Research Article

Effect of biochar-amended soil substrates on the growth of chinese kale in an organic system

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Abstract

Study of the effects of biochar-based growing media on the growth of kale. This study aimed to utilize agricultural waste for biochar production as an alternative to open burning, which is harmful to the environment. The experiment was designed using a completely randomized design (CRD) with 5 replications and 11 treatments. These treatments consisted of biochar produced from various types of agricultural waste, including 1) rice straw, 2) rice husk, 3) longan leaf, 4) longan peel, 5) longan branch, 6) jarul branch, 7) mango leaf, 8) corncob, 9) coffee husk, and 10) tobacco stem, which were mixed with commercially available growing media and cow manure in a ratio of 2:1:1 (growing media: biochar: cow manure).The study investigated the effects of different biochar types on the growth of chinese kale (*Brassica alboglabra*) in organic growing media. The results demonstrated significant improvements in growth parameters, including plant height, fresh and dry weight from substrate mixed with tobacco stems whereas the highest chlorophyll content was found in culture mixed with mango leaf biochar. The incorporation of biochar into the soil culture boosted its chemical and biological properties. Biochars derived from jarul branches, tobacco stems, and corncobs led to higher pH, electrical conductivity, organic carbon content, and amounts of water-soluble phosphorus and potassium compared to the control. Additionally, coffee husk biochar recorded the highest microbial population, reaching 10.7×10^5 CFU g^{-1}soil at harvest time. These findings highlight the potential of various biochar as effective amendments for improving soil fertility and promoting plant growth in organic farming systems.

Keywords: Soil media, Biochar, Chinese kale, Organic system

Introduction

Agriculture in Thailand currently occupies 54.5% of the country's total land area. The northern region of Thailand cultivates many crops, including fruit trees, field crops, and vegetables. A substantial quantity of agricultural plant residues remains in the production system as by-products, termed biomass. Agricultural regions contain extensive dispersal of these residues. In 2017, approximately 296 tons of biomass were generated, of which 136 tons (46%) were utilized, waste materials 159 tons (54%) unutilized [14]. The unutilized biomass is frequently burned up, resulting in environmental concerns. Various strategies have been developed to maintain agricultural residues more effectively, focusing on maximizing their value and reuse in agricultural practices. In Northern Thailand, a region rich in cropping systems, residues are achieved from rice, longan, mango, coffee, tobacco and other crops. For instance, the approach involves converting biomass into compost or biochar. Biochar production is achieved through a thermal decomposition process known as pyrolysis system, which occurs under oxygen-free or low-oxygen conditions. This process results in the formation of a carbon-rich solid composition with a black appearance [11]. Moreover, biochar is characterized by its highly porous structure, low bulk density [23], high cation exchange capacity (CEC) [4,12], and alkaline pH levels [3]. Furthermore, biochar conduces to environmental sustainability by sequestering carbon and mitigating greenhouse gas emissions, particularly carbon dioxide, from agricultural systems [20]. Additionally, biochar attends to as a host for soil microorganisms, supporting microbial activity and biodiversity in the soil ecosystem [18]. Biochar's beneficial properties make it an effective soil amendment, elevating both soil fertility and plant growth conditions. This study aims to prospect the potential of utilizing various types of agricultural residues for biochar production, with a focus on its application as a component of soil media. The experiment investigates the physicochemical properties of biochar derived from different agricultural residues and evaluates its effects on plant growth, using chinese kale (*Brassica oleracea* var. *alboglabra*) as the model crop.

Materials and methods

This greenhouse experiment was conducted from July to October 2021 in Chiangmai, Thailand to examine the effects of different biochar types on chinese kale growth using a completely randomized design (CRD) with five replications. Ten biochar treatments were produced through pyrolysis system (300-400°C) from various dried agricultural residues including rice straw, rice husk, longan leaf, longan peel, longan branch, jarul branch, mango leaf, corncob, coffee husk, and tobacco stem comparing with commercial soil substrate. Hence, this biochar was mixed with commercial growing substate and cow manure (2:1:1 ratio by volume), and 20-day-old chinese kale seedlings were transplanted into 6-inch pots with daily watering of 200 mL water per pot. Growth parameters, including plant height, were recorded weekly until harvesting, chlorophyll content by using a SPAD-502 (Konnica Milnolta) at 45 days after transplanting. After harvesting, fresh weight and dry weight were collected data. Plant samples were dried in an oven at 70°C for 48 hours before weighing to determine the dry biomass.

The chemical properties of the growing media were analyzed both before and after the chinese kale harvest. The samples were ground using a mortar and sieved through 0.5 mm and 2.0 mm mesh sieves. The substrate samples analyses were conducted as following : 1) soil pH was measured using a 1:2.5 soil-to-water ratio [20], 2) electrical conductivity (EC) was determined using a 1:5 soil-to-water ratio [16], 3) soil organic carbon (SOC) was quantified using the Walkley and Black method [19], water-soluble phosphorus and potassium were extracted with distilled water and analyzed accordingly via atomic absorption spectrophotometer [8].

Biological properties of the soil substates were also checked by determining the total visible of microbial population. Soil substrate samples were analyzed using the pour-plate technique on potato dextrose agar (PDA). All samples were incubated at room temperature for 7 days, then microbial colonies were counted and recorded.

The collected data were evaluated to analysis of variance (ANOVA). Duncan's Multiple Range Test (DMRT) procedure was used to calculate Significant Difference between the treatments using the Statistix 10 software.

Results

Chemical properties of growing media before the experiment

The chemical properties of the 11 growing media treatments (one control and 10 biochar-mixed substrates) were analyzed prior to the experiment. The control (a commercial growing medium) and the biochar-mixed substrates (a mixture of biochar, growing medium and cow manure in a 2:1:1 ratio) showed pH values ranging from 8.0 to 9.6, indicating moderately to strongly alkaline conditions. Electrical conductivity (EC) values were high, ranging from 1.8 to 5.5 mS cm^{-1}. Soil organic carbon (SOC) content was also high, ranging from 15.0% to 20.0%. Additionally, the water-soluble phosphorus and potassium levels were detected in the ranges of 17.3 to 94.3 mg P kg^{-1} and 1,692 to 6,994 mg K kg^{-1}, respectively (Table 1).

Table 1 Some chemical properties of planting media before harvesting chinese kale.

Treatment	pH	EC (mS cm^{-1})	SOC (%)	P (mg kg^{-1})	K (mg kg^{-1})
Control	8.0	1.8	18.9	23.3	2,006
Rice straw	8.7	3.1	15.0	94.3	3,530
Jarul branch	8.5	2.2	18.9	34.2	2,090
Longan leaf	8.3	2.0	19.6	27.2	2,133
Longan peel	8.8	2.4	19.5	43.6	3,169
Mango leaf	8.6	2.1	19.6	20.1	1,692
Rice husk	8.4	3.3	19.8	17.3	3,523
Corncob	8.7	2.9	20.0	91.9	3,299
Coffee husk	8.1	2.4	19.8	24.2	2,282
Longan branch	8.2	1.9	20.0	42.7	2,031
Tobacco stem	9.6	5.5	19.6	32.5	6,994

Growth and chlorophyll content in chinese kale

The measurement of chinese kale height over six weeks after transplanting into different planting materials revealed significant statistical differences among the 11 treatments. The kale grown in planting materials mixed with biochar from longan branches and tobacco stems showed the highest growth trends throughout the six weeks (Figure 1A). The growth rate at week 6, these treatments resulted in a 48.3% increase in height compared to the control treatment. However, no significant differences were observed when compared to chinese kale grown in planting materials mixed with biochar from rice straw, mango leaves, and rice husks. The chlorophyll content in chinese kale leaves showed that planting materials mixed with all types of biochar resulted in higher chlorophyll levels compared to the control (commercial soil). The highest chlorophyll content (51.8 SPAD values) was observed in planting materials mixed with mango leaf biochar. However, this was not significantly different from the materials mixed with biochar derived from tobacco stems, longan leaf, rice straw, jarul branch, corn cob, longan branch, and coffee husk (Figure 1B).

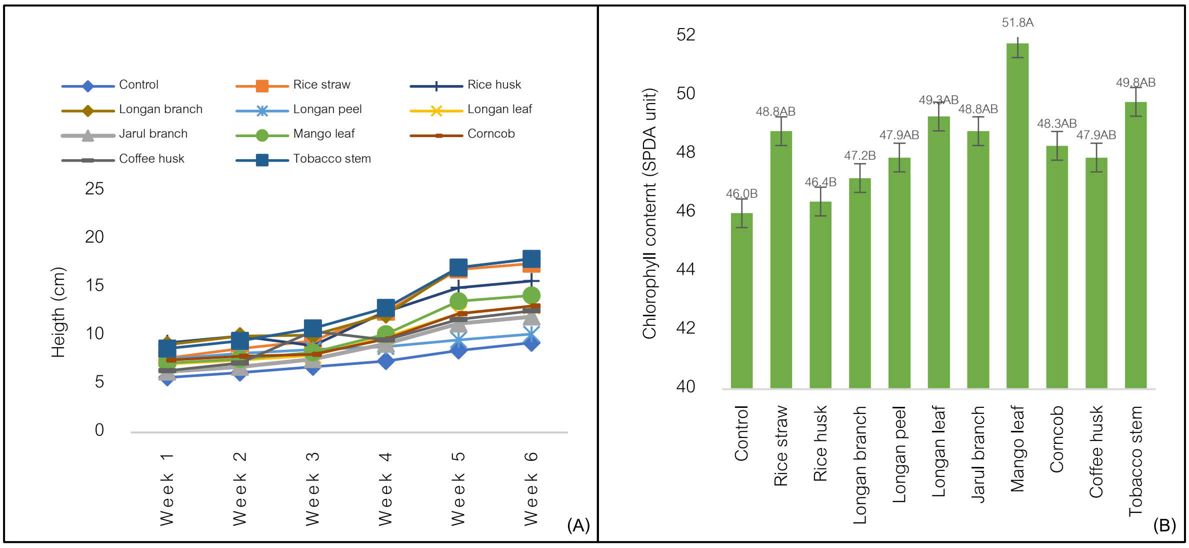

Figure 1: Height of chinese kale and chlorophyll content in chinese kale leave samples. Different letters indicate significant differenced at P< 0.05 between treatments.

Fresh and dry weight of kale after harvesting

Planting materials mixed with all types of biochar resulted in higher fresh and dry weights of chinese kale compared to the control treatment (without biochar). The highest fresh weight (26.2 g per plant) (Figure 2A) and dry weight (2.6 g per plant) (Figure 2B). were observed in plant grown with substrate materials containing tobacco stem biochar. However, these values were not significantly different from those observed in chinese kale plants grown in substrate mixed with rice straw biochar. Specifically, the fresh weight of the plants cultivated in this biochar reached 21.9 grams per plant, while the dry weight was recorded at 2.5 grams per plant. These results indicate that incorporating rice straw biochar into the growing medium provided comparable benefits to plant growth as other treatments, as illustrated in Figure 2.

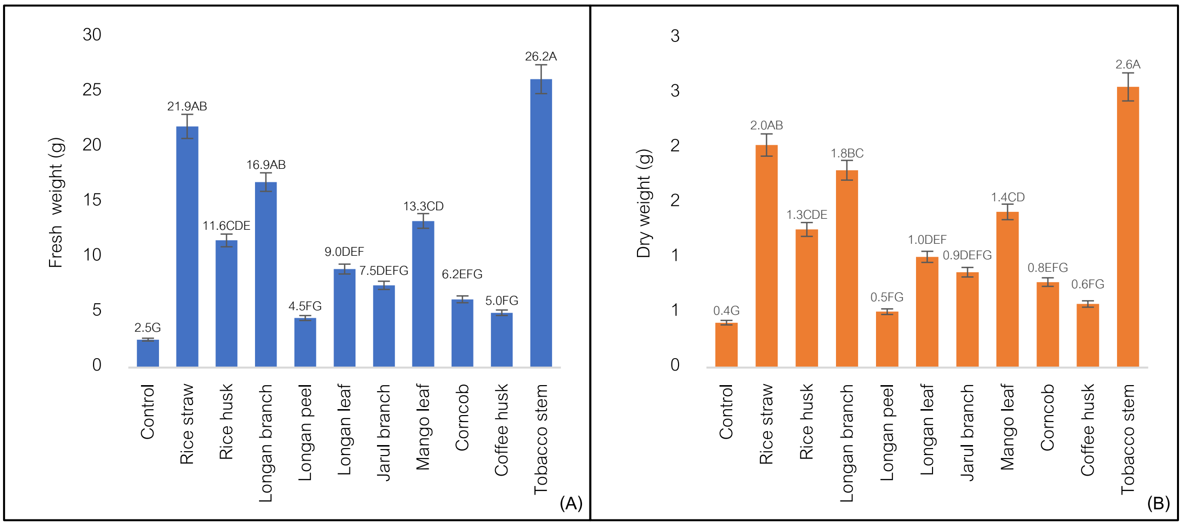

Figure 2: Fresh weight and dry weight of chinese kale after harvest.

Different letters indicate significant differenced at P< 0.05 between treatments.

Chemical properties of planting materials after kale harvesting

The analysis of chemical properties of planting materials after kale harvesting showed that the pH (8.7) was observed in materials mixed with biochar from jarul branches. This was not significantly different from materials mixed with mango leaf, longan branch, and tobacco stem biochar (P<0.01). The highest electrical conductivity (EC) value (0.5 mS cm^{-1}) was found in planting materials containing tobacco stem biochar, with no significant difference from those mixed with longan branch, corn cob, and coffee husk biochar. The control treatment showed in the lowest EC value at 0.2 mS cm^{-1}.

The addition of biochar increased the organic carbon content of planting materials compared to the control. Corn cob biochar resulted in the highest organic carbon content (20.3%) (P<0.01). In contrast, water-soluble phosphorus and potassium levels showed no significant differences among treatments with averaging values of 36.8 mg P kg^{-1} and 314 mg K kg^{-1}, respectively (Table 2).

The incorporation of biochar into the soil substrate led to an increase in soil organic carbon content compared to the control treatment. Among the different biochar types, corn cob biochar contributed the highest soil organic carbon content, reaching 20.3% (P<0.01). On the other hand, water-soluble phosphorus and potassium levels remained relatively stable across treatments, with no significant differences observed. The overall mean of phosphorus content was 36.8 mg P kg^{-1}, while potassium levels averaged 314 mg K kg^{-1}.

Table 2 Chemical properties of planting media after chinese kale harvest.

Treatment	pH	EC (mS cm^{-1})	SOC (%)	P (mg kg^{-1})	K (mg kg^{-1})
Control	7.9^{E}	0.2^{D}	11.0^{F}	32.3	422
Rice straw	8.1^{CDE}	0.3^{BCD}	15.6^{BC}	24.7	402
Rice husk	8.0^{DE}	0.3^{BCD}	14.7^{BCD}	37.3	227
Longan branch	8.3^{BCD}	0.3^{CD}	13.6^{CDEF}	37.9	310
Longan peel	8.4^{AB}	0.4^{AB}	17.0^{B}	37.0	316
Longan leaf	8.4^{BC}	0.3^{CD}	11.3^{EF}	36.3	348
Jarul branch	8.7^{A}	0.3^{BCD}	13.8^{CDE}	30.9	310
Mango leaf	8.6^{AB}	0.3^{BCD}	12.7^{DEF}	40.5	328
Corncob	8.4^{BC}	0.4^{AB}	20.3^{A}	65.2	283
Coffee husk	8.1^{CDE}	0.4^{AB}	15.7^{BC}	32.1	238
Tobacco stem	8.4^{AB}	0.5^{A}	16.1^{BC}	30.0	273
Grand Mean	8.3	0.3	14.7	36.8	314
CV (%)	2.2	21.8	10.6	55.5	34.3
F-test	**	**	**	ns	ns

Mean in the same column followed by different letters were significantly different by DMRT test at ** $P \leq 0.01$, ns = Not significant

Microbial populations in planting materials

Before the experiment, the highest microbial population was found in soil mixed with longan peel biochar (5.7×10^4 CFU g soil^{-1}), with no significant differences from those containing coffee husk and mango leaf biochar (5.6×10^4 and 5.5×10^4 CFU g^{-1}soil, respectively) ($P<0.01$). After harvesting, the microbial populations in all treatments increased by up to 10 times compared to pre-experiment. The highest microbial population was found in treatment with coffee husk biochar (10.7×10^5 CFU g soil^{-1}), which was not significantly different from those with longan branch and tobacco stem biochar at 9.6×10^6 and 9.7×10^6 CFU g soil^{-1}, respectively ($P<0.01$). In contrast, the control treatment showed slightly decreasing in microbial populations (Table 3).

Table 3 Total microbial count of planting media before and after chinese kale harvest.

Treatment	Microbial population count (CFU g Soil^{-1})	
	before planting	after harvested
Control	1.6$^{B}\times 10^4$	0.9$^{D}\times 10^5$
Rice straw	1.3$^{B}\times 10^4$	1.4$^{D}\times 10^5$
Jarul branch	4.0$^{AB}\times 10^4$	4.5$^{CD}\times 10^5$
Longan leaf	2.7$^{AB}\times 10^4$	5.2$^{CD}\times 10^5$
Longan peel	5.7$^{A}\times 10^4$	7.0$^{BC}\times 10^5$
Mango leaf	5.5$^{A}\times 10^4$	7.9$^{BC}\times 10^5$
Rice husk	2.6$^{AB}\times 10^4$	6.5$^{BC}\times 10^5$
Corncob	1.2$^{B}\times 10^4$	4.8$^{CD}\times 10^5$

Treatment	Microbial population count (CFU g $Soil^{-1}$)	
	before planting	after harvested
Coffee husk	$5.6^{A} \times 10^{4}$	$10.7^{A} \times 10^{5}$
Longan branch	$1.1^{C} \times 10^{4}$	$9.6^{AB} \times 10^{5}$
Tobacco stem	$2.9^{AB} \times 10^{4}$	$9.7^{AB} \times 10^{5}$
Grand Mean	3.1×10^{4}	6.2×10^{5}
CV (%)	19.09	17.19
F-test	**	**

Mean in the same column followed by different letters were significantly different by DMRT test at ** $P \leq 0.01$.

Discussion

The study on the effects of various biochar growing media on chinese kale revealed that all biochar-mixed growing media resulted in better kale growth in terms of height, leaf chlorophyll content, fresh weight, and dry weight compared to the control. These findings align with [5], which indicated that biochar promotes plant growth due to its porous structure. This structure enhances water retention and increases nutrient exchange capacity, contributing to improved plant development, as also suggested by [7]. The soil substrate pH and EC values of biochar-mixed materials increased, consistent with [6], who reported higher pH and EC in biochar from corn cob and glass incorporated into soils in different ratios over 165 days of application. Similarly, [1] found that adding biochar at rates of 1.5%, 3.0%, and 5.0% increased soil electrical conductivity, with the 5.0% rate resulting in 60% higher conductivity than the control. The increase in pH is attributed to the high alkalinity of biochar produced through pyrolysis at high temperatures [21], while the EC increase results from salt accumulation in biochar [17]. The organic carbon content in the growing substrate declined compared to pre-experiment levels but remained higher than that of the control treatment. This trend is consistent with the findings of [10], which reported a decrease in organic carbon content after 182 days of soil incubation with goat manure and biochar derived from goat manure. The decrease in organic carbon is likely attributed to soil organism activities, as they use carbon as an energy source [9].

The water-soluble phosphorus levels in biochar-mixed growing substate were higher than those in the control, ranging from 30.0 to 65.2 mg kg^{-1}. This finding similar to [2], which reported increased phosphorus levels in taro fields treated with biochar in 2017 and 2018. Similarly, water-soluble potassium levels after the Chinese kale harvest exceeded those in the control. This is consistent with [15], which found that potassium levels in biochar-enriched cultures increased after water leaching; hence, applied biochar could retain nutrients and reduce rate of leaching [11]. Moreover, microbial populations in biochar-mixed soils increased significantly, as supported by [13], who found higher microbial activity reflecting in the population of bacteria, fungi and actinomycete than in control treatment after applying biochar for six months. This can be attributed to the beneficial properties of biochar, which serves as a habitat for microbes due to its porous structure. [18].

Conclusion

This study found that biochar derived from agricultural residues significantly enhanced chinese kale growth and soil substrate properties. Biochar from rice straw, longan branches, and tobacco stems enhanced plant height, fresh weight, and dry weight, while mango leaf biochar notably increased leaf chlorophyll content. Biochar from jarul branches produced in the highest pH, tobacco stem biochar in the highest EC, and corncob biochar in the highest organic carbon content. Additionally, rice straw biochar supported the highest microbial population, highlighting its potential to enhance soil biological activity.

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