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Research article

Biochar from sewage sludge on soil and plant characteristics of Arugula *(Eruca sativa)*

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Abstract: Swine sewage sludge is challenging to manage due to the large volumes produced and its high pathogen content. Recently, thermal treatments such as pyrolysis have gained interest as a means to convert dried swine sewage sludge into biochar, which is increasingly applied to soils to enhance plant growth. This study evaluated the effects of biochar produced from dried swine sewage sludge on the growth of Arugula (*Eruca sativa*) in a greenhouse. Biochar was created through fast pyrolysis at 500°C. This was applied to the test plants with a Completely Randomized Design (CRD) involving six treatments (T0: Dried Swine Sewage Sludge 100g; T1: biochar 20g; T2: biochar 40g; T3: biochar 60g; T4: biochar 80g; T5: biochar 100g) in four replications. Results indicated that biochar is high in nitrogen (2.52%) and phosphorus (9.85%), while Dried Swine Sewage Sludge is rich in potassium (0.7057%). Increasing biochar to certain levels improved nutrient availability in the soil, leading to significant gains in chlorophyll content (0.1144 µg/mL), total soluble solids (4.50 °Brix), leaf count (7.6 number of leaves per plant at 4th week), and plant height (37.75mm during the 2nd week). Biochar application above 40g had a negative impact on horticultural characteristics, specifically the plant height, plant mass (fresh weight) and number of leaves, suggesting that excessive biochar may inhibit development. Despite this, higher biochar levels still enriched soil nutrients (N, 2.52%; Cu, 0.1448%; Fe, 5.44895%; Mn, 0.61375%; Ca, 0.69275%; P_2O_5, 7.964%; K_2O, 2.303%), highlighting the importance of balancing biochar rates for optimal plant performance.

Keywords: Waste treatment; Pyrolysis; Soil amendment; Horticultural characteristics; Soil nutrient properties

1. Introduction

The management of sewage has been a critical issue since the advent of human settlements, necessitated by the need to process large volumes of wastewater, primarily human excreta [1]. Urbanization and industrialization have intensified water pollution, driving the development of advanced wastewater treatment systems [2]. These advancements, while necessary for managing effluent, have inadvertently increased the production of sewage sludge, creating a growing waste management challenge. Similarly, managing swine waste represents a substantial challenge, characterized by the large quantities produced and its elevated pathogen concentrations, highlighting the urgent need for innovative treatment and resource recovery strategies to mitigate environmental and public health risks [3].

Lately, there has been increased interest regarding thermal processing of this waste. In addition to the conventional methods of sewage sludge disposal such as direct application in agriculture, incineration, and landfilling. The pyrolytic conversion of sewage sludge to biochar is a promising method to manage this waste and simultaneously take advantage of the aforementioned environmental benefits [4]. Thermal treatment offers a promising alternative to traditional approaches, with options like pyrolysis and gasification gaining traction for their ability to reduce waste volume and convert it into useful byproducts. Among the various alternative methods, microwave thermal treatment has also emerged as a potential technique, offering efficient energy use and rapid processing times for sludge management [5].

This study investigates the feasibility of producing biochar from swine waste in varying amounts. The study focuses on evaluating its potential for agricultural use, specifically improving soil and plant characteristics in Arugula cultivation. This approach aims to enhance agricultural soil functions and promote plant growth. The response of plants to biochar is influenced by its interaction with soil properties, nutrient availability, and environmental conditions. However, the effect of biochar application on plant growth can be different due to the variability in the quantity of biochar. In this study, the effect of different amounts of biochar application on the growth of Arugula (*Eruca sativa*) was assessed in a pot experiment.

2. Materials and Methods

2.1 Sewage Sludge

Sewage sludge was obtained from the pig pens of Cebu Technological University –Barili Campus in Cagay, Barili, Cebu, Philippines. The sewage sludge was filtered, sorted and impurities such as leaves and other materials were removed. Sludge was then laid out on a canvass and air dried. Air drying lasted for one month, until it attained a crumbling texture (Figure 1).

Figure 1. Proper texture of dried swine sewage sludge for ready for biochar.

2.2 Biochar Production and Application

Initially, samples were crumbled into pieces about 7–9 cm in diameter to allow for even heat distribution during pyrolysis. Once loaded into the pyrolyzer, the samples were heated to 500°C and regularly checked if the samples had reached the desired blackened state without turning into ash. One hundred grams of dried swine sewage sludge (DSSS) when pyrolyzed will yield approximately 50g of biochar. After complete pyrolysis, the biochar was pulverized with a mortar and pestle and passed through a 0.5mm sieve. The biochar was then weighed according to the study's treatment levels: T0 (DSSS, 100g), T1 (Biochar, 20g), T2 (Biochar, 40g), T3 (Biochar, 60g), T4 (Biochar, 80g), and T5 (Biochar, 100g). Each treatment was thoroughly mixed with soil to ensure even distribution.

2.3 Soil and Biochar Analysis

2.3.1 Laboratory Site

Soil and biochar analysis were conducted in the Department of Chemistry Laboratory at the University of San Carlos – Talamban Campus, Cebu City, Philippines.

2.3.2 Sample Preparation

Upon arrival in the laboratory, the raw soil and biochar samples were air dried for one week, sieved using 180 μm mesh, and homogenized using a ball mill. The samples were then placed in a resealable plastic container for storage and moisture analysis.

2.3.3 Available Phosphorus

The available phosphorus was analyzed using the Chlorostannous Method (Senthilkumar et al. [6]). A 0.5-gram portion of < 2mm air-dried soil was placed in a 50 mL shaking bottle. Fifty milliliters of extracting solution were added, the bottle was stopped, and the contents were shaken for 30 minutes. The supernatant liquid was filtered using Whatman No. 42 filter paper. An aliquot of the sample was transferred to a 50 mL volumetric flask, and a standard P solution containing 2-40 μg P was also prepared using TraceCERT certified reference material (CRM), Pcode: 101743260, in 2% HNO_3 (Sigma Aldrich, Switzerland). Ten milliliters of ammonium molybdate solution and 1 mL of dilute $SnCl_2$ solution were added. The flask was brought to volume with deionized water and mixed well. The absorbance was measured using a UV-Visible Spectrometer at 660 nm after 5-6 minutes but before 10 minutes. A blank, containing all the reagents except the phosphate solutions, was also prepared. The samples were analyzed in triplicate and a recovery test was performed.

2.3.4 Available Potassium

Exactly 5 grams of < 2mm air-dried soil were placed in a 50 mL shaking bottle. Twenty-five milliliters of 1.0 M ammonium acetate extracting solution were added, the bottle was stopped, and the contents were shaken for 30 minutes. The supernatant was filtered using Whatman No. 42 filter paper. The sample was diluted by pipetting a 0.2 mL aliquot and bringing the volume to 10 mL with the extracting solution. The unknown concentration was determined by preparing a standard calibration curve of 10, 20, 30, and 40 ppm using potassium standard solution (TraceCERT certified reference material (CRM), Pcode: 101731961, in 2% HNO_3, Sigma Aldrich, Switzerland) and a wavelength of 766 nm in a microwave plasma atomic emission spectroscopy (MP-AES 4210) following EPA Method 3050B.

2.3.5. Available Nitrogen

Analysis was conducted following the Kjeldahl method. One gram of sample was weighed and placed in an 800 mL Kjeldahl flask that contained approximately 10 grams of sodium sulfate and 0.3-0.5 grams of copper sulfate. Thirty milliliters of concentrated sulfuric acid were added. If any portion stuck to the side of the flask, it was washed down with the acid. The flask was shaken to ensure all sample portions were wet. Digestion was started until all the organic matter was oxidized and a clear blue liquid remained. The mixture was cooled and diluted to 450 mL with deionized water. Exactly 50 mL of 4% boric acid were delivered into a 500 mL Erlenmeyer flask, and 5 drops of methyl red-methylene blue indicator were added. The flask was placed at the collection end of the distillation setup. Seventy milliliters of 50% NaOH were measured and carefully added to the Kjeldahl flask through the side to avoid mixing with the content. Two to three zinc granules were added to prevent bumping during boiling. The flask was stoppered and connected to the distillation apparatus, and the contents were mixed by gently swirling the flask. A low boil was maintained for 15 minutes, then boiling was increased until about 350 mL of distillate was collected in the Erlenmeyer flask. The distillate was titrated with 0.1N sulfuric acid standard solution until a light pink color was observed. A correction blank was run with every batch of determination. Each sample was analyzed in triplicate. The percentage of nitrogen was calculated using the equation provided below:

$$\%N = \frac{((Ts-Tb)\ x\ N\ H2SO4\ x\ N)\ /1000}{weight\ sample,\ g} \text{ x } 100$$

2.3.6 Analysis of Iron

The samples were oven-dried at 50 °C and 0.5 g of air-dried soil samples were accurately weighed and passed through 2 mm sieve. Wet digestion procedure using EPA Method 3050B using acid mixture of $HClO_4/HNO_3/H_2SO_4$ was used for total digestion of soil samples before elemental analysis at a wavelength of 373 nm in Microwave Plasma Atomic Emission Spectrometry (MP-AES 4210).

2.3.7 Analysis of Copper, Zinc, Manganese and Calcium

The samples were oven-dried at 50 °C and 1.000 g of air-dried samples were accurately weighed and passed through 2 mm sieve. Wet acid digestion procedure using EPA Method 3050B was used for total digestion of samples before elemental analysis using Flame Atomic Absorption Spectroscopy (FAAS). A recovery test was also performed.

2.4 Plant Management

Plants were monitored and watered twice daily, or three times on hot days. Each pot received 10 mL of water in the early stage, increasing to 30 mL in the later stage.

2.5 Measurement of Growth Parameters

2.5.1 Number of Leaves

The number of leaves (NL) per plant was obtained by counting the leaves of the Arugula plant.

2.5.2 Plant Height

The plant height (PH) was measured from the base of the plant at the soil level to the tip of the tallest leaf.

2.5.3 Plant Mass Above and Below Ground

The plant mass above ground was obtained by weighing all the parts of the plant that are above ground, while the plant mass below ground was obtained by weighing all the parts of the plant below ground.

2.6 Chlorophyll Content (Chlorophyll A and B, Total Chlorophyll)

The chlorophyll content was estimated spectrophotometrically by the method of Sadasivan and Manicham [7]. Mashed Arugula was macerated with the addition of 20 ml of 80 % acetone to a fine pulp in a mortar and pestle. The paste was centrifuged for 5 min at 5000 rpm. The supernatant was decanted, and the left residue was then ground with 20 ml of 80 % acetone, centrifuged for 5 min at 5000 rpm, and the supernatant was again decanted. The extraction was repeated 4–5 times until the residue was colorless. The extracts were collected in a beaker, filtered and made up to 100 ml with 80 % acetone in a volumetri c flask. The absorbances of the extracted solutions were recorded (Shimadzu UV-1800, Kyoto, Japan) at 645 nm and 663 nm against the solvent (80 % acetone) blank. The amount of chlorophyll present in extract i.e. mg of chlorophyll per gram of tissue on fresh weight basis, was calculated using the following equations:

$$\text{Chlorophyll 'a'(mg/g of tissue)} = [12.7 * X - 2.69 * Y] \times v(1000 \times W)$$

$$\text{Chlorophyll 'b'(mg/g of tissue)} = [22.9 * Y - 4.68 * X] \times v(1000 \times W)$$

$$\text{'Total chlorophyll'(mg/g of tissue)} = [20.2 * Y + 8.02 * X] \times v(1000 \times W)$$

Where:

X = absorbance at 663 nm

Y = absorbance at 645 nm

W = weight of fresh tissue extracted (1 g)

V = final volume of extract in 80 % acetone (100 ml)

2.7 Total Soluble Solids (TSS)

Five grams of freshly harvested Arugula was soaked with 200ml. distilled water for one (1) hour and was mashed with mortar and pestle and filtered. The filtrate was subjected to TSS measurement. TSS in °Brix was measured using a hand-held digital refractometer (Hanna HI 96801) calibrated with distilled water by placing 1-3 drops of juice on the instrument's prism and taking the reading.

2.8 Titratable Acidity (TA)

The TA was determined by titration. A volume of 49.0 mL of distilled water was added to 1.0 mL of pulp in an Erlenmeyer flask, and after stirring, it was titrated with a standardized solution of NaOH at 0.1 M using 1% phenolphthalein as an indicator. The results were expressed in grams of citric acid per 100 g of pulp [8] with the data expressed as a percent TA.

2.9 Experimental Design and Treatments

The study was laid out in a Completely Randomized Design (CRD) with six treatments in four replications. Each replication had five pots that served as a buffer for the unexpected death of the plant. The treatments are the following:

T_0= Dried Swine Sewage Sludge 100g
T_1= 20g biochar
T_2= 40g biochar
T_3= 60g biochar
T_4= 80g biochar
T_5= 100g biochar

Microsoft Excel was used to compute the average values and data variability. Analysis of variance (ANOVA) was performed in STAR Program to assess differences in the parameters across treatments.

3. Results and Discussion

3.1 Nutrient Profile

Values for river water samples ranged from 6.71 to 6.82 ppm for dissolved oxygen. The dissolved oxygen values indicate sufficient oxygen supply to support aquatic life in the river. pH values also ranged between 6.68 and 6.77 for water samples and sediments and 6.71 and 6.82 for sediments.

The nutrient analysis shows significant differences among dried swine sewage sludge, soil, and biochar (Figure 2). Dried sludge had the highest levels of copper (0.15145%), zinc (0.58425%), and manganese (0.5106%), making it a potent source of these trace metals, though high levels raise potential toxicity concerns. These trace metals could have come from the commercial feed additives Mu et al. [9]. On the other hand, soil contained the most iron (4.807%), about 3.5 times higher than in sludge and 43 times higher than in biochar, marking it as the best iron source.

For macronutrients, potassium was highest in sludge (0.7057%), followed by biochar (0.5583%), with soil being much lower (0.0807%). Soil had the highest calcium (0.8914%), while sludge led in magnesium (0.2324%). Biochar was nutrient-dense in nitrogen (2.52%) and phosphorus (9.85%), surpassing soil and sludge, which supports its role as a valuable soil amendment.

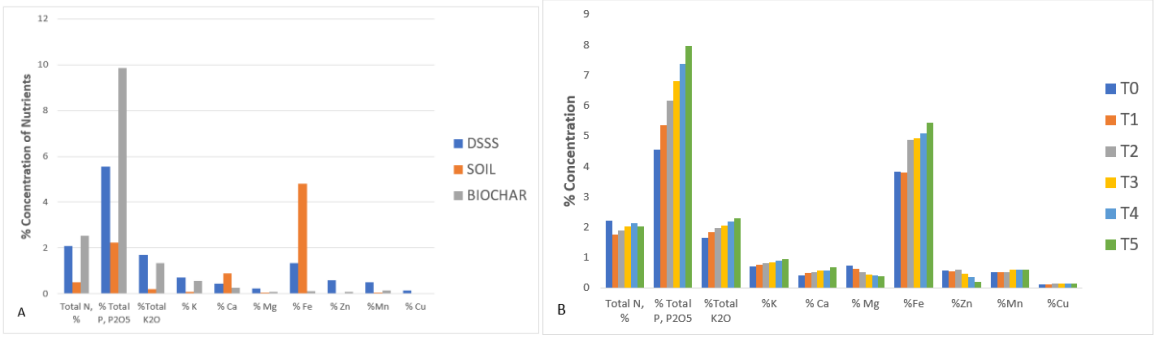

Figure 2. Nutrient Profile (%) of the Raw Materials for Potting Medium (A) and Nutrient Profile (%) of Different Experimental Treatments (B) after Harvest.

Overall, biochar provides essential nutrients like nitrogen, phosphorus, and potassium, while sludge is rich in trace metals and magnesium. Soil, though lower in several nutrients, remains an important calcium and iron source. These distinctions highlight the potential of combining biochar and sludge to enhance soil fertility, though monitoring of trace metals is advised to prevent harmful accumulation.

Trace metal analysis showed copper (Cu) levels increasing from 0.1296% in T_0 to 0.1448% in T_5, while iron (Fe) rose from 3.8141% in T_0 to 5.44895% in T_5, indicating Fe accumulation. Zinc (Zn) peaks at 0.6053% in T_2 but drops sharply to 0.1951% in T5, suggesting reduced Zn retention in higher treatments. Manganese (Mn) steadily increases from 0.51% in T_0 to 0.61375% in T_5, implying improved retention.

For macronutrients, potassium (K) content rises from 0.7217% in T_0 to 0.9561% in T_5, and calcium (Ca) also increases from 0.4173% to 0.69275%. However, magnesium (Mg) declines from 0.73645% in T_0 to 0.39935% in T_5, suggesting reduced availability over time. In overall nutrient content, total nitrogen (N) fluctuates slightly but is lower in T_5 than in T_0. Phosphorus (P_2O_5) increases significantly from 4.551% in T0 to 7.964% in T_5, while potassium oxide (K_2O) grows from 1.66% to 2.303%. Overall, T4 and T_5 are nutrient-rich, particularly in phosphorus and potassium, while nitrogen and magnesium show less consistent trends.

Biochar can influence soil nutrients by reducing leaching losses, a process where nutrients are washed away from the soil profile Laird et al. [10]. Its porous structure, extensive surface area, and negative surface charge enhance the soil's cation exchange capacity, enabling the retention of essential nutrients such as potassium (K) Bird et al. [11], Cheng et al. [12], Downie et al. [13], Novak et al. [14]. Additionally, biochar reduces cation loss by altering soil water movement, promoting a shift from bypass flow to matrix flow, which allows for more efficient nutrient transport and retention Laird et al. [10]. Phosphorus (P), in particular, can adhere to biochar's surface, effectively slowing its leaching and enhancing nutrient availability in the soil Laird et al. [10], Beck et al. [15].

3.2 Horticultural Characteristics

Variations in germination time across treatments were observed in Table 1. Germination times varied slightly among treatments but showed no significant differences. DSSS-alone treatment averaged 7.3 days, serving as a baseline. Treatment with 40g biochar was the fastest at 5.45 days, while with 100g biochar was the slowest at 8.35 days. Intermediate averages were recorded for treatments with 20g, 60g and 80g at 7.05, 7.2 days, and 6.1 days, respectively. This suggests that, while some treatments appeared to promote faster or slower germination, these differences were not substantial enough to indicate a meaningful impact on the germination process. Various studies have also yielded varying results on the effect of biochar on germination rates; high-dose biochar had significant negative effect on germination rate, shoot length and root length of rice and corn seeds Bai et al. [16]; corn-cub bio mixed with soil have positive effects on seed germination of maize seedlings Ali et al. [17], while the study of Carril et al. [18] resulted to no effect on the germination of lettuce.

In terms of number of leaves, varying mean values were observed. For DSSS alone, the number of leaves ranged between 6.25 and 6.75, with an average of 6.65 leaves, marking the lowest leaf count among the treatments. The average number of leaves per plant increased as the level of biochar was increased at 20g increment, peaking at 80g application with an average of 7.6. It decreased to 7.25 leaves when biochar was increased to 100g. Biochar enhances leaf production by improving soil fertility, water retention, and nutrient cycling, supporting vegetative growth. Optimal application boosts leaf development, while excessive amounts may hinder growth due to imbalances or soil alkalinity (Yu et al. [19]. Statistical analysis revealed significant differences in the number of leaves between treatments. This suggests that the treatments had an effect on leaf development, indicating that variations in the number of leaves could be attributed to the different treatments applied. In the study conducted by Jabborova et al. [20], on ginger (*Zingiber officinale*), showed that 2% and 3% addition of biochar significantly increased the number of leaves compared to the control.

Biomass, both above- and below-ground, was highest at 20g and 60g biochar but declined as biochar level was increased, suggesting inhibition. Excess biochar levels appeared inhibitory (Wang et al. [21], though differences were not statistically significant. According to Schulz et al. [22], biochar had no significant impact on plant biomass when applied to sandy substrates. However, on loamy substrates, biomass yield was significantly reduced at the highest application. No consistent trend was observed with increasing biochar application rates.

Table 1. Horticultural characteristics of Arugula as affected by levels of biochar application.

Treatment	Days to Germination	Number of Leaves	Plant Mass Above (gram/plant)	Plant Mass Below (gram/plant)
T_0 = 100g DSSS	7.30^{nsd}	6.65^{b}	2.26^{nsd}	0.33^{nsd}
T_1 = 20g Biochar	7.05^{nsd}	7.00^{ab}	2.55^{nsd}	0.31^{nsd}
T_2 = 40g Biochar	5.45^{nsd}	7.50^{a}	3.69^{nsd}	0.49^{nsd}
T_3 = 60g Biochar	7.20^{nsd}	7.30^{ab}	3.28^{nsd}	0.49^{nsd}
T_4 = 80g Biochar	6.10^{nsd}	7.60^{a}	1.98^{nsd}	0.29^{nsd}
T_5 = 100g Biochar	8.35^{nsd}	7.25^{ab}	1.43^{nsd}	0.14^{nsd}

Values with the same letter are not significantly different ($p>0.05$)
nsd = no significant difference

3.3 Plant Height

At 15 days, significant differences in plant height emerged among treatments, with 40g biochar exhibiting the highest average (37.75mm) implying significant effect at this critical stage. The 15th day provides a valuable snapshot of early plant vigor and the treatment's potential to enhance growth, offering both scientific and practical relevance in agricultural research Baker et al. [23]. The first 15 days, being crucial for seedling establishment, help to gauge how biochar modifies nutrient availability, root development, and overall plant vigor, which are essential for determining its potential in enhancing crop growth and productivity in the long term (Shamim et al. [24], Uslu et al. [25], Liu et al. [26]. Therefore, this early observation period is vital for identifying how biochar treatments might influence the early plant development stages, helping to optimize biochar application in agricultural practices.

These results underscore that biochar application at 40g and 60g positively impacted plant height, with the former showing significantly faster growth by the 15-day mark. The study of Murtaza et al. [27] *Medicago sativa*, *Amaranthus caudatus* and *Zea mays* in saline soils showed that biochar significantly improved by 30% of these crops.

Table 2. Plant Height (n) days from planting, measured in (mm) as affected by levels of biochar application.

Treatment	5 days	10 days	15 days	20 days	25 days
T0 = 100g DSSS	3.85^{nsd}	8.5^{nsd}	25.65^{ab}	56.1^{nsd}	86.4^{nsd}
T1 = 20g Biochar	6.4^{nsd}	12.25^{nsd}	29.7^{ab}	63.95^{nsd}	98.2^{nsd}
T2 = 40g Biochar	9.8^{nsd}	17.95^{nsd}	37.75^{a}	71.3^{nsd}	104.85^{nsd}
T3 = 60g Biochar	6.7^{nsd}	13.65^{nsd}	27.9^{ab}	61.3^{nsd}	94.7^{nsd}
T4 = 80g Biochar	7.75^{nsd}	14.3^{nsd}	33.45^{ab}	67.8^{nsd}	109.35^{nsd}
T5 = 100g Biochar	4.35^{nsd}	8.15^{nsd}	22.3^{b}	48.2^{nsd}	76.1^{nsd}

Values with the same letter are not significantly different ($p>0.05$)
nsd = no significant difference

3.4 Chlorophyll Content

Chlorophyll content increased from dried sewage sludge application to increasing levels of biochar. The control treatment with dried swine sewage sludge consistently recorded the lowest levels of chlorophyll in all measurements while the treatments with highest biochar had the highest chlorophyll concentrations, indicating they most effectively enhanced chlorophyll production in plants (Fig. 3). The results are consistent with other studies that showed biochar treatment significantly increasing the chlorophyll a, chlorophyll b, total chlorophyll and carotenoid relative water of leaf cover Hafeez et al. [28], Yousaf et al. [29] by enhancing soil nutrient availability, improving soil structure, and promoting water retention Zhang et al. [30]. These factors support better overall plant health, which in turn leads to increased chlorophyll levels. It was found that biochar application increased the photosynthesis, chlorophyll content, and transpiration rate in different plants Murtaza et al. [27].

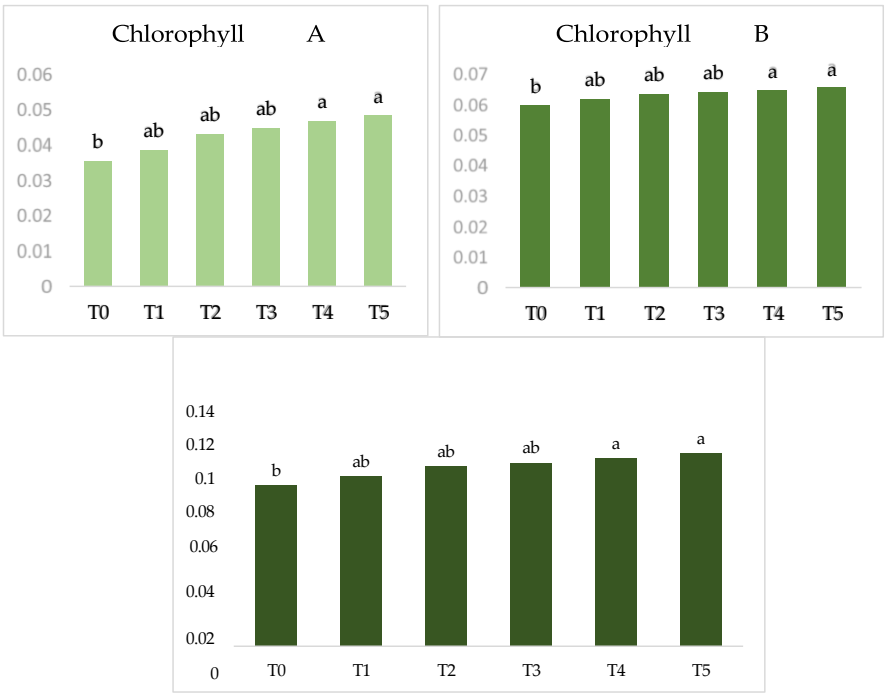

Figure 3. Chlorophyll a (A), b (B) and Total Chlorophyll (C)

3.5 Total Soluble Solids and Titratable Acidity

Figure 4 (A) highlights significant variation in Total Soluble Solids (TSS) across treatments. DSSS-treated plants exhibited the highest TSS mean at 9.63 °Brix indicating maximum soluble solids without biochar application. Conversely, increasing biochar levels reduced TSS, with the most substantial declines observed at 60–100 g biochar. This trend suggests that excessive biochar may suppress soluble solids, likely due to altered nutrient dynamics or stress responses, consistent with findings that high biochar levels can adversely affect plant growth parameters Wang et al. [21]. While biochar has generally been associated with improving plant growth and fruit quality in many cases, its effect on TSS seems to vary depending on factors like the type of biochar, soil conditions, and other treatments applied [31].

Figure 4 (B) shows that the DSSS-treated Arugula had the lowest titratable acidity (TA) at 22.42%, while 80g and 100g biochar showed the highest TA at 28.82% and 32.02%, respectively, suggesting a link between higher biochar levels and increased acidity. Despite these variations, statistical analysis revealed no significant differences in TA across treatments.

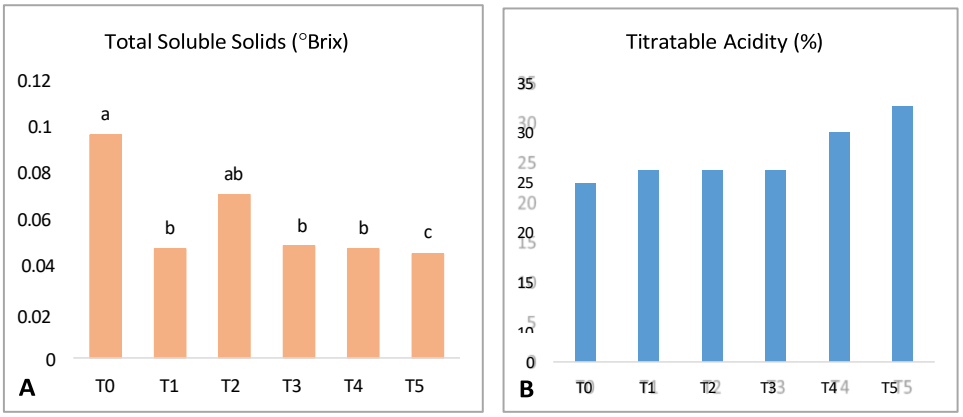

Figure 4. Total Soluble Solids (A) and Titratable Acidity (B).

4. Conclusion

The research indicates that biochar derived from the pyrolytic conversion of swine sewage sludge is a nutrient-rich soil amendment, containing high levels of nitrogen and phosphorus. In contrast, dried sludge is particularly high in potassium. Both materials can be valuable for enhancing soil fertility, with the choice depending on the nutrient needs of specific crops and soil conditions. For optimal results, a biochar application rate of 40 grams per treatment is recommended. This dosage significantly improves soil nutrient content, particularly iron, manganese, potassium, calcium, and phosphorus, while avoiding the inhibitory effects observed with higher application rates. Within just 15 days of application, biochar has been shown to enhance key plant growth parameters, including increased total soluble solids, higher chlorophyll content, a high number of leaves, and improved plant height. These improvements reflect biochar's dual benefit: enhancing crop productivity and soil quality while contributing to sustainable waste management. Careful application based on crop and soil requirements is essential to maximize the agronomic benefits of biochar without risking nutrient imbalance or growth suppression.

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