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Water-Use Efficiency in Vertical Cropping System with Volcanic Ash Media by Using Biochar and Urban Waste Compost Fertilizer as Soil Amendment

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ABSTRACT
Applying volcanic ash as planting media has to cope with several constrains as it quickly becomes sediment and hardened when exposed to water. One of the efforts to improve its physical condition is by utilizing biochar, which is one of amendment materials that can improve the soil quality. The objective of this study was to identify the proper doses combination of volcanic ash, biochar, urban waste compost fertilizer and column population per m^2 to sustain the growth of curly lettuce in vertical cropping system, as well as the water use efficiency. This study was arranged in Completely Randomized Design (CRD) Factorial with three factors. The first, second and third factors consisted of Biochar doses of M1, M2 and M3 (25; 33; and 50 %), compost fertilizer doses of K1, K2 and K3 (25; 33; and 50 %) and column density of P1, P2 and P3 (4 columns. m^{-2}, 3 columns. m^{-2} and 2 columns. m^{-2}), respectively and consisted of 3 replications. Data observed in this study consisted of growth and crops yield variables analyzed using Analysis of Variance and continued with the HSD Tukey test (Honest significant difference) at α =5%. The water use efficiency (g.kg^{-1}) can be formulated as the production of dry material per total water during the cultivation season (g.kg^{-1}). Results of this study showed that the highest fresh consumption yield was obtained from treatment M3K3 in 556 g/column (ratio of volcanic ash, charcoal husk and compost = 25 : 25 : 50 %) and the best water-use efficiency was 2.30 g.kg^{-1}.

Keywords: Biochar, compost, efficiency, lettuce, volcanic ash.

INTRODUCTION

Narrow land resource and the possibility of crop productivity saturation are some of the constrains in food self-sufficiency effort that, consequently, land-efficient agricultural technology is required (Nasrullah *et al*., 1988). Other constrain includes water availability. Agriculture is the largest water user of all water amount used by people activity. Thus, water-use efficiency effort is absolute. Based on the world average, agriculture uses 80% of all water in people activity (Biswass, 1982).

Based on the panel-discussion formulation on the increasing water-use efficiency at farmer-level, the water-use efficiency from agronomy perspective can be done at the cropping level, cropping pattern and land ecosystem unit. It is required to carry out efficient water use together and in harmony with the climate elements (Faculty of Agriculture UGM, 1983). Efficient watering requires knowledge about soil characteristics, relation with the plants, climate, agronomy practices and economic calculation (Sinha, 1977).

Starting from the agricultural crop saturation toward the sunlight intensity in tropical area, in addition to the more limited land and water, especially in Java Island, the possible approach taken to reach land and water efficient agricultural technology includes the intensive utilization on a cropping dimension, such as time and space. One of the effort in time and space utilization is the vertical cropping system. The agricultural cultivation development in rural area is quite difficult due to the limited planting media. One of the planting media that can be used, especially in areas with active volcano, is volcanic ash. With the help of water and organic acids in the soil, deposited volcanic ash on the soil surface experiences chemical weathering. Such natural weathering process consumes a very long period of time (thousand and even million years). The weathering result will increase the cation content (Ca, Mg, K and Na) in the soil, where the Na content is 50% higher than previous condition (Fiantis *et al*., 2006).

According to Zuarida (1999), volcanic ash from Mt. Kelud, East Java contains 45.9% of SiO_2 with intermediary plagioclase as the dominant material. Volcanic ash from Mt. Kelud given to peat soil will increase the soil pH, plant height, as well as the plant dry weight and corn root. The finer the volcanic ash, the more effective it will be for the growth of corn plant.

Volcanic ash contains various useful nutrients for plants. However, it should be given indirectly due to its unfit characteristics for the plant. Therefore, additional amendment material is required. The characteristic of pure volcanic ash is the quick-hardening when exposed to water. Thus, to improve the physical characteristic and soil quality, Biochar as soil amendment is used. Currently, biochar is produced through pyrolysis process, in which the biomass is heated without oxygen at high temperature (350–700 ºC) in a special designed oven. The most used raw material consisted of what is now considered, such as crop residue, wooden debris, construction waste, wood chips, and decorative plant-pruning waste in rural area (Allyson, 2011). Biochar helps produce sustainable production and minimize river and ground water contamination (Barrow, 2012). A research by Afeng *et al.* (2012) indicated that the use of biochar increased rice productivity, soil pH, soil organic carbon and total nitrogen. However, under biochar treatment, soil volume weight in the rice growth cycle decreased and soil respiration was not significantly different from that of control treatment within the first and second year. Biochar can decrease the agricultural input loss of nitrate as well as N_2O and CH_4 emission from the soil to the atmosphere.

In addition to biochar, volcanic ash requires nutrient element intake from both inorganic and organic fertilizer. Urban waste compost is one of the organic fertilizers resulted from household activities. It is generally biodegradable or able to be decomposed into simpler compounds by soil-microorganism activities (Sulistyawati and Nugraha, 2012). The decomposition result of the organic waste contains many elements required by the plants, thus, it is advantageous as organic fertilizer.

This research used lettuce plant (*Lactuca sativa* L.), a commonly consumed vegetable which is favored and used for salad, side dish and garnish. It has colors, texture and aroma that freshens the food appearance and stimulate appetite. It contains sources of mineral, pro-vitamin A, vitamin C and fiber (Rubatzky and Yamaguchi, 1998). The change of people's life style, including the change of way in selecting food material, possibly will increase the demand for lettuce. According to Lingga and Marsono (2007), in the lettuce cultivation, the need of nutrient or fertilizer per hectare comprises 20 ton of manure, 300 kg of NPK, 100 kg of Urea, 250 kg of SP-36 and 100 kg of KCl, as well as 20 kg of supplementary liquid fertilizer. Generally, lettuce can be harvested between 35 to 45 days after the transplanting. The yield per area width unit depends on the lettuce cultivar and the planting space. The harvest yield ranges between 10 to12 ton.ha^{-1}.

The objectives of this study were to make use of the volcanic ash from such environment disturbance into vegetable planting media, especially for curly lettuce, to determine the optimum mixture ratio of planting media made from volcanic ash, biochar and compost in vertical cropping system and to determine the water use efficiency in vertical cropping system.

MATERIALS AND METHODS

Planting media used in this study was the volcanic ash resulted from Mt. Kelud eruption in February 13, 2014, combined with varied doses of biochar (charcoal husk), and urban waste compost fertilizer. Vegetable plant used was curly lettuce.

The main instrument used as media container was a vertical column (PVC pipe) in 6 inch diameter and 133 cm length with 12 planting holes put into an iron frame to enable the measurement of water leaching during the experiment in the glass house by applying drop-watering system. It used 1.5 L plastic bottles assembled with infusing hose where the water drops could be arranged by 1 drop sec^{-1} (Fig.1).

Experiment design applied the Complete Randomized Design (CRD) factorial 3 × 3 × 3 with three replications. The first factor was biochar doses: M1 (25%) , M2 (33%) and M3 (50%). The second was the dose of urban-waste compost fertilizer (K) based on the ratio between the media and fertilizer: K1 (75: 25), K2 (66:33), and K3 (50: 50). The third was the column density per m^2: P1 (4 column m^{-2}), P2 (3 column m^{-2}) and P3 (2 column m^{-2}) with 14 plants per column for each population treatment. Thus, the total combinations were 81 units.

The water use efficiency (g. kg^{-1}) can be formulated

Figure 1. Drip irrigation system using plastic bottles

as the production of dry material per total water during the cultivation season (g kg^{-1}) (Sing and Sinha, 1977; Sumaryanto, 2005; Bezerra, 2012). The plant growth, yield and water use efficiency were analyzed by using the Analysis of variance to identify significant difference. Should there was significant difference (F > F crit.), the data then were subjected to HSD tukey (Honest Significant Difference) test at 5% to identify the significantly different treatment.

RESULTS AND DISCUSSION

This study observed the feasibility of volcanic ash to be used as vegetable planting media especially for curly lettuce in vertical cropping system, based on the improvement of physical and chemical characteristic properties of volcanic ash combined with charcoal husk amendment and urban-waste compost fertilizer.

Physical and Chemical Analysis of the Media and Amendment

The Mt. Kelud volcanic ash used as the planting media in this study consisted of Silt-loam texture dominated by silt fraction (52.24%), sand (43.81 %) and a small amount of clay fraction (3.95%). The volcanic ash acidity was slightly acidic and acidic with undetected N content, a little amount of medium P, and low K, also, with very low Electrical Conductivity (EC) and cation exchange capacity (CEC) (Table 1).

The planting media from volcanic ash was given with amendment to improve the physical and chemical properties. The amendment used was charcoal husk and urban waste compost fertilizer. Referring to Table 2, charcoal husk contained very low N, P, and K with neutral pH and very low EC with 5.24 cmol kg^{-1} of CEC. On the other hand, the urban waste compost pH was slightly alkali, with significantly low EC, and nutrient content of 0.75% N, 0.25% P_2O_5, and 0.83% K. Due to the C/N ratio level of compost medium, the amelioration process was faster because it experienced decomposition. The CEC compost level was classified as high while the

Table 1. Physical and chemical analysis of volcanic ash, charcoal husk, and compost

Number	Parameter (unit)		Physical/Chemical Characteristic Value (Degree)					
			Volcanic ash		Charcoal husk		Compost	
1	Clay	(%)	3.95	Silt-loam	-		-	
2	Silt	(%)	52.24		-		-	
3	Sand	(%)	43.81		-		-	
4	pH H2O		6.31	slightly acid	7.07	Neutral	8.19	Slightly alkali
5	pH KCl		5.38	slightly acid				
6	EC	($mS.cm^{-1}$)	0.15	Very Low	0.50	Low	0.30	Very Low
7	CEC	($cmol.kg^{-1}$)	2.74	Very Low	5.24		22.51	Low
8	N Total	(%)	-		0.52		0.79	
9	P Available	(ppm)	9.88	Medium	0.33	Total*)	0.25	Very Low
10	K Available	($cmol^{+}kg^{-1}$)	0.12	Low	0.96	Total*)	0.83	Very Low
11	C Organic	(%)			5.71		9.60	Low
12	Organic Matter	(%)			11.42		53.90	High
13	C/N	-			10.98		12.15	Medium
14	E. coli						0.00	-

Remarks: *) total

Table 2. Effect of media mixture (Volcanic ash : Charcoal Husk) to the plant growth and yield

Parameter	M1	M2	M3
Plant height (cm)	25.62 (b)	28.07 (a)	28.76 (a)
Number of leaves (sheet)	11.14 (c)	11.74 (b)	12.18 (a)
Fresh consumption weight (g.column^{-1})	454.25 (b)	504.67 (a)	502.93 (a)
Fresh root weight (g.column^{-1})	20.37 (b)	23.85 (a)	23.22 (a)
Total fresh weight (g.column^{-1})	474.63 (b)	528.52 (a)	526.16 (a)
Dry consumption weight (g.column^{-1})	35.89 (b)	39.99 (ab)	46.46 (a)
Dry root weight (g.column^{-1})	2.93 (b)	4.04 (a)	4.21 (a)
Total dry weight (g.column^{-1})	38.83 (b)	43.99 (ab)	50.67 (a)
Plant water-use (kg =l)	22.14 (b)	22.80 (a)	22.25 (b)
Water use efficiency (g.kg^{-1})	1.61 (b)	1.76 (a)	2.08 (a)

Remarks: Means followed by the same letters in the same row are not significantly different according to HSD Tukey test at 5 %.

Table 3. Effect of compost dose to the plant growth, yield and water-use efficiency

Parameter	K1	K2	K3
Plant height (cm)	25.70 (b)	26.85 (b)	29.91 (a)
Number of leaves (sheet)	11.14 (c)	11.70 (b)	12.22 (a)
Fresh consumption weight (g.column^{-1})	444.63 (c)	484.17 (b)	532.65 (a)
Fresh root weight (g.column^{-1})	21.34 (a)	22.74 (a)	23.35 (a)
Total fresh weight (g.column^{-1})	465.97 (c)	507.32 (b)	556.01 (a)
Dry consumption weight (g.column^{-1})	35.89 (b)	39.99 (ab)	46.46 (a)
Dry root weight (g.column^{-1})	3.75 (a)	3.74 (a)	3.68 (a)
Total dry weight (g.column^{-1})	40.17 (b)	43.55 (ab)	49.77 (a)
Plant water-use (kg =l)	22.15 (b)	22.27 (b)	22.76(a)
Water use efficiency (g.kg^{-1})	1.63 (b)	1.75 (ab)	2.06 (a)

Remarks: Means followed by the same letters in the same row are not significantly different according to HSD Tukey test at 5 %.

content of total N, P, and K was classified as very low.

Water-use Efficiency Test in the Vertical cropping system

The result of Analysis of Variance (Anova) showed that the effects of the media, compost fertilizer and plant population as single factor were significant on all observed variables, except for the effect of compost on the fresh and dry root weight that was not different. Meanwhile, the root dry weight and water-use were not significantly affected by plant population. Variables showing no significant difference were not further tested by HSD Tukey.

Data in Table 2 showed that the influence of media mixture was significant on all observed variables including number of leaves, plant height, fresh and dry weight of plants, water-use and the efficiency value. M3 (Medium with volcanic ash:charcoal) showed the highest value (a) of all variables and M1 showed the lowest.

Result of HSD Tukey test between the treatments (Table 3) indicated that most of the effects of compost doses were significantt, especially on the growth and crop yield. The treatment of K3 showed the best effect indicated in the higest values of number of leaves, plant height, dry fresh weight, water-use and the efficiency value of water-use, while the lowest values were observed in K1. However, there was no significant difference observed on fresh and dry weight of root.

Result of HSD Tukey test between the treatments (Table 4) showed that the column density gave significant effects, especially on the plant growth (plant height, number of leaves and total fresh and dry weight). The best/highest water-use efficiency

Table 4. The influence of plant population (column density) to the growth, crop result and water-use efficiency

Parameter	P1	P2	P3
Plant height (cm)	25.72 (b)	28.75 (a)	27.97 (a)
Number of leaves (sheet)	11.00 (b)	11.96 (a)	12.11 (a)
Fresh consumption weight (g.column^{-1})	488.17 (ab)	504.40 (a)	469.28 (b)
Fresh root weight (g.column^{-1})	19.92 (b)	24.84 (a)	22.68 (a)
Total fresh weight (g.column^{-1})	508.10 (ab)	529.24 (a)	491.97 (b)
Dry consumption weight (g.column^{-1})	43.84 (a)	31.92 (b)	46.58 (a)
Dry root weight (g.column^{-1})	3.61 (a)	3.55 (a)	4.02 (a)
Total dry weight (g.column^{-1})	47.48 (a)	35.43 (b)	50.60 (a)
Plant water-use (kg =l)	22.23(a)	22.65 (a)	22.15 (a)
Water use efficiency (g.kg^{-1})	1.95 (a)	1.40 (b)	2.10 (a)

Remarks: The number followed by the same letter in the row is not different in HSD tukey Test 5 %.

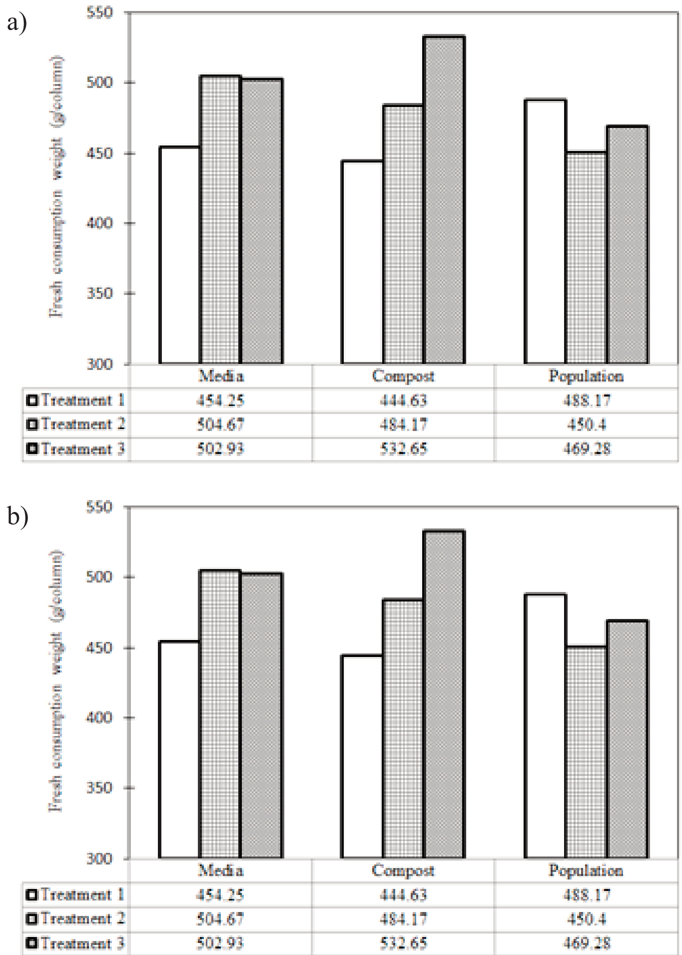

Figure 2. Influence: (a) media (M), compost (K) and population (P) on the fresh consumption weight; and (b) M, K and P on the water-use efficiency (g kg^{-1})

was observed population P1 and P3.

The plant growth, represented by the fresh consumption weight, indicated that the treatment of M3 and K3 (media and compost) resulted in the highest weight as presented in Figure 2a. It means that the higher dose of charcoal husk and compost fertilizer, the better the result. Meanwhile, the fresh consumption weight observed in population P1 (4 columns.m^{-2}) was the highest compared to P3 and P2. The highest water use efficiency observed in treatment of M3 (50 % volcanic ash and 50 % charcoal husk) with water-use efficiency of 2.08.

Increasing water-use efficiency could manipulate the production and water user. By raising the production and limiting the water-use, it would increase the efficiency. Water-use could not be decreased anymore, thus the possibility to increase production was through chemical fertilizing, especially Nitrogen. The effects of media, compost and population in Figure 2b. showed that the highest water use efficiency was obtained from higher dose and from the population of P1 and P3.

Analysis of Variance (ANOVA) results on the two-factor treatment combinations are presented in Attachment 1, 2 and 3. Media and compost treatment combination significantly affected all observed variables except the fresh and dry weight of root. Meanwhile, media and population treatment combination significantly affect all observed variables. Compost and population treatment combination significantly affected all variables, except the dry root weight and water-use. Variables which were not significantly different were not further tested using HSD Tukey test.

The water-use efficiency value of 2.3 $g.kg^{-1}$ in this experiment was better than that of Downes' (1969) *cit.* Singh and Sinha (1977) for Dicotyledonae C4 plant by 3.44 and C3 that was only 1.59 $mg.g^{-1}$. Curly lettuce was classified as C3 where its fresh consumption in this study was still one third of the normal result.

CONCLUSIONS

Volcanic ash can be used as planting media with addition of biochar and compost fertilizer as the amendment materials. The growth of curly lettuce in the vertical cropping system produced the best result under the treatment of biochar media (M3= volcanic ash: biochar, 50:50) and compost fertilizer with the highest compost content (K3= medium: compost, 50:50). The combination of media and fertilizer producing the highest result was M3K3 treatment with fresh consumption weight of 556 gram. Quite well water-use efficiency (highest efficiency value) was 2.1 $g.kg^{-1}$ obtained in treatment P3 (two vertical columns per meter square). This result was not different from the water-use efficiency in P1 treatment (four vertical columns per meter square). In order to obtain optimum result in the vertical cropping system, it is recommended to use M3 media, compost dose of K3 and population columns of P1.

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