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# CHARACTERISTICS OF COMPOSTED BIO-TOILET RESIDUE AND ITS POTENTIAL USE AS A SOIL CONDITIONER

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## ABSTRACT

Bio-toilet is a dry toilet where human excreta is trapped in a lignocelluloses soil matrix such as wood sawdust, then it is decomposed by aerobic bacteria to organic compost rich in minerals such as N, P, and K. The study aimed to characterize the bio-toilet residue and its potential use as a soil conditioner for *Jatropha curcas*. The study was conducted in a private school of Daarut Tauhid in Bandung West Java. A bio-toilet S-50 type of Japan was constructed consisting of a composting chamber, mixer, heater, exhaust fan, and closet. The composting chamber was filled with 63 kg of *Albizzia* sawdust. Feces and urine was loaded daily by 54 students for 122-day observation. At the end of observation, the decomposed bio-toilet residue was evaluated for its physical properties such as bulk density ($r_b$), porosity (%), and water retention ($W_R$). Chemical properties such as pH, C/N ratio, N, P, and K, as well as microbiological properties such as numbers of bacteria, fungi, and worm eggs were evaluated at 14 and 122 days of decomposition process. Effect of the composted bio-toilet residue as plant growth media was evaluated using *J. curcass* as a plant indicator. Before it was used as a growth media, the composted bio-toilet residue was dried in a room temperature for 30 days. The experiment was designed in a completely randomized design 2 x 4 factorial with three replications. The first factor was the rate of composted bio-toilet residue, i.e., 0, 20, 40, and 60% based on weight of the growth media mixture (1500 g pot$^{-1}$), and the second was NPK fertilizer addition at 0 and 2 g pot$^{-1}$. Each pot was planted with 2-month old of *J. curcas* seedlings. Parameters evaluated were leaf number, leaf area, stem height, and stem diameter measured at 12 weeks after planting. The results showed that the bio-toilet residue was suitable as soil conditioner because it had high porosity (76%), low bulk density (0.19 g cm$^{-3}$), high water retention (2.6 ml g$^{-1}$ DM), neutral pH (6.9), C/N ratio 27, and contained N, P, K, and Na of 1.73, 1.15, 1.03, and 0.88%, respectively. Its microbial count showed only two kinds of bacteria, i.e., *Klebsiella pneumonia* and *Escherichia coli,* detected at 14 and 122 days of bio-toilet usage. The composted bio-toilet residue improved vegetative performances of *J. curcas* as indicated by increasing leaf number, leaf area, stem height, and stem diameter.

[***Keywords***: Bio-toilet residue, microbial count, *Jatropha curcas*, soil conditioner]

## INTRODUCTION

Bio-toilet is a dry toilet using lignocelluloses waste material as an artificial soil matrix in decomposing human excreta. Basically, bio-toilet consists of reactor chamber, mixer, heater, and ventilator (Kitsui and Terazawa 1999). Related with the water requirement, bio-toilet is different from flushing type toilet. In the flushing toilet, water is used for cleaning the body and for feces-urine transportation. Survey in Kiaracondong-Bandung West Java showed that the water usage for each defecates in flushing toilet is 10 liters on the average; 68% of respondents used clean water (Municipal Water Supply) and 32% well water (Triastuti and Sintawardani 2006).

In the other side, data showed that 91% of people in Citarum catchment area of West Java discharged their black water (toilet waste) directly to the river and caused water degradation (Soedjana 2006). By using bio-toilet, the water usage for defecate would be reduced by ± 50% because the flushing water is not necessary, and the water degradation can be prevented.

In the bio-toilet, feces-urine is mixed with sawdust in a reactor chamber then it is decomposed by aerobic bacteria resulting carbon dioxide ($CO_2$) and water ($H_2O$). The water is evaporated by the chemical heat that would be released in the decomposing process of organic materials. Meanwhile, mineralized products of organic wastes, such as nitrogen (N), phosphorus (P), and potassium (K) remained in the sawdust. After the bio-toilet is used for about 6 months, the residual sawdust was harvested and used as a soil conditioner (Kitsui and Terazawa 1999).

Lignocelluloses materials, such as agriculture and agro forestry residues are suitable as a matrix for bio-toilet. Some of them have been studied by the previous researchers, such as wood sawdust of Todomatsu

(*Abies sachaliensis* Masters), Karamatsu (*Larix kaempferi* Carriere), and Ezomatsu (*Picea jezonensis* Carr) (Horisawa *et al*. 1999); mix-wood waste sawdust from furniture industry (Liu *et al*. 2005); corn stalk (Sheng *et al*. 2005); and soybean stalk (Qian *et al*. 2006). Study in Indonesia showed that the Albizzia (*Paraserianthes falcataria*) sawdust can be used as matrix without creating bad odor for 4 months (Triastuti *et al*. 2006).

In the bio-toilet system, there are frictions among sawdust particles and between sawdust particles with screw material that caused a fiber loosen in the sawdust surface. This condition stimulates residual sawdust tends to be finer. Mass fraction of 4-18 mesh particles of Albizzia sawdust decreased significantly from 15.59% to 5.74%, meanwhile particle of 18-60 mesh size increased from 55.92% to 75.67% after 4 months of usage. Scanning electron micrograph photograph of raw sawdust surface is uniform and regularly in shape, contrasts with the residual sawdust that has been damaged (Triastuti *et al*. 2008). Therefore, after 4 months of usage, residual sawdust should be replaced with fresh sawdust to maintain the performance of bio-toilet.

Bio-toilet is based on the ecological sanitation. It is a new holistic approach to reduce health risk related to sanitation and water pollution due to human wastes. Furthermore, bio-toilet residues can be composted and used as fertilizer in agriculture (Lopez and Funamizu 2005). Scientifically, cabbage and spinach fertilized with composted bio-toilet residue increased their yield in China (Sun *et al*. 2006). In this study we use it for *J. curcas*, one of potential renewable bio-energy sources.

The objective of this study was to characterize bio-toilet residues and its potential to be used as a soil conditioner of *J. curcas*.

## MATERIALS AND METHODS

### Bio-toilet Construction and Use

Bio-toilet type S-50 produced by Seiwa Denko Co. Ltd. Japan was used in this study (Fig. 1). The composting chamber was filled with 63 g of *Albizzia* sawdust obtained from a sawmill in Bandung city. The sawdust moisture content was 10.75%. Feces and urine was loaded daily by 54 students of a private school in Bandung during 122 days. A mixer was programmed to run-on with 15-minute interval for 2 minutes automatically (one minute to clockwise and one minute to counterclockwise). An exhaust fan was operated continuously to ensure a proper aeration in the composting chamber. Moisture was maintained to 40-60%.

### Characteristic of Bio-toilet Residue

#### Bulk Density

Bulk Density was determined by weighing sawdust in cylinder with 10 replications (Horisawa *et al*. 1999). Bulk density was calculated using Equation 1.

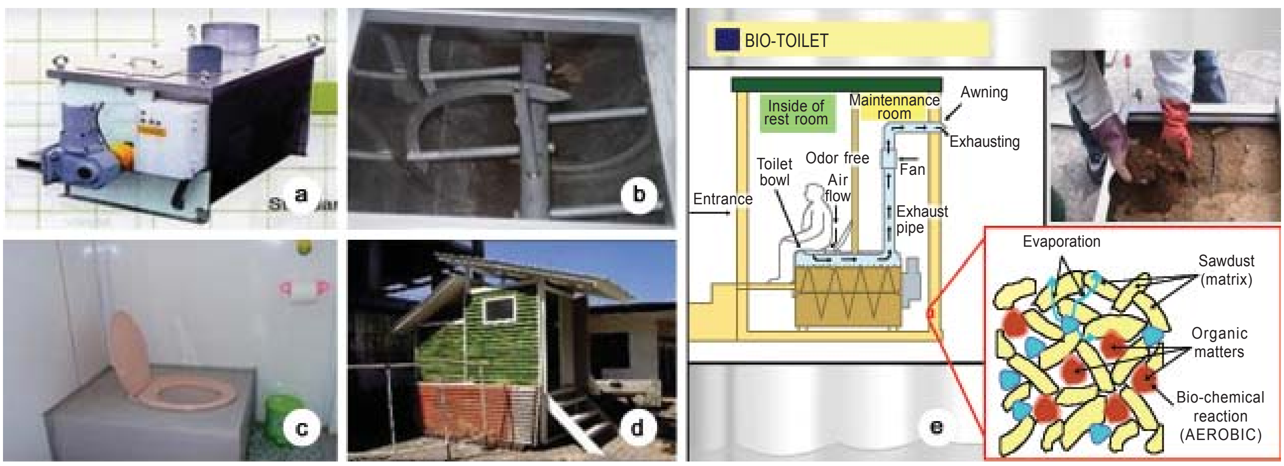


**Fig. 1.** Bio-toilet type S-50 of Seiwa Denko Co. Ltd. Japan constructed at a private school: (a) bio-toilet chamber, (b) mixer, (c) closet, (d) room of bio-toilet, and (e) schematic diagram of bio-toilet system.

$\rho_b = W/V$ .................................................................. (1)

where:
$\rho_b$ = bulk density (g $cm^{-3}$)
W = dry weight of sawdust (g)
V = volume of sawdust ($cm^3$)

## Porosity

Porosity is defined as the fraction of volume of void space area to total volume of medium (Nield and Bejan 1992). In this study, porosity was measured by filling 100 ml of sawdust into a cylinder and adding distilled water gradually using buret. It was allowed for 30 minutes to ensure the water filled and replaced air in pores within sawdust. Addition of distilled water was repeated until the initial volume of sawdust was reached. Porosity is ratio of volume of added water to total volume of sawdust (Equation 2).

$\varphi = Vw/Vs \times 100\%$ ............................................. (2)

where:
$\varphi$ = porosity (% v/v)
Vs = volume of sawdust (100 ml)
Vw = volume of added water (ml)

## Water Retention

Water retention was measured based on Horisawa *et al.* (1999), by filling in ± 50 g of sawdust to Imhoff-cone, and adding 200 ml of distilled water. It was allowed for 30 minutes to water would be absorbed by the sawdust. The valve was then opened and drained for 15 minutes, and the drained or excess water volume was measured. Water retention was calculated using Equation 3.

$W_R = (V_0 - V_1) / M$ ............................................…….. (3)

where:
$W_R$ = water retention (ml $g^{-1}$ DM)
$V_0$ = volume of added distilled water (ml)
$V_1$ = volume of excess water (ml)
M = weight of sawdust (g DM)

Moisture content was determined by heating samples in oven at 105°C for 6-8 hours to reach a constant weight. This water retention value was corrected with the moisture content of the sample.

## Chemical and Microbiological Properties of Bio-toilet Residue

Chemical properties of the bio-toilet residue evaluated were pH, C/N ratio, and N, P, and K contents. As comparation, properties of soil and sawdust raw materials were analyzed. Meanwhile, analyses of microbiological properties of the bio-toilet residue consisted of bacteria and fungi. Samples were taken from the reactor at 14 days (early usage of the bio-toilet) and at 122 days (end of observation). Identification of bacteria was conducted at Health Laboratory in Bandung by using sugar testing method (IMViC test), which are covering of Indole test, motility, Voges-Proskauer, and Simmon's Citrate test. Identification of Enterobacteriaceae is using Mac Conkey bacteria-growth and *Salmonella shigella* media.

## Utilization of Bio-toilet Residue for *J. curcas*

The pot experiment was designed in a completely randomized design of 2 x 4 factorial pattern with three replications. The first factor was a rate of composted bio-toilet residue, i.e. 0, 20, 40, and 60% based on weight of growing medium mixture (1500 g $pot^{-1}$). Before it was used, the bio-toilet residue of 122 days was taken from the reactor, and allowed it to dry for 30 days in room temperature, then mixed with a Latosol soil obtained from Jatinangor-Sumedang, West Java. The second factor was NPK fertilizer rate, i.e. 0 and 2 g $pot^{-1}$. Fertilizer was dissolved in 200 ml of distiled water and then mixed it with growing media. The composition of NPK fertilizer used were nitrogen total (N) 24.8%; nitrogen-ammonium ($N\text{-}NH_4$) 12.8%; nitrogen-nitrate ($N\text{-}NO_3$) 11.8%; phosphate (as $P_2O_5$) 7.0%; potassium (as $K_2O$) 7.0%; magnesium (as MgO) 1.4%; and calcium (as CaO) 4.0%. Mineral content of the soil was analyzed according to the standard methods. Each pot was planted with 2-month old of *J. curcas* seedlings. Parameters evaluated were leaf number, leaf area, stem height, and stem diameter, measured at 12 weeks after planting.

Leaf area is calculated using equation below.

$$L_A = \frac{W_L}{W_S} \times S_A$$

where:
$L_A$ = leaf area ($cm^2$)
$W_L$ = paper weight of leaf area (g)
$W_S$ = weight of standard paper (g)
$S_A$ = standard paper area ($cm^2$)

Data were analyzed by analyses of variance (ANOVA) and then continued with Duncan's Multiple Range Test (DMRT).

## RESULTS AND DISCUSSION

During the study (122-day observation), the bio-toilet constructed was used for urinating, defecating, and both urinating-defecating of 54 students with frequency of 66, 14, and 147 times, respectively. Human waste loaded into the bio-toilet chamber consisted of urine (12.29 kg), feces (3.33 kg), and feces-urine mixture (51.8 kg).

These data indicated that the average discharge of urine was 186 ml per urinate. With assumption that the frequency of urinate is 6-8 times/person/day, total production of urine is estimated 1.12-1.5 liter/person/day. This value is similar with the previous study that has been reported by Mara (1982), i.e. 1.0-1.3 liter/person/day, averagely. Data showed that production of feces (fresh) was 238 g per defecate averagely. It was reported that frequency of defecate mostly is one time/person/day. Therefore, it can be concluded that the average of feces production in this study is 238 g/person/day. Meanwhile, the average production of fresh feces in Africa is 250 g/person/day (Strauss 1985); and data of World Health Organization is 135-270 g/person/day (Mara 1982). The difference can be understood because urine-feces production is depending on individual condition, especially on food habit and health status.

### Bulk Density

Figure 2 showed that bulk density of fresh sawdust was 0.11g $cm^{-3}$, and the bio-toilet residue is 0.19 g $cm^{-3}$. These values are similar the bulk density of Todomatsu, Karamatsu, and Ezomatsu sawdust, i.e. 0.14, 0.19, and 0.15 g $cm^{-3}$, respectively (Horisawa *et al*. 1999). By this low bulk density of bio-toilet residual sawdust, mixing of soil with it will improve soil porosity.

### Porosity

Sawdust is a material consisted of solid matrix with an inter-connected void or pores. Inter-connectedness of void spaces in sawdust materials allows fluids, such as water and air flow through in (Nield and Bejan 1992). Data showed that the porosity of bio-toilet residue decreased compared to fresh one, i.e. from 80 to 76%. It is most likely caused by the coating of sawdust surface with feces-urine decomposed products. As a result, void space of sawdust decreased. Figure 3 showed that the porosity of bio-toilet residue was higher than the Jatinangor soil (76% vs 61%). This indicates that mixing of soil with the bio-toilet residue would increase soil porosity.

### Water Retention

Like soil, sawdust materials hold water by two ways, as a film coating on sawdust particles and in pore spaces between particles. These pore spaces would be filled with water when water infiltrates into sawdust. Figure 4 showed that water retention of bio-toilet residue was 2.6 ml $g^{-1}$, about 10 times higher than water retention of Jatinangor soil. Therefore, the substitution of soil with bio-toilet residue would increase the water availability in a growing media.

### Chemical Properties

Table 1 showed that the pH of bio-toilet residue was 6.90, higher than its raw sawdust (6.2) and the


**Fig. 2.** Bulk density of bio-toilet residue and soil.

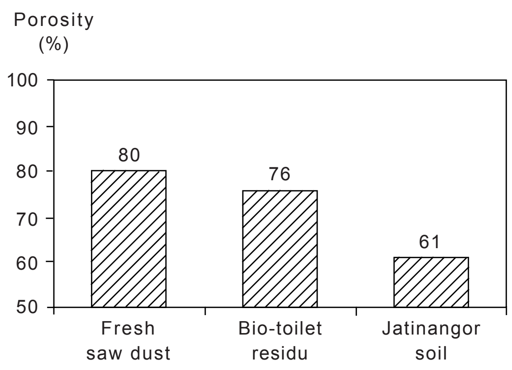


**Fig. 3.** Porosity of bio-toilet residue and soil.

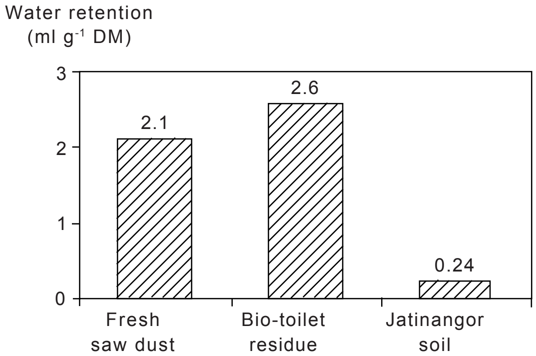


**Fig. 4.** Water retention of bio-toilet residue and soil.

Jatinangor soil (6.0). Addition of this residue to soil would make soil pH to be neutral, the most favorable for plant growth. The C/N ratio decreases with time as the nitrogen will remain in the system, but carbon is released as carbon dioxide (Kitsui and Terazawa 1999). In this study, C/N ratio decreased from 188 to 27 within 122 days. Minerals content on the other hand increased significantly (Table 1).

## Microorganisms in Bio-toilet Residue

Esrey *et al.* (1998) reported that in dry-sanitation systems, pathogenic microorganisms can be reduced through biodegradation, desiccation, or a combination of the two. The fate of entero-microorganisms in the composting toilet, such as *E.coli* and *Salmonella* was also investigated by Otaki *et al*. (2006).

This study showed the fate of some microorganisms during the composting process using bio-toilet, include bacteria and fungi (Table 2). The absence of *Proteus vulgaris*, *Proteus mirabilis*, *Alcaligenes faecalis*, *Enterobacter aglomerans*, *Enterobacter aerogenes*, and *Staphylococcus saprophyticus* in the bio-toilet residue indicated that these bacteria were damaged during the composting process in the bio-toilet chamber. The same pattern showed by the fungi, such as *Aspergillus* sp., *Penicillium* sp., *Geotricum* sp., and *Candida* sp. Nevertheless, bacteria of *Klebsiella pneumonia* and *Escherichia coli* were still detected in the bio-toilet residue. It was suggested that the composting process has not completed with only storage of bio-toilet residue at room temperature for one month, mainly to the last feces loaded (122$^{nd}$ day). It should be considered related with the health risk.

**Table 1. Chemical properties of sawdust and soils used in this study.**

| Parameter | Fresh sawdust | Bio-toilet residue | Jatinangor soil |
|---|---|---|---|
| pH | 6.20 | 6.90 | 6.00 |
| N-total (%) | 0.29 | 1.73 | 0.05 |
| C/N ratio | 188.00 | 27.00 | 20.00 |
| P ($P_2O_5$) (%) | 0.25 | 1.15 | 0.17 |
| K ($K_2O$) (%) | 0.47 | 1.03 | 0.11 |
| Na ($Na_2O$) (%) | 0.04 | 0.88 | - |

## Effect of the Bio-toilet Residue on *J. curcass* Growth

Data showed that the application of composted residual sawdust significantly increased the leaf number of *J. curcas*, but the fertilizer did not affect the leaf number (Table 3). There is no different effect in leaf number by using 0% or 20% of residual sawdust. The increase in leaf number was significant when using 40% or 60% residual sawdust incorporated in the growing media.

**Table 2. Existence of microorganism in sawdust matrix of bio-toilet.**

| Microorganism in the sawdust matrix of bio-toilet | 14 days of bio-toilet | 122 days after bio-toilet usage (residue) |
|---|---|---|
| *Klebsiella pneumonia* | + | + |
| *Escherichia coli* | + | + |
| *Proteus vulgaris* | + | - |
| *Proteus mirabilis* | + | - |
| *Alcaligenes faecalis* | + | - |
| *Enterobacter aglomerans* | + | - |
| *Enterobacter aerogenes* | + | - |
| *Staphylococcus saprophyticus* | + | - |
| *Aspergillus* sp. | + | - |
| *Penicillium* sp. | + | - |
| *Geotricum* sp. | + | - |
| *Candida* sp. | + | - |

+ = exist; - = absence

**Table 3. Effect of residual sawdust and fertilizer on the number of *Jatropha curcas* leaves.**

| Rate of NPK feritilizer (g pot$^{-1}$) | Rate of composted residual sawdust | | | |
|---|---|---|---|---|
| | 0% | 20% | 40% | 60% |
| 0 | 3.33 | 4.00 | 5.33 | 5.33 |
| 2 | 3.00 | 3.67 | 5.67 | 5.67 |
| Average | 3.16a | 3.83a | 5.50b | 5.50b |

Numbers in the same row followed by different letters are significantly different according to DMRT at $\alpha$ = 0.05.

There was a significant interaction effects of the rate of residual sawdust and fertilizer treatments on the leaf area of *J. curcas* (Table 4). On the average, leaf area of control treatment is 58.34 $cm^2$, and it increased to 73.28, 159.49, and 186.21 $cm^2$ by using 20%, 40%, and 60% of residual sawdust, respectively. Leaf area increased 97% on average by adding fertilizer. This means both residual sawdust and fertilizer factors are not independent. Treatment with 60% residual sawdust combined with the addition of fertilizer resulted in the highest (259.20 $cm^2$) leaf area. Meanwhile, the lowest (17.82 $cm^2$) leaf area was resulted from treatment with no addition of fertilizer and no residual sawdust application.

The data showed that there was no effect of the residual sawdust and fertilizer treatment on the plant height (Table 5). However, both treatments significantly affected the stem diameter of the plant (Table 6).

The main nutrients required by the plant in relatively high amounts are N, P, and K. Bio-toilet residue contains these nutrients and thus may be used as an alternative plant nutrient source, as well as for improving soil aeration, porosity, and water retention.

**Table 4. Effect of residual sawdust and fertilizer on *Jatropha curcas* leaf area ($cm^2$).**

| Rate of NPK fertilizer (g $pot^{-1}$) | Rate of composted residual sawdust | | | |
|---|---|---|---|---|
| | 0% | 20% | 40% | 60% |
| 0 | 17.82a | 69.54b | 120.12c | 113.22bc |
| 2 | 98.85bc | 77.01bc | 198.85d | 259.20e |

Numbers in each row, followed by common letters are not significantly different according to DMRT at $\alpha$ = 0.05.

**Table 5. Effect of residual sawdust and fertilizer on *Jatropha curcas* stem height (cm).**

| Rate of NPK fertilizer (g $pot^{-1}$) | Rate of composted residual sawdust | | | |
|---|---|---|---|---|
| | 0% | 20% | 40% | 60% |
| 0 | 18.67 | 19.97 | 21.10 | 21.60 |
| 2 | 19.57 | 20.40 | 20.07 | 21.47 |

**Table 6. Effect of residual sawdust and fertilizer on *Jatropha curcas* stem diameter (mm).**

| Rate of NPK fertilizer (g $pot^{-1}$) | Rate of composted residual sawdust | | | |
|---|---|---|---|---|
| | 0% | 20% | 40% | 60% |
| 0 | 12.20a | 12.07a | 14.20b | 14.84bc |
| 2 | 11.17a | 12.16a | 15.50c | 15.10bc |

Numbers in each row followed by common letters are not significantly different according to DMRT at $\alpha$ = 0.05.

However, further studies are required to improve understanding of the beneficial as well as potential harmful effects on water sanitation, of bio-toilet and its residual utilization for farming.

## CONCLUSION

Albizzia residual sawdust from bio-toilet is a benefial soil conditioner because of its high porosity (76%), low bulk density (0.19 g $cm^{-3}$), high water retention (2.6 ml $g^{-1}$), and neutral pH (6.90). The N, P, and K content of bio-toilet residue were 1.73, 1.15, and 1.03 % DM, respectively, which was much higher than that of Jatinangor soil with N, P, K contents of 0.05, 0.17, and 0.11% DM, respectively. Mixing of Jatinangor soil with bio-toilet residual sawdust improved the soil condition as a growing media for jatropha, as indicated by the increase in leaf number, leaf area, and stem diameter.

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