International Journal of Life Science and Agriculture Research
ISSN (Print): 2833-2091, ISSN (Online): 2833-2105
Volume 04 Issue 03 March 2025
DOI: https://doi.org/10.55677/ijlsar/V04I03Y2025-04
Impact Factor: 7.88 , Page No : 182-190

An Analysis of the Nitrogen Dynamic Impacted by Biochar and Compost on Ultisol Soil Using Stable Isotope N-15

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ABSTRACT

Biochar has been proposed as a potential environmental-friendly soil amendment to increase soil quality and crop production and reduce chemical fertilizer use, especially in low-fertility soils. The combination of biochar with other soil amendment materials, namely compost, is carried out to increase the efficiency of nitrogen fertilizers, in particular on Ultisol soil. An experiment using the isotope stable ^{15}N technique was conducted to investigate the effects of rice husk biochar, compost, and urea fertilizer on nitrogen efficiency, soil pH, EC, and maize production. The pot experiment was designed using Completely Randomized Design, and the treatments were: (1) control; (2) 50% urea; (3) 50% urea + biochar; (4) 50% urea + compost; (5) 50% urea + biochar + compost; (6) 100% urea; (7) 100% urea + biochar + compost. The results showed that combined biochar and compost significantly increased N-uptake derived from ^{15}N-labelled fertilizer, total N uptake by plants, ^{15}N plant recovery, and soil ^{15}N residues, and decreased ^{15}N loss compared to urea alone. This treatment also significantly increased the grain yields and total biomass of the maize plants.

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KEYWORDS: acid soil; fertilizer; isotope ^{15}N; soil amendment; biochar

INTRODUCTION

The challenges of modern agriculture are how to increase agricultural production but at the same time also maintain environmental sustainability. It means continuously increasing food production for food demand sufficiency while minimizing environmental impact to provide a sustainable environment for the next generation's lives. Environment issues such as climate change, land and water pollution, and land degradation, including those caused by agricultural activities, have been getting more attention in recent years. For instance, the application of chemical fertilizers, especially nitrogen sources, is currently a very serious concern because it has a direct impact on soil characteristics. Excessive use of nitrogen fertilizers in crop cultivation causes economic losses and environmental damage. Soil amendment using organic matter is one of the best solutions for overcoming the impact of chemical fertilization, especially urea, in the long term.

Biochar is carbon-rich solid material from biomass (wood, straw, manure, rice husk, etc.) produced through the pyrolysis process with no or limited oxygen (Lehmann & Joseph, 2012). In recent years, biochar has been proposed as a promising environment-friendly soil amendment because it is believed to improve the quality of physical and chemical characteristics of soil (Masulili et al., 2010; Joseph et al., 2010), enhance plant growth and crop yield, and increase soil carbon sequestration (Biederman & Stanley Harpole, 2013; Zhu et al., 2014). In addition, biochar was reported to reduce greenhouse gas emissions (Pramono et al., 2021), and it was believed as a greener approach to reuse the disposed of organic waste (Gunarathne et al., 2019). Biochar was also reported to increase several benefits of compost when applied together, through direct application, or mixed in the composting process (Agegnehu et al., 2017; Oldfield et al., 2018). Biochar can add more stable C when applied to the soil with compost because biochar constraints more stable C (70% and 90%) than compost (2% and 14%) (Boldrin et al., 2009; Hammond et al., 2011). This combination may enhance and sustain soil biophysical and chemical characteristics compared to both alone applications because most of the compost will disappear over time through decomposition, whereas the biochar will stay in the soil for decades (Agegnehu et al., 2017).

The addition of compost into biochar revealed to increase soil pH, reduce exchangeable forms of aluminum and iron in acid soil (Ch'Ng et al., 2016), increase some nutrient availability in the soil (Ch'Ng et al., 2016; Manolikaki & Diamadopoulos, 2019), increase plant growth and yield (Ch'Ng et al., 2016; Agegnehu et al., 2016). Using the Life Cycle Assessment methodology, the combination of biochar and compost was reported to be more environmentally beneficial than mineral fertilizer, which recycles C, N, P, and K (Oldfield et al., 2018). In addition, the biochar alone combined with N fertilizer was also reported to be a potential option to reduce N loss and improve fertilizer N use efficiency (Mia et al., 2017). However, not much research has been done on the effect of biochar and compost combination with N mineral fertilizer on N fertilizer use efficiency and the fate of N fertilizer.

N fertilizer is essential for enhanced crop production, especially on low fertile soil such as ultisol. However, excessive doses and inefficient fertilization practices cause economic losses and environmental damage. It is due to N loss from the soil-plant system via nitrification, denitrification (Bradbury et al., 1993), volatilization (Kahrl et al., 2010), and leaching (Lutes et al., 2016). The N loss from fertilizer harms the environment, such as soil acidification (Johnston et al., 1986) and eutrophication in the water ecosystem (Commoner, 1970). Therefore, identifying innovative strategies to reduce N loss from fertilizer and still maintain or improve crop production is crucial.

The advantages of using ^{15}N as a tracer to study the effect of soil amendment on the N dynamic in agroecosystems have been discussed in a lot of literature (Craswell et al., 2021). The ^{15}N isotope technique is essential to discriminating the different N-source and identifying N priming effects (Fiorentino et al., 2019). In addition, the use of ^{15}N as a tracer on the fate of N added to soil-plant systems provides unique insights into the biochar effect on soil N processes such as fertilizer N use efficiency, N retention and balance, mineralization-immobilization, leaching, and biological N_2 fixation (Craswell et al., 2021). The research that presents most of these insights would not have been possible without using ^{15}N (Craswell et al., 2021).

The study of the impact of urea fertilization which was overcome by applying biochar and compost, was studied on Ultisol-type agricultural land which is a corn planting land. The physicochemical properties of the soil were silty clay soil texture, 4.12 pH (H2O), 2.14% C-organic, 0.24% N-total, 7.81 ppm P Bray 1, 64.85 ppm P (HCl 25%), 0.15 me 100 g^{-1} extractable K (NH_4Ac), 18,97 me 100 g^{-1} Cation Exchange Capacity (CEC) and 16.66% Base Saturation. The objectives of this study were to investigate the effects of biochar, compost, and nitrogen fertilizer (urea-N15) on urea efficiency, soil pH, EC, and maize production in Ultisol. Stable isotope ^{15}N is used to determine the efficiency of nitrogen use from various N sources in the soil.

MATERIAL AND METHODS

The Ultisol soil from Jasinga, Bogor, West Java Province, Indonesia, was used as the experimental soil. The soil was air-dried, sieved through <1 cm sieves, and then filled in a plastic pot with a weight of 11 kg pot^{-1}. The biochar was produced from rice husk using a simple fire stove at a temperature of 400°C. The chemical properties of the biochar were 9.16 pH (H_2O); 18.46% SiO; 14.96% C-organic; 0.47% N-total; and 0.37% P_2O_2. A commercial compost product was used, and the chemical properties were 6.77 pH (H_2O); 30% C-organic; 2% N-total; and 3.52% P_2O_2.

A pot experiment was conducted at a greenhouse facility of the National Research and Innovation Agency, Pasar Jumat, South Jakarta, Indonesia, from September until December 2022. A Completely Randomized Design was used, consisting of 7 treatments and 4 replications. The treatments in this study were: (1) control (no urea, biochar, and compost additions); (2) 50% urea recommendation dose (1.4 g N pot^{-1}, equivalent with 100 kg N ha^{-1}); (3) 50% urea + biochar (210 g pot^{-1} biochar, 1.9% w/w or equivalent with 15 ton ha^{-1}); (4) 50% urea + compost (140 g pot^{-1} compost, equivalent with 10 ton ha^{-1}); (5) 50% urea + biochar + compost; (6) 100% urea (2.8 g N pot^{-1} urea, 1.2% w/w equivalent with 200 kg N ha^{-1}); (6) 100% urea + biochar + compost.

Biochar and compost were mixed evenly with the experimental soil, 1 day before planting. Pioneer 21 hybrid maize cultivar was used as the experimental crop. Four maize seeds were planted directly into each experimental pot, with a depth of ±5 cm from the soil surface. After the sprouts grew (7 DAP), one uniform high plant in each pot was selected as the experimental plant. N Fertilizer used was ^{15}N-labeled urea (1.5% atom ^{15}N abundance). Nitrogen was split-applied: 50% dosage at early tillering (7 days after transplanting) and 50% at panicle initiation. Phosphorus and potassium fertilizers were single superphosphate and potassium chloride at doses of 0.5 g P_2O_5 pot^{-1} (equivalent to 36 kg P_2O_5 ha^{-1}) and 0.7 g K_2O pot^{-1} (50 kg K_2O ha^{-1}). Phosphorus and potassium were applied at early tillering (7 days after transplanting). At the maturity phase (102 days after transplanting), all above-ground plant biomass in each pot was harvested and separated into stover, kernel, and corncob. Soils were also collected for further analysis.

The ^{15}N abundances in soil and plant samples were determined with an isotope ratio mass spectrometer (IRMS, Thermo Fisher). N proportion derived from fertilizer (%-Ndff), N proportion derived from soil (%-Ndfs), N amount derived from fertilizer (mg-Ndff), and N amount derived from soil (mg-Ndfs) were calculated according to Lü et al. (2012):

$$\%Ndff = \left(\frac{^{15}\text{N atom percentage excess in plant (\%)}}{^{15}\text{N atom percentage excess in fertilizer (\%)}} \right) \times 100\% \quad (1)$$

$$\%Ndfs = 100\% - \%Ndff \quad (2)$$

$$\text{Ndff (mg pot}^{-1}) = \%\text{Ndff x N uptake in plant organ (mg pot}^{-1}) \quad (3)$$

$$\text{Ndfs (mg pot}^{-1}) = \%\text{Ndfs x N uptake in plant organ (mg pot}^{-1}) \quad (4)$$

The calculation of plant ^{15}N recovery (%), soil ^{15}N residue (%), and Unaccounted ^{15}N loss (%) were calculated according to Wang et al., (2020):

$$\text{Plant } ^{15}\text{N recovery (\%)} = \frac{\text{Ndff (mg pot}^{-1})}{^{15}\text{N fertilizer rate (g p pot}^{-1})} \text{ X } 100\% \qquad (5)$$

$$\text{Soil } ^{15}\text{N residue (g pot}^{-1}) = \text{N soil x } \left(\frac{^{15}\text{N atom percentage excess in soil (\%)}}{^{15}\text{N atom percentage excess in fertilizer (\%)}} \right) \qquad (6)$$

$$\text{Soil } ^{15}\text{N residue (\%)} = \frac{\text{Soil } ^{15}\text{N residue (mg pot}^{-1})}{^{15}\text{N fertilizer rate (g p pot}^{-1})} \text{ X } 100\% \qquad (7)$$

$$\text{Unaccounted } ^{15}\text{N loss (\%)} = 100 - \text{Plant } ^{15}\text{N recovery (\%)} - \text{Soil } ^{15}\text{N residue (\%)} \qquad (8)$$

RESULTS AND DISCUSSIONS

Soil pH and Electric Conductivity (EC)

Figure 1 is an overview of the impact of urea, biochar, and compost on soil pH and soil EC after harvest time. It can be seen that rice husk biochar addition to the ultisol acidic soil increases soil pH after harvesting time. All biochar treatments, with or without compost addition, significantly increased soil pH between 0.28 to 0.35 units compared to the control. Adding biochar and compost with a 50% N fertilizer treatment was the highest soil pH, but no significant difference with other biochar treatments. Compared to biochar alone, Combining compost and biochar as soil amendments does not significantly affect soil pH. Meanwhile, the addition of compost alone with 50% N significantly increased soil pH compared to 50% urea alone but was not significantly different from other treatments. The results also showed that urea, compost, biochar, and combinations of them did not affect soil EC compared to control.

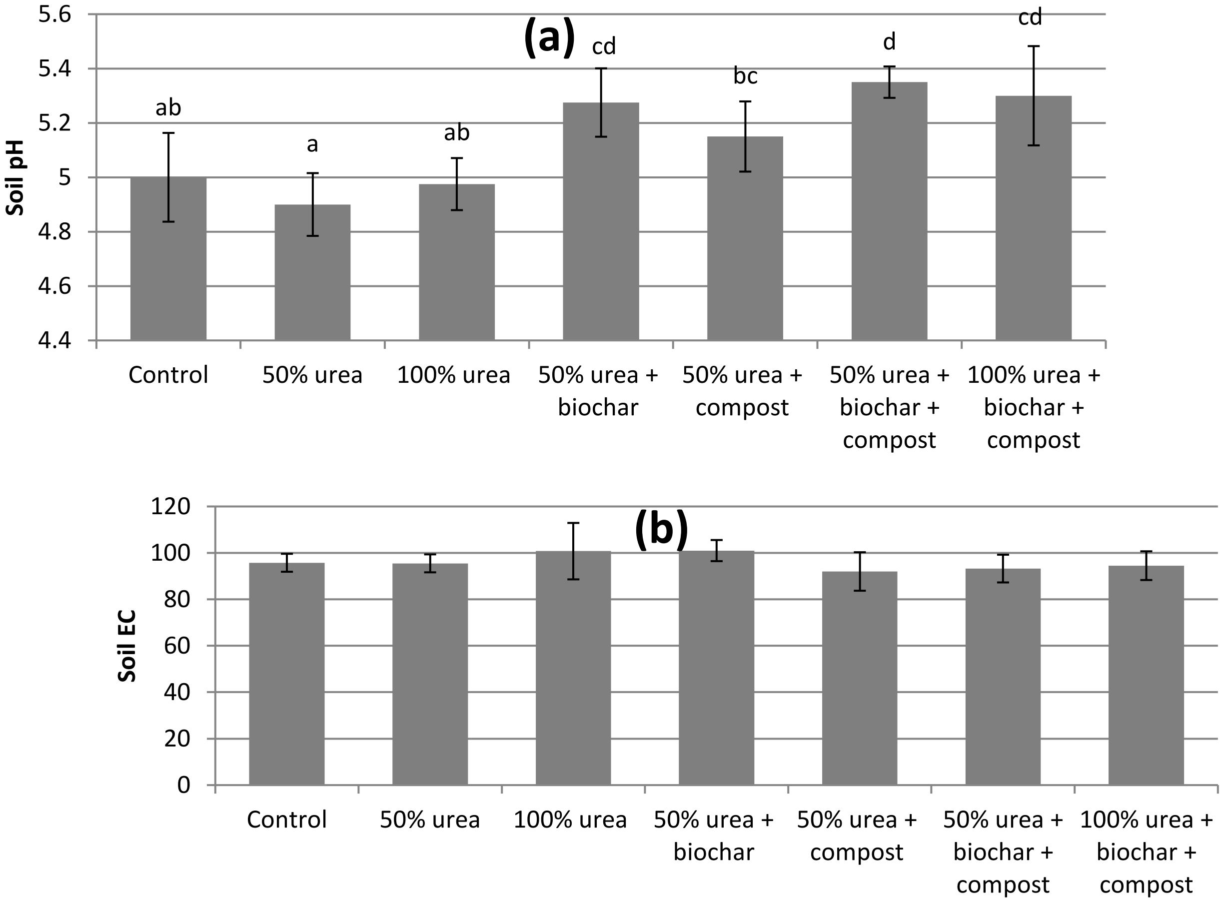

Figure 1. Effect of urea, biochar, and compost on soil pH (a) and electric conductivity (b) after harvest

As the finding in our research, soil pH of Jasinga Ultisol soil was increased when rice husk biochar (1.9% w/w) and compost (1.4% w/w) were applied. Biochar seemed to give a higher liming effect on acidic Ultisol soil than compost. This is probably caused by the high inherent pH owned by Biochar (9.16), higher than compost tested (6.77). The ameliorating effect of biochar on acid soil mainly depends on its inherent pH value, base cation content, alkalinity, $CaCO_3$ content, and mineralization of N organic (Chintala et al., 2014; Shetty & Prakash, 2020). After incorporating highly alkaline biochars with high base cation concentrations into the soil, these base cations can be released into the soil solution. Then, proton consumption reactions can increase the soil pH (Chintala et al., 2014). Another reason for the liming effect of biochar is the presence of negatively charged functional groups phenolic, carboxylic, and hydroxyl on the biochar surface, which could contribute to increasing soil pH by binding the H^+ ions in the soil solution (Gul et al., 2015).

In this study, the increment soil pH of ultisol Jasinga by rice husk biochar treatments was about 0.28 – 0.35 units. The increasing soil pH by biochar addition is consistent with results in previous studies (Chintala et al., 2014; (Martinsen et al., 2015; Ghorbani et al., 2019; Hailegnaw et al., 2019; Shetty & Prakash, 2020). Applying wood biochar at 5 – 10 ton ha^{-1} rates in the incubation study was very effective in increasing the soil pH and decreasing the soluble and exchangeable Al in the soil (Shetty & Prakash, 2020). Laboratory study of the biochar effect across soils with a wide range of physicochemical properties reported that a significant increment of soil pH began from a 2% biochar addition rate in acidic to slightly acidic soils, while began from an 8% biochar rate increased pH significantly in all soils (Hailegnaw et al., 2019). In this study, the maximum increment of soil pH was only about 0.35 units. It may occur due to the relatively high clay content of the Ultisol soil tested (54.7 %). The pH soil increment depends on soil type and biochar application rate, which the increment is higher in soils that have relatively low original pH, CEC, exchangeable Ca^{2+} content, and clay content (Hailegnaw et al., 2019). The low increment in soil pH in soils with high clay contents is similarly due to the high buffering capacity of clay soils compared with sandy soils (Jones Jr., 2012). However, in this study, biochar, compost, and urea treatment did not affect the EC value of ultisol soil. Previous studies have found contradictory results; some studies reported that biochar increased soil EC value (Chintala et al., 2014; Shetty & Prakash, 2020). Other studies reported a significant effect on soil EC value with biochar addition (Mavi et al., 2018; Ghorbani et al., 2019).

The findings of Sun et al (2022) stated that EC value had the highest response to fine-texture soils. On average, soil pH, CEC, SOC, TC, and the C:N ratio showed consistently positive responses to biochar amendment at a lower initial soil pH (acidic), whereas soil EC showed a positive response when the initial soil pH was alkaline. In this study, the soil pH tended to be acid (4.12) and clay texture. These two conditions are thought to be the cause of biochar and compost applications not causing an increase in soil EC value.

Plant Biomass and N Uptake

Urea, biochar, and compost significantly affected maize plant biomass and N uptake in Ultisols (data can be seen in Table 1). Both urea-only treatments, 50%, and 100% N, significantly increased grain yield, corncob, and total above-ground biomass of the maize plant. These treatments also increased N uptake by the plant (stover, grain, corncob, and total N uptake) compared to control (no N additions). However, no significant effects were observed among these treatments, except on stover N uptake. Additions of N fertilizer only increased grain yield and total N uptake, up to 353% and 386% respectively.

Table 1. Effect urea, biochar and compost on grain yield, dry matter and N uptake of maize plant

Treatment	**Dry weight (g pot^{-1})**			**Total Biomass (g pot^{-1})**	**N Uptake (mg pot^{-1})**			**Total N uptake (g pot^{-1})**
	Stover	Grain	Corncob		Stover	Grain	Corncob	
Control	33.6 a	14.3 a	3.4 a	51.3 a	163.0 a	180.0 a	13.8 a	0.36 a
50% N	47.1 bc	64.9 bc	9.2 b	121.2 bc	508.8 b	878.5 b	48.9 b	1.44 bc
100% N	43.0 ab	54.4 b	7.4 b	104.8 b	726.4 c	983.7 b	42.9 b	1.75 c
50% N + biochar	50.3 bc	69.5 bc	7.8 b	127.5 bc	574.6 b	904.4 b	38.6 b	1.52 bc
50% N + compost	50.5 bc	68.1 bc	8.0 b	126.6 bc	567.6 b	901.1 b	38.4 b	1.51 bc
50% N + biochar + compost	52.7 bc	60.8 bc	7.9 b	121.4 bc	527.3 b	673.3 b	41.3 b	1.24 b
100% N + biochar + compost	58.7 c	82.7 c	9.7 b	151.1 c	794.8 c	1335.4 c	42.8 b	2.17 d

Remarks: *Mean values within a column followed by the same letters are not significantly different at $p < 0.05$ according to Duncan's Multiple Range Test.

Additions of biochar and compost, either with 50% or 100% N, also increased plant biomass and N uptake compared to control. The 100% N + biochar + compost treatment caused the highest grain yield, total plant biomass, N uptake by grain, and total N uptake. This treatment significantly increased grain yield by 478% and 26% compared to control and 100% N, respectively. However, significant differences were not found when compared with other treatments. This treatment also increased total N uptake by maize plant, about 503% and 24% compared to control and 100% N treatment. However, 50% N with additions of biochar, compost, or both combinations, had no significant effect on plant biomass and N uptake, compared with 50% N alone treatment.

In this study, the maximum grain yield and total N uptake were reached by biochar and compost with full recommendation of N fertilizer treatment. This result indicates that adding biochar and compost in recommended doses of urea improved grain yield and N uptake of maize plant compared to control and urea alone. These improvements align with previous studies (Masulili et al., 2010; Agegnehu et al., 2016; Zahra et al., 2021; Pramono et al., 2021). It may occur due to improved soil properties by biochar and compost additions, such as increasing soil pH, soil organic matter content, availability of nutrients, CEC, decreasing soil bulk density, exchangeable Al, and soluble Fe. The application of rice husk biochar improved some soil properties of the acid sulfate soil of West Kalimantan, Indonesia, and improved rice growth (Masulili et al., 2010). The dry biomass of rice was significantly positively correlated with soil organic matter and P total content and negatively correlated with exchangeable Al and soluble Fe (Masulili et al., 2010).

The effectiveness of biochar and compost as soil amendments depends on the characteristics of organic amendments, climatic conditions, and soil type. In a temperate climate, biochar addition to sandy loam soil positively and negatively impacts maize yield depending on the type of biochar (Gaskin et al., 2010). Applying rice husk biochar and compost in 6 consecutive seasons increased 17% the grain yield of paddy fields on average in Inseptisol tropical soil (Pramono et al., 2021). In tropical Ferrasol, biochar and compost additions increased 20% of grain yields and 7.6% total biomass of maize (Agegnehu, Bass, et al., 2016). In subtropical field conditions, biochar and compost treatment increased the grain yield of maize by about 46.29% compared to control (Zahra et al., 2021).

Sources of N (^{15}N) Uptake in Maize Plant

The proportion of N absorbed by the plant from urea fertilizers (%Ndff) in this study was about 47% - 65% (table 2). Meanwhile, the amount of N uptake derived from unlabeled source or soil (%Ndfs) by all treatments were about 35% - 53%. In relative terms, N absorbed from fertilizer was slightly higher than N absorbed from the soil. The %Ndff value increased while the %Ndfs value decreased as the dose of N fertilizer increased. However, additions of compost and biochar did not affect the %Ndff and the %Ndfs compared to urea alone at the same dose.

Table 2. Effect urea, biochar and compost on N derived from labeled urea (Ndff) and N derived from soil (Ndfs) of maize plant

Treatment	N rate (g N pot^{-1})	%Ndff (labeled)	%Ndfs	Ndff (labeled) (g)	Ndfs
Control	0	0.0 a	100.0 c	0.0 a	0.34 a
50% N	1.38	48.8 b	51.2 b	0.70 b	0.74 b
100% N	2.76	64.6 c	35.4 a	1.11 c	0.64 b
50% N + biochar	1.38	47.4 b	52.6 b	0.72 b	0.80 b
50% N + compost	1.38	47.2 b	42.8 b	0.70 b	0.80 b
50% N + biochar + compost	1.38	50.5 b	49.5 b	0.63 b	0.62 b
100% N + biochar + compost	2.76	61.0 c	39.0 a	1.33 d	0.85 b

Remarks: *Mean values within a column followed by the same letters are not significantly different at $p < 0.05$ according to Duncan's Multiple Range Test.

The amount of N uptake derived from urea fertilizer (Ndff) was affected by the dose of urea, biochar, and compost additions. The higher dose of N fertilizer caused higher Ndff in maize plants, which, combined with compost and biochar, caused the highest Ndff. The addition of biochar and compost with 100% N fertilizer treatment caused 1.33 g pot^{-1} from 2.76 g pot^{-1} urea taken by the plant, increasing about 19.8% compared to 100% N fertilizer alone. This treatment also increased the amount of Ndff compared to all treatments. The result indicated that biochar and compost additions improve the N fertilizer uptake by the plant. Even though additions of biochar or compost or both of them with 50% N did not significantly affect the amount of Ndff compared to 50% N alone.

Compared to control, urea, compost, and biochar additions significantly increased the N uptake derived from soil or unlabeled sources (Ndfs). These treatments increased N uptake from the soil by about 82.4% - 150% compared to control. However, there was no significant difference between urea, compost, and biochar additions.

Nitrogen fertilizer was a vital N source for the maize plant. It was expressed by the proportion of ^{15}N absorbed by the plant from ^{15}N labeled fertilizers (%Ndff), about 47% - 65% of total N absorbed. Biochar and compost additions with N fertilizer improved the N absorbed from fertilizer by 19.8% compared to N fertilizer alone. It was probably caused by the ability of biochar and compost to enhance the retention of inorganic N (NH_4^+ and NO_3^-) from being lost, and they can be released again and become available to utilize by plants, thus improving N from fertilizer absorbed by maize plants. Studies have reported that Biochar and compost additions reduced the contents of NO_3^- and NH_4^+ in leachates by 34% and 34.7%, respectively (Ch'Ng et al., 2016).

As a consequence of increasing N fertilizer absorbed by the plant, the nitrogen fertilizer use efficiency or plant recovery N also increased. We found that biochar and compost additions increased plant recovery by 7.7% at the 100% recommended dose of N fertilizer. The result indicates that biochar and compost can be used to improve N fertilizer use efficiency on ultisol. Studies have revealed the different effects of biochar on nitrogen use efficiency. Some studies recorded a positive effect on nitrogen use efficiency (Huang et al., 2014; Ma et al., 2020). In some studies, plant ^{15}N recovery in the biochar treatment was less than control (Gao et al., 2019; Sun et al., 2019). Another study showed that rice straw biochar applied at 10 g kg^{-1} improved N use efficiency in 2 from 7 acidic red soils tested (Zhu et al., 2014).

The Rate of ^{15}N Recovery, Retention and Loss

Total ^{15}N recovery in above-ground maize biomass was 45% - 52% (table 3). Without biochar and compost additions, increasing the dose of N fertilizer decreased the plant recovery rate significantly. Additions of biochar and compost with 100% urea significantly increased plant recovery rate compared to 100% urea alone. This treatment increased 8% urea uptake by the plant compared to 100% urea alone. However, combinations of 50% N with biochar, compost, or both, did not significantly affect the plant recovery rate compared to 50% N alone.

Without biochar and compost additions, increasing the dose of N fertilizer did not significantly affect the soil N retention/residual rate. Otherwise, increasing the dose of N fertilizer increased the N loss rate. Additions of biochar alone or combined with compost increased soil N residue rate compared to 50% N alone. Combining biochar and compost with 50% N caused the highest proportion of soil ^{15}N residual. Additions of compost alone did not significantly affect soil N residue rate compared to 50% N alone.

Table 3. The fate (%) of ^{15}N urea (the plant recovery, soil residual, and unaccounted N loss) affected by biochar and compost

Treatment	Plant Recovery N (%)	Soil N Residue (%)	Unaccounted N loss (%)
Control	0,0 a	0,0 a	0,0 a
50% N	50,8 c	28,0 bc	21,2 bc
100% N	40,3 b	20,1 b	39,6 d
50% N + biochar	52,1 c	34,4 de	13,5 b
50% N + compost	50,6 c	32,3 cde	17,1 bc
50% N + biochar + compost	45,3 bc	40,1 e	14,6 b
100% N + biochar + compost	48,0 c	24,9 bcd	27,1 c

Remarks: *Mean values within a column followed by the same letters are not significantly different at $p < 0.05$ according to Duncan's Multiple Range Test.

Additions of biochar or compost, or both with 50% urea, slightly decreased fertilizer N loss, but statically was insignificant compared to 50% urea alone. Combining biochar and compost with 100% urea significantly decreased N loss compared to 100% urea alone. Decreasing fertilizer N loss by combining biochar and compost was about 12.5%.

We also observed that the combination of biochar and compost also increased ^{15}N retention on ultisol soil. This combination increased soil ^{15}N retention up to 12.1% compared to N fertilizer alone at the same dose. Biochar properties such as porosity, large surface area, and the presence of both polar and nonpolar surface sites can increase the soil's nutrient retention capacity (Hossain et al., 2020). These polar surface sites can contribute to increasing the CEC of soil, thus improving nutrient retention and reducing nutrient losses (Mukherjee et al., 2011; Tomczyk et al., 2020). Schofield et al., (2019) suggested that improved nutrient retention by biochar may be due to biochar's ability to retain ions and molecules through the porosity and the high cation and anion exchange capacities of biochar.

The plant + soil recovery percentage can be used to indirectly estimate the ^{15}N losses as the 'unaccounted-for' ^{15}N balance. We observed that biochar and compost additions reduced N losses up to 11.1% compared to urea alone at the same dose. The capacity of biochar and compost to increase N fertilizer use efficiency and soil N retentions reduced N losses. After N fertilizer is applied to the soil, some N from fertilizer can be lost through several pathways, such as leaching, runoff, and volatilization (Dong et al., 2020). Studies have shown that biochar effectively reduces N loss (Ahmed et al., 2019). Ahmed et al., (2019) used ^{15}N urea added to soil columns and found that biochar addition reduced leaching of the ^{15}N was 73% in the first season and 50% in the following season. Another study using ^{15}N-labelled urine revealed that adding biochar reduced NH_3 volatilization by 45% (Taghizadeh-Toosi et al., 2012). However, applying biochar with high pH can increase ammonia volatilization due to increased soil alkalinity (Liu et al., 2018). The degree of ammonia volatilization will depend on the extent of soil pH change and the ammonium retention capacity of biochar.

Urea, compost, and biochar additions increased the N uptake derived from soil (Ndff). This result indicated that urea, compost, and biochar give a positive priming effect, implying higher bioavailability of native mineral N in the soil, and increased N uptake from native soil N. The previous study reported that the additions of wheat straw biochar, produced by both 550ºC and 350ºC pyrolysis processes, increased total mineral N from soil organic matter degradation by up to 17% and 7%, respectively (Fiorentino et al., 2019). There were significant interactions when urea was added in combination with biochar, increased soil native NH_4^- -N and NO_3^--N (Fiorentino et al., 2019). The mineral N is a consequence of higher retention of soil organic N mineralized, not a consequence of higher retention of soil organic N mineralization (Fiorentino et al., 2019). In this study, the plant's absorption of N from the soil, except control (no N added), was about 35.4% - 52.6%. The relative proportion of N uptake from soil decreased as the N fertilizer dose increased. This result was relatively similar to Rimski-Korsakov et al., (2012). This fact indicates that soil organic matter mineralization is vital as a source of N for the plant.

ACKNOWLEDGEMENT

This article is to commemorate Anggi Nico Flatian's, who passed away at the time this writing is being compiled. He dedicated his knowledge to designing, implementing, and compiling the data in this research. We also would like to thank the field crew and analysts for their assistance regarding the implementation of research and data collecting.

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