EVALUATING THE EFFECTS OF CHARGING AND INOCULATING BIOCHAR DERIVED FROM INVASIVE SPECIES EFFECTS ON GROWTH AND YIELD OF CROPS AND SOIL HEALTH IN OXISOL AND MOLLISOL SOILS

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ABSTRACT

Invasive species such as *Leucaena leucocephala* are encroaching on arable lands in Hawaiʻi, affecting agricultural productivity. Converting this biomass into biochar offers a multifaceted solution for eradication, arable-land reclamation, and production of a high-quality sustainable soil amendment that enhances soil health and crop yields. Although biochar is a carbon-rich material with proven benefits, the necessity of pre-application inoculation/charging (e.g., with biology and nutrients) remains unclear. Here, biochar was produced from Leucaena wood using a small-scale retort kiln. Eight treatments were tested across Oxisol and Mollisol soils in greenhouse pot trials at the University of Hawaiʻi: (1) soil alone (control), (2) soil + biochar, (3) soil + compost, (4) soil + biochar-assisted compost, (5) soil + biochar + fish emulsion, (6) soil + biochar + compost, (7) soil + biochar + compost + fish emulsion, and (8) soil + biochar-assisted compost + fish emulsion. Biochar and compost were applied at the rates of 5 and 10 t/ac, respectively. Biochar charging/inoculation was performed 3 days before planting, with 64 pots established (2 soils × 8 treatments × 4 replicates) using beets and pak choi as test crops; measurements included fresh/dry biomass (yield), leaf chlorophyll content, tissue nutrient concentrations, and soil health indicators (pH, CO_2). Charged/inoculated biochar treatments increased the crop fresh weight by ~50% and leaf chlorophyll content, 35% and 41% for beet, and 49% and 41% for pak choi under Oxisol and Mollisol soils, respectively compared to the control. In both soil types, nutrient uptake increased up to 95% for N, 200% for P, and 75% for K compared to the control. Soil pH increased by 45% and 20% under Oxisol and Mollisol, respectively, compared to the control. CO_2 respiration rate increased by 75% in both soil types compared to the control. These results confirm Leucaena-derived biochar is an effective amendment and emphasize the importance of charging/inoculating the biochar for optimal crop productivity and soil health in Hawaiian agroecosystems.

INTRODUCTION

In Hawaiʻi, invasive plant species like *Leucaena leucocephala*, commonly known as haole koa, pose serious challenges to agricultural land. These plants spread quickly, producing vast amounts of seeds, forming dense thickets, and outcompeting native vegetation. As a result, they reduce farmland availability and threaten food security in the islands (Graebner et al., 2012). Globally, invasive species present major risks to agriculture. A study of 1,300 invasive species across 124 countries found they significantly reduce crop yields and jeopardize food security (Paini et al., 2016). For Pacific islands, food security and self-sufficiency are top priorities. Hawai‘i, for instance, imports about 85–90% of its food, with reserves typically lasting only two weeks at any time (Leung and Loke, 2008).

Biochar is a stable, carbon-rich material produced by pyrolyzing organic feedstocks under low-oxygen conditions, and it has emerged as a promising soil amendment (Berek, 2015). It is valued for its large surface area (Figure 1), which enhances soil nutrient retention, improves water-holding capacity, and provides a habitat for beneficial soil microorganisms (Leng et al., 2021). Previous research has demonstrated that biochar application can increase soil water-holding capacity (Laird et al., 2010; Silber et al., 2010), release plant nutrients into the soil (Smider and Singh, 2014), retain nutrients and prevent leaching (Berek and Hue, 2013), reduce greenhouse gas emissions (Kammann et al., 2011), promote beneficial soil microorganisms (Xu et al., 2014), remove heavy metals and organic pollutants from soil or water (Uchimiya et al., 2012), and enhance plant resistance to diseases while promoting growth (Elmer and Pignatello, 2011).

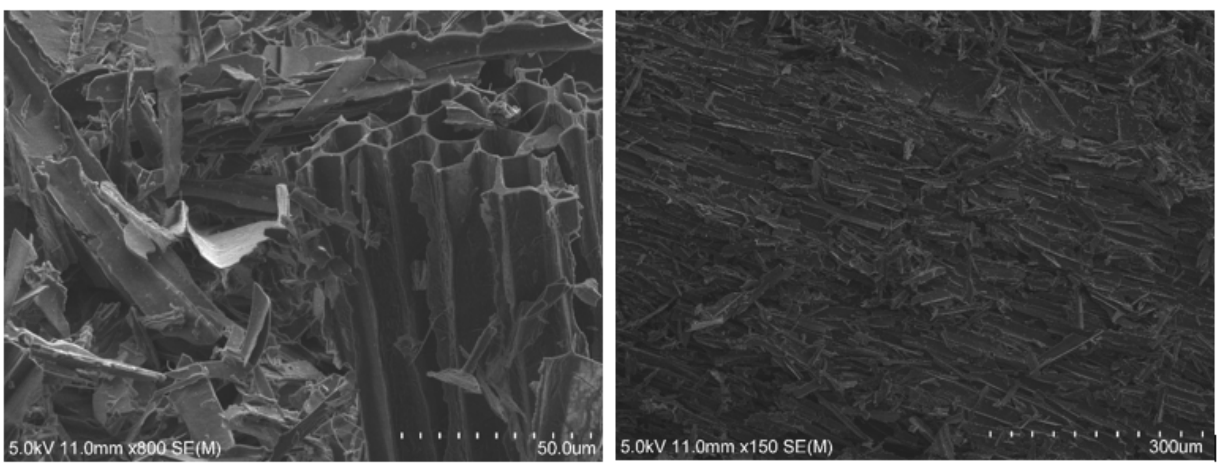

Figure (1): Microscopic pictures of biochar particles showing high surface area.

Composting offers a sustainable way to recycle organic waste into beneficial soil amendments, and Hawai‘i’s year-round growing season provides abundant composting materials. Applying organic materials like compost improves soil properties and crop yields. However, using invasive species in compost or animal feed carries risks, typical composting or digestion conditions often fail to eliminate seed viability (Pan, et al., 2022). In contrast, producing biochar through pyrolysis effectively eliminates seed viability, preventing re-establishment of invasive plants (Namaswa et al., 2023; Woolf et al., 2010). Using invasive species to process into biochar is expected to come with many benefits, including reclaiming arable lands and supporting the invasive species eradication effort, producing high-quality sustainable soil amendments, and improving soil and crop productivity.

Affordable biochar production equipment, like the steel-drum retort kiln systems used in this experiment, can be constructed or purchased locally at a fraction of the cost of commercial kilns. This project establishes a proof of concept using *Leucaena leucocephala* as a model invasive species, with results intended to be used across other problematic invasives. The central question this study investigates is: Should farmers inoculate (load with microorganisms) and/or charge (load with nutrients) biochar prior to field application to maximize its benefits in agricultural systems? This study investigates the dual benefits of converting invasive Leucaena biomass into biochar using low-cost, DIY fabricated steel-drum pyrolysis systems and evaluate the effectiveness of charging and inoculating the locally produced biochar prior to applying to soils on pak choi and beetroot growth and yield and soil health parameters under Oxisol and Mollisol soils.

MATERIALS AND METHODS

Two pot trials were conducted in 2025 to evaluate charging and inoculating biochar on the growth, yield/pot, and tissue nutrient content of beet (*Beta vulgaris*) variety Merlin and pak choi (*Brassica rapa* subsp. Chinensis) variety Mei Qing Choi, and soil health of Oxisol and Mollisol soils. Oxisol soil was collected from the Poamoho Research Station, while Mollisol soil was collected from Waimanalo Research Station. Biochar was produced at the Waimanalo Research Station using leucaena. The biochar was prepared using retort kiln pyrolysis chambers (figure 2). The pyrolysis chamber is made of 2 steel drums (60-L and 210-L). The inner 60L (16 gallon) steal drum stores the wood to be turned into biochar, and the outer 210L (55 gallon) barrel stores wood for combustion to heat the inner chamber. The Biochar Assisted Compost (BAC) was produced with locally produced compost at Hawaiian Earth Works Products (https://hawaiianearth.com) mixed at 5% biochar of the compost pile volume. Eight treatments were determined to answer the biochar charging and inoculation need questions as described below.

T1: Soil only: Control.
T2: Soil + Biochar.
T3: Soil + Compost.
T4: Soil + Biochar assisted compost (BAC).
T5: Soil + Biochar + Compost.
T6: Soil + Biochar + Fish Emulsion.
T7: Soil + Biochar + Compost + Fish Emulsion.
T8: Soil + Biochar + BAC + Fish Emulsion.
Note: Biochar was applied at 12,500 kg/ha (5 t/ac) and compost/BAC were applied at the rate of 25,000 kg/ha (10 t/ac). Treatments 2-8 were the amendments (biochar, compost,

BAC, FE based on each treatment) were incubated together in sealed ziplock bags for 3 days, then thoroughly mixed into the soil based on each treatment individually.

Quality assessment based on the International Biochar Initiative (IBI) standard were conducted by the Soil Control Lab (https://www.controllabs.net/) on the locally produced biochar compared to commercially available biochar brand (https://www.fbn.com/direct/product/cool-terra-organic/specimen-label) showed they have very similar quality values in total carbon content and surface area (Figure 3), ash content, and pH (Figure 4). A total of 64 (8 treatments X 4 replicate X 2 soils) 2-gallon pots were used in the trials for each crop. The 8 treatments X 2 soils pots were distributed randomly on 2 greenhouse benches, divided into 4 blocks. Beet seeds were planted directly into each pot at the rate of 3 seeds/pot. Then plants were thinned to 1 plant after germination. Pak choi seeds were planted into 50-cell trays and then transplanted after producing true leaves at the rate of 1 seedling per pot. Nitrogen fertilizer was applied at the rate of 50 and 100 kg N/ha using 6-4-6 Sustane organic fertilizer for beet and pak choi, respectively. The fertilizer was calculated based on the soil weight in each pot. An overhead irrigation system was utilized for both trials.

Leaf relative chlorophyll content using SPAD Minolta meter was measured for both crops, and all treatments and replicates prior to harvest. Beetroot and pak choi fresh weights were measured at harvest. Beetroot and pak choi were dried using a conventional oven for 72 hours at 70°C, then percent dry weight was recorded. Due to the small amount of dry biomass collected, a composite sample for each treatment was submitted for chemical analysis to measure nitrogen (N), phosphorus (P), and potassium (K) tissue content. Soil samples were collected from each pot to measure soil pH using pH/EC combo meter and CO_2 respiration rate using Solvita Kit. Analysis of variance (ANOVA) for RCBD was performed using Statistix Software V. 10 (https://www.statistix.com) to evaluate the effect of the 8 treatments on the study parameters (plant growth and soil health) and determine significance level.

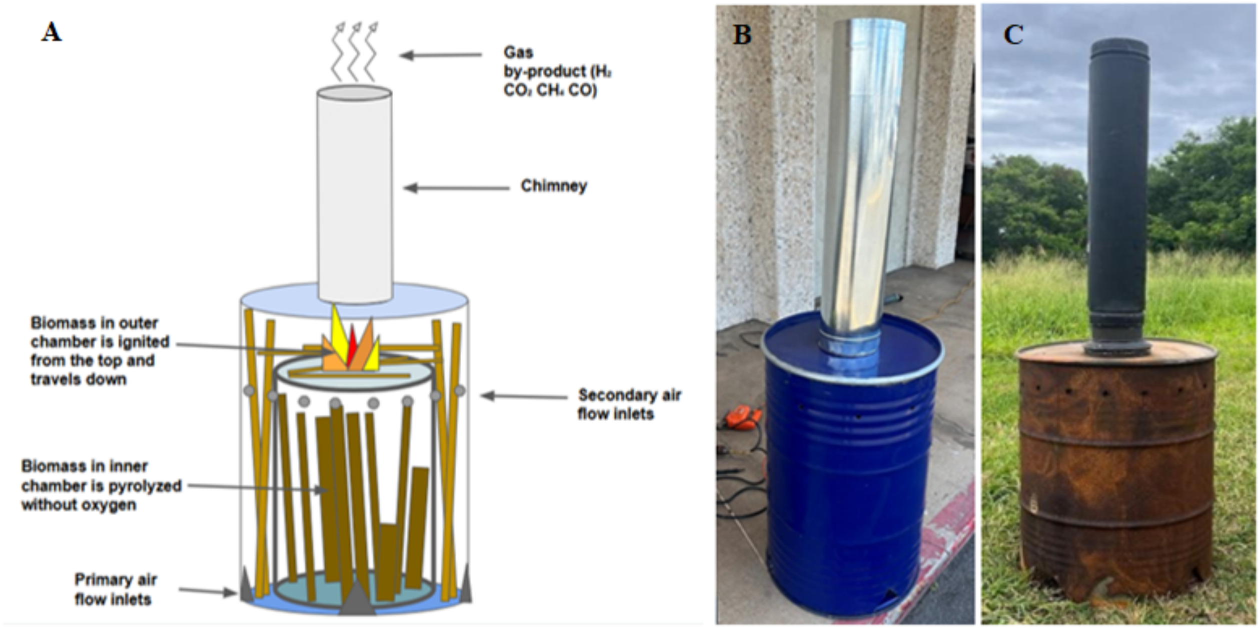

Figure (2): A diagram (A), the actual retort kiln used in the trials before the 1st burn (B), and the retort kiln after multiple burning (C).

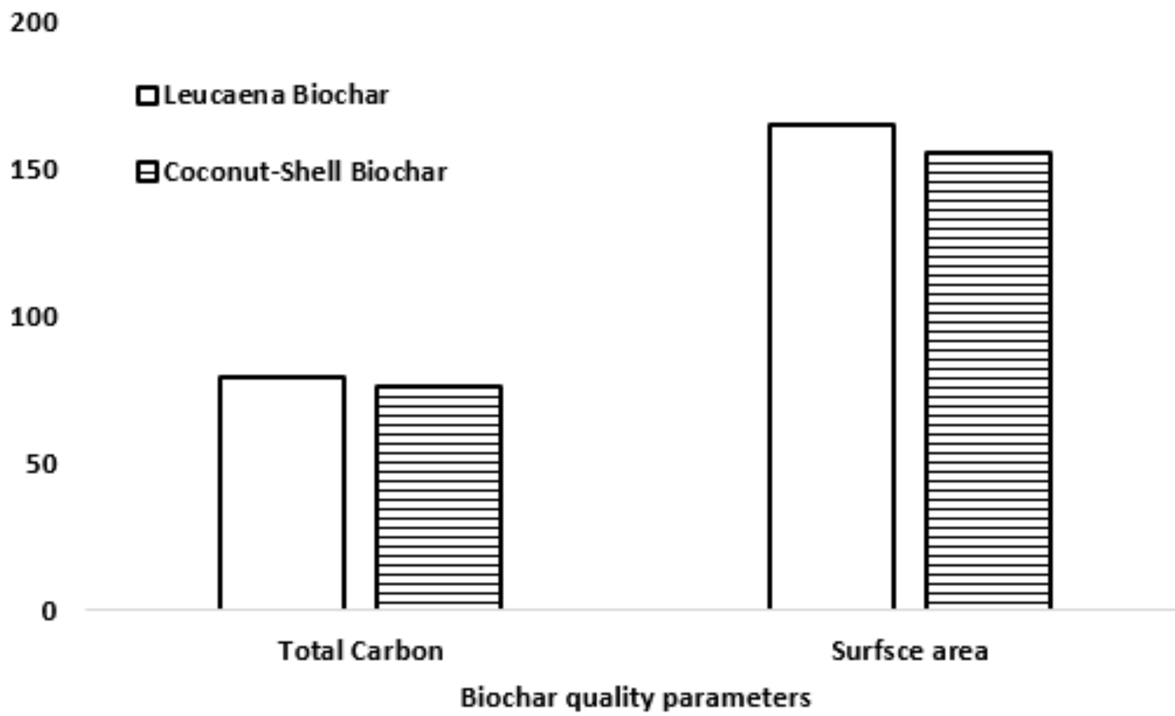

Figure (3) Total carbon (%) and surface area (m^2/g) in the locally produced vs. commercial biochar based on the IBI standard.

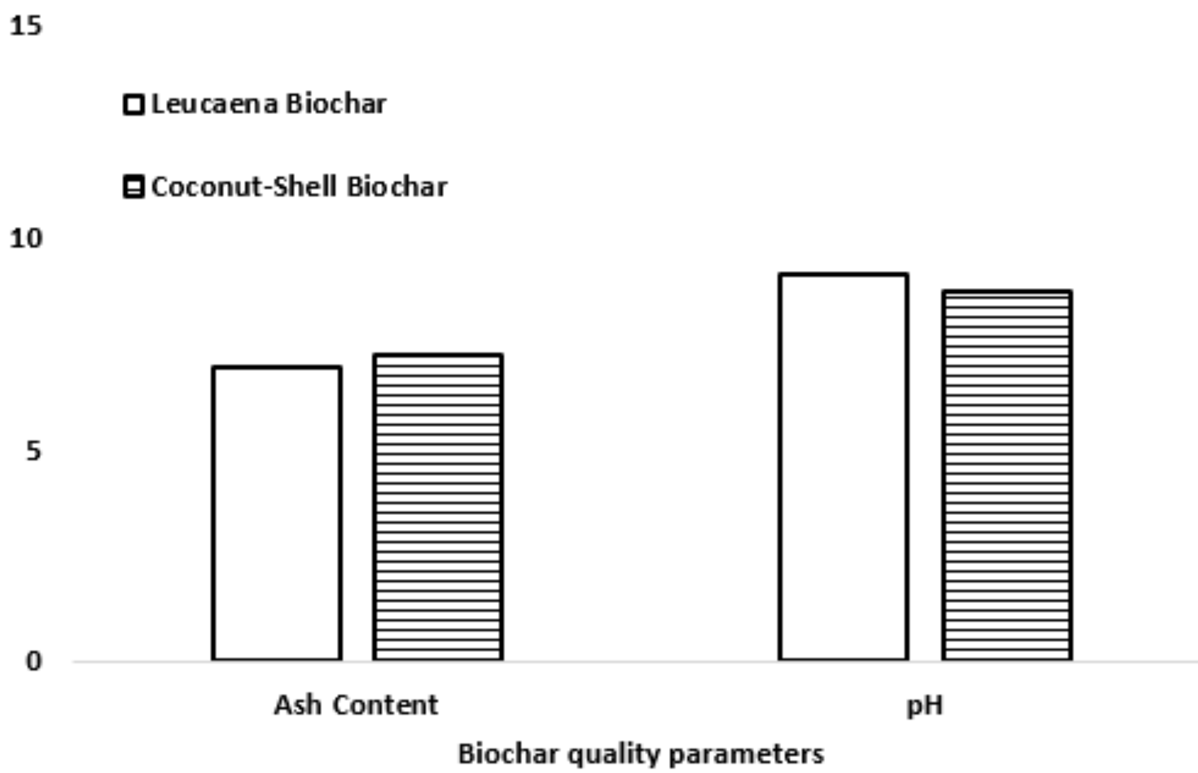

Figure (4) Ash content (%) and pH in the locally produced vs. commercial biochar based on the IBI standard.

RESULTS AND DISCUSSION

Statistical analysis:

The analysis of variance results showed that pak choi and beetroot fresh and percent dry weights have shown a highly significant ($p>0.01$) response to the study treatments. However, relative chlorophyll content showed significant ($p>0.05$) response to the study treatments. Both soil health parameters (soil CO^2 respiration rate and pH) showed a significant ($p>0.05$) response to the study treatments based on the ANOVA results.

Crop growth and yield:

Both pak choi and beetroot showed a steady increase in plant growth from the control treatment (T1-soil only) to T8 (Soil + Biochar + BAC + Fish Emulsion). The results showed that charging and inoculating the biochar prior to application to soil have benefitted the study crops (Figure 5). Similar growth pattern and response were observed for both crops under the two soil types. Additionally, the results showed that although all biochar and compost application treatments were better than soil only (T1-control) treatment, but the charged and inoculated biochar (T4-T8) treatments performed better than biochar and compost application only (T2 and T3).

Figure (5) pak choi (upper) and beetroot (lower) harvested under the 8 treatments under Oxisol soil.

Charged/inoculated biochar treatments substantially increased the crop fresh and percent dry weight (Figure 6-9). Pak choi fresh weight increased by up to 81% and 65% compared to the control under Oxisol and Mollisol, respectively (Figure 6). The fresh weight of beetroot increased by up to 83% and 50% compared to the control, under Oxisol and Mollisol, respectively (Figure 7). Pak choi dry weight increased by up to 83% and 50% compared to the control under Oxisol and Mollisol, respectively (Figure 8). Beetroot dry weight increased by up to 26% and 31% compared to the control under Oxisol and Mollisol, respectively (Figure 9). The results is an agreement with what Asirifi, et al (2025) reported of combining biochar and compost showed significant results in soybean growth and yield. Also, Berek (2015) reported that biochar+compost application improved the growth and biomass in pak choi. Antonangelo, et al (2021) have reported in their review that various crops have shown significant response to the application of biochar-compost combination compared to biochar only or control (soil only).

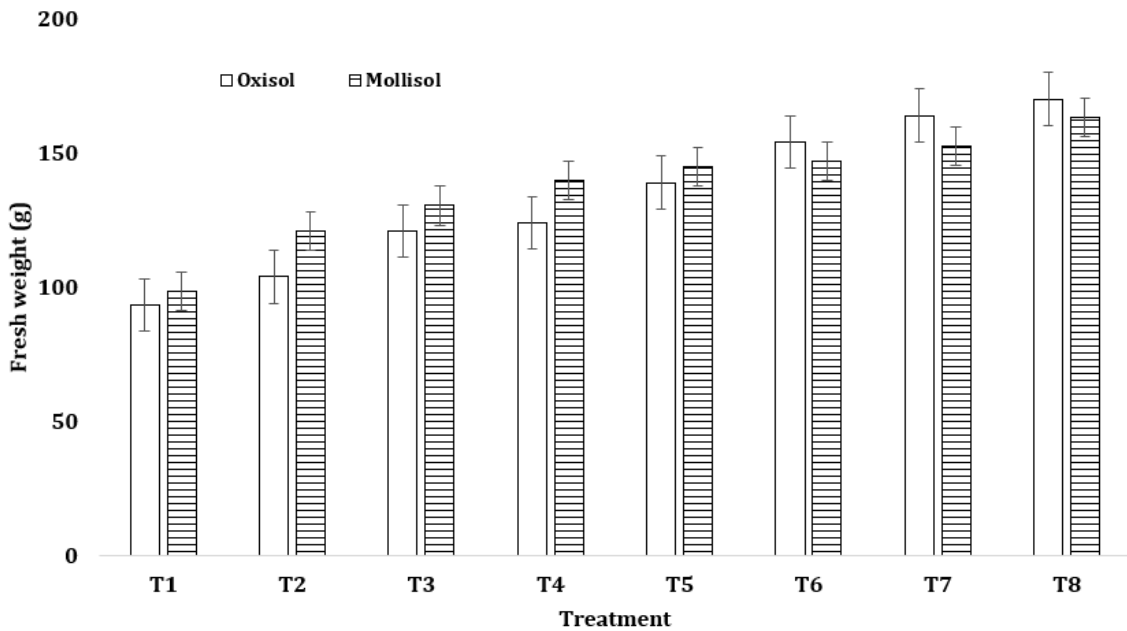

Figure (6) Fresh weight (g) of pak choi under the 8 treatments and soil types.

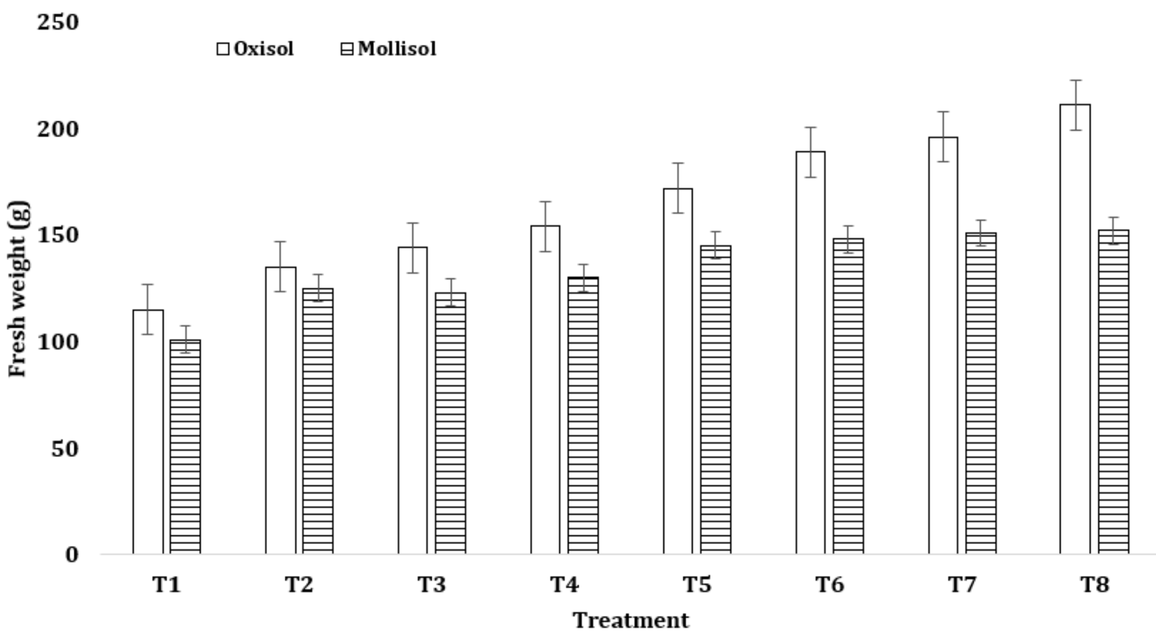

Figure (7) Fresh weight (g) of beetroot under the 8 treatments and soil types.

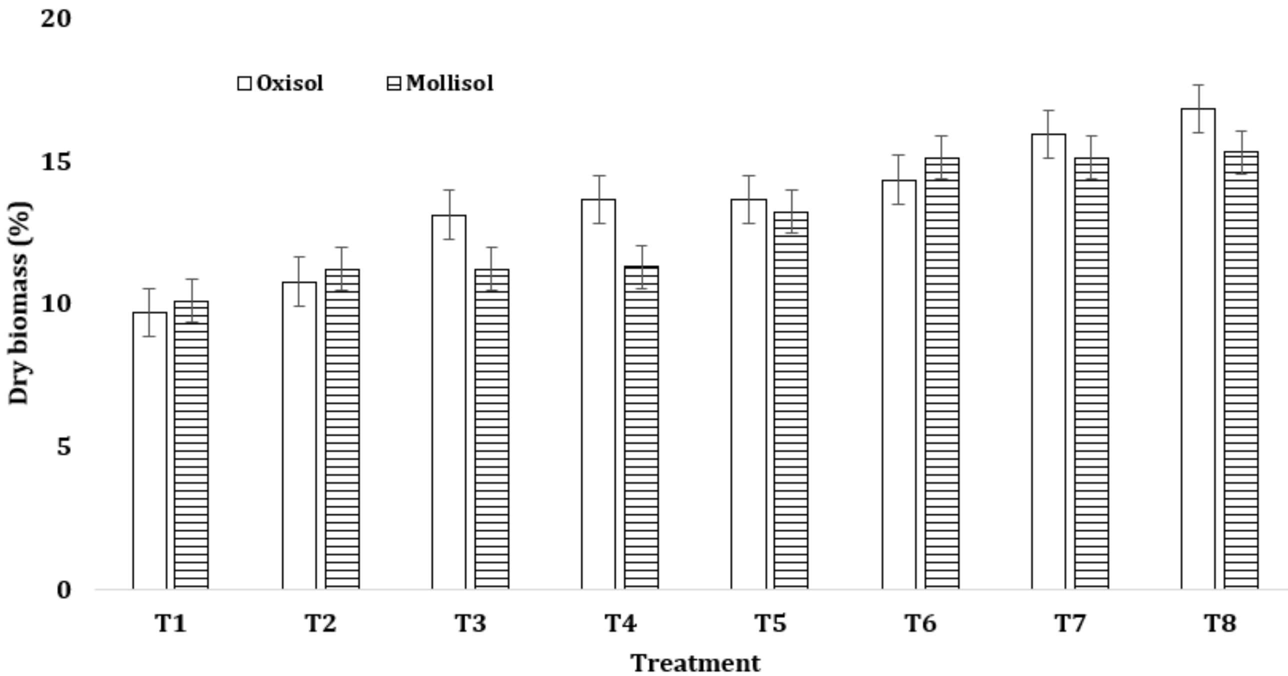

Figure (8) Percent dry weight (% DW) of pak choi under the 8 treatments and soil types.

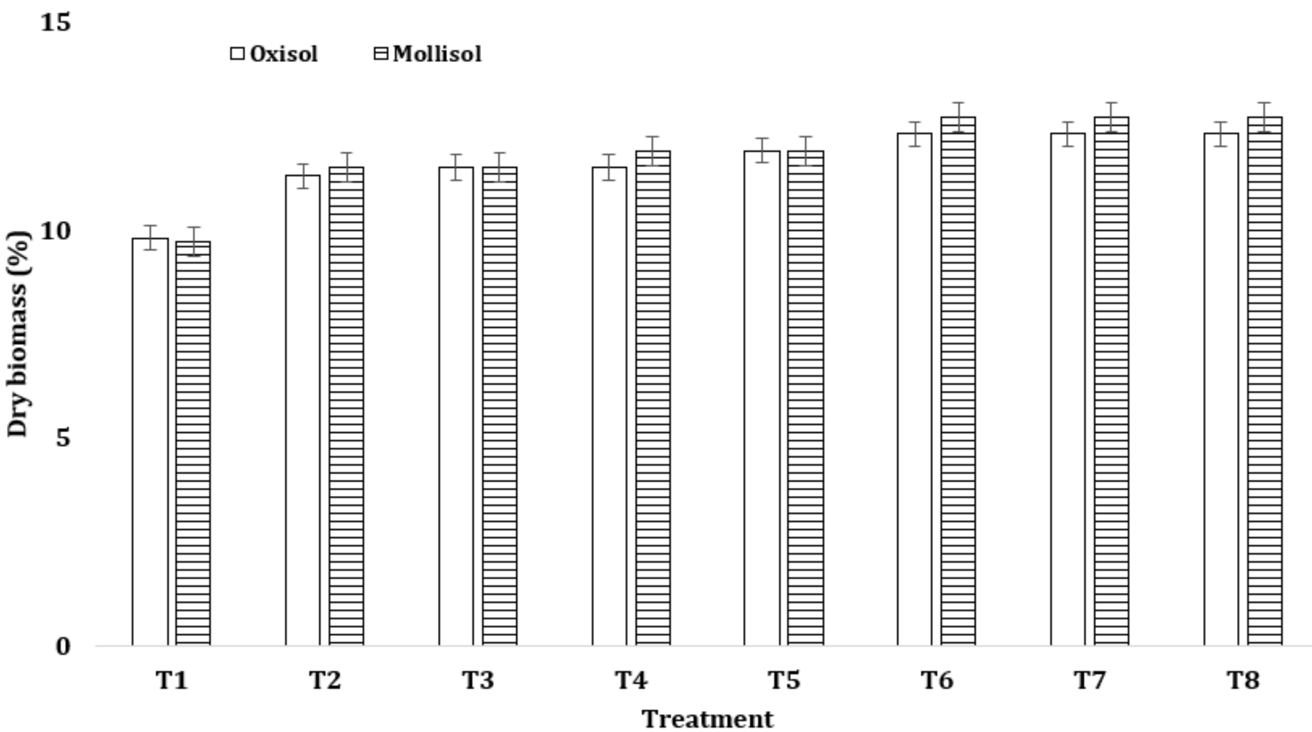

Figure (9) Percent dry weight (% DW) of beetroot under the 8 treatments and soil types.

Leaf chlorophyll content also increased by up to 35% and 41% for beetroot, and 49% and 41% for pak choi under Oxisol and Mollisol soils, respectively (Figure 10-11). These findings suggest that the charged/inoculated biochar treatments increased overall growth of the crops for many reasons, with some being the increased nutrient availability and improved soil health due to the treatments. The increased nutrient availability would explain the increased fresh and dry weight of the crops. With more nutrients available, the crops were able to grow more and faster in a faster time than the crops with no or fewer amendments. The increased leaf chlorophyll content also suggests that there was increased nitrogen available to the plant in the soil which is likely due to the treatments used. The leaf chlorophyll content was calculated using a SPAD meter, which stands for Soil Plant Analyis Development and is used to allow growers to estimate the nitrogen availability in the soil. So, with a higher SPAD reading, it is showing that there is more nitrogen available for the plant to use and uptake. The results are in agreement with Bekchanova, et al (2024) study which reported improved crop growth under biochar application. Also, Agegnehu, et al (2015) reported that peanut crop leaf chlorophyl content improved significantly under biochar-compost application compared to biochar only.

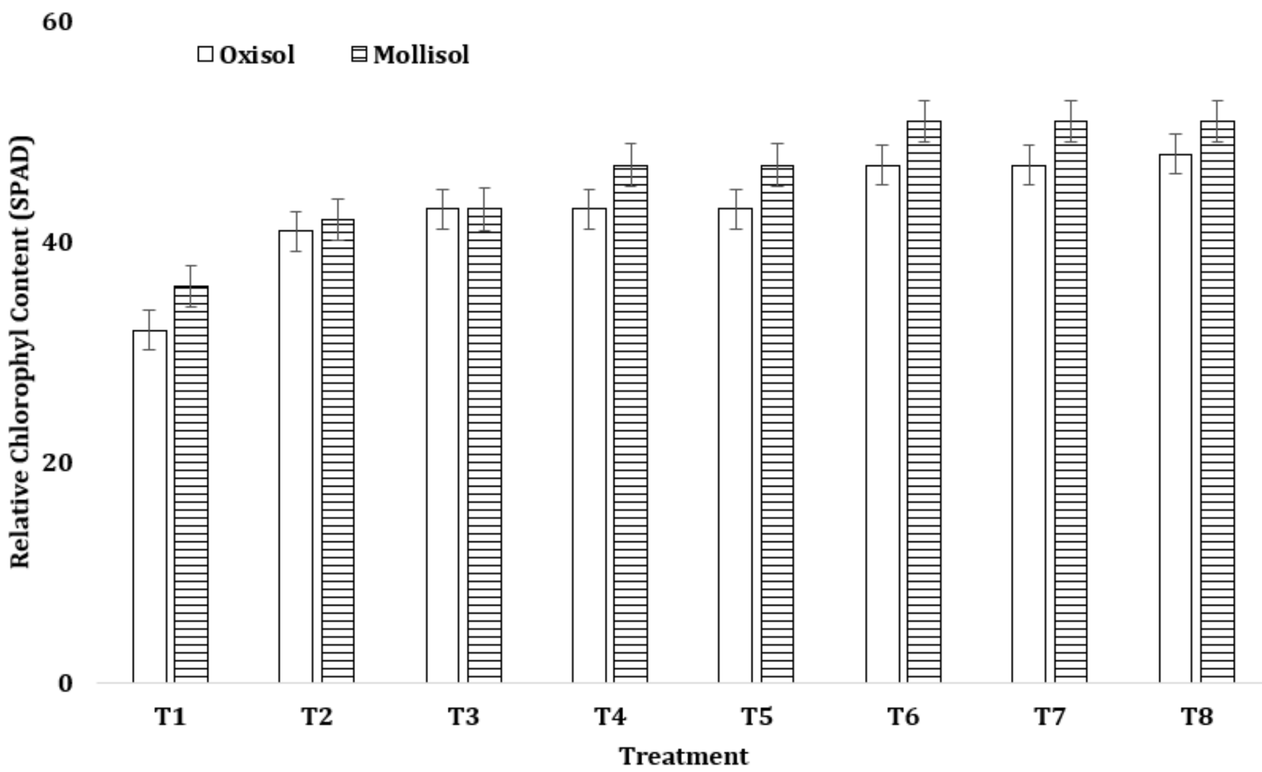

Figure (10) Relative chlorophyll content in pak choi leaves under the 8 treatments and soil types.

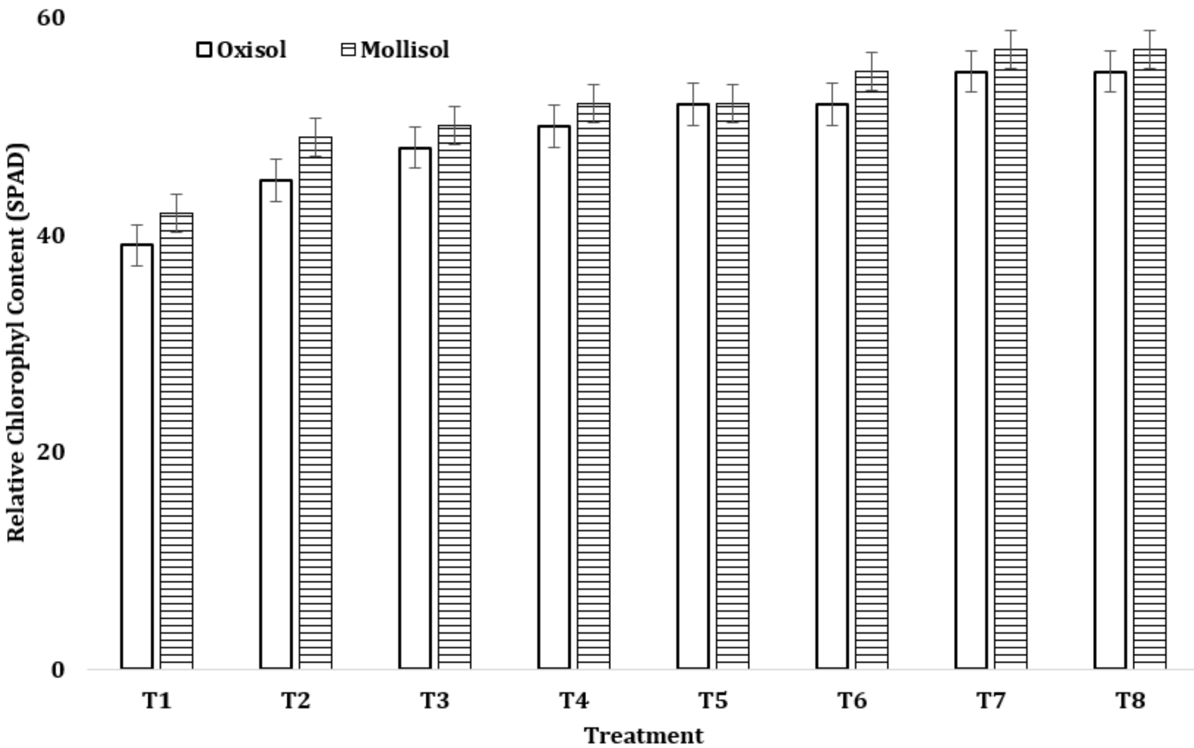

Figure (11) Relative chlorophyll content in beetroot leaves under the 8 treatments and soil types.

Nutrient uptake also improved under charged/inoculated biochar treatments compared to the control (soil only) and biochar only, The highest nitrogen (N%), phosphorus (P%), and potassium (K%) levels were observed in T8 (soil + BAC + FE), T7 (soil + biochar + compost + FE), and T6 (soil + biochar + FE), with values reaching approximately 3.9% N, 0.30% P, and 3.3% K, respectively—representing increases of up to 95% for N, 200% for P, and 75% for K compared to the control (T1: soil only, 2.0% N, 0.10% P, 1.8% K) treatment (Figure 12 and 13). These elevated macronutrient contents in the tissue align with enhanced nutrient availability and the nutrient-retention properties of charged/inoculated biochar and BAC, which can reduce nutrient leaching and improve cation exchange. Biochar alone (T2) and compost alone (T3) produced moderate improvements, while combinations (charging and inoculation) consistently outperformed single amendments. Along with the enhanced nutrient availability, the charged/inoculated biochar started out with more nutrients to begin with which also explains the increased macronutrient content in the tissue. While studies have shown that biochar over multiple years will have the most impactful benefits on nutrient cycling and availability (Bekchanova et al. 2024), this study suggests that charging and inoculating at time of application is best to see improved results quicker. The results from Agegnehu, et al (2015) study found that tissue nutrient content in peanut crop increase significantly under biochar-compost application compared to biochar only.

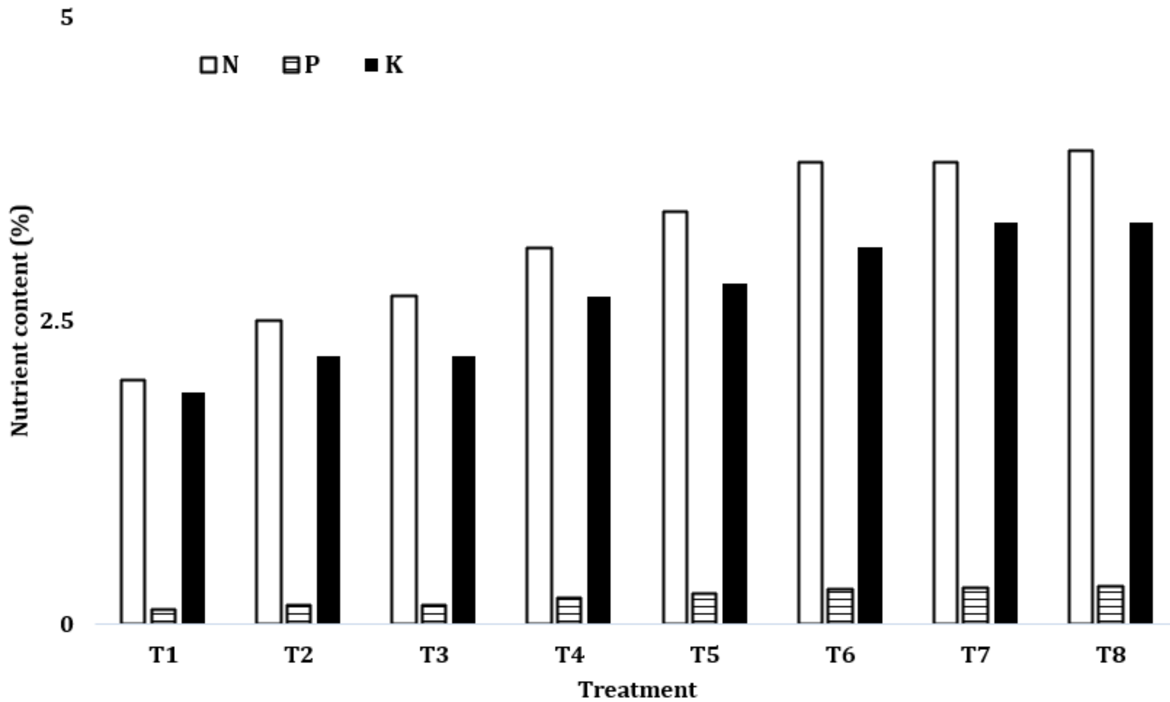

Figure (12) Nitrogen (N), phosphorus (P) and potassium (K) content (%) in pak choi tissue under the 8 treatments regardless of soil type.

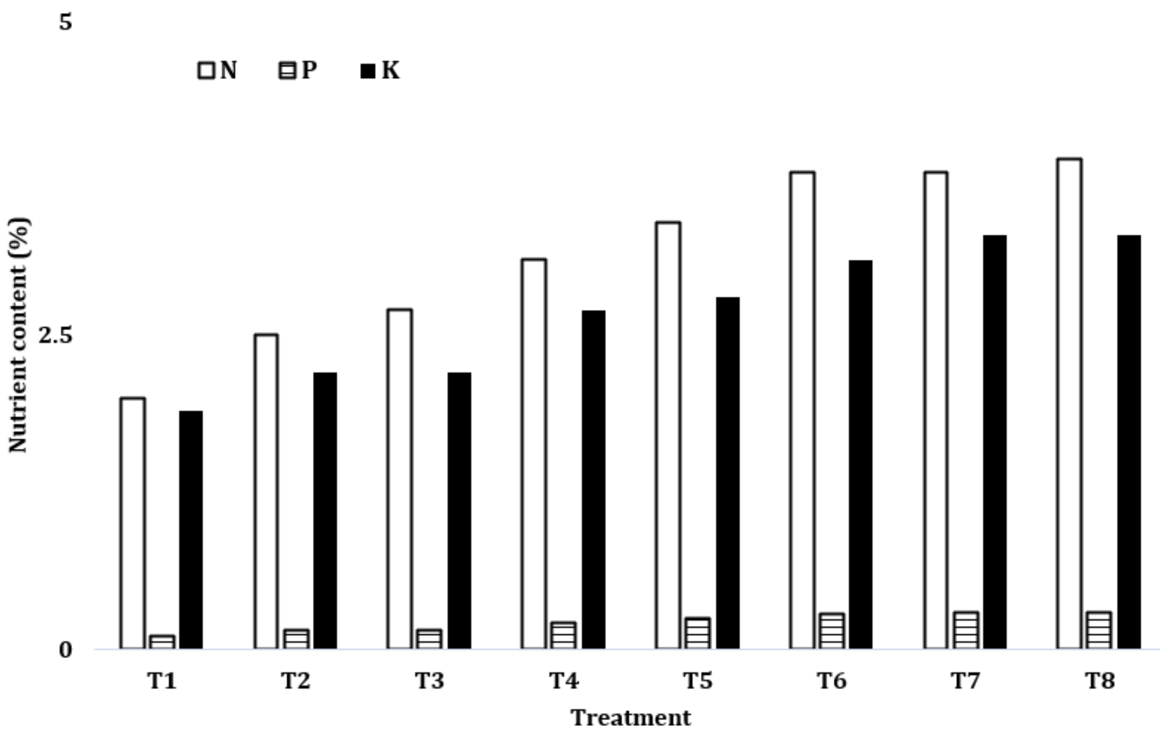

Figure (13) Nitrogen (N), phosphorus (P) and potassium (K) content (%) in beetroot tissue under the 8 treatments regardless of soil type.

Soil Health:

Elevated soil pH (45% increase under Oxisol and 20% increase under Mollisol) and CO_2 respiration rate (75% increase under both soils) in both soil types occurred for the charged/inoculated biochar and BAC, compared to soil and biochar only, indicating improved soil health. Soil CO_2 respiration rates, which measures for microbial activity and organic matter decomposition, were highest in T8, T7, and T6, and similar high-amendment treatments (3.2–3.3 g/m^2), compared to the control (1.8 g/m^2) (Figure 14), reflecting increased growth of microbes and, in effect, microbial respiration and enhanced biological activity. These findings are consistent with prior research showing that biochar, especially when charged or combined with compost and nutrient-rich liquids like fish emulsion, enhances microbial biomass and nutrient availability, while also improving soil health parameters. The increased nutrient availability and organic matter that is present in the charged/inoculated biochar treatments also helps provide suitable conditions for these beneficial soil microorganisms to thrive and in turn improve soil health.

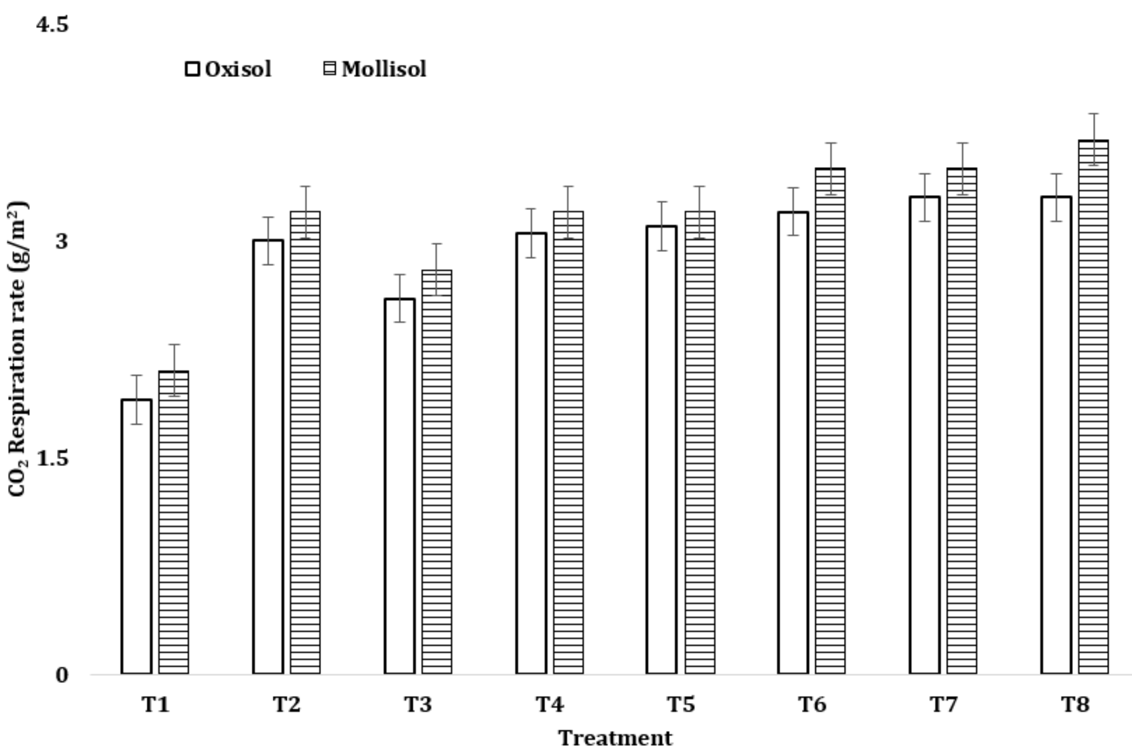

Figure (14) Soil CO_2 respiration rate (g/m^2) under Oxisol and Mollisol soils regardless of crop.

Soil pH followed a similar pattern as the CO_2 respiration rate, with the highest values (6.7–6.8) in the most complex treatments (T8, T7, and T6) and the lowest (5.0) in the control (Figure 15), indicating that organic amendments—particularly those incorporating compost, BAC, and biochar—buffered acidity and raised pH toward the optimal range for beetroot growth (6.0–7.0). This pH shift likely contributed to improved nutrient uptake (Berek, 2015). With this improved nutrient uptake, we noticed that tissue nutrient content in beets showed a clear gradient increase across treatments. With the pH increased to a suitable range for beetroot, it allowed for not just increased macronutrient uptake but also suggests that there was an increase in micronutrient uptake, overall healthier plants due to optimal soil pH, and reduced possibility for any nutrient toxicity. This increase in soil pH is expected as it has been found that biochar, in addition to BAC, can cause that increase (Tomczyk et al., 2020). While these amendments can act as a pH buffer, the initial soil properties do play a role in how much the pH will be impacted, as a more acidic soil such as the Oxisol used in this study will have a bigger increase in pH compared to a more neutral soil such as the Mollisol used. The results are in agreement with Agegnehu, et al (2015) which they found that biochar-compost application improved soil properties compared to biochar only under peanut crop. Also, Antonangelo, et al (2021) have reported in their review that soil properties and health under the application of biochar-compost combination improved compared to biochar only or control (soil only). Rawat, (2019) reported improved soil health parameters under biochar application.

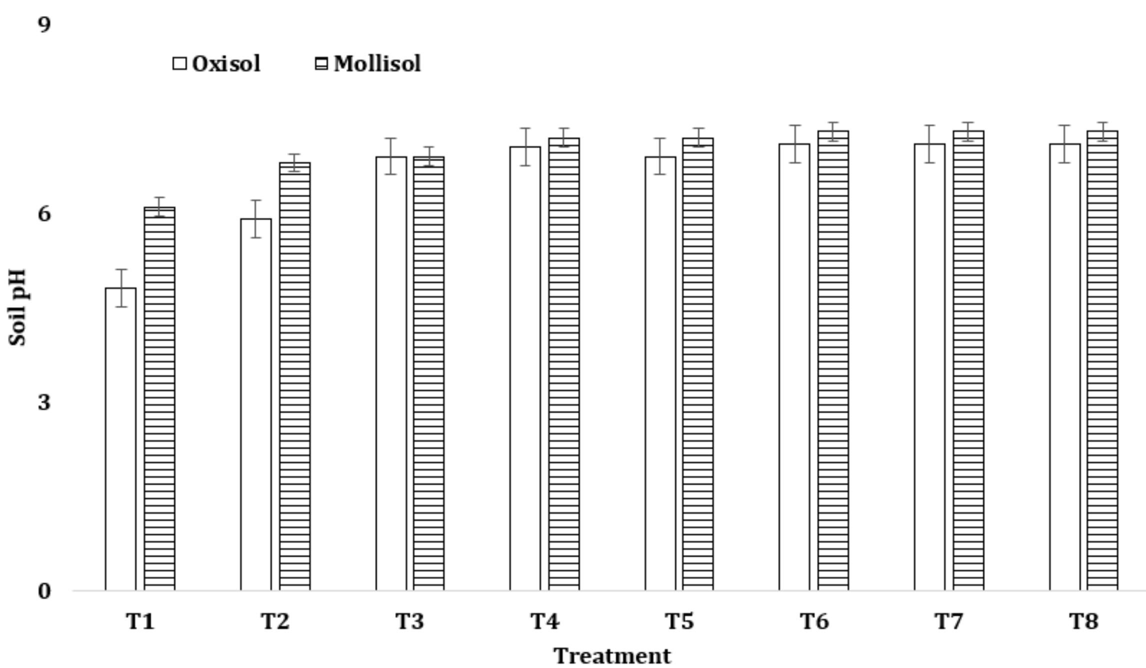

Figure (15) Soil pH under Oxisol and Mollisol soils regardless of crop.

Conclusions

Overall, the results demonstrate that integrating invasive species-derived biochar with organic amendments offers a strategy to increase crop nutrient and improve soil health, with the greatest benefits observed in treatments combining biochar charging and inoculation together. Along with sampling two different soil types, it was reflected that the biochar with organic amendment was beneficial to both of them. In addition to that, the results confirmed that charging/inoculating the biochar prior to applying it to soils is beneficial to soil properties and crops growth and yield. While this study is limited in condition as a pot trial, it is possible for future studies to investigate the impact of the 8 different treatments in a field plot setup to include soil profile depth/equilibrium effect/interaction.

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