Application of Biochar and Compost Tea of Lotus Plants in the Cultivation of Green Spinach (*Amaranthus* spp.) in Non Tidal Lowland Soil

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Abstract- Non tidal lowland soil is a potential land for cultivating green spinach. Even though its natural fertility is low, the land can be improved through fertilization methods using biochar and compost tea derived from natural resources. Therefore, this research aimed to test the optimal doses of lotus compost tea and biochar by using Nitrogen-Phosphorus-Potassium (NPK) fertilizer to enhance nutrient availability in non tidal lowland soil. The results showed that the three types of fertilizers significantly interacted with the chemical properties of non tidal lowland soil (pH, N-total, P-available, K-dd), nutrient uptake of N, P, and K, growth, and green spinach yield. Meanwhile, the combination of 20 tons ha^{-1} of biochar with 40 ml tan^{-1} of lotus compost tea and 50% NPK fertilizer was the best treatment for enhancing growth, production, and nutrient uptake. This treatment reduced fertilizer use by 50% in non tidal lowland soil and NPK availability correlated positively with the uptake in green spinach plants.

Keywords: biochar, compost tea, spinach, lotus plants, non tidal lowland

I. INTRODUCTION

Non tidal lowlands are categorized as sub-optimal land used for crop cultivation (Arbi *et al.*, 2022) with two different planting conditions (Wildayana & Armanto, 2018). During the inundated and dry periods, the land is used for rice and vegetable cultivation (Ali *et al.*, 2014). According to the Director General of Agricultural Infrastructure and Facilities (PSP) in 2023, the potential of non tidal lowlands in South Sumatra reached 1.35 million hectares, and only a small portion has been used for agriculture. Soil analysis showed a pH range of 4.0-5.5 (very acidic to acidic), with P_2O_5, K_2O, and P-Bray contents classified as very low to medium. In addition, Cation Exchange Capacity (CEC) values range from very low to high (Pujiharti, 2017). The development of non tidal lowlands into agricultural land faces many limiting factors due to the classification as sub-optimal land, which has low soil fertility and productivity (Susilawati *et al.*, 2020).

The efforts to manage soil fertility chemically, biologically, and physically are achieved by applying fertilizers and soil amendments. Fertilization is an alternative for managing soil fertility to support plant growth. Research by Huda & Hidayati (2022) showed that the application of 300 kg ha^{-1} of NPK fertilizer optimized the growth and yield of green spinach compared to control treatments and lower doses. The increased demand for fertilizers drives innovation in soil fertility management using biochar as a soil amendment. The addition of biochar influences the increase in soil pH, the availability of Ca, Fe, K, Mg, Na, and P in the soil, as well as significantly enhances the growth of green spinach up to three times over two different seasons on degraded land with low fertility (Zemanová *et al.*, 2017). Compost tea is a commonly used alternative for managing soil fertility. This liquid organic fertilizer is derived from the extraction of solid compost in water using aeration or non-aeration methods (Shaban *et al*., 2015) with a pH range of 6-7 (neutral). Compost tea contains nutrients such as N, P, and K, as well as different phytohormones and beneficial microbes (El-Tahlawy, 2018).

Green spinach (*Amaranthus* spp.) is a vegetable with high nutritional value and economic potential, containing various minerals, such as Fe, Mg, K, Na, Zn, Mn, Cu, Ca, and P (Gedi *et al.*, 2017; Roberts & Moreau, 2016). Besides the mineral content, the vegetable is also high in vitamin A and β-carotene, with lower concentrations of folic acid, C, E, and K (Murcia *et al.*, 2020). Green spinach is a popular vegetable among Indonesians but the production has declined from 171,706 to 170,821 tons (BPS, 2022). An alternative to increasing plant production is improving soil fertility to support land and crop productivity (Havlin & Heiniger, 2020).

Biochar and compost tea production can use natural resources with potential as raw materials. The lotus (*Nelumbo nucifera*) is commonly found in the non tidal lowland areas of Ogan Ilir Regency, South Sumatra, where 35% of the region consists of waterlogged swamps (Ridhowati *et al.*, 2023). According to Chen *et al.* (2014), lotus leaf extract had antibacterial properties capable of inhibiting pathogen growth. Analysis has shown that lotus leaves contain various bioactive compounds and flavonoids (Chen *et al*., 2012). The biomass contains various nutrients with the potential to be used as raw materials for fertilizer production (Liu *et al*., 2023) and planting media (Kanaga & Deivanayaki, 2017). Testing related to the use of lotus as a raw material for producing biochar and compost tea is rare. Therefore, this research aimed to examine the potential of biochar and compost tea in improving soil fertility, reducing inorganic fertilizers, as well as enhancing the growth and production of green spinach cultivated on soil from non tidal lowlands.

II. MATERIALS AND METHODS

Research Location and Time

Initial soil analysis was conducted at Soil Science Laboratory, Faculty of Agriculture, Sriwijaya University. Post-planting soil and tissue analyses were performed at BPSIP (Agricultural Instruments Standardization Agency) Bengkulu. Fertilizer testing was carried out in the Greenhouse of the Faculty of Agriculture, Sriwijaya University from October 2023 to March 2024.

Production of Lotus Biochar and Compost Tea

Biochar and compost tea were made from lotus plants growing in the swamps of Pemulutan Induk District, Ogan Ilir Regency, South Sumatra Province. In addition, lotus biochar was obtained from the dried stems of the plant and the production was carried out using a kiln method. The stems were cut into 5 cm pieces and placed in the kiln at a temperature of 200℃ for 1-1.5 hours until the material turned black. In this context, the obtained biochar was sieved to ensure uniform size.

Lotus compost is made from leaves mixed with cow manure in a 5:1 ratio (w/w). The process takes approximately one month for the compost to mature, indicated by a texture and smell similar to typical soil. The mature lotus compost is placed in a filtration cloth and soaked with a compost-to-water ratio of 1:5 (w/v) for 72 hours. Meanwhile, the compost tea is produced aerobically using an aerator.

Fertilizer Testing on Green Spinach Cultivation

The application doses of compost tea and lotus biochar, combined with NPK fertilizer, were tested on green spinach cultivation. This was achieved using soil from non tidal lowlands and the Factorial Randomized Block Design (FRBD) consisted of three factors. The first factor was the dose of lotus biochar with three levels of treatment, namely 0, 10, and 20 tons ha^{-1}. The second factor was the dose of lotus compost tea with three levels of treatment, namely 0, 20, and 40 mL plant^{-1}. Meanwhile, the third factor was the recommended NPK dose with three levels of treatment, including 0, 50, and 100%. The recommended NPK dose was 300 kg ha^{-1} and the cultivation process commenced with preparing the growing media using non tidal lowland. The soil was limed at a dose of 8.5 tons ha^{-1} before applying biochar according to the treatment. Subsequently, seedlings were grown to 14 days of age, transplanted and maintained for 35 days post-transplanting until harvest. NPK fertilizer was also applied to the soil around the plants at one and two weeks after transplanting. Compost tea was applied when the plants were 7, 14, 21, and 28 days old after transplanting.

Soil Analysis

Initial and post-planting soil analyses included soil pH, organic carbon content (c-organic), total nitrogen (N-total), available phosphorus (P-available), and potassium level (K-dd). These analyses were conducted at the Soil Science Laboratory, Faculty of Agriculture, Sriwijaya University, and the BPSIP Bengkulu Laboratory. Soil pH was measured using an electrode with a meter, and c-organic was determined using the Walkey and Black method. Meanwhile, N-total, P-available, and K-dd were analyzed using Kjeldahl, Bray I, and Morgan-Wolf methods, respectively.

Plant Analysis

Plant growth and production were observed throughout the cultivation process until harvest. The observations included plant height, number of leaves, leaf greenness, fresh shoot weight, and N, P, and K content. Tissue analysis was conducted at the BPSIP Bengkulu Laboratory, where N, P, and K were analyzed using semi-micro Kjeldahl, dry ashing, and wet ashing methods with a mixture of concentrated HNO_3 and $HClO_4$ acids. The concentrations of P and K were measured using a UV-VIS spectrophotometer. The nutrient uptake was calculated by multiplying the dry weight of the plants by the nutrient content.

Data Analysis

Data were processed using R Studio application and an Analysis of Variance (ANOVA) was conducted to assess the effects of the treatment on the observed variables. The treatments with significant effects were followed by the Least Significant Difference (LSD) test with $P \leq 0.05$ to determine differences between the levels. Meanwhile, correlation regression tests were performed on soil N and P variables.

III. RESULT AND DISCUSSION

Initial Soil Analysis

According to the initial soil analysis, the characteristics of lowland swamp soil include pH of 3.52, high c-organic at 3.48%, moderate N-total content of 0.32%, high P-available content of 13.17 mg kg^{-1}, low K-dd at 0.12 cmol kg^{-1}, moderate CEC of 20 cmol kg^{-1}, and very low Al-dd at 0.63 cmol kg^{-1}. Based on the soil criteria, the overall fertility of non tidal lowland soil used was low for crop cultivation.

The physical and chemical conditions classify non tidal lowlands as suboptimal land, characterized by high soil acidity and unpredictable waterlogging (Handayani *et al.*, 2023). The soil fertility and crop productivity are typically low, supported by analyses showing low pH and nutrient content (Widowati *et al.*, 2022). These factors significantly influence the growth and yield of crops cultivated in the soils. Therefore, management practices including organic and non-organic fertilizers are necessary to improve fertility and productivity in non tidal lowland areas.

Based on Energy-Dispersive X-ray Spectroscopy (EDS) testing, lotus biochar contains K, P, Ca, Mg, and S. Fourier Transform Infrared (FTIR) analysis shows that the structure of lotus biochar contains C=C (aromatic), C-OH (phenol), and C-H (lignin, cellulose, and hemicellulose) functional groups (Gofar *et al.*, 2023).

Soil pH Value

There is an increase in soil pH is reported after planting or applying fertilizer. This result is consistent with Islam *et al*. (2017) where the application of organic fertilizers can increase soil pH.

The soil pH values, which remained acidic until the end of the planting period, are influenced by plant metabolism processes that indirectly influence changes. Research by Ferdush & Paul (2021) suggested that CO_2, generated through plant respiration, increases the amount of the dissolved gas in soil water, leading to acidification. The LSD test at a 5% significance level shows that the combination of treatments, 0 ton ha^{-1} biochar + 40 mL plant^{-1} lotus compost tea + 0% NPK fertilizer, resulted in the highest average soil pH value of 5.15. The addition of 40 mL plant^{-1} lotus compost tea was effective in increasing soil pH without biochar or NPK fertilizer addition.

Table 1. Interaction of lotus biochar, compost tea, and NPK on soil pH value

Treatment		Soil pH Value		
		NPK Dose (N) (%)		
Biochar (ton ha^{-1})	***CT* (ml tan^{-1})**	**0**	**50**	**100**
0	**0**	4.35 ^{q}	4.79 ^{g}	4.45 ^{op}
	20	4.56 ^{l}	4.92 ^{e}	4.46 ^{p}
	40	5.15 ^{a}	4.53 ^{m}	5.08 ^{b}
10	**0**	4.68 ^{j}	5.01 ^{c}	4.75 ^{op}
	20	4.49 ^{no}	4.51 ^{mn}	4.96 ^{d}
	40	4.48 ^{no}	4.68 ^{j}	4.72 ^{i}
20	**0**	4.85 ^{f}	4.48 ^{no}	4.63 ^{k}
	20	4.66 ^{j}	4.54 ^{lm}	4.52 ^{m}
	40	4.78 ^{gh}	4.75 ^{hi}	4.87 ^{f}
LSD 5%		0.050		

Note: Numbers followed by the same letter in the same row or column indicate no significant difference in LSD test at 5%.

Compost and vermicompost tea has been shown to increase soil pH for plant cultivation (El-Shaieny *et al*., 2022; Fouda & Niel, 2021). The lotus used has a neutral pH ranging from 6.27 to 7.00. Due to the neutral pH, Amer (2017) stated that compost tea contained base cations exchanged in moderate to high categories. The compost contains various types of important microbes to improve soil fertility (Nur *et al*., 2023). Meanwhile, the presence of base cations and soluble microbes contributes to increasing soil pH. According to Lladó *et al.* (2017), microbes maintain soil pH balance by decomposing organic matter, producing acids or bases for altering pH values.

Organic Carbon, N, P, and K Content of Soil

Based on the LSD test at a 5% significance level, the combination of treatments 20 ton ha-^{1} biochar + 40 mL plant^{-1} lotus compost tea + 50% NPK fertilizer resulted in highest average c-organic content of 10.99% (Table 2), highest N-total content, and P-available, as well as K-dd of 0.61% N (Table 3), 10.01 mg kg^{-1} P (Table 4), and 1.00 cmol©kg^{-1} K (Table 5). After planting, the c-organic content ranged from 7.49% to 10.99% and was categorized as very high. The content enhances plant nutrient availability through humification processes including microorganism activities in N fixation from the air (Guo *et al.*, 2020). In this context, organic matter plays a crucial role in improving soil fertility, and nutrient availability, as well as enhancing pH (Agbede, 2021).

Hammad *et al.* (2020) stated that the addition of organic fertilizers to the soil could increase c-organic. This statement was consistent with the result, where the addition of biochar and lotus compost tea at the highest doses significantly increased the content. Biochar is a carbon-rich material (Tenic *et al.*, 2020) and the addition benefits soil quality by increasing c-organic content, leading to a positive interaction (El-Naggar *et al.*, 2018). Meanwhile, compost tea contains microorganisms that play a role (Godishala & Kumari, 2019) in enhancing soil c-organic. The results show that the combination of biochar and lotus compost tea with 50% NPK tends to be more effective in increasing the content than 100% NPK treatment. In this context, higher NPK application rates reduce soil c-organic levels. Menšík *et al.* (2018) suggested that long-term use of inorganic NPK fertilizers decreased soil c-organic due to higher mineralization rates.

Table 2. Interaction of biochar, lotus compost tea, and NPK on soil c-organic content

Treatment		Soil C-organic Content (%)		
		NPK Dose (%)		
Biochar (ton ha^{-1})	**CT (ml tan^{-1})**	**0**	**50**	**100**
0	**0**	7.49 ^{x}	7.52 ^{w}	7.96 ^{u}
	20	7.54 ^{v}	9.58 ^{k}	9.72 ^{i}
	40	8.94 ^{o}	10.05 ^{e}	9.74 ^{h}
10	**0**	8.50 ^{t}	10.00 ^{f}	10.57 ^{c}
	20	8.62 ^{s}	9.46 ^{n}	9.73 ^{hi}
	40	8.63 ^{s}	9.53 ^{l}	10.87 ^{b}
20	**0**	8.83 ^{r}	9.49 ^{m}	9.61 ^{j}
	20	8.88 ^{q}	9.87 ^{g}	10.21 ^{d}
	40	8.90 ^{p}	10.99 ^{a}	10.85 ^{b}
LSD 5%		0.016		

Note: Numbers followed by similar letter in the same row or column show no significant difference in the LSD 5% testing.

Table 3. Interaction of biochar, lotus compost tea, and NPK on soil N-total content

Treatment		Soil N- total (%)		
		NPK Dose (%)		
Biochar (ton ha^{-1})	**CT (ml tan^{-1})**	**0**	**50**	**100**
0	**0**	0.03 ^{i}	0.04 ^{hi}	0.04 ^{hi}
	20	0.03 ^{i}	0.05 ^{gh}	0.06 ^{g}
	40	0.04 ^{hi}	0.48 ^{cd}	0.45 ^{e}
10	**0**	0.03 ^{i}	0.47 ^{d}	0.49 ^{c}
	20	0.03 ^{i}	0.04 ^{hi}	0.06 ^{g}
	40	0.03 ^{i}	0.04 ^{hi}	0.53 ^{b}
20	**0**	0.03 ^{i}	0.04 ^{hi}	0.05 ^{gh}
	20	0.03 ^{i}	0.40 ^{f}	0.48 ^{cd}
	40	0.03 ^{i}	0.61 ^{a}	0.48 ^{cd}
LSD 5%		0.012		

Note: Numbers followed by similar letters in the same row or column indicate no significant difference in the LSD 5% testing.

The soil analysis after planting still shows acidity, and some nutrient levels remain low. According to Ferdush & Paul (2021), CO_2 produced by plant respiration increases the amount of the dissolved gas in soil water through roots, leading to acidification. Meanwhile, Carillo *et al*. (2021) stated that nutrient depletion after harvest was due to plant uptake for growth and development.

Based on the criteria of the soil analysis, total N content, P-available, and soil K-dd of 0.03% to 0.61%, 0.22 to 10.01 mg kg^{-1}, and 0.29 to 1.00 cmol© kg^{-1} were classified as very low to high, very low to moderate, and low to high, respectively. The N, P, and K nutrients in the soil also increased with fertilizers, as shown in Tables 3 to 5. The extensive and continuous use of fertilizers negatively influenced soil and the environment. Meanwhile, the use of biochar and compost tea contributed to soil nutrient availability and NPK fertilization efficiency. Gao & DeLuca (2016) suggested that biochar reduced nutrient leaching, while compost tea enhanced soil availability (Makhlouf & Helmy, 2022). The combination of organic and inorganic fertilizers also improved soil fertility and productivity (Roba, 2018).

Table 4. Interaction of biochar, compost tea lotus, and NPK on P-available content in soil

Treatment		P-available in Soil (mg kg^{-1})		
		NPK Dosage (%)		
Biochar (ton ha^{-1})	**CT (ml tan^{-1})**	**0**	**50**	**100**
0	0	0.22 ^{u}	0.52 ^{p}	0.53 ^{p}
	20	0.37 ^{t}	0.60 ^{n}	1.38 ^{h}
	40	0.63 ^{m}	4.95 ^{f}	4.19 ^{g}
10	0	0.43 ^{s}	0.67 ^{l}	9.10 ^{c}
	20	0.47 ^{q}	0.55 ^{o}	0.89 ^{j}
	40	0.43 ^{s}	0.76 ^{k}	9.76 ^{b}
20	0	0.55 ^{o}	0.63 ^{m}	0.78 ^{k}
	20	0.45 ^{r}	1.05 ^{i}	6.80 ^{e}
	40	0.59 ^{n}	10.01 ^{a}	9.07 ^{d}
LSD 5%		0.013		

Note: Numbers followed by similar letters in the same row or column show no significant difference in the LSD 5% testing.

Table 5. Interaction of biochar, lotus compost tea, and NPK on soil K-dd content

Treatment		K-dd tanah (cmol© kg^{-1})		
		NPK Dosage (%)		
Biochar (ton ha^{-1})	***CT* (ml tan^{-1})**	**0**	**50**	**100**
0	0	0.29 ^{q}	0.38 ^{m}	0.38 ^{m}
	20	0.33 ^{p}	0.39 ^{m}	0.50 ^{g}
	40	0.42 ^{l}	0.52 ^{f}	0.50 ^{g}
10	0	0.36 ^{n}	0.46 ^{j}	0.59 ^{c}
	20	0.38 ^{m}	0.39 ^{m}	0.48 ^{hi}
	40	0.36 ^{n}	0.44 ^{k}	0.88 ^{b}
20	0	0.39 ^{m}	0.42 ^{l}	0.47 ^{ij}
	20	0.34 ^{o}	0.49 ^{gh}	0.54 ^{e}
	40	0.39 ^{m}	1.00 ^{a}	0.57 ^{d}
LSD 5%		0.013		

Note: Rows or columns with the same letter followed by similar letters show no significant difference in the LSD 5% testing.

Plant Height

The combination of 20-ton ha^{-1} biochar + 40mL tan^{-1} compost tea lotus + 50% NPK fertilizer produced the highest average height at 18.13 cm. However, there was no significant difference compared to the treatment of 10 tons ha^{-1} + 0 mL tan-1 of lotus compost tea + 100% NPK fertilizer (Table 6).

The combination of biochar, lotus compost tea, and NPK provides better nutrition for the growth of green spinach cultivated on non tidal lowland soil. Biochar enhances soil porosity and friability (Garg *et al.*, 2021), enabling plant roots to access nutrients and water more efficiently for growth (Wang *et al.*, 2020). Meanwhile, compost tea is a liquid organic fertilizer used to enhance nutrient availability (Bako *et al.*, 2021), This organic fertilizer also contains microbes for converting nutrients into absorbable forms for plants (Stewart-Wade,(Stewart-Wade, 2020). NPK fertilizers contain essential macro-nutrients required in significant amounts, especially N, which plays a crucial role in vegetative growth (Luo *et al.*, 2020). The treatment combinations reduce NPK fertilizer usage by up to 50%. This was consistent with Sari & Gofar (2023), where organic fertilizer application on chili plants grown in Ultisols could optimize growth.

Table 6. Interaction of biochar, lotus compost tea, and NPK on the height of green spinach plants

Treatment		Plant Height (cm)		
		NPK Dosage (%)		
Biochar (ton ha^{-1})	***CT* (ml tan^{-1})**	**0**	**50**	**100**
0	0	4.38 ^{mn}	7.13 ^{ghijkl}	6.38 ^{hijklm}
	20	5.75 ^{jklmn}	9.63 ^{efg}	10.75 ^{de}
	40	8.13 ^{fghijk}	8.88 ^{efgh}	12.75 ^{bcd}
10	0	3.38 ^{n}	10.75 ^{de}	17.50 ^{a}
	20	4.78 ^{lmn}	8.20 ^{fghij}	11.00 ^{cde}
	40	5.63 ^{klmn}	10.58 ^{def}	13.88 ^{b}
20	0	8.75 ^{efghi}	9.80 ^{ef}	9.63 ^{efg}
	20	6.50 ^{hijklm}	10.63 ^{def}	13.50 ^{bc}
	40	6.25 ^{ijklm}	18.13 ^{a}	14.00 ^{b}
LSD 5%		2.522		

Note: Identical numbers followed by the same letter within the same row or column indicate no significant difference in the LSD 5% testing.

Number of Leaves

The treatment combination of 20 tons ha^{-1} biochar + 40 mL lotus compost tea + 50% NPK fertilizer resulted in the highest average number of green spinach leaves at 19.00. However, the process did not differ significantly from the combination of 10 tons ha^{-1} biochar + 0 mL lotus compost tea + 100% NPK fertilizer, as reported in Table 7.

Table 7. Interaction of biochar, lotus compost tea, and NPK on the number of green spinach leaves

Treatment		Number of Leaves (Helai)		
		NPK Dosage (%)		
Biochar (ton ha^{-1})	**CT (ml tan^{-1})**	**0**	**50**	**100**
0	0	5.25 ^{f}	6.00 ^{ef}	5.00 ^{f}
	20	5.75 ^{ef}	6.00 ^{ef}	9.00 ^{c}
	40	7.75 ^{cde}	9.00 ^{c}	6.50 ^{def}
10	0	5.00 ^{f}	6.75 ^{def}	18.75 ^{a}
	20	5.25 ^{f}	6.75 ^{def}	7.50 ^{cde}
	40	6.00 ^{ef}	6.75 ^{def}	16.00 ^{b}
20	0	9.25 ^{c}	7.50 ^{cde}	9.50 ^{c}
	20	6.00 ^{ef}	8.50 ^{cd}	17.25 ^{ab}
	40	7.75 ^{cde}	19.00 ^{a}	18.00 ^{ab}
LSD 5%		2.039		

Note: Numbers followed by the same letter in the same row or column indicate no significant difference in the LSD 5% testing.

A crucial factor influencing leaf formation is the availability of nutrients in the soil. Biochar enhances plant growth by improving soil structure and fertility (Agegnehu *et al*., 2017). In this context, fertile soil provides nutrients for plants, supporting root growth within the soil (Schjoerring *et al.*, 2019). Compost tea also plays a role in meeting the requirements of plant nutrients. Moreover, Bako *et al.* (2021) suggested that this fertilizer contains soluble nutrients essential for leaf formation. According to Ros *et al.* (2020), the application significantly increases the average number of spinach. The leaf can be supported through the application of NPK fertilizers, which contain essential macronutrients necessary for vegetative and generative growth. In this context, organic fertilizer application yields the highest average number of spinach and optimizes NPK efficiency by 50% to 75% (Adileksana *et al.*, 2020).

Leaf Greenness Index

The treatment with 20 tons ha^{-1} biochar + 40 mL of lotus compost tea + 50% NPK fertilizer resulted in the highest average leaf greenness index of 13.53 (Table 8). Meanwhile, the leaf greenness index reflects the amount of chlorophyll present in the plant. A higher index shows more chlorophyll, which is closely related to photosynthesis and plant nutrition (Kalaji *et al.*, 2017).

The index is influenced by N (Noulas *et al*., 2018), which is essential for chlorophyll synthesis in plants (Fathi, 2022). Biochar can enhance N fixation, mineralization and immobilization, thereby increasing the availability in the soil for plants (Gao & DeLuca, 2016). Zaccardelli *et al.* (2018) reported that compost tea application increased the leaf greenness index due to N nutrients (Nur *et al*., 2023). Therefore, plant N requirements are also met through NPK fertilizer applications containing substantial amounts of the nutrient. Application of 50% recommended NPK fertilizer significantly increases the leaf greenness index of spinach plants compared to control and 100% dosage (Muhammad *et al*., 2023). Increasing the doses of biochar and lotus compost tea could save up to 50% of NPK fertilizer usage and yield a better leaf greenness index than other combinations.

Table 8. Interaction of biochar, lotus compost tea, and NPK on the leaf greenness index of green spinach leaves

Treatment		Leaf Greenness Index (SPAD unit)		
		NPK Dosage (%)		
Biochar (ton ha^{-1})	***CT* (ml tan^{-1})**	**0**	**50**	**100**
0	**0**	6.28 ^{no}	8.88 ^{ghi}	9.60 ^{ef}
	20	7.40 ^{m}	10.15 ^{cd}	8.33 ^{jk}
	40	8.70 ^{hij}	7.85 ^{lm}	10.65 ^{b}
10	**0**	6.40 ^{no}	10.40 ^{bc}	9.23 ^{fg}
	20	5.68 ^{p}	6.40 ^{no}	8.08 ^{kl}
	40	6.20 ^{o}	9.10 ^{gh}	7.45 ^{m}
20	**0**	6.48 ^{no}	8.53 ^{ijk}	10.38 ^{bcd}
	20	6.68 ^{n}	9.28 ^{fg}	7.78 ^{lm}
	40	6.48 ^{no}	13.53 ^{a}	9.93 ^{de}
LSD 5%		0.466		

Note: Identical numbers followed by similar letter in the same row or column show no significant difference in the LSD 5% testing.

The average leaf greenness index of spinach plants is classified as low (<10 SPAD units). Previous results suggested that leaves were typically characterized as yellowish at this level. However, this research reported light green color of spinach leaves due to the influence of the optiscience measuring instrument used.

Fresh Shoot Weight

The combination treatment of 20 tons ha^{-1} biochar + 40 mL tan^{-1} compost tea lotus per plant + 50% NPK fertilizer resulted in the highest average fresh shoot weight of 19.18 grams. However, there was no significant difference compared to the treatment of 10 tons ha^{-1} of biochar + 40 mL tan^{-1} compost tea lotus + 100% NPK fertilizer (Table 9). The shoot refers to the entire part of the plant above the soil surface, while the roots are the part below. In addition, the shoot consists of organs that play roles in photosynthesis, gas exchange, and transpiration (Chang *et al*., 2019). Fresh shoot weight reflects the production yield and growth of the plant. According to Matsui *et al.* (2016), better plant growth resulted in higher fresh shoot weight. In this context, good root growth enhances plant height and weight gain (Nur & Gofar, 2023).

Table 9. Interaction of biochar, compost tea lotus, and NPK on fresh shoot weight of green spinach

Treatment		Fresh Shoot Weight (g)		
		NPK Dosage (%)		
Biochar (ton ha^{-1})	**CT (ml tan^{-1})**	**0**	**50**	**100**
0	**0**	0.35 ^{n}	1.45 ^{lm}	1.50 ^{lm}
	20	0.60 ^{n}	2.08 ^{l}	5.15 ^{f}
	40	2.95 ^{jk}	6.95 ^{e}	4.83 ^{fg}
10	**0**	0.63 ^{n}	3.25 ^{ijk}	16.83 ^{b}
	20	1.03 ^{mn}	1.88 ^{l}	4.40 ^{g}
	40	0.90 ^{mn}	3.70 ^{hi}	18.75 ^{a}
20	**0**	2.03 ^{l}	2.88 ^{k}	3.60 ^{hij}
	20	0.75 ^{n}	4.18 ^{gh}	11.10 ^{d}
	40	1.78 ^{l}	19.18 ^{a}	11.93 ^{c}
LSD 5%		0.648		

Note: Numbers followed by similar letters in the same row or column show no significant difference in the LSD 5% testing.

Nur & Gofar (2023) stated that organic matter influenced the fresh weight of plants by improving soil porosity and water absorption. This was consistent with the current examination, where high biochar doses improved soil fertility. Application of compost tea at a ratio of 1:5 (v/w) and 5 tons per hectare led to higher shoot and root weights than other treatments (Banu & Tefa, 2018). The highest doses of biochar and compost tea lotus combined with NPK fertilizer formed a balanced soil nutrition and conditions, optimizing spinach plant production.

Nutrient Uptake of N, P, and K by Plant Tissues

The combination treatment of 20 tons ha^{-1} biochar + 40 mL plant^{-1} compost tea lotus + 50% NPK fertilizer formed the highest average nutrient uptake of N, P, and K by plants, which were 9.08 g plant^{-1} (Table 10), 0.947 g plant^{-1} (Table 11), and 6.073 g plant^{-1} (Table 12), respectively. The nutrients absorbed by plants play distinct roles in growth and production. In this context, N, P, and

K are essential macronutrients required in large quantities. Nutrient N plays a crucial role in vegetative growth and the photosynthesis process of plants. The nutrient supports leaf and stem formation and is a constituent of chlorophyll (Kumari, 2017). Meanwhile, P plays a significant role in plant metabolism, stimulating root growth, flowering, and fruit formation (Bhantana *et al*., 2021). K is essential for activating enzyme activities and enhancing resilience (Hasanuzzaman *et al.*, 2018). High nutrient uptake reflects the availability and the ability of the plant to conduct absorption (Karthika *et al*., 2018).

Table 10. Interaction of biochar, compost tea lotus, and NPK on N uptake in green spinach plants

Treatment		Plant N Uptake (g plant^{-1}) NPK Dosage (%)		
Biochar (ton ha^{-1})	**CT (ml tan^{-1})**	**0**	**50**	**100**
	0	0.17 ^{l}	0.58 ^{hijkl}	0.52 ^{hijkl}
0	**20**	0.20 ^{kl}	0.73 ^{hij}	1.75 ^{e}
	40	0.84 ^{ghi}	2.42 ^{d}	1.78 ^{e}
	0	0.25 ^{jkl}	1.30 ^{efg}	8.11 ^{b}
10	**20**	0.30 ^{jkl}	0.68 ^{hijk}	1.52 ^{ef}
	40	0.25 ^{jkl}	1.25 ^{fg}	8.32 ^{b}
	0	0.49 ^{ijkl}	1.00 ^{gh}	1.32 ^{efg}
20	**20**	0.24 ^{kl}	1.57 ^{ef}	4.65 ^{c}
	40	0.55 ^{hijkl}	9.08 ^{a}	4.90 ^{c}
LSD 5%		0.480		

Note: Numbers followed by similar letters in the same row or column show no significant difference in the LSD 5% testing.

Table 11. Interaction of biochar, compost tea lotus, and NPK on P uptake by spinach plants

Treatment		Plant P uptake (g plant^{-1}) NPK Dosage (%)		
Biochar (ton ha^{-1})	**CT (ml tan^{-1})**	**0 (**	**50**	**100**
	0	0.022 ^{j}	0.065 ^{ij}	0.058 ^{ij}
0	**20**	0.026 ^{j}	0.080 ^{hij}	0.183 ^{e}
	40	0.105 ^{ghi}	0.261 ^{d}	0.188 ^{e}
	0	0.033 ^{j}	0.140 ^{efg}	0.832 ^{b}
10	**20**	0.040 ^{j}	0.073 ^{ij}	0.164 ^{ef}
	40	0.035 ^{j}	0.138 ^{efgh}	0.848 ^{b}
	0	0.067 ^{ij}	0.113 ^{fghi}	0.143 ^{efg}
20	**20**	0.032 ^{j}	0.165 ^{ef}	0.464 ^{c}
	40	0.070 ^{ij}	0.947 ^{a}	0.484 ^{c}
LSD 5%		0.059		

Note: Numbers followed by similar letters in the same row or column show no significant difference in the LSD 5% testing.

NPK fertilizers provide nutrients quickly to plants, but long-term use at higher doses negatively influences fertility (Majhi *et al.*, 2021). Biochar also plays a role in improving soil density, allowing roots to absorb water and nutrients efficiently. Meanwhile, the application of compost tea enhances the availability of nutrients for plants. According to El-Shaieny *et al.* (2022), compost tea is a nutrient solution to improve soil fertility, provide nutrients, and aid absorption. The fertilizer also includes various types of microbes that serve as biofertilizers, biostimulants, and biopesticides (Mbogning *et al*., 2024).

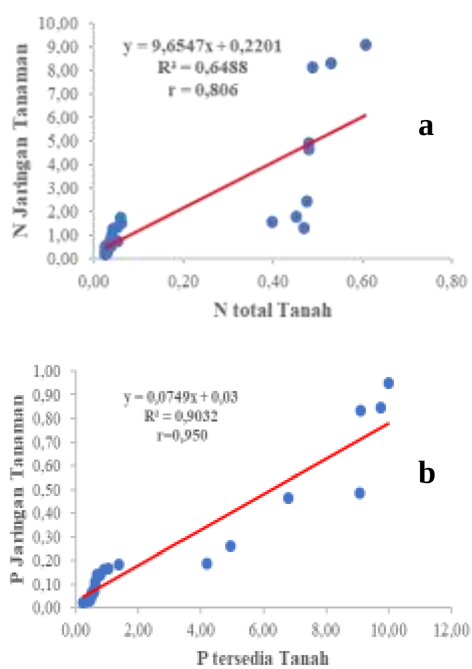
Table 12. Interaction of biochar, lotus compost tea, and NPK on K uptake in spinach plants

Treatment		Plant K Uptake (g plant^{-1}) NPK Dosage (%)		
Biochar (ton ha^{-1})	***CT* (ml tan^{-1})**	**0**	**50**	**100**
	0	0.159 ^{k}	0.439 ^{hijk}	0.394 ^{ijk}
0	**20**	0.178 ^{k}	0.544 ^{hij}	1.245 ^{e}
	40	0.717 ^{ghi}	1.719 ^{d}	1.245 ^{e}
	0	0.226 ^{jk}	0.943 ^{efg}	5.381 ^{b}
10	**20**	0.267 ^{jk}	0.506 ^{hijk}	1.100 ^{ef}
	40	0.232 ^{jk}	0.930 ^{efg}	5.508 ^{b}
	0	0.456 ^{hijk}	0.763 ^{fgh}	0.985 ^{efg}
20	**20**	0.223 ^{jk}	1.109 ^{ef}	2.989 ^{c}
	40	0.477 ^{hijk}	6.073 ^{a}	3.096 ^{c}
LSD 5%		0.350		

Note: Numbers followed by similar letters in the same row or column show no significant difference in the LSD 5% testing.

Relationship between Soil and Plant Tissue NPK

Based on correlation and regression analysis, soil and plant tissue NPK contents are strongly and positively related, as shown in Figure 1.



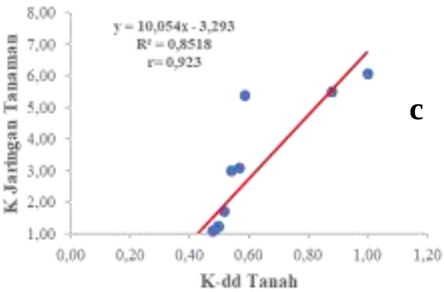


Figure 1. Relationship between soil N-total and plant tissue N (a), soil P-available and plant tissue phosphorus (P) (b), and soil K-dd and plant tissue potassium (K) (c) of green spinach in non tidal lowland soil.

The coefficient of determination (R^2) reports that N-total, P-available, and soil K-dd influenced 64.9%, 90.3%, and 85.2%, respectively. This is supported by the result that soil content affects nutrient uptake by plants (Guo *et al.*, 2019). Other important factors are respiration, root growth and distribution, as well as soil pH (Custos *et al*., 2020).

IV. CONCLUSION

In conclusion, the treatments of biochar, lotus compost tea, and NPK fertilizer were reported to significantly interact with several chemical properties of non tidal lowland soil post-planting, as well as the growth and production of green spinach. The dose of 20 tons ha^{-1} biochar and 40 mL $plant^{-1}$ lotus compost tea effectively optimized NPK fertilizer by 50%. This enhanced soil nutrient availability, growth, production, and uptake of green spinach. In addition, soil NPK availability showed a positive correlation and a very strong relationship with the uptake in plants.

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