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# EFFECT OF BIOGAS SLURRY FERTILIZER ON DYNAMICS OF SOIL CONSISTENCY AND TILLAGE POWER REQUIREMENT

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## *ABSTRACT*

*Biogas slurry (BS) is a waste used as an organic fertilizer that could improve soil properties. This study was aimed to explore the dynamic of soil consistency and tillage power requirement due to BS fertilizer. Soil consistency and tillage power requirement were analyzed by the liquid (LL), plastic (PL), and adhesive (AL) limits, plasticity index (PI), workability range (WR), and liquidity index (LI). The study was conducted with incubation time and the BS type factors that include control (K), liquid BS (P1), and solid BS (P2). The incubation time factors comprised 2 (I1), 4 (I2), 6 (I3), 8 (I4), 10 (I5), and 12 weeks incubation (I6). The ANOVA test showed that BS fertilizer significantly affected LL, PL, AL, PI, and LI but did not significantly impact WR. The liquid BS fertilizer decreased LL and PI by 2%, increased LI 0.022, and decreased tillage power requirement by 1 horse power (HP). The solid BS, increased LL and PL 3%, PL 3% and AL 2%, while LI decreased by 0.074. The mathematic modeling with a first-order kinetic model was acceptable to describe soil consistency and tillage power requirement ($R^2$>80% and $X^2$<$X^2$ table). The rate of AL for K, P1, and P2 were -0.022/day, -0.032/day, and -0.049/day, respectively. The minus is symbol of decreasing rate. The rate of WR for K, P1, and P2 were 0.024/day, 0.046/day, and 0.079/day, respectively. The form of BS fertilizer (liquid, solid) has changed the soil consistency which in turn has an impact on tillage power requirement.*

**Keywords:** *Biogas slurry; kinetic model; soil consistency; tillage power requirement*

## INTRODUCTION

### Background

Biogas is a renewable energy source with raw materials for livestock manure (Putri, *et al.*, 2012). The production of biogas requires paying attention to managing the final waste known as biogas slurry. It contains many organic matter and nutrients for plants and is useful as organic fertilizer (Zheng, *et al.*, 2017). The organic matter from fertilizers improves the physical and mechanical properties of soil, including reducing soil density and increasing the tillage duration (Hemmat, *et al.*, 2010). Zhang (1994) stated that it also improves soil consistency and reduces plasticity.

In literature, the merits of biogas slurry for soil are able to increases organic matter content, porosity, water storage capacity, reduces volume weight, improve the cation exchange capacity, and reduces the erodibility (Kumar, *et al*., 2015; Bassouny & Abuzaid, 2017; Zheng, *et al*., 2017). Here, the main role of biogas slurry is organic matter which could change the composition of micro and macro pores of soil. The micro pores have a function to store the water. So, the biogas slurry further will affect other soil properties related to water such as tillage.

Tillage is a mechanical effort to obtain good soil conditions to support plant growth. This is done by changing the soil structure so that a balanced state is achieved between the space for air in the macro pores and water in the micro pores. When soil get force from tillage tools, they will respond in the form of resistance to deformation. This property known as soil consistency.

Soil consistency determines the appropriate soil water content in tillage because the process provides pressure that changes soil shape (Sanggu, 2019). Tillage is usually carried out using a hand tractor. Based on Santosa (2006), the soil tillage power is influenced by the plasticity index, a soil consistency value. This study determines the effect of liquid or solid biogas slurry on soil consistency and tillage power requirement.

## MATERIALS AND METHOD

The main materials used were liquid and solid biogas slurries (BS) and clay-textured rice fields soil. Biogas slurry was taken from cattle shed built by the Faculty of Agricultural Technology UGM in Balecatur village (7°44′28″ S and 110°22′00″ E), Gamping district Sleman regency Special Region of Yogyakarta. Top soil (0 to 30 cm) was taken from rice field in Pleret district (7°53’8,3” S, 110°24’9,4” E) Bantul regency Special Region of Yogyakarta. The soil was homogenized before being mixed with BS. The equipment used are liquid limit devices BS 1377, 1997-2, ASTM D4318, AASHTO T89) or Casagrande method, Mortar and Pestle Tools Set, and sieve 2 mm, glass plate, spatula, saucer, oven, and desiccator.

This study was conducted on an experimental pot scale using the Completely Randomized Design (CRD) method. The treatment consisted of the form of the biogas slurry and the incubation time. The fertilizer type factor consisted of control (K), liquid (P1), and solid (P2) biogas slurries. Hemmat, *et al*., (2010) showed that a low dose of fertilizer did not significantly affect the liquid limit of soil. The 25 tons/ha dose showed no significant change, while 50 tons/ha and 100 tons/ha gave a significant difference. However, a dose treatment did not show a significant difference. Therefore, this study used a dose of 50 tons/ha for solid and liquid biogas slurries. The incubation time factor comprised six levels, including 2 (I1), 4 (I2), 6 (I3), 8 (I4), 10 (I5), and 12 weeks (I6). So, 18 treatment combinations were obtained, repeated five times each, resulting in 90 experimental units. The soil was incubated under laboratory conditions and kept the moisture content at 60% by adding water once a week. Also, the consistency (liquid, plastic, and adhesive limits, processing time, plasticity, and liquid indices) was observed every two weeks. The data were analyzed statistically using the two-way ANOVA method and the correlation between soil consistency and organic matter. Changes in the bond limit and the treatment period were modeled using the first-order kinetic model equation. Equations 1 to 3 show formula of first-order kinetic equation (Asropi, *et al*., 2019).

$$\frac{dC}{dt} = -k(C - C_e) \qquad (1)$$

$$\frac{(C_t - C_e)}{(C_o - C_e)} = e^{-kt} \qquad (2)$$

$$C_t = e^{(-kt)} \times (C_o - C_e) + C_e \qquad (3)$$

where $C_t$: the value of the observed variable at time t, $C_o$: the value of the observed variable when t moves to 0, $C_e$: the value of the observed variable at equilibrium, *k*: rate of change constant, *t:* time.

The soil tillage power was analyzed based on the value of its plasticity index. Rice fields are usually tillage using a single moldboard plow in hand tractor (8.5 to 11 horse power). The tractor generally has length, width, high, and weight 2.75 m, 0.86 to 1.13 m, 1.27 to 1.41 m, 254 to 293 kg, respectively. The power required to cultivate the soil was analyzed using Equation 4 proposed by Santosa (2006).

$$P_1 = \frac{D_s \times d \times L \times n \times V \times 100}{Ed \times 75} \text{ .................... (4)}$$

where $D_s$: the soil specific draft (kg/cm$^2$), $d$: the tillage depth (cm), $L$: tillage width (cm), *n:* the number of plowshares, *V:* the tillage speed (m/s), *Ed:* the efficiency of transmitting power from the engine to towing rod (%)

The specific draft for tillage is calculated based on the empirical formula as shown in Equation 5 and 6.

$$D_s = \frac{80 \times D_s{}^1}{75{,}5 - Ip} \text{ .................................. (5)}$$

$$D_s{}^1 = \frac{Ci^1}{600} + \frac{1}{Ci} \text{ ............................... (6)}$$

where $D_s{}^1$: the modified soil specific draft with soil *Ip* (kg/cm$^2$), *Ip*: the soil plasticity index (%), *Ci*: the cone index (kg/cm$^2$)

The cone index value is calculated using the empirical equation of (Kumar, *et al.*, 2012), as shown in Equation 7.

$$Ci = 2{,}185 + 0{,}016(sa) - 0{,}053(mc) + 0{,}0051(d) \text{ ........................................... (7)}$$

where *sa*: the sand fraction (%), *mc*: the soil moisture (%), *d:* the depth (mm)

Several assumptions are used in analyzing the tillage power by referred to Amin, *et al*., (2015). The acceleration due to gravity is 9.8 m/s$^2$, soil moisture content is 60%, soil depth is 20 cm, and tractor speed is 1.03 m/s. Other assumptions are tillage depth and width are 18 cm and 21 cm, respectively. Number of plowshares is 1, coefficient of rolling resistance is 0.2, and tolerance is 30%. The tillage was carried out using a hand tractor weighing 221 kg, with 80% *Ed* and *Ew*. *Ew* is efficiency of transmitting power from engine to tractor wheel.

## RESULTS AND DISCUSSION

### Biogas Slurry and Soil Properties

Soil in this study has clay texture with bulk density 1.07 g/cm$^3$, particle density 2.59 g/cm$^3$, and porosity 59% (Table 1). The bulk density and particle density represent mineral soil properties and it is suitable for flooded irrigation for rice planting. The biogas slurry properties can be seen in Figure 1.

**Table 1.** Physical properties of soil

| Properties | Value |
|---|---|
| Texture | |
| - Sand (%) | 4.69±2.81 |
| - Silt (%) | 30.83±2.81 |
| - Clay (%) | 64.47±2.81 |
| Texture class | Clay |
| Bulk density (ρb, g/cm$^3$) | 1.07±0.06 |
| Particle density (ρs, g/cm$^3$) | 2.59±0.04 |
| Porosity (%) | 58.83±2.82 |

Description: $\rho_s$= *particle density*, $\rho_b$= *bulk density*, N= porosity

According to Indonesian Standard SNI 19-7030-2004, the slurry properties in Figure 1 are not in accordance with the standard of certified and marketed organic fertilizer. The maximum value for water content is 50%, minimum organic matter is 27%, and the minimum pH is 6.8 and the maximum is 7.89. This shows that the slurry used in this study has not yet matured properly to become compost and processing is needed to obtain the appropriate results. Visually, this study observed that solid slurry is still slightly moist whereas the liquid slightly bright colors.

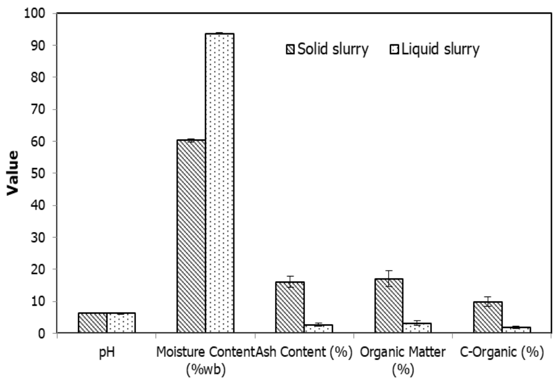


**Figure 1.** Comparison of properties between liquid and solid biogas slurry

## Soil Organic Matter

The dynamics of organic matter content during the observations are shown in Figure 2. The BS treatment had a significant effect (P<0.01) on soil organic matter, while incubation time had no significant effect (P>0.05). The organic matter content in the soil threated with liquid biogas slurry was almost the same as the control. Because the original liquid slurry as seen in Figure 1, has lesser of organic matter. When it is applied to soil as fertilizer then there is no difference in rising of organic matter.

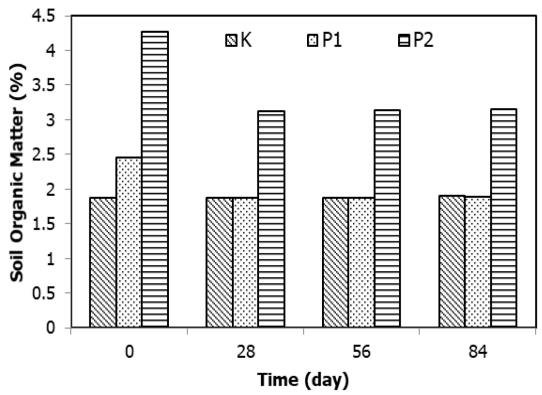


**Figure 2.** Changes in organic matter in the soil: K is control, P1 is liquid biogas slurry fertilizer, P2 is solid biogas slurry fertilizer

## Soil Consistency

The soil consistency was characterized by liquid limit, plastic limit, adhesive limit, plasticity limit, liquid index, and tillage period. All the parameters are based on soil water content. Figure 3(a) shows the changing of the liquid limit of the soil. Here, the type of biogas slurry significantly affected the liquid limit (P<0.05). Conversely, the incubation time and the interaction of the two treatments did not have a significant effect (P>0.05). Figure 3(b) shows the dynamics of the plastic limit of soil. The type of biogas slurry, incubation time, and interaction of the two treatments significantly affected the plastic limit (P<0.05). Figure 3(c) shows the dynamics of the soil's adhesive limit, which was significantly affected by the type of biogas slurry and incubation time (P<0.05). But the interaction of the two treatments did not have a significant effect (P> 0.05).

Similarly, Figure 3(d) the soil plasticity index was significantly affected by the type of biogas slurry and incubation time (P<0.05). On the contrary, the interaction of the two treatments did not have a significant effect (P>0.05). Figure 3(e), the dynamics of the tillage period was significantly affected by the incubation time treatment (P<0.05). However, the type of biogas slurry and the interaction of the two treatments did not have a significant effect (P>0.05). Figure 3(f) shows the dynamics of the soil liquid index was significantly affected by the treatment of the type of biogas slurry (P<0.05). The incubation time and the interaction of the two treatments did not have a significant effect (P> 0.05).

The liquid limit is influenced by soil texture, organic matter content, and the mineral content (Prabhakar & Satyeswararao, 2012; Ying, *et al.*, 2021). The plastic limit is influenced by soil texture and organic matter content (Sari, *et al.*, 2017). The adhesive limit is influenced by soil texture and organic matter content. The plasticity index is affected by soil texture, organic matter, and mineral content in the soil (Prabhakar & Satyeswararao, 2012). The tillage period is influenced by the clay content and soil organic matter (Paul, *et al.*, 2020), while the liquid index is affected by the liquid limit and the plasticity index. The results showed that the soil texture for all treatments and mineral content were same and did not affect the soil consistency values. So, consistency changing is rely affected by organic matter released by BS fertilizer.

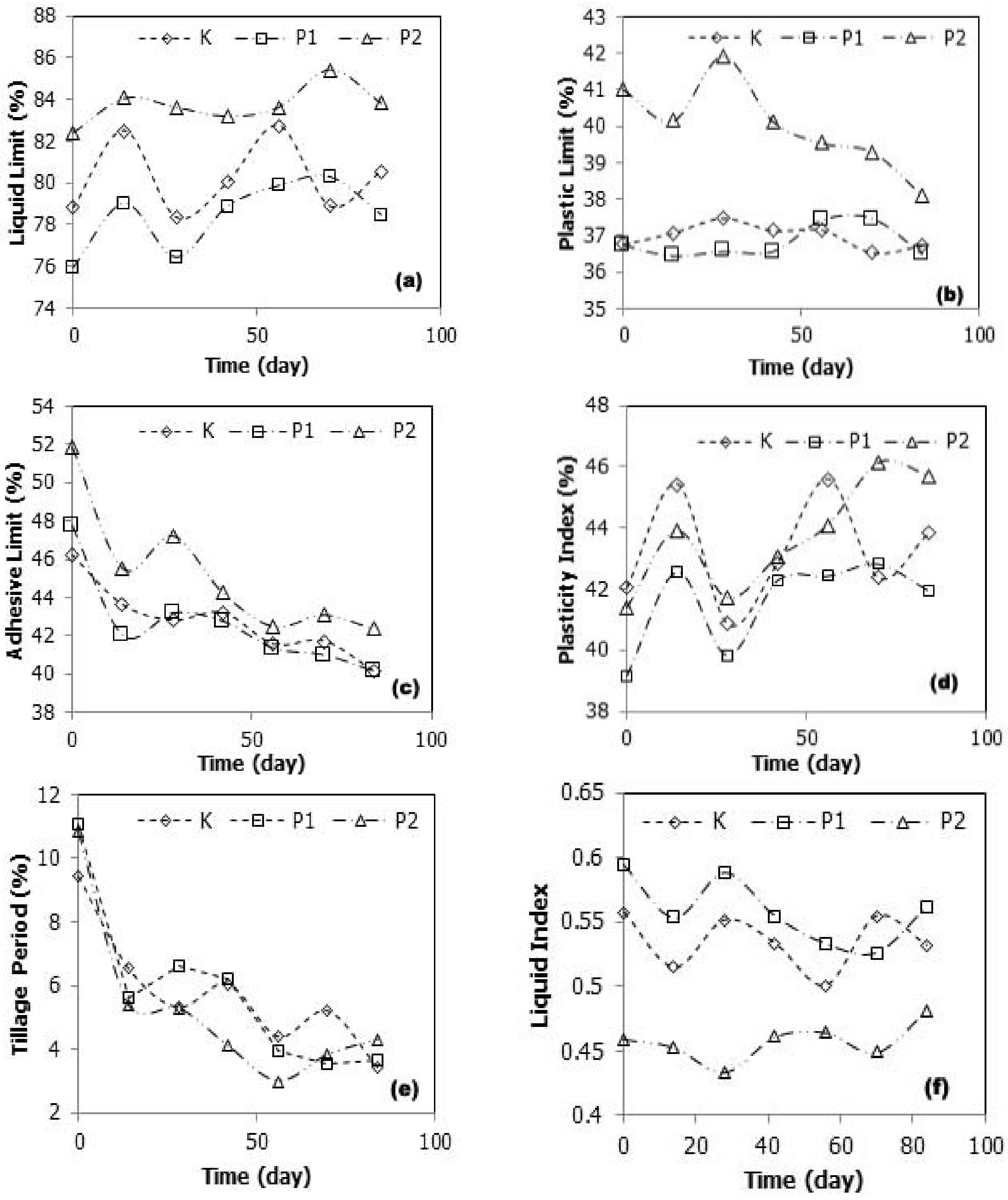


**Figure 3.** Dynamics of soil liquid limit (a), soil plastic limit (b), soil adhesive limit (c), soil plasticity index (d), tillage period (e), and soil liquid index (f). K is control, P1 is liquid biogas slurry fertilizer, P2 is solid biogas slurry fertilizer

The correlation test between the organic matter and parameter of consistency showed that organic matter was significantly and positively correlated with liquid, plastic, and adhesive limits ($r=0.58$ and $P<0.05$). This means that the increase in organic matter increases these limits (Sari, *et al.*, 2017; Prabhakar & Satyeswararao, 2012). The studies showed that the increase in organic matter increases the liquid, plastic, and adhesive limits. According to Intara, *et al.*, (2011), organic matter binds soil particles into aggregates, increasing the pore space. Subsequently, soils with a higher organic matter content have better structure and retain more water. As a result, the liquid, plastic, and adhesive limits occur in higher water content conditions.

The organic matter did not correlate with the plasticity index and tillage period (r=0.58 and P>0.05). According to Blanco-Canqui and Benjamin (2013), an increase in the soil organic matter increases the plasticity index. However, the results showed that organic matter did not affect the soil plasticity index. According to Lal and Shukla (2004), it may occur due to the gaining of the organic matter above 5% which cause an increase in the liquid and plastic limits but may not affect the plasticity index. Furthermore, the addition of organic matter did not affect the tillage period because the soil used has a high clay content. Adding 50 tons/ha of biogas slurry only increases organic matter to 2-4%. Moreover, the organic matter has not improved the tillage period of the test soil compared to the 60% clay content.

Solid BS was higher in organic matter content and liquid limit as compared to other treatments. Based on the organic matter content, the P1 treatment should have a liquid limit value higher or almost the same as the control. However, this treatment had the lowest liquid limit value, similar to the plasticity index in the P1 treatment, which could be caused by the mineral content. According to Sari, *et al*., (2017), organic fertilizers could contain mineral. However, the use of organic fertilizer cannot significantly affect the liquid limit when the mineral level is moderate. On the contrary, liquid biogas slurry may contain high mineral. Ying, *et al*., (2021) stated that an increase in mineral concentration causes a decrease in the liquid limit of clay soil by reducing the thickness of the electric double layer (diffuse double layer). This layer plays a role in the binding process of water molecules.

The liquid index was affected by the liquid limit and the plasticity index, while the P2 and P1 treatments were lower and higher than K, respectively. This was because P2 has a higher liquid limit than K and requires a higher water content to reach the liquid phase. In contrast, the liquid limit in the P1 treatment was lower than K and with the same water content, meaning that P1 was closer to the liquid phase.

**Modeling of Adhesive Limit and Tillage Period**

The comparison of Adhesive Limit (AL) observations and predictions is shown in Figure 4 and Table 2. The table shows the comparison of *k* values, modeling equations of time (x) and AL (y), and validation of model. It shows that the rate of AL reduction was higher with the biogas slurry. The *k* is vector value where the minus symbolized the decreasing process. The higher AL was expected to increase the tillage period. But the decrease was higher with biogas slurry because changes in AL are also influenced by changes in the soil organic matter. As seen in Figure 2, the decrease in organic matter in the P2 was highest. Therefore, although this treatment had a higher AL value than others, the rate of change was also higher due to a significant decrease in organic matter. Validation of model was carried out using the coefficient of determination ($R^2$) and the goodness of fit test using the chi-square value ($X^2$). The value of $R^2$> 80% and the value of $X^2$<$X^2$ table, mean that model was acceptable.

The comparison AL observations and predictions is shown in Figure 5. Table 3 shows that the rate in the tillage period (TP) was higher with biogas slurry fertilizer. TP was expected to be high, making the soil easier to cultivate. However, there was a significant decrease of biogas slurry. This is because the TP is affected by the AL value, which decreases due to changes in organic matter. Furthermore, the P2 treatment had a higher change in organic matter and a significant decrease in AL, resulting in a higher rate of change in TP. The value of $R^2$> 80% and the value of $X^2$<$X^2$ table, mean that the first-order kinetic model acceptable to describe the dynamics of the tillage period.

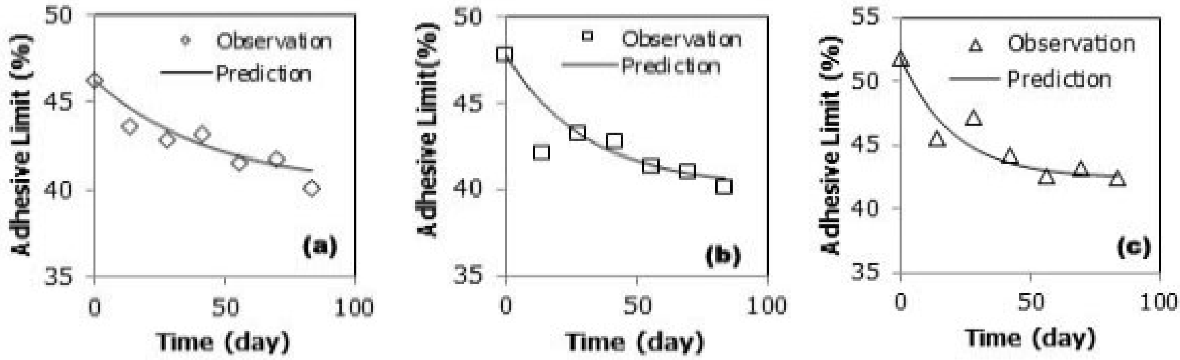


**Figure 4.** Graph of $AL_{obs}$ and $AL_{pred}$ in treatment K (a), P1 (b), and P2 (c). K is control, P1 is liquid biogas slurry fertilizer, P2 is solid biogas slurry fertilizer

**Table 2.** The value of *k*, kinetic equation of time and AL, and validation of model ($R^2$)

| Treatment | *k* (1/day) | Kinetic equation | $R^2$ | $X^2$ |
|---|---|---|---|---|
| K | 0.02 | $y = 6.07e^{-0.02x} + 40.13$ | 0.90 | 0.06 |
| P1 | 0.03 | $y = 7.66e^{-0.03x} + 40.13$ | 0.80 | 0.21 |
| P1 | 0.05 | $y = 9.44e^{-0.05x} + 42.39$ | 0.81 | 0.20 |

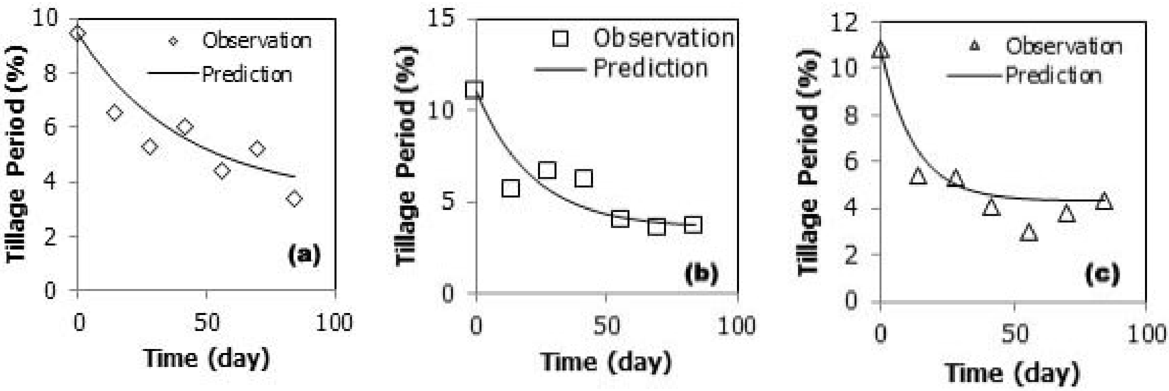


**Figure 5.** Graph of TP observation and TP prediction in treatments K (a), P1 (b), and P2 (c). K is control, P1 is liquid biogas slurry fertilizer, P2 is solid biogas slurry fertilizer

**Table 3.** The value of *k*, kinetic equation of time and TP, and validation of model ($R^2$)

| Treatment | *k* (1/day) | Kinetic equation | $R^2$ | $X^2$ |
|---|---|---|---|---|
| K | 0.02 | $y = 6.03e^{-0.02x} + 3.40$ | 0.85 | 0.73 |
| P1 | 0.05 | $y = 7.41e^{-0.05x} + 3.63$ | 0.84 | 1.19 |
| P1 | 0.08 | $y = 6.52e^{-0.08x} + 4.30$ | 0.95 | 0.73 |

**Dynamics of Tillage Power**

Soil-specific draft (Sd) is a mechanical property that shows the magnitude of the horizontal force to cut the soil per unit cross-sectional area of the soil piece (one unit each into tillage and width of tillage). Sd is influenced by the soil plasticity (IP) and cone index (Santosa, 2006). During the observation, the specific draft value can be seen in Figure 6. It shows that the P1 treatment has a lower Sd value than the other treatments, with no significant difference between K and P2. This is because a lower IP value decreases the Sd.

The test soil with liquid biogas slurry fertilizer had a lower IP and SD than other treatments.

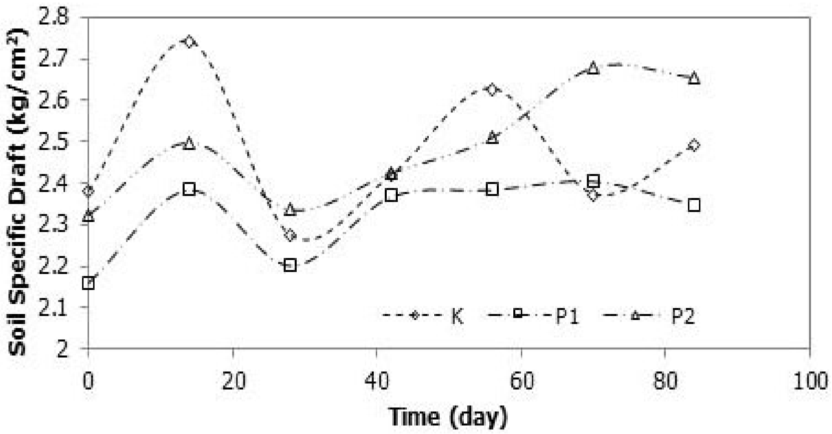


**Figure 6.** Dynamics of soil specific draft due to biogas slurry.
K is control, P1 is liquid biogas slurry fertilizer, P2 is solid biogas slurry fertilizer

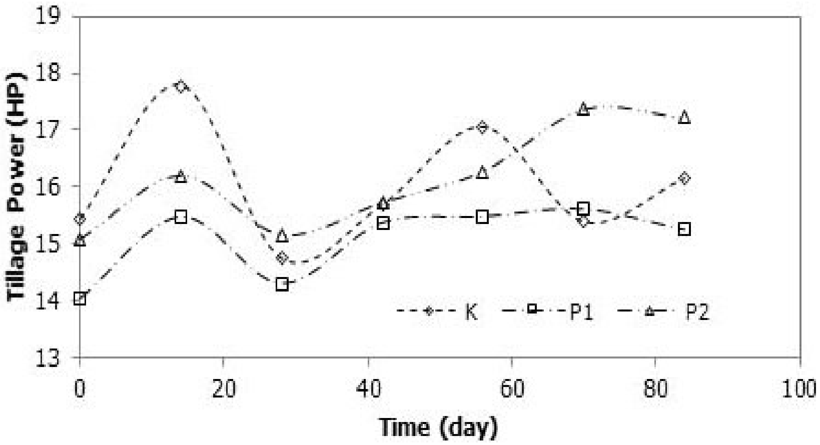


**Figure 7.** Dynamics of Tillage Power due to biogas slurry.
K is control, P1 is liquid biogas slurry fertilizer, P2 is solid biogas slurry fertilizer

Figure 7 shows the dynamics of tillage power needed to move the tiller (Santosa, 2006). Treatment P1 has lower power than other treatments, with no significant difference between treatments K and P2. This is because tillage is directly proportional to Sd. Because the Sd decrease by BS, then the required tractor power is also lower. It could be said that the liquid biogas slurry has caused a decrease in the plasticity index of the soil which further reduces the tillage power of the soil.

## CONCLUSION

The observations and analyses resulted in the following conclusions: Due to the biogas slurry fertilizer, soil consistency has changed which was indicated by the liquid limit of soil (76-82%), the plastic limit (36-42%), the adhesive limit (40-52%). The biogas slurry also has changed the plasticity index (39-46%), the tillage period (3-12%), the soil liquid index (0.4 to 0.6). The first-order kinetic model was excellent to describe the adhesive limit (AL) and the tillage period (TP) behavior due to biogas slurry fertilizer. The decreasing rate of AL for K (control), P1 (dose 1), and P2 (dose 2) were 0.02/day, 0.03/day, and 0.05/day, respectively, while the TP were 0.02/day, 0.05/day, and 0.08/day, respectively. Liquid biogas slurry fertilizer could reduce the soil liquid limit and plasticity index by 2%, increase the liquid index by 0.02 and reduce the tillage capacity of the soil by 1 horse power (HP). Solid biogas slurry could increase the liquid limit and plasticity index by 3%, the adhesive limit by 2% and decrease the liquid index by 0.07.

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