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Soil Quality Improvement Using Compost and its Effects on Organic-Corn Production

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ABSTRACT

Intensive agriculture has been well known to cause decline in soil organic matter and nutrient content of the soils. Therefore, efforts should be taken to avoid this from happening. Addition of organic fertilizers like compost has been increasingly become more important in Indonesian agriculture in the last couple of decades. The objectives of this study were to produce high quality compost using Indore method and to investigate its effects on organic-corn production. The study was conducted in the Integrated Agriculture Zone (IAZ), University of Bengkulu for two years (2012 and 2013). The study consisted of three steps: (i) soil fertility identification, (ii) compost production, and (iii) organic-corn field production. Soil fertility identification involved physical, chemical, biological analysis of soil samples collected from less fertile and moderately fertile soils. A randomized completely block design was employed in the field study which involved five rates of compost and two levels of soil fertility with three replications. In 2012, high quality compost was black, had pH 8, fine, odorless, and sufficiently high in NPK contents. Organic-corn yielded 2.94 and 5.69 Mg ha^{-1} of dried kernels on less fertile and moderately fertile soils, respectively at 20 Mg ha^{-1} compost. Similarly, in 2013 high quality compost was black, had pH 8, moderate, odorless, and high in NPK contents. The corn yields were 3.75 and 1.93 Mg ha^{-1} on less fertile and moderately fertile soils, respectively at 22.50 Mg ha^{-1} compost.

Keywords: Corn yield, indore method, organic fertilizer, soil fertility

INTRODUCTION

Food supply depends largely on the availability of fertile soil, high-yield crop variety, and production technology. The area of fertile soils for food production in Indonesia has been decreasing in the last few decades (Hartemink 2003), particularly due to soil degradation and land conversion of fertile soils in agriculture area into non-agriculture land uses. The area of critical (degraded) land in Indonesia is about 78 million ha comprising 47.61, 23.31 and 6.89 million ha of severely, moderately, and fairly critical, respectively (Prawito 2009). The main problems of the critical lands include low in physical, chemical, and biological fertility.

Since 2010 some efforts have been planned and implemented by the Government of Indonesia to improve soil quality (fertility) for food production, such as by organic movement, where the use of organic fertilizer has been encouraged instead of inorganic fertilizers. Nevertheless, the target could not be achieved, partly due to slow mind-shift from the green revolution to organic farming and shortage of organic fertilizer production (Anonim 2011). Therefore, organic farming movement should be enhanced from very basic needs such as organic fertilizer development.

There are several advantages of the use of organic fertilizers compared to the inorganic counterparts. Not only do organic fertilizers supply plant nutrients for plants, but also improve other properties of agricultural soils. They improve soil physical properties such as soil water content, soil aggregation and structure; soil chemical properties such as cation exchange capacity, soil buffering capacity, and nutrient retention; and soil biological properties such as microbial activity and development (HDRA 1998; 2001). All these positive effects are certainly influenced by the quality of the organic fertilizers. Although inorganic fertilizers have rapid effects on plant growth, they are expensive to most small farmers. Thererefore, organic fertilizers such as compost are more promising alternative (Inckel *et al*. 2005).

Compost is one of most common organic fertilizers used in the developing countries. It is usually produced from various organic materials such as remnants of animals and plants fermented for certain time, resulting in dark, crumb, and pleasant materials (HDRA 1998, 2001). Compost use is generally prefered compared to other organic fertilizers such as surface mulch and green manure because of several reasons, namely (i) high temperature during the fermentation would kill weeds, pests, and plant pathogens contained in the source materials; (ii) compost tends to preserve essensial elements and organic matter in soils relatively longer; and (iii) compost limits investation of mice as it happens in surface mulch (van Scholl and Nieuwenhuis 2004).

This research was aimed to produce high quality composts and to determine their effects on organic-corn production on soils with less and moderate fertility levels.

MATERIALS AND METHODS

Study Site

This research project was conducted in 2012 and 2013 in the Integrated Agricultural Zone (IAZ) belongs to the Faculty of Agriculture, University of Bengkulu, Bengkulu. Experiment were research design using a randomized completely block design (RCBD). The treatments consisted of two soil fertility levels (less and moderate) and five rates of compost with three replications. The compost rate and the plot size, however, were different for 2012 and 2013. The compost rates of 2012 were 0, 5, 10, 15 and 20 Mg ha^{-1} and 0, 7.5, 15, 18.75, and 22.5 Mg ha^{-1} for the 2013. In 2012 experiment, plot size was 3 × 4 m with planting space of 30 × 80 cm, resulting in 50 individual plants, while in 2013 the plot size was 6 × 8 m with planting space of 30 ×80 cm, resulting in 200 individual plants. The corn variety used in both years was BISI2.

Compost production was produced from various materials, including goat manure dan plant materials with different C/N ratios. Plant materials with low C/N ratios (< 30) were *Widelia rostrata*, *Asystasia gangetica*, and *Thitonia diversifolia*; while those with high C/N ratios (>30) were rice straw, rice husk, and leaves. Ratio of goat manure and plant materials based on air dry weight was 1:1. Thus, the compost was produced from 600 kg of goat manure mixed with air-dried plant materials of the same weight.

All the studies consisted of three stages: soil fertility identification, compost production, and compost field application. Stage I, soil fertility identification was conducted by evaluating 18 soil properties which then were scored from 1 (very bad) to 5 (very good). These values of each soil property were summed and divided by the sum of the highest scores. The soils were then classified into Not Fertile <45, Less Fertile 46-55, Moderately Fertile 56-69, Fertile 70-79, and Very Fertile 80-100 (Riwandi *et al*. 2009).

In the Stage II, the compost was produced using *Indore* technique as explained in Riwandi *et al.* (2012) and HDRA (2001). The quality of the compost was determined by weekly measurements of the temperature, water content, color, smell, odor, fine-coarse, fungal infestation, soil worms, and nutrient contents (N, P, and K). The temperature was measured using soil thermometer, water content by gravimetric method, color using Munsell Soil Color Chart, odor by smelling, fine-coarse by rubbing between mother and thumb fingers, fungal infestation by measuring surface area covered by fungal body, and the number of soil worms by counting individual worm during the sampling. Nitrogen, P, and K contents were analyzed using standarized methods in the soil laboratory (Balittanah 2005).

Compost Application and Corn Harvest the Stage III, the compost was applied on organic corn field production, involving land preparation, plot establishment, compost application, seed plantation, maintenance, soil sampling, corn harvest, data collection, and statistical analysis. Land was cleared from weeds and shrubs, and the soil was then plowed and smoothened. The plots were established as planned for the respective years, followed by corn-seed planting (two seeds per hole) with planting spaces of 30 x 80 cm and 100-cm distance between plots. Compost with respective rates was broadcast and buried in the planting lines. After emergence, only one corn seedling was maintained for plant growth observation. In addition, irrigation and pest control were also conducted whenever necessary. Soil samples were taken before and after corn harvest using methods suggested by Balittanah (2004a, b, and c). The samples were then brought to Soil Science Laboratory for analysis using standarized methods (Balittanah 2005). Corn harvest was conducted when the corn husks were bright yellow. Experimental data acquired in the field experiment were plant height, leaf number, husk weight, corn kernel weight, and nurient (N, P, and K) contents.

Statistical analysis was conducted for Analysis of Variance at F α 0.05, and Duncan Multiple Range Test.

RESULTS AND DISCUSSION

Soil Fertility Level

Soil fertility identifications in both 2012 and 2013 resulted in soil fertility classes as presented in Table 1.

Based on the calculation scores in both years, soils in the Integrated Agricultural Zones could be classified into less and moderately fertile. The less fertile soil had lower scores in several soil properties, particularly soil pH, basic cation availability, and earthworm population compared to those of the moderately fertile soil. Soil pH, basic cation availability, and earthworm population in less fertile soil are low.

Compost Properties

Properties of the composts produced in two different places, the Integrated Agricultural Zone (UNIB-1) and Waste Management Unit (UNIB-2), are presented in Table 2. Compost UNIB-2 produced in 2013 had better quality than compost UNIB-1 as indicated by higher nutrient contents (N, P, and K). This was particularly due to better production management, such as better mixing of the raw materials. However, based on their properties as shown in Table 2 these two composts were classified as good quality composts (Riwandi *et al*. 2012; Isroi 2008).

Effects of Compost on Soil Fertility in 2012 and 2013

In 2012 the effects of compost application on soil fertility were based on the evaluation of pH and bulk density (BV) of the soils. These two parameters were considered to be representative of acid soil and soil compaction properties, respetively. Less fertile soil in the Intergrated Agricultural Zone (IAZ) was acid (pH <5) and slightly compacted (BV >1). Apparently compost application had increased the soil pH with 0.1 to 0.3 unit and did not influence the soil BV (Table 3). Moderately fertile soil in IAZ was acid (pH <5) but had better physical properties (crumb) with BV <1, due to higher contents of organic matter (7.56% C) and significant amount of peat materials (Riwandi *et al*. 2012).

In 2013 a deeper evaluation on soil fertility level was conducted in the less fertile and moderately fertile in IAZ. Soil fertility levels were characterized by some soil properties as oulined in Tables 4 and 5. Table 4 shows that soil water and soil C contents were significantly different between the control and

Table 1. Scores of soil fertility level on less fertile and moderately fertile soils in Integrated Agriculture Zone (IAZ) and Padang Betuah district before composting.

No	Soil Properties	IAZ			
		Less Fertile Soil		Moderately Fertile Soil	
		Year 2012	Year 2013	Year 2012	Year 2013
1	Color	5	4	5	4
2	Moisture Content	1	3	3	3
3	Topography Level	5	5	5	5
4	Texture	1	4	1	5
5	Structure	1	3	3	4
6	Organic Matter Content	1	3	5	5
7	Salinity	5	2	5	5
8	pH	1	1	1	1
9	Earthworm	1	1	3	3
10	Cover Crop	5	1	1	3
11	Erosion	5	5	5	4
12	Compactness	1	1	5	3
13	Surface Vegetation	3	4	3	4
14	Cation Exchange Capacity	-	2	-	3
15	Basic Cation	-	1	-	1
16	Exchangeable Al	-	3	-	3
17	Total N	-	3	-	2
18	Available P	-	5	-	3
	Sum of Score	35	51	45	62
	Percentage of Score	53%	56%	69%	68%
	Soil Fertility Level	less fertile	less fertile	moderately fertile	moderately fertile

Source: Riwandi *et al*. (2012; 2013)

Table 2. Properties of compost fertilizer on IAZ and organic waste management unit by 1.5 months of composting time.

Compost Name	Temperature (^oC)	Moisture Content (%)	Color	Texture	Smell	pH	N (%)	P (%)	K (%)
UNB-1	42	64	black	fine	no	8	0.30	0.51	1.05
UNB-2	42	75	black	medium	no	8	0.67	0.75	1.80

Table 3. Effect of compost fertilizer on soil properties in less fertile and moderately fertile soils of IAZ of Bengkulu in year 2012.

Compost rates	Less Fertile Soil		Moderately Fertile Soil	
(Mg ha^{-1})	pH (H_2O) 1:2.5 (g v^{-1})	BV (Mg m^{-3})	pH (H_2O) 1:2.5 (g v^{-1})	BV (Mg m^{-3})
0	4.4	1.02	4.3	0.60
5	4.5	1.03	4.4	0.66
10	4.5	1.06	4.5	0.61
15	4.7	1.07	4.3	0.64
20	4.5	1.10	4.2	0.60

Table 4. Effects of compost fertilizer on soil fertility in less fertile soils of IAZ of Bengkulu, year 2013.

Compost rates (Mg ha^{-1})	Soil Properties				
	Moisture Content (%)	Total C (%)	N (%)	Al-exchangeable (cmol kg^{-1})	H-exchangeable (cmol kg^{-1})
0	22.84 ab	2.64 b	0.20 a	2.19 a	1.24 a
7.5	23.27 ab	2.57 b	0.21 a	2.39 a	1.04 a
15	23.35 ab	2.55 b	0.18 a	2.36 a	0.76 a
18.75	23.67 a	2.79 a	0.23 a	2.63 a	1.43 a
22.50	22.08 b	2.78 a	0.24 a	1.50 a	1.05 a

Table 5. Effects of compost fertilizer on soil fertility in moderately fertile soils of IAZ of Bengkulu, year 2013.

Compost rates (Mg ha^{-1})	Soil Properties				
	Moisture Content (%)	Total C (%)	N (%)	Al-exchangeable (cmol kg^{-1})	H-exchangeable (cmol kg^{-1})
0	56.99 a	13.56 a	0.71 a	4.91 a	1.25 a
7.5	57.29 a	14.30 a	0.64 a	4.99 a	1.17 a
15	56.89 a	13.56 a	0.70 a	4.52 a	1.36 a
18.75	56.99 a	14.30 a	0.75 a	4.41 a	1.62 a
22.50	53.85 a	12.52 a	0.61 a	4.25 a	1.36 a

highest compost rate (22.50 Mg ha^{-1}). Soil water content in less fertile soil was more than 20%, C content increased from 2.64% at control to 2.76% at 15 Mg ha^{-1} compost rate. If this C content was converted into a ha, assuming one ha contains 1 million kg soil at 10 cm depth, C content was 1500 kg C or 2580 kg soil organic matter. There were no signficant differences in N and exchangeable Al and H concentrations between control and compost treatments in the less fertile soil. Table 4, however, shows that N tended to increase and exhangeable Al and H tended to decrease with compost addition.

Fertility levels in the moderately fertile soil were not significantly affected by compost addition (Table 5). However, compost addition at 15 Mg ha^{-1} or more tended to decrease exchangeable Al concentration from 4.91 to lower than 4.52 cmol kg^{-1}. Relatively high content of exchangeable Al at highest compost rate (22.50 Mg ha^{-1}) apparently had toxic effects on corn plants. Field observation showed that corn plants in the moderately fertile soil had abnormal colors, yellow, and pink.

Effects of Compost on Corn Yield, N, P, K Uptake, and Root Distribution in 2012

Corn Yield in 2012

Effects of compost on the corn yields on the less fertile and moderately fertile soil in IAZ were significant (Table 6 and 7). The effects appeared to follow the Law of Minimum by von Liebig. The lower the fertility of a soil, the better the response of plant growth to fertilizer addition. Table 6 and 7 show that highest compost rate produced highest corn yields and other plant growth parameters such as plant height and leaf number. Corn yields in moderately fertile soil were about two times higher thant those in the less fertile soil. This was mainly attributed to higher water availability, particularly in the dry season even with irrigation.

Corn yields in the less fertile soil seem to be linear with compost rates (Table 6). This means that the compost rates were still lower than the expected optimum level. The highest corn yield at compost rate of 22.50 Mg ha^{-1} (*i.e* 2.90 Mg ha^{-1}) in the less fertile soils was much lower than the national average yield (*i.e* 9 Mg ha^{-1}). Therefore, in 2013 experiment an additional of 25% NPK fertilizer was applied. Difference in corn yields might be due to the leaf number. At compost rates of 15 and 20 Mg ha^{-1}, corn plants produced much more leaves than compost rates of 0, 5, and 10 Mg ha^{-1}. Plants with higher leaf number were expected to have been better supplied with photosynthates, resulting in higher corn yields (Salisbury and Ross 1992). Leaf number of corn plants in this experiment was only

Table 6. Effects of compost fertilizer on corn yield at less fertile soil of IAZ of Bengkulu in year 2012.

Compost rates (Mg ha^{-1})	Corn Yield/Plant			
	Plant Height (cm)	Leaf Green Grade	Number of Leaf (blade)	Drying Seed Weight (g)
0	33.33 d	30.95 a	7.00 c	0 b
5	54.17 c	32.41 a	8.33 b	35.11 b
10	62.17 bc	34.05 a	8.00 bc	707.79 b
15	69.67 ab	32.67 a	9.00 ab	1058.32 b
20	74.33 a	30.24 a	9.67 a	3523.91 a

Table 7. Effects of compost fertilizer on corn yield at moderately fertile soil of IAZ of Bengkulu in year 2012.

Compost rates (Mg ha^{-1})	Corn Yield/Plant			
	Plant Height (cm)	Leaf Green Grade	Number of Leaf (blade)	Drying Seed Weight (g)
0	74.67 c	36.83 a	8.33 c	2517.80 c
5	93.83 bc	38.60 a	10.67 b	3683.07 b
10	100.50 bc	41.57 a	11.33 ab	4334.73 b
15	118.00 b	39.98 a	11.67 ab	6357.3 a
20	146.33 a	40.81 a	12.33 a	6832.53 a

Table 8. Effects of compost fertilizer on nitrogen, phosphor, potassium of corn leaf at less fertile and moderately soils of IAZ of Bengkulu in Year 2012.

Compost rates (Mg ha^{-1})	Less Fertile Soil			Moderately Fertile Soil		
	N (%)	P (%)	K (%)	N (%)	P (%)	K (%)
0	0.144	0.06 b	0.07 b	1.93	1.24 a	2.06 a
5	0.196	0.14 b	0.57 b	2.98	3.81 a	5.11 a
10	0.753	0.35 b	0.17 b	5.01	2.27 a	4.27 a
15	0.612	0.58 b	0.90 b	2.43	2.16 a	2.91 a
20	2.251	1.13 a	2.31 a	3.91	2.24 a	3.07 a

in average 9.67 leaves, which was much lower than their potentials (15 leaves).

In the moderately fertile soil, compost addition significantly increased plant height, leaf number, and corn yields (Table 7). Plant height at the highest rate was about two times higher than that at the control. Similarly, corn-yield at the highest compost rate was 5.70 Mg ha^{-1}, which was almost three times higher than that at the control (*i.e* 2.52 Mg ha^{-}1) and fairly close to the national average corn yields (between 7 and 9 Mg ha^{-1}).

Nitrogen, P, and K Concentrations in Plant Tissues in 2012

Under the less fertile soil N, P, and K concentrations in plant tissues increased with compost addition and they were highest at the compost rate 20 Mg ha^{-1} (Table 8). Compost addition 20 Mg ha^{-1} had probably improved soil properties such as soil water content, cation exchange capacity, nutrient release, and microbial activity, enhancing nutrient uptake from the soil. Although it was not significantly different, compost addition tended to increase nutrient concentration in the plant under moderately fertile soil.

Corn Root Distribution in 2012

Root growth of corn plants on the less fertile soil without compost addition was very restricted, short and low root density. When compost was applied, however, root grew much better, long, and well distributed (Figure 1). On the moderately fertile soil, plant roots grew well and compost addition at rates of 5, 10, and 20 Mg ha^{-1} still improved growth and root distribution (Figure 2).

Effects of Compost Addition on Corn Leaf N, P, K Concentration and Corn Growth in 2013

Corn plant is sensitive to environmental condition. Plant height variations due to compost treatment occured at the second week after planting. Plant height was similar at compost rates of 7.5, 15, and 22.5 Mg ha^{-1}, and achieved the highest (182 cm) at 18.75 Mg ha^{-1} compost. Wangayana *et al*. (2010) stated that average height of corn plant BISI2 was 217 cm with addition of manure at 10 Mg ha^{-1}, while potential height is 232 cm (Balit Serealia 2010). Indication of corn plant's sensitivity to environmental condition was also reported by Burhanudin *et al*. (2010), who found that corn plant height achieved 175.30 cm at field capacity and addition of 3 g N plant^{-1}.

Compost effects on plant height on the less fertile soil were more obvious compared to those on the moderately fertile soil. On more fertile soil plant height significant by response to compost addition was only found at the highest rate (22.50 Mg ha^{-1}). Corn yield was a product of photosynthetic proceses; therefore plant condition during vegetative stage determines quantity as well

Figure 1. Corn root distribution on less fertile soil of IAZ at difference rates of compost (lef: no compost; right: 20 Mg ha^{-1} of compost)

Figure 2. Corn root distribution on moderately fertile soil of IAZ at difference rates of compost (lef: no compost; right: 20 Mg ha^{-1} of compost)

as quality of corn yields. In this experiment corn yield on less fertile soil increased with compost addition at 18.75 Mg ha^{-1} (Figure 3 and Table 9). The highest corn yields on less fertile soil was 3.75 Mg ha^{-1}.

Unlike on the less fertile soil, compost addition on the moderately fertile soil did not significantly influence corn yields (Tabel 10). During the 2013 experiment the rainfall was relatively high with wet dry season and had caused flooding on the moderately fertile soil. Under such condition compost

Figure 3. Corn performance of 113 day at less fertile soil with variety of compost rates.

Table 9. Effects of compost fertilizer on corn yield at less fertile soils of IAZ of Bengkulu in year 2013.

Compost rates (Mg ha^{-1})	Corn Yield/Plant		
	Husked Corn Weight (g)	Corn Weight without Husk (g)	Kernel Weight (g)
0	57.73 b	49.87 a	29.25 c
7.5	110.17 ab	98.54 bc	61.65 b
15	99.94 b	89.08 bc	56.30 bc
18.75	273.73 a	164.38 a	104.43 a
22.50	156.93 ab	138.39 ab	84.83 ab

Tabel 10. Effects of compost fertilizer on corn yield at moderately fertile soils of IAZ of Bengkulu in year 2013.

Compost rates (Mg ha^{-1})	Corn Yield/Plant		
	Husked Corn Weight (g)	Corn Weight without Husk (g)	Kernel Weight (g)
0	3.66 b	3.15 b	2.25 a
7.5	11.57 ab	10.15 ab	6.37 a
15	12.86 ab	11.37 ab	7.56 a
18.75	11.38 ab	10.30 ab	6.62 a
22.50	15.04 a	14.01 a	9.27 a

Table 11. Effects of compost fertilizer on corn leaf NPK concentration in less fertile and moderately fertile soils of IAZ of Bengkulu in year 2013.

Compost rates	Less Fertile Soil			Moderately Fertile Soil		
(Mg ha^{-1})	N (%)	P (%)	K (%)	N (%)	P (%)	K (%)
0	0.35 c	0.02 c	0.33 b	0.94 a	0.11 a	1.71 a
7.5	0.88 bc	0.06 bc	1.01 ab	0.73 a	0.08 a	0.89 a
15	0.79 bc	0.06 bc	0.93 ab	1.09 a	0.12 a	1.42 a
18.75	1.67 ab	0.13 ab	1.71 a	0.70 a	0.08 a	1.04 a
22.50	2.03 a	0.15 a	1.92 a	1.21 a	0.15 a	1.71 a

addition might not be effective due to nutrient leaching and enhanced formation of toxic organic compounds. Although the corn plants were relatively tall with compost addition at 22.50 Mg ha^{-1}, plant height could not necessarily be effective indicator of corn yields. Saputra (2013) and Efendi (2013) reported that corn husk size well correlated with stem diameters. Stem was considered as a storage of starch which could be converted into glucose which then be easily translocated to corn husk (Ryogo 1988). In 2013 experiment the average corn yield in the moderately fertile soil was 1.93 Mg ha^{-1}. The yield dropped during 2013 growing season because of the 2-day heavy rain causing flooding on the corn field. The flooding apparently had affected plants to suffer from leaf yellowing and restricted root growth, resulting in low corn yields. Flooding led to strong changes in soil due to a switch from aerobic to anaerobic conditions favoured the reduction of NO_3^- to NH_4^+. Subsequently, N may loss through volatilization as NH_3 or N_2O (Reddy and Delaune 2008, Hairani and Susilawati 2013).

Compost addition above 20 Mg ha^{-1} rates significantly increased N, P, and K uptake by corn plants under the less fertile soil. In contrast, there were no significant differences in N, P, and K uptake under the moderately fertile soil (Table 11). Flooding condition during the experiment on the moderately fertile soil might have contributed to lack of plant response to compost addition.

CONCLUSIONS

High quality compost produced in this research had black color, fine to moderate coarseness, and moderate to high content of N, P, and K elements. Compost increased the fertility of soil with low fertility level. In 2012 compost addition at 20 Mg ha^{-1} produced average organic corn yields of 2.94 and 5.70 Mg ha^{-1} on the less and moderate fertility soils, respectively. While in 2013 compost addition at 22.50 Mg ha^{-1} produced average corn yields of 3.75 and 1.93 Mg ha^{-1} on the less and moderate fertility soils, respectively.

Organic farming for corn production using locally available compost materials need to be better developed. Within 3-5 years to come corn yield of 9 Mg ha^{-1} could be achieved under an organic farming system.

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