Efficiency of Biochar and Bio-Fertilizers Derived from Maize Debris as Soil Amendments

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ABSTRACT

Unsuitable handling of crop residues can result in many environmental problems such as air pollution and soil degradation. In the northern parts of Thailand, such problems are partly caused by the burning of agricultural debris after harvesting. The use of maize debris as an amendment for degraded soil can reduce such problems. The aims of this research were twofold. Firstly, to produce biochar and bio-fertilizer from maize debris to improve the quality of degraded agricultural soil. Secondly, to study the efficiency of biochar and bio-fertilizer in Chinese kale (*Brassica alboglabra*) cultivation with two different water regimes. From the study, it was found that 2.8 kg of dry maize debris could produce 1 kg of biochar and could store 13.6% organic carbon, while 0.5 kg of dry maize debris mixed with 1.1 kg of cow dung could produce 1 kg bio-fertilizer and could store 16.4% organic carbon. Watering once a day resulted in an increase in the yield which was comparatively greater than watering twice a day. By adding bio-fertilizer at 25% (w/w) in soil, the fresh weight of the kale plants was found to be about six times greater than those grown in an untreated soil. A suitable amount of bio-fertilizer to be added to soil for Chinese kale cultivation ranged between 15-30% (w/w), while a maximum of 25-30% (w/w) bio-fertilizer in soil was sufficient for plant growth and it was not necessary to add biochar to the soil.

1. INTRODUCTION

Thailand is predominantly an agricultural country with more than 50% of the population dependent on the agricultural sector. Each year, more than 134 million tons of agricultural residues such as rice straws and husks, sugar cane residue, palm bunches and maize stalks are abandoned (Department of Alternative Energy Development and Efficiency, 2013). One such handling of such crop residues is burning them in the fields before the starting of the next agricultural season. This leads to problems related to air pollution and soil degradation. To tackle such issues and utilize the agricultural debris sustainably, farmers and villagers can create products derived from the debris to increase their income. Agricultural debris can be used as a raw material in the production of bio-fertilizer to restore soil fertility and increase crop productivity (Bureau of Agricultural Quality Development, 2012; Zheng et al., 2010; Sika, 2012; Coomer et al., 2012; Schulz and Glaser, 2012). Biochar is another viable option to manage agricultural debris and could be utilized as a soil amendment along with bio-fertilizer. Biochar is a carbon-rich material with high porosity and is produced via pyrolysis, under limited oxygen. Its structure is very efficient in retaining water and water-soluble nutrients, while providing a conducive habitat for microorganism, and improving soil fertility (Suksawang, 2009; Lehmann et al., 2006; Ricks, 2007; Akhtar et al., 2014; Wang et al., 2012; Upadhyay et al., 2014; Giulia et al., 2015; Robertson et al., 2012; Hunt et al., 2010).

Therefore, this research attempted to utilize stalks of dry maize left after harvesting for the production of biochar and bio-fertilizer, for water storage and a source of plant nutrients. The physical and chemical characteristics of these soil amendments were analyzed and added to a degraded soil to improve the soil structure and properties. Chinese kale (*Brassica alboglabra* L.H. Bailey) was then planted in the amended soil with two types of watering regimes and their weights were measured. The objective of this setup was to investigate the efficiency of biochar and bio-fertilizer as soil amendments. As a result, specifics related to a suitable ratio of these amended materials and watering regimes, were also determined. This study can serve as a guideline for solving soil fertility problems through the rapid transfer of recycled nutrients from agricultural debris to the degraded soil. This can help to reduce the amount of chemical fertilizers used and in the sustainable management of soil and water.

2. METHODOLOGY

2.1 Biochar and bio-fertilizer production

Maize debris was collected and air-dried at room temperature. Sample weights were recorded prior to the production of biochar and bio-fertilizer. Biochar was produced by using a 2 layer traditional burner with an air control system. The top of the burner was closed and very little air was allowed to flow continuously from the bottom of the outer burner tank (Figure 1). After the combustion was complete, one kg of maize biochar was sent to the laboratory in the Department of Agriculture at Chiang Mai province, to determine the porosity, pH, organic matter (OM), primary and secondary nutrient elements, and electrical conductivity (EC).

(a) (b)

(c) (d) (e)

Figure 1. The various steps during the production of biochar from maize: a) Maize stalk chopping; b-c) Placement of firewood and rice husks in the outer burner tank; d) Biochar fire starter; e) Continuous combustion.

Bio-fertilizer was made by mixing chopped maize stalk and cow dung in a ratio of 4:1 (v/v). The outside part of the fertilizer stack was watered once a day and the inside was filled every 10 days. It was observed that the maize stalks completely decayed within 2-3 months and could be used as a fertilizer (Figure 2). Samples from the fertilizer were also sent to the above-mentioned laboratory to determine the porosity, pH, OM, primary and secondary nutrient elements, and EC.

(a) (b) (c) (d)

Figure 2. Maize bio-fertilizer stacks during: a) second, b) fourth, c) sixth and d) eighth weeks, respectively.

Biochar and bio-fertilizer produced from maize debris were applied to 1 hectare (ha) of compacted soil at a site located in the Faculty of Environment and Resource Studies (North Center), Mahidol University, Lampang province, which was not conductive for crop cultivation (Figure 3). Due to soil compaction, only grasses were able to grow in the site after heavy machinery was removed.

2.2 Soil collection and analysis

Soil samples were systematically sampled from 4 points by using an undisturbed soil sampling method to analyze the bulk and particle densities, porosity, and permeability. Disturbed soil samples were also sampled from 4 points and composited. Stones and plant roots were removed from the soil samples and large clods of soil were broken, followed by screening through a pre-cleaned 2 mm plastic sieve. After air-drying at room temperature, one kg of the composite soil sample was sent to the Soil Laboratory at the Faculty of Forestry, Kasetsart University to analyze for soil texture, pH, OM, total carbon, primary, nutrient content (N, P, K, S, Ca, and Mg), and Cation Exchange Capacity (CEC), following the standard methods of soil analysis (Pansu and Gautheyrou, 2006).

(a) (b)

Figure 3. The study site at the Faculty of Environment and Resource Studies, Mahidol University, Lampang province: a) the colored patch represents the study site from which the soil samples were taken; b) grass cover in the site after the removal of heavy machinery.

2.3 Cultivation of Chinese kale planting on the amended soil

A factorial design arranged in a randomized complete block design (RCBD) was used to generate 28 experimental units, with soil, bio-fertilizer/ biochar addition, and 2 types of watering regimes (once and twice a day) as the factor variables (Table 1). In one kg of planting material, the soil weight ranged between 0.7-1.0 kg, while the bio-fertilizer and biochar weight ranged between 0-0.3 kg. The control treatment was 1.0 kg of degraded soil without the addition of any amendment. In each experimental unit, 10 Chinese kale seedlings were planted. Half of the experimental units were watered once a day, while the rest were watered twice a day. Five Chinese kale seedlings were also cultivated by using chemical fertilizer and watered twice a day, similar to the general cultivation techniques used for growing kale plants.

2.4 Data analysis

Fifty days after of seedling transplantation, Chinese kale was harvested and fresh weight measured. Fresh kale was dried in a hot air oven at 80°C for 24-48 hours and the weight was re-measured. The differences between fresh and dry weights were compared and the percentage of weight change was calculated. The individual and interaction effects of adding bio-fertilizer/biochar and the 2 types of watering regimes on the growth of Chinese kale were finally performed by using the statistic of multivariate general linear model (GLM). The multivariate GLM provides for a regression analysis and analysis of variance for multiple dependent variables with one or more factor variables or covariates, in order to select the best proportion of soil amended materials for plant cultivation.

Table 1. Experimental design for Chinese kale cultivation on 1.0 kg of amended soil.

Treatments	Water regimes	Biochar (%: w/w)	Bio-fertilizer (%: w/w)
T1A/B*	1/2	0	0
T2A/B	1/2	0	5
T3A/B	1/2	0	10
T4A/B	1/2	0	15
T5A/B	1/2	0	20
T6A/B	1/2	0	25
T7A/B	1/2	0	30
T8A/B	1/2	5	0
T9A/B	1/2	5	5
T10A/B	1/2	5	10
T11A/B	1/2	5	15
T12A/B	1/2	5	20
T13A/B	1/2	5	25
T14A/B	1/2	10	0
T15A/B	1/2	10	5
T16A/B	1/2	10	10
T17A/B	1/2	10	15
T18A/B	1/2	10	20
T19A/B	1/2	15	0
T20A/B	1/2	15	5
T21A/B	1/2	15	10
T22A/B	1/2	15	15

Table 1. Experimental design for Chinese kale cultivation on 1.0 kg of amended soil. (cont.)

Treatments	Water regimes	Biochar (%: w/w)	Bio-fertilizer (%: w/w)
T23A/B	1/2	20	0
T24A/B	1/2	20	5
T25A/B	1/2	20	10
T26A/B	1/2	25	0
T27A/B	1/2	25	5
T28A/B	1/2	30	0

3. RESULTS AND DISCUSSION

3.1 Analysis of soil, biochar, and bio-fertilization properties

The physical properties of bulk and particle density, porosity, and permeability of the degraded soil, at depths of 0-5, 5-10 and 10-15 cms, were not significantly different (Table 2). The soil was slightly acidic and was categorized as a sandy clay loam type. The percentages of organic matter, total carbon, nutrient elements (N, P, K, Ca, Mg, and S), and CEC are also shown in Table 2.

The Bureau of Land Conservation and Land Use Planning (2005) suggested that the general characteristics of Alfisols soil, found in and around the study site were a result of the deep to very deep clay soil type rising from a fine mass parent material, found in mountainous regions. This type of soil is either neutral or alkaline, with a good to moderately good drainage, and moderate fertility. The soil samples characteristics derived from the study site were different due to soil compaction. However, the soil characteristics of these samples were anomalous as they were transported from other sites and compacted for the purpose of heavy machinery placement. McKenzie (2010) explained that soil compaction reduces the ability of soil to hold water and air, increases the chances of soil erosion, impedes root expansion, decreases the ability of crops to absorb nutrients and water, and as a result, reduces the potential crop yield.

The physical and chemical properties of biochar and bio-fertilizer derived from maize debris are quatified in Table 2. It was found that the biochar and bio-fertilizer were medium to slightly alkaline, while the nutrients were enough for plant growth, in accordance with the organic fertilizer standard set by the Department of Agriculture in 2005. Extraneous materials such as plastic, glass, and other sharp objects were not found. Wood vinegar, a byproduct of the maize biochar process, was also collected through the course of the experiment (Figure 4).

(a) (b)

Figure 4. Products from maize debris as soil amendments: a) biochar; b) bio-fertilizer.

By comparing the weights of dry maize debris and biochar, it was found that 2.8 kg of debris could produce around 1.0 kg of biochar. Although derived from a small sample size, a strong correlation was found between the weights of debris and biochar (from 3 batches of production), with a coefficient of determination (r^2) of 0.999 at $p<0.01$, as shown in Figure 5. On the other hand, 1 kg of debris fertilizer could be produced from 0.5 kg of maize debris and 1.1 kg of cow dung, while 0.6 kg was lost due to biodegradation. The stored organic carbon content in maize biochar and bio-fertilizer in the soil was around 13.6 and 16.4% of the total dry weights, respectively (Table 3).

Table 2. Physical and chemical properties of the compacted soil at various depths.

No.	Depth (cm)	Density (g/cm^3) Bulk	Density (g/cm^3) Particle	Porosity (%)	Permeability (cm/s)	Soil Texture (%) Sand	Soil Texture (%) Silt	Soil Texture (%) Clay	pH	OM (%)	C (%)	N (%)	S (%)	P (mg/kg)	K (mg/kg)	Ca (mg/kg)	Mg (mg/kg)	CEC (cmol/kg)
	0-5	1.26	2.74	54.00	1.38E-03													
1	5-10	1.11	2.68	58.57	7.86E-05	66.0	11.0	23.0	6.57	1.57	0.80	0.11	0.54	205.35	70.64	2,572.00	1,234.00	38.43
	10-15	1.15	2.63	56.20	2.70E-04													
	0-5	1.27	2.79	54.44	2.19E-04													
2	5-10	1.38	2.78	50.29	1.27E-05	62.0	15.0	23.0	5.99	1.80	1.01	0.11	0.36	478.83	44.08	1,224.00	427.60	19.14
	10-15	1.40	2.76	49.33	9.93E-05													
	0-5	1.29	2.70	52.38	1.08E-03													
3	5-10	1.28	2.74	53.30	1.65E-03	61.0	16.0	23.0	5.69	2.73	2.02	0.18	0.39	321.23	194.60	2,465.00	890.20	29.53
	10-15	1.19	2.73	56.36	5.41E-05													
	0-5	1.18	2.79	57.69	2.06E-03													
4	5-10	1.41	2.78	49.21	2.68E-04	58.0	11.0	31.0	6.64	3.01	1.71	0.13	0.31	368.13	288.60	3,167.00	810.10	33.88
	10-15	1.09	2.73	60.11	3.41E-03													
Average		1.25	2.74	54.32	8.81E-04	61.8	13.3	25.0	6.22	2.28	1.39	0.13	0.40	343.39	149.48	2,357.00	840.48	30.25

It was found that biochar was highly alkaline (pH=10), similar to biochar produced from other monocot and dicot plants (Weerasekara, 2015; Zhu et al., 2014; Zhu et al., 2015; Martinsen et al., 2014; van Zwieten et al., 2010; Major et al., 2010; Solaiman et al., 2010). However, the same raw materials could be used to produce biochar of various pH values (Manaonok et al., 2017; Solaiman et al., 2010), due to different combustion temperatures inducing dehydroxylation, dehydrogenation, and aromatization (Li et al., 2013).

EC value of maize biochar was 1.0 dS/m, which was safe for plant growth and did not reduce yield, when applied as a soil amendment. Many researchers suggested that biochar production with a variety of raw materials having EC value less than 4 dS/m did not inhibit plant growth (Weerasekara, 2015; van Zwieten et al., 2010). However, Li et al. (2013) found an increase in the level of EC with increasing combustion temperature, as did the pH value.

The maize biochar was relatively low in nutrient content which was inadequate for plant growth, especially in the absence of phosphate. Therefore, it was necessary to add compostable nutrients in the form of bio-fertilizer to improve the soil properties for plant growth. In this research, the bio-fertilizer was produced following the Maejo engineering method (Sawangpanyangkun, 2015), in which the nutrient content was to comply with the compost standard (grade 2) of the Land Development Department and the Joint Service Center, Department of Agricultural Extension, Thailand.

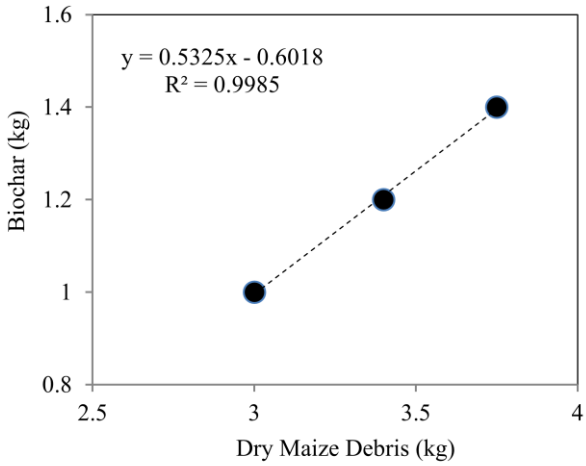

Figure 5. Correlation between the weights of the dry maize debris and biochar derived from the combustion process

Table 3. Some physical and chemical properties of maize biochar and bio-fertilizer.

Item	Test value	
	Biochar	Bio-fertilizer
pH	10.0	8.4
Moisture (%)	5.2	6.0
Total N (%)	1.1	1.6
Total phosphate (%)	Not detected	1.1
Total potash (%)	2.3	0.8
Organic matter (%)	23.4	28.3
Organic carbon (%)	13.6	16.4
C:N ratio	12:1	10:1
Sodium (%)	Not detected	Not detected
EC (dS/m)	1.0	0.7
Complete degradation (Germination index: %GI)	145.4	216.8
Plastic, glass, sharp objects	Not detected	Not detected

3.2 Growth of Chinese kale in the amended soils

A total of 285 Chinese kale were planted for 90 days (40 days for seedlings and 50 days for potted plants) with a 100% survival rate. Following the suggestion of Chen et al. (2016) who reported that a wood vinegar solution of 0.25 mL/L concentration did not show significant differences from the control group in lettuce growth, wood vinegar obtained during the biochar extraction process at a concentration of 0.25 mL/L was used as an insect repellant after every 7 days. The fresh weight of Chinese kale, measured after 90 days of cultivation, (M=21.38, SD=11.86) indicated that the best combination was a mixture with 75% degraded soil, 25% bio-fertilizer, and 0% biochar weigh/weight (w/w), watered once a day (M=46.17, SD=10.47) (Figure 6(a)). The total dry weight of kale plants (M=2.38, SD=1.11) also indicated that an experimental setup with 75% degraded soil, 25% bio-fertilizer, 0% biochar, (w/w) watered once a day, produced the highest yield, similar to the total fresh yield weight (M=4.71, SD=1.14) (Figure 6(b)). Moreover, using the kale fresh weight, the overall growth of Chinese kale planted in the amended soil, with once a day watering, resulted in a faster growth compared to watering twice a day (M=27.58; SD=13.13 and M=15.17; SD=5.17, respectively). In previous studies, the appropriate amount of bio-fertilizer and biochar for soil amendment was not exactly suggested, but the minimum amounts of bio-fertilizers for rice and vegetable plants was reported at 12.5 and 25 tons/ha, respectively (Office of technology transfer and to supervise land development, 2007). Norsuwan et al. (2013) suggested an insignificant difference in the weight of rice grain cultivated after the addition of biochar at 0, 4, 8 and 16 tons/ha. These results were similar to the study done by Liang et al. (2014), who found that the annual yield of either wheat or maize did not increase significantly after the application of biochar, but the cumulative yield for the next 4 growing seasons increased significantly due to a significant decrease in soil bulk density combined with an increase in the soil water holding capacity.

Although the soil amended with 25% bio-fertilizer (w/w) induced the highest Chinese kale yield, the amendment using biochar and watering once a day gave a better Chinese kale yield compared to the yield in degraded soil watered twice a day (Figure 6). The results are in accordance with the study of Ma et al. (2016), who reported that the organic carbon content in a soil, mixed with biochar, enhanced the water absorption capacity with the water available for plant use for an extended period of time. Liu et al. (2017) also reported that the molecular structure of biochar changed when it was humidified which could help to increase the gap between the soil particles, in turn leading to a higher absorption of water for a longer period of time. However, the lower nutrient content of biochar was not sufficient for maximizing plant growth and as such, bio-fertilizer could be used for water absorption similar to biochar due to higher content of organic compounds and organic carbon and could enhance crop yields due to the increased nutrient accumulation.

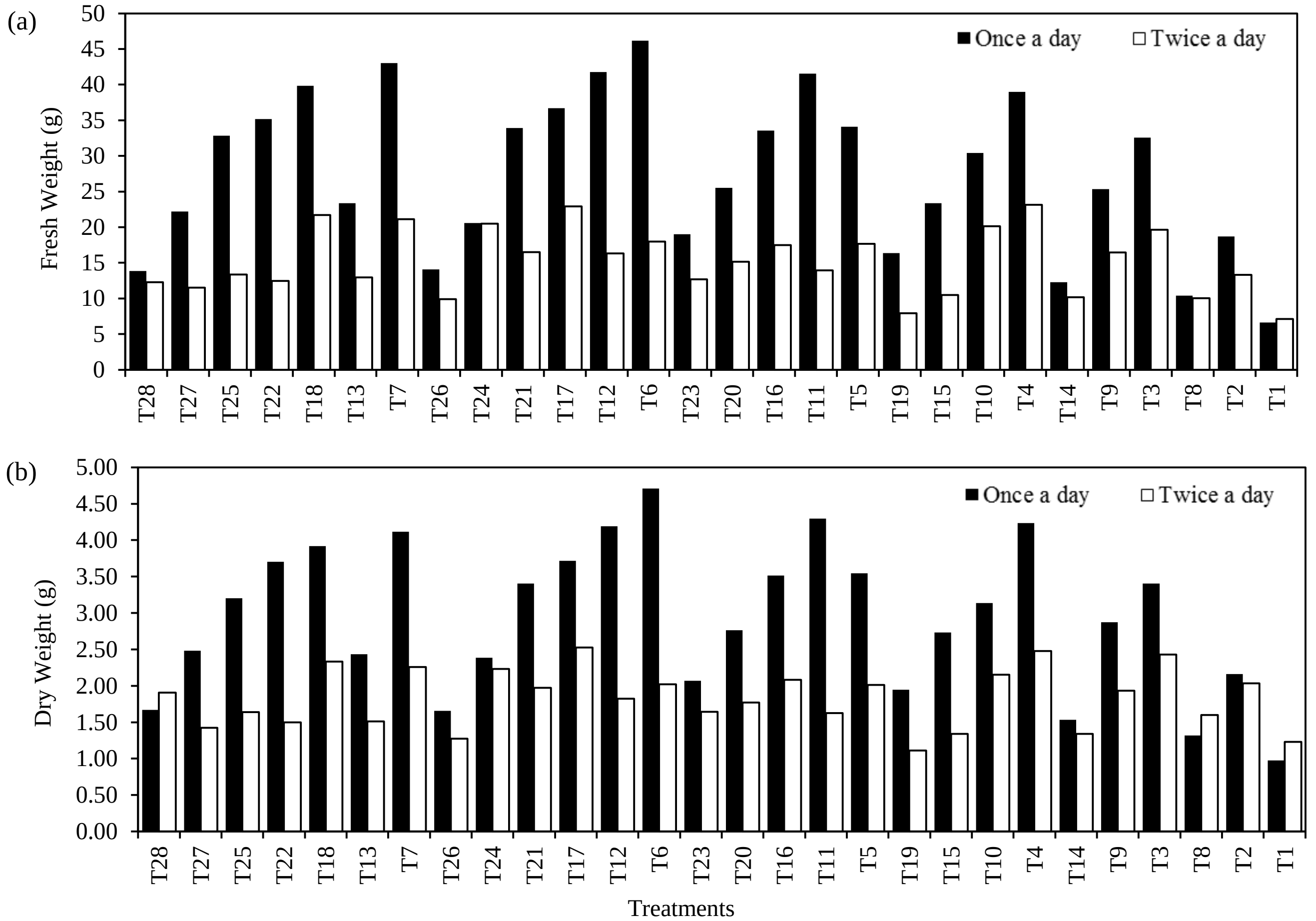

Figure 6. The mean weight of Chinese kale obtained after watering once and twice a day in all experiments: a) fresh weight; b) dry weight.

3.3 Efficiencies of bio-fertilizer and biochar as soil amendments

The yield of kale in soil without amendments, in terms of the fresh and dry weights, were used to calculate the efficiencies of bio-fertilizer and biochar as soil amendments with 2 types of watering regimes (once and twice a day), as shown in Figure 7. For experiments in which watering was done once a day, it was found that Chinese kale planted in degraded soil, amended with 25% bio-fertilizer, was the most conducive and the total yield in terms of fresh and dry weights increased by 599.1% and 383.2% (5.99 and 3.83 times), respectively, compared to the cultivation in soil with no amendments, watered once a day. For the case of watering done twice a day, when compared with cultivation in soil without amendments, Chinese kale planted in degraded soil amended with 15% bio-fertilizer returned the highest fresh weight, as indicated by an increase of 225.3% (2.25 times), while the highest dry weight of 105.5% (1.05 times) was obtained in degraded soil amended with 15% bio-fertilizer and 10% biochar.

It was hypothesized that the variations in kale yields were a result of adding bio-fertilizer and biochar as soil amendments. A multivariate analysis of variance (MANOVA) was conducted on these variables across two groups watered once and twice a day. Results from the MANOVA demonstrated a significant effect of bio-fertilizer on the fresh and dry weights of Chinese kale, $F(6, 224) = 42.29$, $p<0.01$, $\eta^2=0.53$ and $F(6, 224) = 28.14$, $p<0.01$, $\eta^2=0.43$, respectively. Two regimes of watering once and twice a day also induced a significant difference in kale fresh and dry weights with a value of $F(1, 224) = 249.18$, $p<0.01$, $\eta^2=0.53$ and $F(1, 224) = 181.23$, $p<0.01$, $\eta^2 = 0.45$, respectively. On the contrary, changing the amount of biochar did not lead to a significant effect on the fresh and dry weights. The interaction of bio-fertilizer and biochar induced variations in the fresh and dry weights as indicated by a value of F (15, 224) =3.24, $p<0.01$, $\eta^2=0.18$ and F (15, 224) =2.58, $p<0.01$, $\eta^2=0.15$, respectively. Bio-fertilizer and watering regimes also interacted and significantly affected the fresh and dry weights of Chinese kale with F (6, 224) =11.66, $p<0.01$, $\eta^2=0.24$ and F (6, 224) =10.28, $p<0.01$, $\eta^2=0.22$, respectively. The interaction of biochar and watering regimes did not relate significantly to the change in yields, while the interaction of these 3 variables (bio-fertilizer, biochar, and water regimes) significantly affected the variations in the fresh and dry weights of Chinese kale as observed by the values F (15, 224) =1.99, $p<0.05$, $\eta^2=0.12$ and F (15, 224) =1.87, $p<0.05$, $\eta^2=0.11$, respectively.

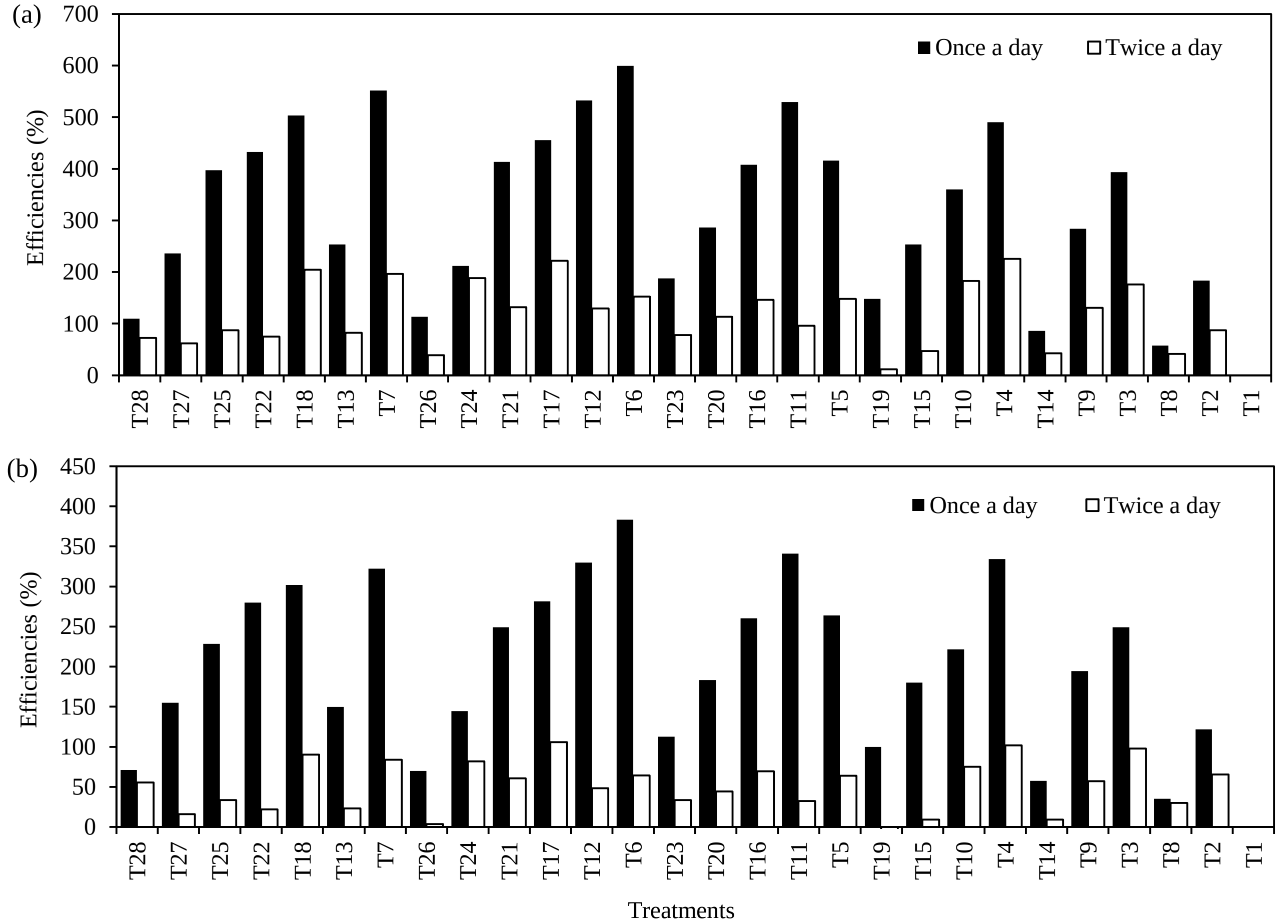

Figure 7. Efficiencies of bio-fertilizer and biochar for soil amendment in Chinese kale planting: a) fresh weight; b) dry weight.

ANOVA was also used to investigate the difference in the fresh weights of Chinese kale. It was seen that in at least 2 experiments, watered once a day, resulted in a different fresh weight. The post hoc tests indicated that the highest fresh weight of Chinese kale cultivated in degraded soil amended with 25% bio-fertilizer was not significantly different from the weights obtained from the other 6 experiments, with bio-fertilizer and biochar in the ratio of 15:00, 15:05, 15:10, 20:05, 20:10 and 30:00 (w/w), with fresh weights ranging between 36.69-46.17 gm/plant. Using this information, the appropriate proportion of bio-fertilizer and biochar (w/w) for Chinese kale cultivation was found to be 15-30% and 0-10%, respectively. If the amount of bio-fertilizer mixed was greater than 25% (w/w), it was not necessary to amend the degraded soil with biochar or other amended materials.

Chinese kale cultivated with watering twice a day also resulted in different fresh weight in at least 2 experiments. The post hoc tests indicated that the highest fresh weight (23.16 gm/plant) was obtained from the kale cultivated in a degraded soil amended with 15% bio-fertilizer (w/w). It was not significantly different from the other 6 experiments, with bio-fertilizer and biochar ratios of 5:20, 10:00, 10:05, 15:10, 20:10, and 30:00 (w/w), resulting in fresh weights ranging between 19.65-23.16 gm/plant. However, the fresh weight of Chinese kale cultivated in degraded soil with the application of chemical fertilizer and watered twice a day was 39.49 gm/plant and was close to the highest fresh weight obtained in amended soil watered once a day.

The ratio of bio-fertilizer, biochar, and watering frequency were important factors during Chinese kale cultivation. The relationship of these factors with the fresh weights can be expressed using the equation obtained from a multiple regression analysis as follows:

$$W = 33.118 - 12.407M + 6.869C/10, \quad (1)$$

where W is the Chinese kale fresh weight (gm), M is the watering regimes (M=1 or 2) and C is the percentage of bio-fertilizer ($0 \leq C \leq 30$). The change in any of these factors could be used to explain the variance in growth of Chinese kale by up to 52.7% ($p<0.01$). Using the equation, it was found that a soil amended with 30% bio-fertilizer (w/w) and watered once a day resulted in the highest yield, while the maximum yield obtained with watering twice a day was only half of that from watering once a day (Figure 8).

These results are supported by studies done by Martinsen et al. (2014) and Yeboah et al. (2016), who stated that biochar could be used to restore and increase the water retention capacity of the soil, but the level of nutrient content could not be improved. Chemical and bio-fertilizers could be used together to maximize plant growth and yield. Wongwicharn et al. (2002) used 25 and 50 ton/ha of bio-fertilizer obtained from sugarcane sludge mixed with 312.5 kg/ha of chemical fertilizer for soil improvement and kale cultivation. The yields from these 2 experiments were not significantly different but were higher than the yield when only 625 kg/ha of chemical fertilizer was used.

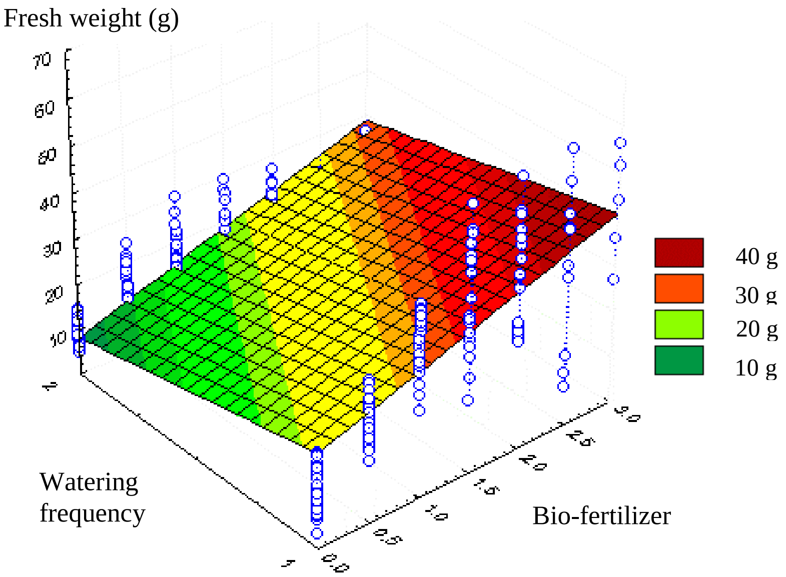

Figure 8. Relationship between bio-fertilizer, watering frequency, and Chinese kale fresh weight.

4. CONCLUSIONS

The application of maize bio-fertilizer and biochar to improve both physical and chemical properties of soil to be used for plant cultivation was studied. The soil was compacted with a slight acidity, was low in nutrients, and had low water permeability. Biochar produced from maize debris was alkaline and was suitable to neutralize the slightly acidic soil with an increased water permeability and absorption. A combination of bio-fertilizer, obtained from maize debris, and cow dung was slightly acidic and had sufficient nutrients for plant growth, in accordance with the bio-fertilizer standards. When this bio-fertilizer and biochar was used in Chinese kale cultivation, it was observed that watering once a day resulted in growth maximization, as indicated by the highest fresh weight, especially in a degraded soil amended with

25% bio-fertilizer (w/w). The optimum proportion of the bio-fertilizer and biochar for soil amendment was 15-30 and 0-10% (w/w), respectively. For the case when bio-fertilizer exceeded 25-30% (w/w), biochar was not necessary to be added for soil amendment purposes.

The use of biochar and bio-fertilizer for soil amendment is a viable option compared to the direct use of chemical fertilizers in terms of reducing the plant production cost and maximizing the yield. Although bio-fertilizer and biochar can be produced from agricultural debris at a fairly low cost, the optimum proportion of bio-fertilizer and biochar for soil amendment for each crop will have to be taken into account and examined before cultivation, in order to maximize the yield. In further studies, chemical fertilizers shall be applied in appropriate amounts to enhance the performance of bio-fertilizer and biochar, in order to increase yields and resistance to diseases and insects.

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