CEC were significantly increased (3.36-37.14%) following the amendment of both biochars compared to control.

The application of *Parthenium hysterophorus* and *Lantana camera* biochar @ 2.5 t ha^{-1}, 5.0 t ha^{-1} and 10.0 t ha^{-1} along with 75% RDF not significantly influenced P availability in the soil. The higher available P was found in T_8 (12.16 kg ha^{-1}) treatment followed by T_5 (12.00 kg ha^{-1}), which was at par with T_7, T_4, T_3 and T_2 but significantly higher than T_1 treatment. It was observed that *Parthenium hysterophorus* and *Lantana camera* biochar addition @ 2.5 t ha^{-1}, 5.0 t ha^{-1} and 10.0 t ha^{-1} to soil increased the available K by 2.11 to 32.62% as compared with T_1 depending on the quantity of biochar application. Biochar had significant amount of available K due to presence of the ash. Hence, application of biochar might have significant positive effect on available K in soil [24]. The higher available S was found in T_8 (29.12 kg ha^{-1}) treatment followed by T_5 (28.84 kg ha^{-1}), which was at par with T_7 and T_4. Application of *Parthenium hysterophorus* and *Lantana camera* biochar @ 10.0 t ha^{-1} along with 75% RDF increased available S by 71.80% and 70.14% as compared to T_2 treatment. Khan *et al.* [25] also reported similar findings that application of cow dung and sewage sludge biochar @ 5.0 t ha^{-1} increased available S content 85.36 to 99.64 ppm and 83.36 to 97.65 ppm, respectively in loamy soil. Application of *Parthenium hysterophorus* and *Lantana camera* biochar @ 2.5 t ha^{-1}, 5.0 t ha^{-1} and 10.0 t ha^{-1} along with 75% RDF, significantly increased availability of micronutrients in post harvest soil over T_1 and T_2 while Cu availability was not influenced by the types and quantity of biochar. Application of *Parthenium hysterophorus* and *Lantana camera* biochar @ 10.0 t ha^{-1} along with 75% RDF increased availability of Fe, Zn and Mn by ~47% , ~139% , ~61% respectively as compared to T_1 treatment (Fig. 1). The application of *Lantana camera* biochar showed higher micronutrient availability in soil at similar application quantity. Similar finding were also reported by [26].

4. CONCLUSIONS

From this study it may be summarized that application of invasive weed biochar along with inorganic fertilizer showed the positive effect towards the physical and chemical soil health indicators. Application of *Parthenium hysterophorus* and *Lantana camera* biochar (@ 2.5 t ha^{-1} to 10.0 t ha^{-1}) along with 75% RDF had significant positive effect on soil bulk density, particle density, water holding capacity, soil organic carbon, cation exchange capacity and increase the availability of macro and micro nutrient in post harvest soil. At the same time it could help in reducing chemical fertilizer requirement to some extent. In general, *Lantana camera* biochar was superior over *Parthenium hysterophorus* biochar. Utilization of these weed biomass materials for preparation of biochar would be a good weed management strategy besides improvement in soil health indicators.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERNCES

1. Gonzaga MIS, de Jesus Santos JC, de Almeida AQ, da Ros K, Santos WM. Nitrogen and phosphorus availability in the rhizosphere of maize plants cultivated in biochar amended soil. Archives of Agronomy and Soil Science. 2021;68:31-43.
2. Lehmann J, Joseph S.Biochar for environmental management: science, technology and implementation. London: Taylor and Francis In: Lehmann J, Joseph S, editors. *Biochar for Environmental Management: Science,* Technology and Implementation. 2015:1–13.
3. Sohi SP, Krull E, Lopez-Capel E, Bol R. A review of biochar and its use and function in soil. Advances in Agronomy. 2010;105:47-82.
4. Santos FM, Pires JC. Nutrient recovery from wastewaters by microalgae and its potential application as bio-char. Bioresource Technology. 2018;267:725-731.
5. Zhu X, Chen B, Zhu L, Xing B. Effects and mechanisms of biochar-microbe

interactions in soil improvement and pollution remediation: a review. Environmental Pollution. 2017;227:98-115.
6. Pandit NR, Schmidt HP, Mulder J, Hale SE, Husson O, Cornelissen G. Nutrient effect of various composting methods with and without biochar on soil fertility and maize growth. Archives of Agronomy and Soil Science. 2019;66: 250–265.
7. Ahmed R, Uddin MB, Khan MASA, Mukul SA, Hossain MK. Allelopathic effects of Lantana camara on germination and growth behavior of some agricultural crops in Bangladesh. Journal of Forestry Research. 2007;18:301-304.
8. Patel S. Harmful and beneficial aspects of Parthenium hysterophorus: an update. 3 Biotech. 2011;1:1-9.
9. Singh HP, Batish DR, Pandher JK, Kohli RK. Phytotoxic effects of Parthenium hysterophorus residues on three Brassica species. Weed Biology and Management. 2005;5:105-109.
10. Zhang Z, Chen L, Wang J, Yao J, Li J. Biochar preparation from Solidago canadensis and its alleviation of the inhibition of tomato seed germination by allelochemicals. RSC Advances. 2018;8:22370-5.
11. Venkatesh G, Gopinath KA, Reddy KS, Reddy BS, Prasad JVNS, Rao GR, Pratibha G, Srinivasarao C, Chary GR, Prabhakar M, Kumari VV. Biochar production and its use in rainfed agriculture: experiences from CRIDA. ICAR - Central Research Institute for Dryland Agriculture, Hyderabad. 2018: 50.
12. Prasad M, Mahawer SK, Govindasamy P, Kumar S. Assessment of Soil Fertility Attributes in Selected Districts of Bundelkhand Region of Central India. Current Journal of Applied Science and Technology. 2020;39: 326-334.
13. Prasad M, Chaudhary M, Ramakrishnan S, Singh HV, Kumar S, Ghosh PK. Impact of long term land use changes on carbon dynamics and soil quality in the semi arid bundelkhand region of India. Fresenius Environ Bull. 2021;30: 2536–2544.
14. Black CA. Methods of Soil Analysis, Part I, Physical and Mineralogical Properties of Soil, (including statistics of measurement and sampling) no.9 in the series Agronomy, Am. Soc. Agronomy., USA; 1965.
15. Jackson ML. Soil chemical analysis, Prentice Hall of India Private Limited, New Delhi, India. 1973;498:151-154.
16. Walkley A, Black IA. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Science. 1934;37: 29-38.
17. Tandon HLS. Methods of Analysis of Soils, Plants, Waters, and Fertilisers. H. L. S. Tandon (Ed.). New Delhi: Fertiliser Development and Consultation Organisation. 1993;63.
18. SAS Institute. SAS/STAT. Version 9.3 for windows. SAS Institute, Inc., Cary (NC, USA); 2011.
19. Blanco-Canqui H. Biochar and soil physical properties. Soil Science Society of America Journal. 2017;81:687-711.
20. Das SK, Ghosh GK. Soil hydro-physical environment as influenced by different biochar amendments. International Journal of Bio-resource and Stress Management. 2017;8:668-673.
21. de Sousa Lima JR, de Moraes Silva W, de Medeiros EV, Duda GP, Corrêa MM, Martins Filho AP, Clermont-Dauphin C, Antonino ACD, Hammecker C. Effect of biochar on physicochemical properties of a sandy soil and maize growth in a greenhouse experiment. Geoderma. 2018;319:14-23.
22. Jiang J, Zhang RZ, Wu J, Cai LQ, Dong B. Effect of different biochar application rates on soil organic carbon in the semi-arid Loess Plateau, China. Communications in Soil Science and Plant Analysis. 2021;52:423-431.
23. Tsutomu I, Takashi A, Kuniaki K, Kikuo O. Comparison of removal efficiencies for ammonia and amine gases between woody charcoal and activated carbon. Journal of Health Science. 2004;50:148-153.
24. Husien A, Bedadi B, Dechassa N. Effect of biochar, farmyard manure and nitrogen fertilizers on soil chemical properties in Sinana District, South Eastern Oromia, Ethiopia. International Journal of Applied Agricultural Sciences. 2017;3: 148-153.
25. Khan TF, Salma MU, Hossain SA. Impacts of different sources of biochar on plant growth characteristics. American

Journal of Plant Sciences. 2018;9:1922-1934.

26. Kraska P, Oleszczuk P, Andruszczak S, Kwiecińska-Poppe E, Różyło K, Pałys E, Gierasimiuk P, Michałojć Z. Effect of various biochar rates on winter rye yield and the concentration of available nutrients in the soil. Plant, Soil and Environment. 2016;62:483-489.

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