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Towards a zero-waste model in longan farms: Impact of longan biochar and corn mulch on longan plantation soils

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Abstract

Conventional intensive farming, that focuses on product volume (cash farming), has resulted in large amounts of raw material consumption, especially mineral fertilizers and chemical herbicides that unavoidably affect the environment and consumer safety. In this work, an alternative, sustainable farming practices that focused on improving soil fertility by using in-farm produced longan (*Dimocarpus longan* Lour) biochar was examined. Biochar, produced from pruning residues, and corn stover compost was studied to evaluate their impact on soil chemical properties and how they might contribute to a “zero-waste” farming model. The farm soil was loamy sand with high acidity and low primary macronutrients (less than optimal for most plants). When different longan-biochar volumes were applied to longan plantation soil, positive effects on some chemical properties were recorded. The highest average soil pH increased at the maximum application rate of 20% v/v biochar by 21.2% (±0.2) and electrical conductivity (EC) increased highest at the biochar application rate of 5.0% v/v by 20% (±6). In addition, SEM/EDX analysis suggested that an exchange of some useful elements between the biochar, the soil and the compost occurred. The use of the in-farm longan biochar not only improved soil condition but also contributed to better environmental and financial outcomes through recycling waste and reducing the need for external fertilizer input.

Keywords: corn mulch, longan biochar, SEM/EDX analysis, zero-waste model

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1. Introduction

Land use change, by conversion of native forest to fruit orchards, with poor orchard management practices has negatively impacted on soil physical, chemical and biological properties and has consequently led to lower yields [1]. However, low crop yields may also be attributed to other factors such as: soil nutrient imbalances [2], nutrient leaching and erosion [3], introduction of new diseases, insect pest and weeds [4], and low pollination [5, 6]. The establishment of longan (*Dimocarpus longan* Lour) orchards in previously forested areas in tropical areas of northern Thailand has caused degradation of the soil conditions by acidification and lowering plant nutrients.

Conventional agriculture in Thailand has focused on intensive farming to produce incomes that provide for more than a subsistence existence. This intensive farming emphasizes large, single crop production and has led to the overuse of chemicals, particularly mineral fertilizers (NPK) [7, 8, 9] and herbicides [10] that affect soil acidity. Change from conventional agricultural practices to sustainable methods will mitigate the risk of excessive use of chemical based substances. For example, [11] showed that sustainable agricultural management using no tillage, spontaneous vegetable cover and annual recycling of pruning material could improve water storage from rainfall, reduce soil and water losses and increase carbon sequestration.

Biochar has been widely used as a soil amendment in agriculture to help improve soil properties that lead to greater, sustainable production. It has been reported to have increased soil pH [12], improved soil fertility [13, 14, 15] and water retention [16] and prevented erosion [17]. It may also assist in mitigating climate change by carbon sequestration in soil, where it can last for very long periods; from centuries to millennia [18, 19, 20].

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Table 1 Example of soil properties from the longan farm, Wiang Pa Pao District, Chiang Rai, Thailand

pH	Organic matter (%)	N (%)	Avai P (mg/kg)	Avai K (mg/kg)	E.C. (1:5) (ms/cm)	Sand (%)	Silt (%)	Clay (%)
4.8	2.95	0.15	12	119	0.019	71.36	14	14.64

Compost as organic fertilizers has been used in agriculture to improve soil productivity and crop yield for many years [21, 22, 23], however, the use of compost combined with biochar as a soil amendment has not been extensively investigated. Despite this, [24] reported some interesting, synergistic effects that indicate that their combination may increase crop yields. Research presented here studied how a biochar amended compost effects soil chemical properties in a mesocosm under natural condition over 6 months. The study used recycled materials from an annual longan harvest by charring the longan wood (pruning residues) to produce the biochar. The biochar was applied at different rates in combination with compost to longan plantation soil. Corn waste from outside the farm was used for composting with cow manure. The biochar amended compost (BAC) was applied to determine how it affects soil nutrient levels, plant growth (height), soil pH and electrical conductivity.

2. Materials and methods

2.1 Biochars, compost and soils

Biochar was produced from regular annual pruned longan materials after normal fruit harvesting. The longan branches and twigs were pruned, the leaves removed and left on the ground for further decomposition in the farm and the wood was chopped to lengths ≤ 50cm and air-dried for one month before charring. The material was charred in a 200L metal kiln [25] with maximum temperature of 550°C for 3.5 hrs. All charred material was grounded and sieved to ≤ 2mm to guarantee a more homogeneous biochar application.

Compost was produced from corn waste and cow manure using Maejo Engineering 1 method [26]. Maize milling waste and cow manure were mixed by layering in piles of 1.5m high with moisture kept at approximately 60-70% for 2 months before being used. The compost was milled to ≤ 2mm before being thoroughly mixed with the biochar and soil. The soils were collected from Wiang Pa Pao District, Chiang Rai, Thailand (19°08'41.1"N 99°29'20.5"E) at a depth of 0-30cm. The soil was a loamy sand with the properties shown in Table 1.

They were sieved to ≤ 2 mm and the larger plant remains removed. The ground biochar was mixed with soil and compost at different rates (0.0, 2.5, 5.0, 10.0 and 20.0% v/v). The milled compost was mixed with the biochar and soil at the equal rate of 5% w/w. The BAC was then added to each of the experimental pots at the designated volume.

2.2 Mesocosm experimental design

A pot experiment under natural rain conditions was conducted using a Completely Randomized Design. Biochar was applied at designated rates and contained within 250 mm diameter plastic pots (4 replicates per treatment). The bottom of the pots was packed with plastic netting (mesh size 1.5x1.5 mm) to prevent soil leakage and the pots were placed at 50cm intervals on a 40 cm-high shelf for hygiene purposes.

2.3 Longan trees

To study growth, one (1-year-old) longan tree *(Dimocarpus longan* Lour) was planted in every pot. Watering was applied regularly to keep enough soil moisture to prevent water stress, as is common practice. Insect pests were prevented using wood vinegar (1 wood vinegar:200 water) when required.

2.4 Sampling and measurement of soil pH and EC

The soil pH and EC was measured at the beginning of the experiment and every 15 days after planting. Soil measurements included: electrical conductivity (Electrical Conductivity Water Tester Aquarium Long Probe 1999 micro Siemens/cm EC Meter, model number: EC-104), pH, primary macronutrients (NPK), and soil textures (hydrometer method). pH and EC was measured every 15 days while the other components were measured at the beginning of the experiment and again at 6 months. The soil in the pots was watered before the measurement of pH; pH was measured using a pH meter (1:1 soil:water).

2.5 Sampling and measurement of tree growth

Plant growth parameter that were measured in this study was the height of the tree measured from the trunk base 5 cm above ground to the apical bud. All the growth observations were taken every 15 days.

2.6 SEM-EDX analysis

A Scanning Electron Microscope (SEM) equipped with Energy Dispersive X-ray spectrometer (EDX) analysis was used to determine the details of the surface characteristics of the biochar and the nutrient composition of the soil and biochar samples. The analyses were performed by the Institute of Product Quality and Standardization (IQS) of Maejo University, Chiang Mai, Thailand. The sample analyses were conducted on the treatments at the beginning of the experiment, and again at two and six months later. However, the results shown in this report were at the 2-month analysis due to at the 6-month the elements concentrations in the samples were small that resulted in poorly identified in most of the sample analysis.

2.7 Statistical analysis

Analysis of variance (ANOVA) was conducted by performing regression analysis combining with an assessment of differences between means.

3. Results

3.1 Compost

The compost was analyzed and met the Thailand Organic Fertilizer standard of 2005 [27] where the composition and conditions were within the range recommended.

3.2 Soil acidity (pH)

The average soil pH was different at the first measurement immediately after the 48 hrs equilibrium (Figure 1). The control and the low biochar content treatments of 2.5 and 5.0% commenced with higher pH before rapidly dropping after a few days. After this, the pH of all three treatments increased and then tended to stabilize followed by a slight decrease (Figure 1). Soil pH started highest in the 5.0% biochar applied treatment of 6.1 before it dramatically declined.

The higher biochar levels, however, initially had lower pH values than those of the controls, the 2.5 and 5% biochar treatments. In this case the pH initially increased and then stabilized in a manner similar to that of the lower biochar treatments. After 6 months, there was a significant difference between the pH values of the different biochar treatments with 2.5 to 20% biochar tending to have higher pH values (Figure 1) than the control.

3.3 Soil Electrical Conductivity (EC)

The soil EC of all treatments displayed similar results as induced by the BAC (Figure 2). The average values after 6 months increased from the beginning from the lowest increment at -11% of the control to 20% of the 5% biochar as the highest. However, there was no statistically significant difference between treatments with biochar and the control.

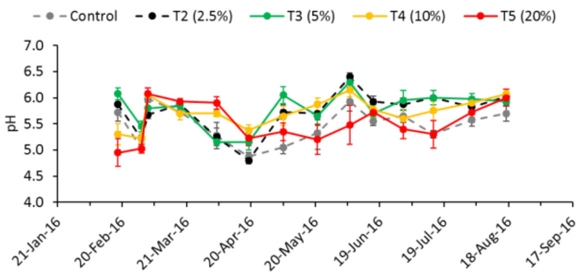

Figure 1 Soil pH dynamics during the early experimental period for treatments. Control (Soil + Compost), T2 (Soil + Compost +2.5% Biochar), T3 (Soil + Compost + 5.0% Biochar), T4 (Soil + Compost + 10.0% Biochar), and T5 (Soil + Compost + 20.0% Biochar). Each value represents the mean of four replicates with standard error shown by the vertical bars.

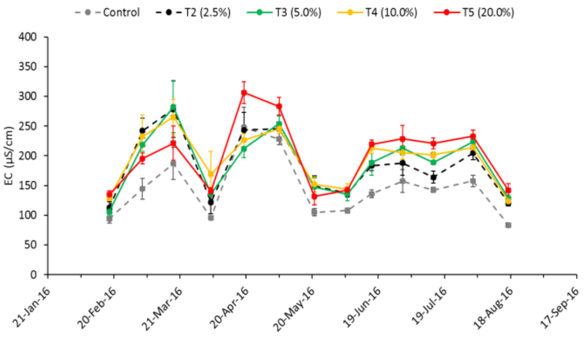

Figure 2 Soil EC dynamics during the early experimental period for treatments Control (Soil + Compost), T2 (Soil + Compost +2.5% Biochar), T3 (Soil + Compost + 5.0% Biochar), T4 (Soil + Compost + 10.0% Biochar), and T5 (Soil + Compost + 20.0% Biochar). Each value represents the mean of four replicates with standard error shown by the vertical bars.

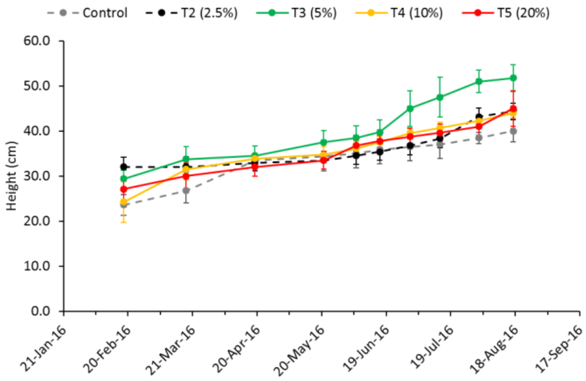

Figure 3 Longan growth rate identified from tree height of Control (Soil + Compost), T2 (Soil + Compost +2.5% Biochar), T3 (Soil + Compost + 5.0% Biochar), T4 (Soil + Compost + 10.0% Biochar), and T5 (Soil + Compost + 20.0% Biochar). Each value represents the mean of four replicates with standard error shown by the vertical bars.

3.4 Longan growth

The growth rates were identified from the plotting of the tree height against time. The linear trends were generated on each individual treatment data set with the slope of each trend used to represent the growth rate (height). Growth rates of all treatments were different (Figure 3). The highest growth rate was from the 5% biochar with the trend slope of 0.125 while the lowest rate was from the 2.5% biochar with a rate of 0.067. The second-highest rate was from the 10% biochar treatment with the trend slope of 0.096. The highest biochar applied treatment of 20% had low growth rate of 0.092 which is a little better than the lowest treatment from the 2.5% biochar applied treatment.

3.5 SEM-EDX analysis

The spectra of the elements measured using SEM-EDX are illustrated in Figure 4. There was an increase in some elements and decrease in others in the biochar and soil particles at the beginning; 48 hrs after mixing the BAC ingredients. After two months, some essential plant nutrients (P, Si, and Fe) increased in biochar while they decreased in the soil. Carbon concentration was high in biochar at the early stages and decreased dramatically, while, at the same time, increased in most of the soil samples. Nitrogen increased in both biochar and soil while potassium decreased.

4. Discussion

The soil pH of most treatments decreased quickly after a few days of the experiment before increasing again (except 20.0% biochar). This can be the effect of the acidic nature of biochar itself and short-term biochar oxidation in the soil [28]. The 20.0% biochar application treatment that did not decrease but increased slightly when the others decreased, may have done so because of the more alkaline nature of the soil due to the higher biochar concentration. The subsequent changes that occurred are likely to be due to the daily watering that tends to leach out basic cations (i.e. hydrogen ions) or leach K^+ ions as seen from the SEM-EDX analysis (Figure 4). Nonetheless, the tendency of the changes as seen from the experiment were still uncertain, a longer experimental period is required to obtain more conclusive information, however, the 5% biochar appears to have the greatest effect providing a pH near the optimum for nutrient availability [29] of all the experimental period.

The EC of all treatments changed similarly with time, with a rise and fall. As the EC values went up and down for all treatments with no significant difference between the treatments, the variation could be attributed to the environmental effects of soil temperature and soil chemical properties. Higher soil temperatures, in particular, are known to influence EC [30, 31]. In general, there was no significant differences due to the biochar treatments. This may be due to the short duration of the test period or the biochar application rates were too low to make a difference.

The SEM-EDX analysis indicated that there was exchange of elements between biochar, soil and compost. Some elements in biochar increased from the original level (Al, P, Si and Fe). While these increased in biochar, they decreased in the soil at the same time. Similarly, some elements in biochar decreased their concentration, particularly carbon. However, there were elements that behaved similarly on both biochar and soil, K^+ decreased while N increased in both. The increase of many elements in the biochar indicated that the biochar particles have significant adsorption capacity.

Carbon sequestration in agricultural soil from charring can persist for hundreds of years with very little decay. Some studies indicate that biochar remains in soil for as long as 1,300-4,000 years [18]. In the study area in Chiang Rai, Thailand, burning of farm residues is a common practice used to remove agricultural waste. Biochar production from the annual longan pruning is one of the best options for several reasons, for example, the soil fertility improved via the use of biochar as a soil amendment, the pruning residues are used to support better on farm environmental management, and especially economic benefit to the farm. The recycling of the residues for the biochar production and its use on the farm is estimated to reduce labor costs compared to other methods of removal to outside-farm area, by approximately one-labor-day for 3 Rai or 0.5 ha. This experiment presents a good model for Thai fruit farming that can help protect the environment with better economic outcomes.

5. Conclusions

The BAC for soil amendment made from the recycled longan pruning (biochar and corn mulch compost) showed positive effects to soil chemical properties. The soil pH from the 10% v/v biochar applied treatment provided the highest pH improvement while the highest EC was from the 5% v/v treatment. The SEM-EDX analysis showed that there are some exchangeable elements between biochar and soil. The elements increased in biochar particles after mixing with compost and soil and may be retained in the biochar and available for prolonged plant use. The highest longan tree was from the 5% v/v biochar applied treatment. In addition to soil chemical property changes and the tree height, the economics of a farm may also be improved through reduced labor costs. Thus, the results should justify the transfer of the finding to agricultural farming practices of similar circumstances.

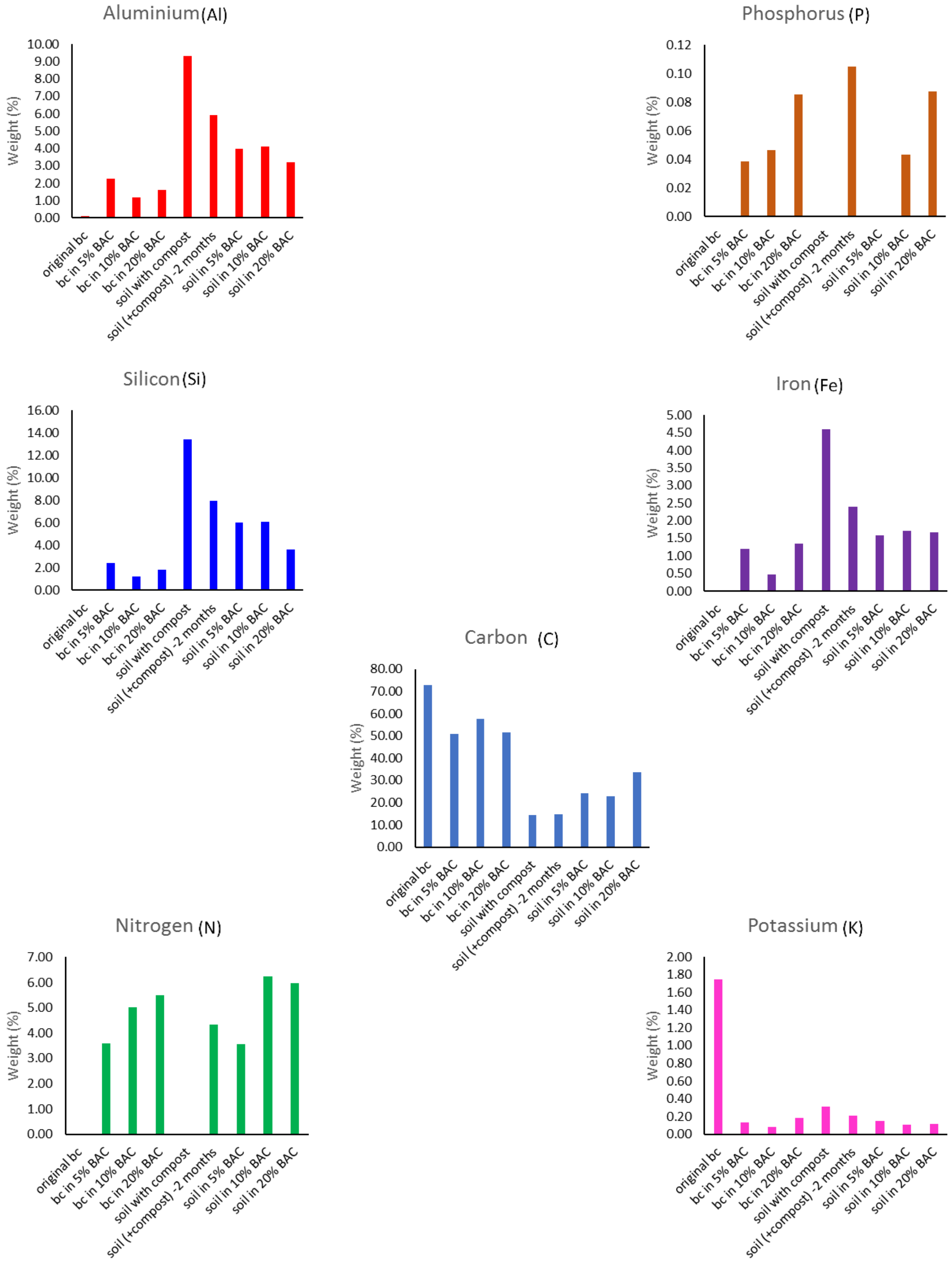

Figure 4 SEM-EDX analysis results after two months of biochar amended compost (BACs) were applied to the soils, showing element concentrations identified from soils and biochar particles: bc = biochar

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