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Effect of Biochar Treatments on Soil Available N and N Uptake by Corn Plants

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Abstract: Incubation and pot experiments were carried out to study the effect of biochar on available N, N concentration, and N uptake of corn plant grown in two soils. Soils used were clay loam and loamy sand of Basrah province, south of Iraq. The biochar was produced from either corn stover or rice residues. Each biochar was composted with organic residues (alfalfa and poultry) or uncomposted. Three levels (5, 10 and 20 ha -1) as well as control of biochars were tested in the incubation experiment, while 20 ton ha-1 was employed in the pot experiment. Results showed that increased biochar levels significantly increased available N contents in the two soils. N concentration and uptake were increased with 20 ton ha -1 over than control. For biochar source, rice-derived biochar had the higher available N, N concentration and uptake compared with corn-derived biochar in the two soils, with a superiority percents of 8. 94 and 7. 66 % for available N, 5. 81 and 14. 00 % for N concentration, and 35. 29 and 21. 95 and 76. 47 % for N uptake. Composted biochar had the higher available N, N uptake relative to uncomposted biochar. The inceasing percents were 25. 36 and 24. 99 % for available N, 7. 94 and 32. 72% for N concentration and 27. 50 and 93. 37 % for N uptake, at clay and sandy soils, respectively.

Key points: biochar, corn, N availability, N uptake, composting.

INTRODUCTION

Soils of arid and semi-arid regions are characterized as a low agricultural production because of poor- fertility and negative impacts of environment. Severe droughts, lack rainfall scarcity, high ambient temperature and pure water deficit as well as bad management of agricultural practices make such soils with less fertility levels. Farmers (especially small farmers) used to add extensive chemical fertilizer amounts to reach an economically reasonable yield, but that may caused deterioration of soil properties and environmental (soil, air and water) pollution in long term. Thus, to enhance soil fertility and mitigate global environmental hazards, suitable agricultural practices are required that promote soil properties and nutrients availability. One of the potential strategies to improve soil properties is use of organic amendments, such as compost, manure and biochare.

Biochar can defined as carbonaceous porous material produce by organic residues pyrolysis at controlled temperature and limited oxygen demands. Biochar C persists longer time than other C in soil and considers as soil C sink because of aromatic C moieties makes it more resistance to microbial decomposition (Santin *et al*., 2015; Baldock and Smernik, 2002). In last decade, the importance of decrease accelerating global warming and land degradation, has caused a strong interest in biochar use (Shmidt *et al*., 2017). Many benefits have been obtained after amendment soils with biochar, including increasing water holding capacity, reducing bulk density, reducing nutrients leaching, increasing CEC, and more. The porous biochar characteristics are charged with nutrients of soil and subsequent reversible binding (Capture and release) of nutrients, and biochar may serve as carrier material, and slowing the leaching and other losses. Conte and Nestle (2015) stated that ions and organic molecules enter inside microporous structure of biochar as well as inside nanoporous by water movement. Biochar, also has been shown to inhance soil mirobial community structure (Liang *et al*., 2010). The inhancement of soil nutrients availability after addition of biochar may be related to the large surface of biochar providing adsorption sites (Bhattacharjya *et al*., 2016).

Biochar can increase available N in soil, due to improvement of soil properties, addition further N sources to soil solution or increasing soil biological activity. Saifullah *et al*. (2018) reported that biochar can release essential elements such as Ca, K, N, pand Zn in soil. Nguyen *et al.* (2017) suggested that the mechanisms envolving soil inorganic N enhancement after additing of biochar including adsorption / desorption process and controlling the conversion of N mineralization and other transformations. Acid functional groups (carboxylic, hydroxyl, lactnre and lactol) on the surface of biochar have a negative charge and adsorb NH_4 ions (Zheng *et al*., 2010). Forthermore, the base functional groups (chromenes, ketones and pyrones) on biochar can facilitate NO_3 ions adsorption as well as NO_3 bonds with the biochar surface by unconventional H-bond (Amonette and Joseph, 2009; Kammann *et al*., 2015). Xu *et al*. (2015) reported an increase of N mineralization after addition of biochar to soil.

It has been reported that using pure (fresh) biochar may limite crop production due to nutrient immobilization, so blending with compost or a co-composting of biochar has been practiced for many decades. Studies indicated that composting of biochare with amendment can (1) adjust C/N ratio (Dias *et al*., 2010) , (2) improve the retention of N (Steiner *et al*., 2010) , (3) reduce heavy metals mobility (Hua *et al*., 2009) , (4) increase the formation of stable humic compounds (Diasad *et al* 2010 ; Jindo *et al*., 2012) , (5) suppress N_20 emissions in sludge composting (Wang *et al*., 2013) , and (6) change microbial composition (Jindo *et al*., 2012). At biochar composting, the biochar pores are charged with nutrients, so stimulating microbial growth, improving biochar surface reactivity and promoting dissolved organic C adsorption and coating (Doan *et al*., 2014; Zimmerman, 2010; Smebye *et al.,* 2015). At initial mixing of organic materials with biochar, the natural ions naturghin and organic molecules can entere into the microporous Tand nanopere system by water movements (Conte and Nestle, 2015).

Therefore, the present research was aimed to investigate available N in soil, N concentration and uptake in corn plants grown in soils treated with biochar derived from corn stover or rice residues. The role of composting the biochar with organic residues compard with uncomposting biochar was also studied.

MATERIALS AND METHODS

soil and biochar sampling:-

Samples from Safwan region, south of Basrah (sandy soil) and from Qurna region, north of Basrah (clay soil) were collected near 0-30cm layer. Samples air-dried, crushed and pass through an 2 mm sieve then placed into plastic bags.. Initial physical and chemical properties were determined according to Richards (1954) and page *et al*. (1982) and presented in table(1).

Fresh corn stover (leaves, stalks and cops) was collected from a field at Abul-Khasib region, and the rice residues (husks and straw) was collected from rice field at Najaf province. The two materials were dried to a constant weight at 60C ^{o} and ground into Imm, placed in crucibles, then pyrolyzed in muffle furnace at 400 ^{o} C for 30 min, ajusting rate of 10 ^{o} C for each min. A portion of each kind of biochar was composed with organic residues for 12 weeks windrows at aerobic quality composting method. The organic materials used were alfalfa leaves and poultry residues at ratio of 1:1 (w/w) then mixed thoroughly with biochare with a percente of 30% of total mixure weight. The composte piles were weekly turnover and maintaing the moisture at 60% by weight. After composting, mixures were air-dried and grounded through 2 mm sieve.

The biochars were characterized for C, H and N contents by using an elemental analyzer (Elemental analysis, Eure EA, BPC Analysis Centre, Baghdad). Biochar specific surface area, pore volume and pore diameter were determined using surface area and pore analyzer (Taban Lab., 888, IRAN). pH and EC were measured at1:1 biochar: water ratio. orcanic C was determined by LOI method at 550 ^{0} C for 8 hrs. Biochar density was determined by weighing a particular valume of the biochar. Aditional elements (N, P, K, Fe, Cu, Zn and B) in brochars were measured after digesting with H_2SO_4 + $HClO_4$ acids (Cresser and parsons, 1979) for N, P, K, Fe, Cu and Zn and ashing method for B (Chapman and Pratt, 1961). Biochars characteristics were presented in table(1).

Incubation experiment:-

The incubation experiment included 96 unites (2 source of biochar ;2 composting treatments; 4 levels of biochar; 2 soil; 3 replicates). Bibchar In each biochar treatments (corn or rice source and composted or uncompacted) , 300g of soil was thoroughly mixed with 0, 0. 75, 1. 50 and 300g (equal to 0, 5, 10 and 20 ton ha^{-1}, respectively) of biochar in a 500 cm^3 plastic jar. Nitrogen was added to each jar at level of 125kg N ha^{-1}(equal to 0. 067 g urea jar^{-1}). Initial physical and chemical properties were determined according to Richards (1954) and page *et al*. (1982) and presented in table(1). After 30 days, a set of samples were take to analyze for total available N which extracted by 2M KCl solution (Bremner and keeney, 1996) , then determined by steam distillation technique (Bremner and Edwards, 1965) using MgO heavy and Devarda' s alloy mixture.

Pot experiment:

Based on the results of incubation experiment, biochar level of 20 kg ha^{-1} was selected along with the biochar sources (corn stover and rice residues) ; composting treatments (composted and uncomposted) and soil type (clay and sandy). Control treatment (no biochar) was also conducted. Corn was planted in a pot for two month to reach plant biomass. Each pot contains 5 kg air-dried soil. Nitrogen was applied at 125 kg N ha^{-1} (equal to 1. 12 g urea pot^{-1}) at two supplementary applications on sowing time and after 30 days of sowing. On the basis of local recommendations of corn, phosphorus and potassium were added at levels of 125 kg P_2O_5 ha^{-1} and 100 kg k_2O ha^{-1} as from of triple superphosphate and potassium sulfate, respectively. Pots were irrigated by tap water to reach full field capacity for each soil all over the experiment period.

After 60 days, plants were manually harvested to determine shoot biomass and N concentration in the shoot part. Samples were oven dried at 65^{0}C, the weight was recorded, ground into powder to pass I mm sieve, then digested by using $HCLO_4$ + H_2SO_4 mixture (Cresser and Parsons, 1979). Total nitogen in the digest was determined according to steam distillation technique (Bremner, 1970). The nitogen uptake was calculated by multiplication shoot dry weigt with N concentration.

Statistical analysis:

Each soil (sandy and clay) was analyzed separately for all parameters. Experiment was arranged as CRD and ANOVA analysis was performed using GenStat programe to analyze the data. Significant differences among mean were obtained by using RLSD test at 0. 05 probubility.

Table (1): Analytical parameters of biochars and soils

	Corn stover biochar		Rice residues biochar			
Parameter	Composted	Uncomposted	Composted	Uncomposted	clay soil	Sand soil
pH	8.56	9.70	8.64	10.50	7.77	8.15
EC (dS m^{-1}).	22.75	22.20	8.70	9.30	4.50	1.28
Organic C(gkg^{-1}).	486.50	403.60	562.10	486.41	2.22	0.93
H(%).	9.41	10.25	6.18	10.25	___	___
Density(Mg m^{-3})	0.52	0.54	0.43	0.46	1.38	1.62
Total pore volume (cm^3 100 g^{-1})	13.43	3.43	15.02	9.26	47.93	38.70
Mean pore diameter. (nm)	6.95	2.38	1.85	2.38	1.85	2.38
Specific surface area. BET(m^2 g^{-1})	9.29	9.46	54.46	12.89	____	____
Water holding Capacity(%)	____	____	____	____	30.16	17.00
Total N(gkg^{-1}).	17.50	8.62	19.25	9.00	0.22	0.11
Total P (g kg^{-1}).	4.76	4.36	3.31	3.06	___	___
Total K(g kg^{-1}).	42.50	38.39	28.98	20.20	___	___
Total Fe(mg kg^{-1}).	2650.00	2102.50	1562.50	1224.00	___	___
Total Zn (mg kg^{-1}).	582.00	362.50	471.00	232.20	___.	___
Total Cu (mg kg^{-1}).	20.75	11.05	40.00	16.23	___	___
Total B(mg kg^{-1}).	76.00	67.60	92.00	72.00	___	___
Total Si(mg kg^{-1}).	2035	1881	2443	1996	___	___
Available N (mg kg^{-1}).	____	____	____	____	90.09	60.33
Available P(mg kg^{-1}).	____	____	____	____	12. 14	8.00
Available k(mg kg^{-1}).	____	____	____	____	123.00	96.16
C/N Ratio.	27.80	46.82	29.20	54.04	10.09	8.45
Carbonates(g kg^{-1}) 290.78	___	___	___	___		353.9
CEC($Cmol^{+}kg^{-1}$)	___	___	___	___	27.62	7.40
Sand(%).	___	___	___	___	24.4	82.71
Silt(%).	____	___	____	___	39.80	3.81
Clay(%).	___	___	____	___	35.80	13.47
texture. san	___	___	___	___	Clay loam	Loamy

RESULTS AND DISCUSSION

Soil available N:

Available N in soil significantly increased with increasing biochar levels with a mean values of 130. 53, 165. 64, 235. 14 and 271. 24 mg kg^{-1} for clay soil and 105. 60, 130. 07, 171. 37 and 203. 09 mg kg^{-1} for sandy soil, at 0, 5, 10 and 20 ton ha^{-1}, respectively. This means that the biochars used were a further source of N for soil (table1) which confirmed the results of Saifullah *et al.* (2018) who reported that biochar can release essential elements such as Ca, K, N, P and Zn in soil. Sun *et al.*

(2017) suggested that biochar would decrease N losses via ammonia volatilization due to adsorption of NH_4^+ by function groups presented on biochar surface and / or by biochar pores (Zhibin *et al.*, 2017). Active acid functural groups such as carboxyl, hydroxyl, lactol and lacton, and less phenols and carbonyl can adsorbed NH_4^+ ions by electrostatic attraction (Zheng *et al.*, 2010). Biochar adsorption of NO_3^- by base functional groups such as chromenes, ketones and pyrones as well as NO_3^- adsorption is also facilital by unconventional H-bond between biochar surface and NO_3^- ions (Amonette and Joseph, 2009 ; kammann *et al.*, 2015). Furthermore, biochar can increase the inorganic N by affecting mineralization, immobilization, nitrification and denitrification processes in soil, depending on organic residues source, pyrolysis temperature, time of application and C/N ratio of biochar (Nguyn et al., 2017). Addition of biochar as a new C substrate can stimulate soil microorganisms activity to mineralize biochar organic compounds and then the remineralization and co-metabolisation of soil organic matter occur (Kuzyakov et al., 2000 ; Singh and Cwie, 2014). Xu et al. (2016) found an increase in nitrogen mineralization of 18. 8, 19. 5 and 20. 2 % after addition of biochar at rates of 2, 4 and 8 %, respectively.

The data of tables (2 and 3) showed that rice biochar increased the available N by 8. 94 and 7. 66 % over corne biochar, for clay and sandy soil, respectively. Similar findings were obtained by Bhattacharjya *et al*. (2016) and Alzubaydi (2019). Since the adsorption potential depend mainly on carboxylic group found on biochare surface, the feedstock used (corn stover or rice residues) influence the carboxylic groups in biochar to adsorb NH_4^+ ions. Harvey et al. (2012) found that biochar derived from grass have higher carboxylic groups in biochar derived from woody residues because of high concents of cellulose, alkali salts and alkali metal oxides in grass, which oxidized more efficiently to carboxylic acids during pyrolysis. In our study, the superiority of rice biochar for nitrogen content (tab. 1) and for effect on different soil properties including bulk density, water holding capacity, pH ,CEC, and organic matter content (in previous study, Shehan and Abdulkareem, 2025) will comfirmed it efficiency on available N compared with corn biochar .

The available N content in soil treated with composted biochar was significantly higher than uncomposted biochar with an increase percents of 25. 36 and 24. 99% for clay and sandy soils, respectively. During composting, oxygen-containing functional groups are formed on biochar surfaces resulting in an increase of CEC and facilitate NH_4^+ adsorption as well as the organic residues (alfalfa and pultry) added to biochar during composting are a sources of total N. Wang *et*

Table (2): Effect of source, composting and level of biochar on available N (mg kg^{-1}) in clay soil.

Biochar source	Biochar composting	Biochar level (ton ha $^{-1}$) 0	5	10	20	mean	mean of Biochar Source
Corn stover	composted	130.53	169.33	288.96	298.30	221.78	192.05
	uncomposted	130.53	150.70	166.10	201.96	162.32	
Rice residues	composted	130.53	167.80	298.90	301.40	224.65	209.22
	uncomposted	130.53	174.75	186.60	283.30	193.79	
mean		130.53	165.64	235.14	271.24		

$RLSD_{0.05}$; Source=* ; composting =* ; level=2.04 ; S*C = ns ; S*L= 0.022 ; C*L =4.09 ;S*C *L = ns

Table (3): Effect of source, composting and level of biochar on available N (mg kg^{-1}) in sandy soil.

Biochar source	Biochar composting	Biochar level (ton ha $^{-1}$) 0	5	10	20	mean	mean of Biochar Source
Corn	composted	105.60	123.23	195.80	228.16	163.19	146.9
stover	uncomposted	105.60	120.10	139.80	156.96	130.61	
Rice	composted	105.60	146.46	200.80	250.16	175.75	158.16
residues	uncomposted	105.60	130.50	149.10	177.10	140.57	
mean		105.60	130.07	171.37	203.09		

$RLSD_{0.05}$; Source=* ; composting =* ; level=1.83 ; S*C =ns ; S*L= 3.88 ; C*L = 3.89

;S*C*L = 7.77

al. (2014) and Romero *et al*. (2021) stated that initial presence of organic residues with biochar will increase the functional groups and inriche the biochar with essential nutrients, especially N and P as well as improving the humus development in soil. Furthermore, composted biochar have more N content than uncomposted biochar (table1) and affect soil properties (Shehan and Abdulkareem, 2025). These finding could explain the higher inorganic N in soil in response to composting biochar.

For the interaction affects, data in tables (2 and 3) indicated a higher available N was obtained in treadments including addition of composted biochar compared with uncomposting treatment along with other factors. However, using uncomposting biochar also caused a significant increased in available N over the control, that means the biochars produced by composting or uncomposting are a preciable for enhancing the availabily N in both soils. On the same way, although the higher available N obtained with rice biochare, the corn biochar significantly increased available N over control. These findings were true for the two soils. The higher available N were associated with a values of using 20 ton ha^{-1} of rice composted biochar with a values of 301. 40 and 250. 16 mg kg^{-1} for clay and sandy soils, respectively. These values were higher than controls of respect soils by percents of 130. 90 and 136. 89 % for clay and sandy soils, respectively.

N concentration and uptake in corn plant:

The date of pot experiment suggested that addition of biochar at rate of 20 ton ha^{-1} significantly increased N concentration and uptake in both soils over control (tables 4-7). The mean values of N concentration were 30. 26 and 27. 37 g kg^{-1} DW at 20 ton ha^{-1} for clay and sandy soils, respectively, While were 20. 00 and 20. 00 g kg^{-1} DW at controles for the same soils. Similarly, the mean values of N uptake were 0. 59 and 0. 36 g pot^{-1} at 20 ton ha^{-1} for clay and sandy soils, respectively, while were 0. 32 and 0. 11 g pot^{-1} at controles for the same soils. Similar results were obtained by Jones *et al*. (2012) and Mcleod (2022) for the effect of biochars on N concentration and uptake. They comfirmed that to inhance soil physical properties. In our study, the improvement of available N content after addition of biochar (tables 2 and 3) reflected the N concentration and uptake, since the nutrient concentration in plant tissue is a function for available amount in soil (Cooper, 2008).

The results presented in tables 4-7 showed that rice biochar had a higher N concentration and uptake compared to corn biochar at the two soils. Similar result was obtained by Bhattacharjya *et al*. (2015) who found a different N-uptake with different source of biochar (pine residues and

Table (4): Effect of source, composting and treatment of biochar on N concentration(g kg^{-1} D. W.) of corn grown in clay soil.

Biochar source	Biochar composting	Biochar treatment 0	20	mean	mean of Biochar Source
Corn stover	composted	20.00	30.00	25.00	24.42
	uncomposted	20.00	27.69	23.84	
Rice residues	composted	20.00	34.36	27.18	25.84
	uncomposted	20.00	29.00	24.50	
mean		20.00	30.26		

$RLSD_{0.05}$; Source=* ; Composting =* ; Treatment=* ; S*C = ns ; S*T = 0.57 ; C*T =0.58

;S*C *T = ns

Table (5): Effect of source, composting and treatment of biochar on N concentration(g kg^{-1} D. W.) of corn grown in sandy soil.

Biochar source	Biochar composting	Biochar treatment 0	20	mean	mean of Biochar Source
Corn stover	composted	20.00	30.00	25.00	22.14
	uncomposted	20.00	18.55	19.28	
Rice residues	composted	20.00	38.06	29.03	25.23
	uncomposted	20.00	22.88	21.44	
mean		20.00	27.37		

$RLSD_{0.05}$; Source=* ; Composting =* Treatment=* ; S*C =ns ; S*T = 1.31 ; C*T = 1.24

;S*C*T = 0.046

Table (6): Effect of source, composting and treatment of biochar on N uptake (g pot^{-1}) by corn grown in clay soil.

Biochar source	Biochar composting	Biochar treatment 0	20	mean	mean of Biochar Source
Corn stover	composted	0.32	0.55	0.43	0.41
	uncomposted	0.32	0.47	0.39	
Rice residues	composted	0.32	0.85	0.58	0.50
	uncomposted	0.32	0.52	0.42	
mean		0.32	0.59		

$RLSD_{0.05}$; Source=* ; Composting =* ; Treatment=* ; S*C = ns ; S*T = 0.03 ; C*T =0.03 ;S*C *T = ns

Table (7): Effect of source, composting and treatment of biochar on N uptake (g pot^{-1}) by corn grown in sandy soil.

Biochar source	Biochar composting	Biochar treatment 0	20	mean	mean of Biochar Source
Corn stover	composted	0.11	0.32	0.21	0.17
	uncomposted	0.11	0.15	0.13	
Rice residues	composted	0.11	0.72	0.41	0.30
	uncomposted	0.11	0.27	0.19	
mean		0.11	0.36		

$RLSD_{0.05}$; Source=* ; Composting =* Treatment=;* S*C =0.018 ; S*T = 0.020 ; C*T = 0.02 ;S*C*T = 0.037

Lantana residues). The difference in N concentration and uptake is logic consequence of the dffernt N available in soil (tables 2 and 3) as well as different effect on soil properties (Shehan and Abdulkareem, 2025) making plant more effective to absorb N from soil solution. The data in tables 4-7 showed that application of composted biochar significantly increased N concentration and uptake over uncomposted biochar. The increasing percents in N concentration were 7. 94 and 32. 66 % for clay and sandy soils, respectively and the increasing percents in N uptake were 25. 00 and 93. 75 % for the same soils. Blending biochar with compost or co-compostig process revealed substantial improvements in soil and plant performance. In this case, porous of biochar and adsorptive surface sites are charged with nutients (Prost *et al*2013. ;Steiner *et al*., 2010) and stimulating microbial diversity (Doan *et al*., 2014). It is likely that biochar mixed with compost captured dissolved nutrients, reducing leaching, gaseous losses and/or immobilization (Schmidt *et al*., 2015). In the present study this results matched with the results of N availability in soils(tables 2 and 3).

As for interaction effects, application of biochar at rate of 20 ton ha^{-1} significantly increase N concentration and uptake of corn plants at both sources and composting treatments, compared with controls (no addition of biochar). This was true for the two soils. The concentration of nitrogen were 31. 68 and 30. 47 g kg^{-1} DW for treatments of rice biochar added at 20 ton ha^{-1} for clay and sandy soils, respectively with a superiority percents of 58. 40 and 52. 35% at the two soils, compared with controls. And also, the N uptake were 0. 69 and 0. 49 g pot^{-1} for treatments of rice biochar added at 20 ton ha^{-1} for clay and sandy soils, respectively with a superiority percents of 115. 62 and 345. 45% at the two soils, compared with controls. Similar results were obtained for the superiority of composted biocharas compared with controls with an increase percents in N concentration of 60. 90 and 70. 15% for clay and sandy soils, respectively and an increase percents of 118. 75 and 37. 72 % for the mentioned soils. Furthermore, the data in table 4-7 illustrated that addition of treatments including corn biochar and uncomposted biochar also increased N concentration and uptake of corn plant at the two soils, indicatiny the possibility of using them to inhance N utillzation by plant. The biochars used in this experiment are with a hybride material with its carbon and other nutrinents working as high surface carrier serving nutrient and exchange with soil, soil biota and plants (Schmidt *et al*., 2015).

Conclusion

The experiment results showed that application of biochars derived from corn stover or rice residues influence the N availability, N concentration in corn shoot, and N uptake. These are higher with rice biochar compared with corn biochar. The higher N availability, N concentration and N uptake were obtained by using composted biochar over uncomposted one. More experiments are clearly needed to suggest the optimal organic residues-biochar ratio as well as test another organic residues – biochar ratio as well as test another organic residues. Afield trial is so necessary for statement the performance of biochar supported by an economic feasibility study.

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