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Effects of different types, application rates and sizes of biochars on water and nutrient retention in clay and sandy loam soils

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Abstract: A laboratory experiment using column leaching test was conducted to investigate the effects of different types, application rates and sizes of biochar on water retention, nutrient retention, pH and CEC in clay and sandy loam soils. Two types of biochar (mangrove and rubber), two application rates (20 and 40 ton ha^{-1}), and two sizes (1 mm and 5 mm) were used. The results indicated that application of both types of biochar significantly increased water, NH_4^+ and NO_3^- retention capacity in both soils. The significant increase in water retention was observed only with the application rate of 40 ton ha^{-1}, by 5-6% with mangrove biochar, and 11-15% with rubber biochar. Leaching of NH_4^+ was reduced by 45-49% with rubber biochar at 40 ton ha^{-1} in clay soil, and by 10-12% in sandy loam soil. On the other hand, at the same application rate, NO_3^- leaching was reduced by 40-50% with mangrove biochar and by 34-39% with rubber biochar in clay soil. Effects of biochar application on pH was observed only in sandy loam soil with an increase of 1.32 to 1.65 unit with rubber biochar, and 0.95 to 1.05 with mangrove biochar. Overall, it was found that sandy loam soil responded more significantly to biochar application than clay soil, and rubber biochar showed larger effects to soil when compared to mangrove biochar. The effect of size of biochar was not clearly observed.

Keywords*:* Type of biochar, sandy loam soil, clay soil, water retention, NH_4^+ retention, NO_3^- retention.

1. Introduction

Soil is a vital natural resource and non-renewable. Therefore, it is very important to maintain its quality and/or productivity for a long time. However, overexploitations such as excessive application of chemical fertilizers and intensive tillage and cultivation in attempting to increase crop production have resulted in the declination of soil fertility, reduction in soil organic matter and soil carbon content, and increase in emissions of greenhouse gases (GHGs) into the atmosphere [1-4]. Various amendments such as manure and compost have been used to maintain or improve soil property and crop productivity in agriculture [5-8]. However, manure and compost are difficult to obtain for many farmers and excessive use can cause serious groundwater and stream nutrient pollution [9] and can enhance greenhouse gases (GHGs) emissions into the atmosphere [10]. In addition, manures and composts usually contain pathogens, heavy metals and pharmaceuticals [9]. In contrast to manure and compost, biochar has been recommended as soil conditioner to reduce greenhouse gas (GHG) emissions, reduce the nutrient leaching, improve and maintain the soil fertility and the crop yield [9, 11-16].

Biochar, a carbon-rich material, is a product of thermal decomposition of biomass such as crop residues and other wastes, woodchips and animal manures in a restricted or low level of oxygen (O_2) condition [10,15,17]. Carbon in biochar is resistant to biological and chemical degradation when compared to other organic compounds [18]. Biochar has been recommended for improving soil health, simultaneously reducing pollution, reducing fertilizer use in agriculture, mitigating greenhouse gas emissions and enhancing soil carbon sequestration [19-21]. These beneficial effects of biochar for soil improvement are attributed to its high surface areas and porosities, which result in reduced bulk density of soil and enhanced soil ventilation. The high porosities allow the retention of water and nutrients, and increases the soil sorption properties [22-25]. The increased soil water holding capacity and nutrients content in soil may give strength to the application of biochar as a climate change adaption tool [26]. Most of biochar have alkaline pH therefore offers some degree of acid-neutralizing capacity through the negative charge on its surface. These properties can buffer the acidity in soils and provide a proper condition for microbial activity in acidic soil [27]. The amendment with biochar increases the soil cation exchangeable capacity (CEC) due to biochar has abundant surface area, high pore-space, and various charges that have the potentials to increase base saturation percentage when added to the soil [23]. However, depending on the feedstocks from which biochar is derived and pyrolysis conditions such as temperature and time, properties and characteristics of biochar such as the amount of carbon and nutrient content vary greatly [28-29]. In this regard, a careful consideration of the characteristics related to each specific biochar and its effects is necessary. Complicated interactions between soil texture and biochar may alter for instance water holding capacity and nutrient retention capacity after being applied with the same biochar in different soil types [14, 30-31]. However, scientific studies aiming to compare biochar derived from different feedstocks but applied in site-specific soil conditions are rare. This research was aimed to investigate the biochar which was produced from different feedstocks (mangrove and rubber) and their interactions on different soils (clay and sandy loam) in terms of the soil water adsorption and retention, soil nutrient leaching and soil properties (pH and CEC).

2. Materials and Method

2.1 Materials

Depending on the physicochemical properties of the soil, soil water and nutrients retention may respond to biochar application differently. Thus, two different soil types were used for this study (sandy loam soil and clay soils). Soil samples were collected from the 0-20 cm soil layer from agricultural field, KMUTT Ratchaburi Campus, Ratchaburi province (sandy loam soil) and Tha Nat sub-strict, Damnoen Saduak district, Ratchaburi province (clay soil) in Thailand. The soil samples were air-dried, crushed, passed through a 2 mm sieve, sealed in bags and stored at room temperature until use. The detailed properties of soils are presented in Table (1).

The two commercially available biochars were used in this study; (1) mangrove biochar (MB) produced by Yisarn Community, Samut Songkram Province, and (2) rubber biochar (RB) obtained from the commercial producer at Pru Din Na Subdistrict, Khlong Thom District, Krabi Province. Both biochars were produced at a temperature of approximately 500-700°C with very low oxygen by a local pyrolysis plant (Mound Kiln). Biochar was crushed and passed through 1 mm sieve and 5 mm sieve before mixing with soil sample for the incubation study. The chemical and physical properties of mangrove and rubber biochars including pH, surface area, porosity, percentage of total carbon and nitrogen, and cation exchange capacity (CEC) are presented in Table 2.

Table 1. Basic soil properties.

Parameters	Soil Types	
	Clay	Sandy Loam
Moisture at field sampling (% by weight)	12.5	0.54
Bulk Density (g cm^{-3})	1.63	1.46
pH (1:1 H_2O)	7.52	5.65
EC (dS m^{-1})	0.6	0.03
CEC (cmol kg^{-1})	36.72	0.02
Total N (%)	0.15	0.14
Available P (mg kg^{-1})	5.52	5.62
Available K (mg kg^{-1})	92	32.1
Organic Matter (%)	0.92	1.11
Organic C (%)	0.37	0.48
Humus (%)	0.63	0.83

2.2 Experimental design

An incubation experiment was conducted (at 30±1°C for 7 days) in the laboratory. The experiment was carried out in a series of specially designed polyvinyl chloride (PVC) columns (50 cm long, 7.5 cm internal diameter). A PVC end cap having a drilled hole at the center was fixed at the bottom and 3 mm diameter of drainage silicon tube was inserted into the hole at the end of each column. Before adding the soil-biochar mixture, cheesecloth was placed at the bottom of each column to create or facilitate free drainage and to prevent soil loss. Each soil column was packed with 1.78 kg (oven-dry basis) of soil along with two different types of biochar; mangrove (MB), rubber (RB) and two different sizes of biochar; 1 mm and 5 mm at application rate of 0 ton ha^{-1}, 20 ton $ha^{-1}$and 40 ton ha^{-1}. Before mixing the soil and biochar, the biochar was evenly placed on the surface of the soil. Mixing was carried out by hand and a shovel evenly for 30 times. Then to add the soil-biochar mixture into the PVC column, a small shovel was used to avoid soil losses and to get the uniform packing. The top of the soil layer was then covered with cheesecloth and filter paper to distribute water evenly over the surface. A beaker was placed under the drain opening for collecting the leachate draining out from the bottom of the column.

The columns were subjected to one of the following treatments for each soil when applied with each biochar separately: (1) no biochar application (as control, CON), (2) 1 mm size of biochar applied at 20 ton ha^{-1}; ($T_{20,1}$), (3) 5 mm size of biochar applied at 20 ton ha^{-1}; ($T_{20,5}$), (4) 1 mm size of biochar applied at 40 ton ha^{-1}; ($T_{40,1}$), and (5) 5 mm size of biochar applied at 40 ton ha^{-1}; ($T_{40,5}$). There were three replicates (n=3) for each treatment. After packing, all soil columns were saturated with distilled water (300 ml) for 24 hours to have a homogenously moist column. During the leaching period, 300 ml of distilled water was added into soil-biochar columns by separating into 3 times per day as 50 ml, 100 ml, and 150 ml at 0 min, 10 min and 40 min, respectively. Leachate was collected and its amount was recorded at 1 hour, 2 hours, 3 hours, 5 hours, 8 hours, and 24 hours. The leachate samples were stored in the dark at -16°C in refrigerator prior to analysis. The leachate solution was also analyzed for cations (NH_4^+) and anions (NO_3^-) by using Ion Chromatography Spectrophotometry (as described in Guidelines for Acid Deposition Monitoring in East Asia, March 2000) [32], pH (HANNA 221 pH Meter) and CEC by Ion Chromatography Spectrophotometry as described in recommended methods for determining soil cation exchange capacity (Ross, 1995) [33]. Water retention was quantified by using the following equation (Eq1).

$$\text{Water Retention (\%)} = \frac{Added\ Water\ (ml) - Leached\ Out\ Water\ (ml)}{Added\ Water\ (ml)} \times 100\ \% \qquad (1)$$

2.3 Statistical analysis

All experimental data were statistically analyzed by using IBM SPSS (SPSS Inc., Chicago, IL, USA) statistical software program version 21 and expressed as means of three replicates. Data were analyzed using one-way analysis of variance (ANOVA) and differences between treatments means were tested using Ducan multiple range test (DMRT) at 95% confident level (p ≤0.05).

Table 2. Properties and elemental composition of biochar.

Biochar property		Biochar Feedstocks	
		Mangrove	Rubber
Surface area (m^2 g^{-1})		74.35 (1 mm), 36.20 (5 mm)	365.27 (1 mm), 135.48 (5 mm)
Pore volume (cm^3 g^{-1})		43.03 (1 mm), 1.24 (5 mm)	1.38 (1 mm), 1.12 (5 mm)
VM[a] (%)		35.27	14.97
FC[b] (%)		63.01	80.31
Ash (%)		1.71	4.72
HHV[c] (cal g^{-1})		6799	7374
CEC (cmol kg^{-1})		38.63	33.62
pH (1:1 H_2O)		7.75	10.4
EC (dSm^{-1})		0.59	0.68
Elemental composition (%)	C	70.61	86.87
	H	3.78	3.14
	O	0.29	0.61
	N	0.32	0.39
	P	0.08	0.1
	K	0.21	0.48

[a]VM; volatile matter, [b]FC; Fixed carbon, [c]HHV High heating value.

3. Results and Discussion

3.1 Biochar effects on soil pH

In the case of pH, it was found that soil types responded differently to biochar application. In clay soil, the pH change was not significant ($p > 0.05$) compared to the control treatment when amending with both types of biochar (Table 3). There was no effects of the size nor application rate of mangrove biochar on soil pH. This was in part due to the relatively high pH level (7.5) of the original soil (Table 1) and indicates the relatively high buffering capacity of clay soil even applied with high pH biochar (rubber biochar). In sandy loam soil, the original soil pH was significantly lower than that of the clay soil. When both biochar types were added, its acidic soil pH was markedly ($p \leq 0.05$) increased; by 0.95 to 1.05 units with mangrove biochar and 1.32 to 1.65 units with rubber biochar, when compared to the control treatment (Table 3). Moreover, there was also no effects of the size nor application rate of biochar on soil pH. Thus, feedstock can greatly affect biochar properties and the effects had significantly alter the original pH values of soils. The degree of final soil pH change is depending on the pH of biochar and original pH of soils. In this study, high pH of rubber biochar had higher impacts on soil pH when compared to mangrove biochar. In addition to this, we found that rates of application and sizes of biochar did not have any significant effects on changing pH of both soils. Previous study reported that the ability to change soil pH by biochar is well correlated with the biochar ash content in which the higher ash content of biochar resulted in higher soil pH [17]. In another study [34], it was also observed that high content of ash in biochar indicating the higher accumulation of inorganic minerals could raise soil pH, EC, and CEC of amended soils. The higher ash content of rubber biochar and its impacts on pH of both soil types are in line with these previous reports. These results reveal that biochar can be used to increase soil pH, but the magnitude of pH change depends on the original soil pH and the pH of biochar itself.

3.2 Biochar effects on soil cation exchangeable capacity (CEC)

The cation exchange capacity (CEC) of the soil is the measurement of how good cations (Ca^{2+}, Mg^{2+}, K^{+}, etc.) are bound in the soil. The CEC value indicates the capacity of soil to retain available soil nutrients, thus is a useful parameter for soil and crop management. Similar to the case of soil pH, we found that the effects of biochar on CEC varied on soil types (Table 4). Sandy loam soil amended with mangrove biochar was resulted in remarkably higher CEC ($p \leq 0.05$) while there was no significant effect in case of clay soil in comparison with the control treatment. The application of different rates and sizes of rubber biochar did not show a significant difference in CEC values ($p > 0.05$) in clay soil but its application in sandy loam soil had significantly higher ($p \leq 0.05$) in $T_{20,5}$ and $T_{40,5}$ treatments compared to the control treatment.

It is noted that the initial CEC values of clay soil and both types of biochar were quite similar. It is thus expected that adding biochar to clay soil would not change the CEC significantly (Table 4). However, the responses of sandy loam soil were quite different. For this soil, mangrove biochar showed much higher CEC increases when compared to rubber biochar. From the basic properties of biochar shown in Table 2, mangrove biochar has higher CEC, higher pore volume and volatile matters than that of the rubber biochar. Other biochar properties such as surface area, ash content, and fixed carbon are comparable between these two biochars. The high porosity and high surface charge density have been suggested to enable the retention of ions on biochar surface [23, 27]. However, this was not in our case. When applied to clay soil, rubber biochar with much higher surface area had less impacts on CEC changes than mangrove biochar. This was partly due to the initially high CEC of clay soil. The previous study [35] also reported that biochar addition did not increase the CEC of soil with a relatively high initial CEC though it increased the CEC of soils that had relatively low initial CEC. The incorporation of biochar increased the CEC of an acidic soil when the base cations exchanged with exchangeable Al^{3+} and H^{+} on soil negative-charge sites and thus decreased soil exchangeable acidity and increased soil exchangeable base cations [36]. Thus, soil pH was also another important reason for the increase of soil cation exchangeable capacity, particularly for that observed in sandy loam soil.

3.3 Biochar effects on soil water retention

The response of water retention to the application of biochar depends on biochar application rate, its particle size, and feedstock type as well as soil types (Table 5). The results in Table (5) are for Day 1 only because the soil was already saturated with water and/or reached the equilibrium during the first day. It means that the total amount of leachate from each treatment in the following days from Day 2 to Day 7 was almost the same to the amount of added water.

Table 3. Effects of mangrove and rubber biochar application on the pH of clay and sandy loam soils.

Treatment	pH value			
	Clay Soil		Sandy Loam Soil	
	Mangrove Biochar	Rubber Biochar	Mangrove Biochar	Rubber Biochar
CON	(7.54 (0.05^{a}A)	7.53 (0.16^{a}A)	5.72 (0.10^{b}B)	5.83 (0.09^{b}B)
$T_{20,1}$	7.56 (0.10^{a}A)	7.55 (0.06^{a}A)	6.68 (0.04^{a}C)	7.18 (0.17^{a}B)
$T_{20,5}$	7.53 (0.10^{a}A)	7.58 (0.02^{a}A)	6.67 (0.05^{a}C)	7.15 (0.22^{a}B)
$T_{40,1}$	7.59 (0.04^{a}A)	7.59 (0.12^{a}A)	6.72 (0.08^{a}C)	7.32 (0.17^{a}B)
$T_{40,5}$	7.57 (0.11^{a}A)	7.61 (0.05^{a}A)	6.77 (0.09^{a}C)	7.48 (0.32^{a}B)

Data are means (SD) (n=3). Upper case and lowercase letters are used to compare the effects of treatments, and of the biochar types, respectively. Mean values with different uppercase letters in the same column are significantly different ($p \leq 0.05$). Mean values with different lowercase letters in the same row are significantly different ($p \leq 0.05$).

Table 4. Effects of biochar application on the soils cation exchangeable capacity (CEC).

Treatment	**CEC (cmol kg^{-1})**			
	Clay Soil		**Sandy Loam Soil**	
	Mangrove Biochar	**Rubber Biochar**	**Mangrove Biochar**	**Rubber Biochar**
CON	36.33 (0.71^{b}A)	36.80 (2.87^{a}A)	0.02 (0.01^{b}B)	0.02 (0.01^{b}B)
$T_{20,1}$	38.45 (1.91^{ab}A)	37.64 (1.17^{a}A)	0.32 (0.11^{a}B)	0.03 (0.00^{ab}C)
$T_{20,5}$	38.53 (1.41^{ab}A)	37.82 (3.93^{a}A)	0.39 (0.14^{a}B)	0.05 (0.02^{a}C)
$T_{40,1}$	39.11 (2.45^{ab}A)	37.99 (3.13^{a}A)	0.48 (0.23^{a}B)	0.03 (0.00^{ab}C)
$T_{40,5}$	40.12 (2.14^{a}A)	38.79 (1.95^{a}A)	0.50 (0.17^{a}B)	0.05 (0.02 ^{a}C)

Data are means (SD) (n=3). Upper case and lowercase letters are used to compare the effects of treatments, and of the biochar types, respectively. Mean values with different uppercase letters in the same column are significantly different ($p \leq 0.05$). Mean values with different lowercase letters in the same row are significantly different ($p \leq 0.05$).

Generally, the biochar application increased water retention capacity of soil when compared with the corresponding controls. For mangrove biochar, the water retention of clay soil was increased by 2.6, 4.6, 5.3 and 5.11% for $T_{20,1}$, $T_{20,5}$, $T_{40,1}$, and $T_{40,5}$ treatments, respectively, compared to the control (CON). In sandy loam soil, it was increased by 2.1, 1.0, 6.1 and 5.44% for $T_{20,1}$, $T_{20,5}$, $T_{40,1}$, and $T_{40,5}$ treatments, respectively. The statistical analysis shows that water retention of clay soil with the application at 20 ton ha^{-1} ($T_{20,1}$ and $T_{20,5}$) was not different ($p>0.05$) while this was significantly increased ($p\leq0.05$) with the application rate of 40 ton ha^{-1} ($T_{40,1}$ and $T_{40,5}$). In sandy loam soil, $T_{40,1}$ showed significantly increased ($p\leq0.05$) but other treatments did not cause any significant change when compared with the control. As a result, there was no significant difference in soil water retention under different sizes of mangrove biochar in both soils. For rubber biochar, the water retention of clay soil was increased relative to control by 6.9, 5.8, 12.4, and 11.9% in $T_{20,1}$, $T_{20,5}$, $T_{40,1}$ and $T_{40,5}$, respectively and in sandy loam soil, it was increased 5.3, 5.1, 11.0, 15.2% in $T_{20,1}$, $T_{20,5}$, $T_{40,1}$, and $T_{40,5}$, respectively. The result also shows that rubber biochar application at 20 ton ha^{-1} ($T_{20,1}$ and $T_{20,5}$) did not significantly increase ($p>0.05$) soil water retention while it significantly increased water retention ($p\leq0.05$) at 40 ton ha^{-1} application rate ($T_{40,1}$ and $T_{40,5}$).

Previous studies have indicated that generally biochar application to soil have resulted in improving soil water retention capacity, available water content (AWC), and plant available water [31, 37-41]. In our study, the significant increase in soil water retention was observed only at high application rate (40 ton ha^{-1}, Table 5). This was true regardless of sizes. Because the smaller biochar particles contain a high specific surface area per unit of mass [42], when the biochar with a high specific surface area is incorporated into the soil it contributed to increasing the soil surface area to absorb water [43]. However, we did not observe such effects and this was probably due to the amount was still not sufficient to have significant effects on water retention. This was true for both 1 mm and 5 mm particle size of both biochar. Therefore, to have the desirable effects on water retention, it is the application rate of biochar but not the size and type that may be the key determinants. In addition, from these results, it can be also said that in both soils, the application of rubber biochar indicates a better water retention capacity than mangrove biochar application.

3.4 Biochar effects on nutrients leaching

3.4.1 Ammonium (NH_4^+)

It is apparent that regardless of types of soil and biochar, application rate and size of biochar, the sole application of biochar was resulted in lesser about of NH_4^+ leached from soils (Fig. 1). However, when looks into details the capacity of biochar to retain NH_4^+ and the interactions between biochar and soils varied. For example, higher application rate (40 ton ha^{-1}) and bigger sizes (5 mm) showed higher capacity to retain NH_4^+ when compared to low application rate (20 ton ha^{-1}) and smaller size (1 mm). In this experiment, when biochar was freshly added into the soil, the significant ($p\leq0.05$) lower NH_4^+ leaching than the CON was observed after day 5 leaching progress under the mangrove biochar application and after day 3 under the rubber biochar application in both soils (Fig. 1).

For clay soil, mangrove biochar treatments reduced ($p\leq0.05$) the leaching of ammonium ions compared to the control treatment (Fig.1a). The NH_4^+ losses of 0.07 mg from both $T_{20,1}$ and $T_{20,5}$, 0.06 mg from $T_{40,1}$ and 0.05 mg from $T_{40,5}$ were found on day 7. The results showed that the cumulative leaching losses of soil NH_4^+ significantly reduced ($p\leq0.05$) when applied with 5 mm size and at rate of 40 ton ha^{-1} when compared to other rates and sizes. Rubber biochar addition was also resulted in the decreased leaching of NH_4^+ from the clay soil compared to the control treatment ($p\leq0.05$) and the cumulative losses of NH_4^+ through leaching decreased with the increasing the amount of biochar application (Fig. 1b). For sandy loam soil, biochar treatments also significantly decreased ($p\leq0.05$) the NH_4^+ leaching compared to the control treatment (Fig. 1c and 1d). However, for mangrove and rubber biochar there was no significantly difference ($p>0.05$) in the cumulative NH_4^+ leaching among the biochar treatments though the leaching rate slightly decreased with the increasing mangrove biochar application rate.

After amending with mangrove biochar in sandy loam soil, the NH_4^+ retention was increased relative to control (CON) by 9.77, 9.29, 12.14 and 10.34% in $T_{20,1}$, $T_{20,5}$, $T_{40,1}$, and in $T_{40,5}$, respectively. For rubber biochar application, these were 19.11, 13.07, 20.96, and 18.67% compared to the control in $T_{20,1}$, $T_{20,5}$, $T_{40,1}$, and $T_{40,5}$, respectively. Furthermore, the highest NH_4^+ retention of clay soil under the addition of mangrove biochar was found in $T_{40,5}$ (41.49%), followed by $T_{40,1}$ (30.97%), $T_{20,5}$ (23.56%), and $T_{20,1}$ (19.63%), respectively, and under the rubber biochar application was also found in $T_{40,5}$ (48.59%), followed by $T_{40,1}$ (45.18%), $T_{20,5}$ (29.05%), and $T_{20,1}$ (27.72%), respectively.

The effects of biochar on leaching loss of NH_4^+ from soil have been reported in various studies but direct comparison on types of soil and of biochar is rare. The results described above and shown in Fig. 1 indicate the followings; 1) the primary features standing out from the overall results are the different responses between soil types, 2) size of biochar have a clear effect only in case of clay soil, indicating the interactions between clay soil particle, biochar and NH_4^+, 3) application rate of biochar also affects NH_4^+ retention and this was clear only in the case of clay soil. The effects of biochar on NH_4^+ retention can be explained by the fact that biochar can adsorb NH_4^+-N predominantly through its high CEC [44]. Studies have found that biochar can increase the pore volume of soil [38,45]. The increase in surface area and pore space with biochar application was critical to increasing the ability of the soil to retain the nutrients. The study of Downie et al. [26] also reported that the nutrient retention capability of biochar is attributed to its great surface area to provide adsorption sites for inorganic nutrients.

3.4.2 Nitrate (NO_3^-)

Unlike NH_4^+, the effects of biochar application on nitrate leaching was immediately observed from Day 1. When biochar was added to soil, significantly ($p\leq0.05$) lower NO_3^- leaching than the CON was observed (Fig. 2).

Table 5. The response of clay soil and sandy loam soil water retention (ml) to biochar types.

Treatment	Water Retention (ml)			
	Clay Soil		Sandy Loam Soil	
	Mangrove Biochar	Rubber Biochar	Mangrove Biochar	Rubber Biochar
CON	154 (11^b^A)	165 (7^b^A)	99 (4^b^C)	109 (6^c^C)
$T_{20,1}$	162 (6^ab^A)	186 (8 ^ab^A)	106 (17^ab^D)	122 (17^bc^C)
$T_{20,5}$	168 (5^ab^B)	182 (11^ab^A)	102 (1^ab^D)	121 (8^bc^C)
$T_{40,1}$	170 (11^a^B)	202 (12^a^A)	118 (6^a^D)	139 (7 ^ab^C)
$T_{40,5}$	170 (1^a^B)	201 (15^a^A)	108 (5^ab^D)	152 (11^a^C)

Data are means (SD) (n=3). Upper case and lowercase letters are used to compare the effects of treatments, and of the biochar types, respectively. Mean values with different uppercase letters in the same column are significantly different ($p\leq0.05$). Mean values with different lowercase letters in the same row are significantly different ($p\leq0.05$).

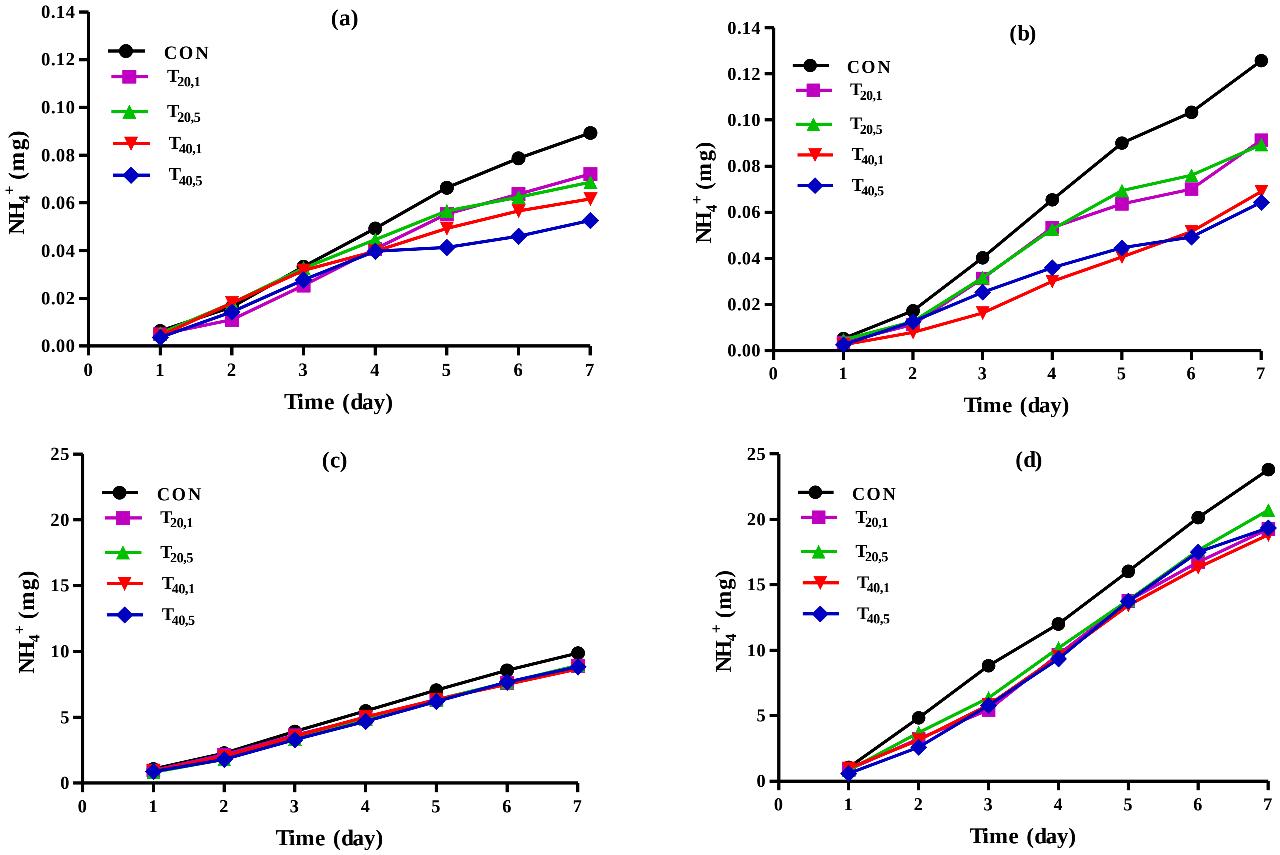

Figure 1. Cumulative ammonium (mg) leaching from CON, $T_{20,1}$, $T_{20,5}$, $T_{40,1}$, and $T_{40,5}$ from Day1 to Day7; (a) mangrove biochar application in clay soil, (b) rubber biochar application in clay soil, (c) mangrove biochar application in sandy loam soil, and (d) rubber biochar application in sandy loam soil.

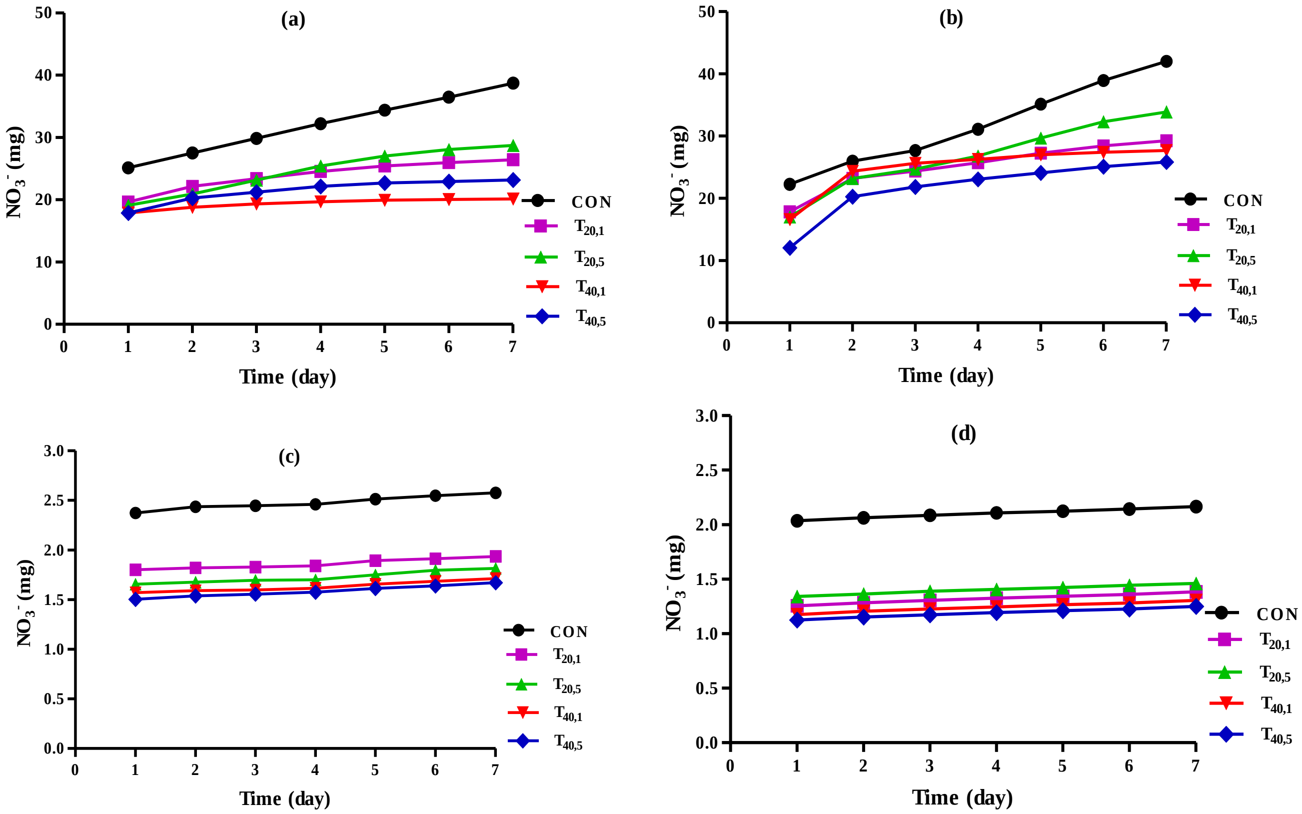

Figure 2. Cumulative nitrate (mg) leaching from CON, $T_{20,1}$, $T_{20,5}$, $T_{40,1}$, and $T_{40,5}$ from Day1 to Day7. (a) mangrove biochar application in clay soil, (b) rubber biochar application in clay soil, (c) mangrove biochar application in sandy loam soil, and (d) rubber biochar application in sandy loam soil.

Table 6. Effects of biochar size and application rate on soil pH, CEC, and retention of water, NH_4^+, NO_3^- in clay and sandy loam soils (95% confidence interval).

Soil Types	Parameters	Mangrove Biochar: Biochar vs Non-biochar	Mangrove Biochar: Size	Mangrove Biochar: App. Rate	Rubber Biochar: Biochar vs Non-biochar	Rubber Biochar: Size	Rubber Biochar: App. Rate
Clay	pH	×	×	×	×	×	×
	CEC	$T_{40,5}$	×	×	×	×	×
	Water	$T_{40,1}$/$T_{40,5}$	×	×	$T_{40,1}$/$T_{40,5}$	×	×
	NH_4^+	✓	$T_{40,1}$/$T_{40,5}$	✓	✓	×	✓
	NO_3^-	✓	×	✓	✓	×	$T_{20,5}$ /$T_{40,5}$
Sandy Loam	pH	✓	×	×	✓	×	×
	CEC	✓	×	×	$T_{20,5}$ /$T_{40,5}$	×	×
	Water	$T_{40,1}$	×	×	$T_{40,1}$ /$T_{40,5}$	×	$T_{20,5}$ /$T_{40,5}$
	NH_4^+	✓	×	×	✓	$T_{20,1}$ /$T_{20,5}$	$T_{20,5}$ /$T_{40,5}$
	NO_3^-	✓	×	×	✓	×	×

Notes: *× = non-significant difference in all treatments, #✓ = significant difference in all treatments, $T_{20,1}$ = significant difference only in treatment $T_{20,1}$, $T_{20,5}$ = significant difference only in treatment $T_{20,5}$, $T_{40,1}$ = significant difference only in treatment $T_{40,1}$, $T_{40,5}$ = significant difference only in treatment $T_{40,5}$.

In clay soil with mangrove biochar, the leached NO_3^- were 26.42, 28.42, 20.13 and 23.19 mg from $T_{20,1}$, $T_{20,5}$, $T_{40,1}$ and $T_{40,5}$ treatments, respectively (Fig. 2a). Although the leaching was higher in case of 5 mm size compared to 1 mm size, the statistical analysis showed that it is the rate of application but not the size of biochar that significantly affected NO_3^- leaching ($p \leq 0.05$). For rubber biochar, the cumulative loss of NO_3^- through leaching also decreased with the increasing the amount of biochar application (Fig. 2b). As a result, $T_{40,5}$ showed the lowest NO_3^- leaching amount as 25.85 mg and followed by $T_{40,1}$, $T_{20,1}$, and $T_{20,5}$ as 27.70, 29.90, and 33.88 mg respectively. In the case of rubber biochar, NO_3^- leaching with application of 5 mm size biochar was significantly higher than that of the 1 mm size. This indicate the important of surface areas that rubber biochar was much higher than mangrove biochar, thus affecting the NO_3^- absorption. Up to about 50% of nitrate leaching was reduced when applied with 1 mm mangrove biochar at 40 ton ha^{-1} ($T_{40,1}$). This was followed by 40.22, 31.86 and 25.64% in $T_{40,5}$, $T_{20,1}$, and $T_{20,5}$ treatments, respectively. Under the rubber biochar addition, $T_{40,5}$ showed the highest NO_3^- retention capacity as 38.56% and followed by $T_{40,1}$, $T_{20,1}$, and $T_{20,5}$ as 34.07, 30.33 and 19.43%, respectively. The ability to retain anions such as NO_3^- by biochar was explained by anion exchange capacity of biochar [46]. This anion exchange can be either pH independent, which is mediated by oxygen containing functional groups such as oxonium functional groups, or pH dependent mediated by both pyridinic functional groups and non-specific proton adsorption by condensed aromatic rings. In sandy loam soil, the application of both mangrove and rubber biochar remarkably resulted in lower leaching of NO_3^- in comparison with the control treatment ($p \leq 0.05$) (Fig. 2c and 2d). Among both mangrove and rubber biochar received treatments, there was no significantly different in the relative cumulative leaching losses NO_3^-, though the leaching rate slightly decreased with the increasing biochar application rate (Fig. 2c) and (Fig. 2d). After mangrove biochar application, the retention of NO_3^- was increased relative to control by 24.44, 29.40, 32.27, and 35.17% in $T_{20,1}$, $T_{20,5}$, $T_{40,1}$, and $T_{40,5}$, respectively, and after the rubber biochar application, it was increased 36.20, 32.61, 39.81, and 42.33% in $T_{20,1}$, $T_{20,5}$, $T_{40,1}$, and $T_{40,5}$, respectively, in compared with the control.

Table 6 summarizes the effects of biochar application on key soil parameters described above. It is obvious that the significant differences in most cases were found between soil with and without biochar application, and the most affected soil properties were nutrient leaching. These results indicate the complex interactions between soil type and biochar type, the application rate and size of biochar. When biochar is used in agriculture, the appropriate application rate and its effects on key soil parameters should be tested. This results also suggest that farmers can use biochar as a potential soil amendment not only to improve soil health but also to increase soil water and nutrients absorption and retaining in soil. However, the effect of biochar application on retaining inorganic nutrients losses in soils through leaching needs to further assessed before large-scale application of biochar to agriculture fields can be recommended.

4. Conclusions

This study tested the effects of two biochars (mangrove and rubber) on soil water and nutrients adsorption and retention capacity, soil pH and soil CEC in clay soil and sandy loam soil over 7 days of leaching experiment**.** The overall results can be summarized as follows;

1) When compared with and without biochar application, biochar application affects most of the parameters tested. This is true regardless of soil types and biochar types. However, for some parameters such as water retention and ammonium retention, high application rate is required to see the effects. The pH and CEC of soil were not affected by biochar application, except high application rate in clay soil.

2) Size of biochar did not have any significant effect on changing pH and CEC of both soils as well as water and NO_3^- retention. However, NH_4^+ retention showed significant size effect at 40 ton ha^{-1} application rate of mangrove biochar in clay soil.

3) Different rate of biochar application significantly affected NH_4^+ and NO_3^- leaching in clay soil. In sandy loam soil, it was significant for water retention and NH_4^+ leaching only in the case of 5 mm size of rubber biochar application.

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