Eco. Env. & Cons. 26 (June Suppl. Issue) : 2020; pp. (S95-S101)
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ISSN 0971–765X

Vermicomposting process of mixed food waste and black soldier fly larvae composting residue by using *Eudrilus eugeniae*

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(Received 27 September, 2019; Accepted 10 March, 2020)

ABSTRACT

The composting process by utilizing Black Soldier Fly (BSF) Larvae has increasingly been carried out in practice. This is due to the high level of organic waste reduction and the rapid composting time. However, shorter duration of composting may limit the larvae ability to digest organic material containing a lot of cellulose materials, eventually generating BSF larvae residues. These waste residues can be potentially further reduced by vermicomposting applying *E. eugeniae*. In order to get more substrate, an amount of food waste was added in the vermicomposting process of the waste that had been pre-composted by BSF larvae. Therefore, the aims of this study were to determine the degradation level of BSF larvae composting residue mixed with food waste and to analyze the quality of the vermicompost produced. The experiment was carried out in duplicate for 60 days. The amount of worms added to the substrate and the composition of the substrate (i.e., food waste and BSF larvae residues) were evaluated and discussed. The results showed that the highest degradation rate was observed when applying the composition of the substrate 1:2 with 15 g worms/kg substrate. The reduction rate was 59.92% and vermicompost production was 75.47%. The best quality of vermicompost was achieved in the same composition but with 20 g worms/kg substrate. The results obtained were pH 7.7, temperature 26 ºC, moisture content 59.47%, organic C/N 15.35, and total C/N 15.18.

Key words: *Vermicomposting process, Food waste, Fly larvae, Eudrilus eugeniae*

Introduction

Almost 60% waste in Indonesia is contributed by organic waste. Organic waste that decomposes easily can be linked as a source of disease and environmental pollution if it is not well managed. In general, organic waste is processed by the composting method (Davis *et al.*, 2014). Waste composting can reduce 50% by volume and 50% of organic material in waste in dry weight (Zhang *et al.*, 2010).

There are innovations in the composting methods including utilization of Black Soldier Fly (BSF) larvae. This method has increasingly been carried out in practice because of the ability of BSF larvae to reduce organic waste in a shorter composting time than the usual composting method, i.e., 12 days in the larval phase, followed by harvesting after 12 days (Saragi and Bagastyo, 2015). Harvesting is the process of separating larvae from compost. The harvesting products consist of larvae, compost, and residues. BSF larvae residue is a lump-shaped material that can not pass the screen of sieving machine.

The residue can not be used as fertilizer because of cellulose-rich content. In the process of harvesting, residue will remain on the screening and will eventually be removed (Dortmans *et al.,* 2017). The ratio of BSF larvae residue: compost weight produced is normally 1:2 (Verstappen *et al.,* 2017). Based on BSF larva breeding data report at the Jambangan Compost House in 2018, the reduction rate of waste ranges from 50-70%. In December 2018, 4,704 kg of waste feed produced 1,920 kg of compost and 960 kg of residual compost. The number of BSF larvae residues will increase if there is no further treatment process.

Another alternative for organic waste composting is vermicomposting. The advantage of vermicomposting is the composting time, which is half of the time quicker than the conventional composting. In addition, vermicompost product has better nutritional content compare to the conventional compost (Munroe, 2003). In principle, vermicomposting media must be pre-composted (Anwar, 2013).

The common species used in the vermicomposting process is *E. eugeniae*. This worm has faster degradation ability and reproduction than the other species (Coulibaly and Zoro, 2010). Therefore, the objectives of the study were to determine the optimum ratio of food waste to BSF larvae residue and to evaluate to what extent the degradation of the waste that can be achieved. In addition, the characteritics of the vermicompost product was also discussed in this study.

Materials and Methods

The amount of BSF larvae residues after the 12th day of harvesting was 20.104 kg, food waste was 32.184 kg, and *E. eugeniae* was approximately 520 g of two month-old species. The ratio of food waste to BSF larvae residue studied were 1:1 (SRA) and 1:2 (SRB). "Fresh" food waste was immediately collected 1-2 days after disposal at TPS 3R Jambangan. Food waste used was a mixture of left over rice, bread, tea, fish, vegetables and fruit (mustard greens, cabbage, potatoes, carrots, beans, and kale). The amount of worms added per kg substrate (the mixed waste) in this study were 0 g/kg (as a control); 10 g/kg; 15 g/kg; and 20 g/kg.

The study was carried out in duplicates for 60 days with a combination of worm acclimatization and pre-composting together for 10 days, followed by vermicomposting process for 50 days. Reactor for pre-composting had a size of 45 cm x 30 cm x 45 cm. There were 16 reactors for vermicomposting with the size of 3 cm x 24 cm x 18 cm, and 2 reactors for acclimatization of worms with the size of 30 cm x 24 cm x 18 cm. The inner side of reactor was layered with screen protector and covered with 1-2 cm of banana sheath as bedding. After putting the required amount of *E. Eugeniae* and a mixture of food waste and/or BSF larvae residue, the reactor was then covered with banana fronds, and final cover cloth at top of the reactor.

Preliminary research was conducted to obtain the characteristics of waste materials by means of density, temperature, moisture content, volatile solid, pH, and C-organic content, Total Kjedahl Nitrogen (TKN), nitrate, ammonium, and C/N ratio ofthe food waste and BSF larvae residues. The initial characteristic of waste material is prsented in Table 1.

Table 1. Initial Characteristics of Vermicomposting Waste Materials

Parameters	Food Waste	BSF Larvae Residue
Density (g/cm^3)	1.87	1.03
Temperature (^oC)	38	40
pH	5.3	7.9
Moisture Content (%)	72.67	48.30
Volatile Solid (%)	38.86	68.22
C-Organic (%)	22.54	39.57
Ammonium (%)	0.017	0.014
Nitrate (%)	0.003	0.037
TKN (%)	0.928	0.772

The initial characteristic of waste materials shown above indicates that the BSF larvae residue overall has temperature, pH, volatile solid, C-organic, nitrate, TKN, N-organic, C/N higher than the food waste. Based on the results of volatile solid analysis and TKN, BSF larvae residues can be used as a source of carbon, whereas food waste can be used as a source of nitrogen in the vermicomposting process.

In the process of acclimatization, the worms used in this study were 2 months old productive worms having a size of about 10-15 cm. Worm acclimatization useda banana stem as a shelter media, then bagasse was added as a substrate feed for worms. A small amount of food waste and BSF larvae residue was given every 3 days during acclimatization of *E.eugeniae* in the reactor. It was intended that the worm can adapt to the substrate that would beits further growing medium in the vermicomposting process. The reactor was kept at normal air recirculation by spraying every 4-5 days and providing a hole in the side. From this acclimatization process, the remained worms in the reactor were used for further process.

Then pre-composting was done to reduce ammonia, moisture content, pH and to stabilize the temperature. It was done by mixing food waste and BSF larvae residue. In the SRA and SRB composition, the waste was mixed as much as 4.640 kg of residue and 8.776 kg of waste, and as much as 6.184 kg of residue and 5.848 kg of waste, respctively.

The vermicomposting process was carried out for 50 days. During the vermicomposting process, the stirring and spraying were done every 4-5 days. This moisture content must be maintained because if the conditions are too dry, the worm will die, but if the conditions are too wet the worm will move to another place.

Results and Discussion

Pre-composting and Vermicomposting

Pre-composting was carried out in two reactors, each containing a different substrate composition. In order to avoid dryness and clumping of the substrate, the reactor was stirred during pre-composting. At the time of pre-composting, two compositions were similar in terms of color, odor, and temperature. Since BSF eggs were still contained in the residue, there would be a competition between worms and larvae in the vermicomposting process. Therefore, the mixed waste wasdried for 10 to 20 minutes and then sifted by using a 1-cm sieve screen. In addition, the pre-composting process was very necessary to prepare the ingredients before the vermicomposting process. The results of pre-composting has the quality that the substrate was not a crumb, not smooth, blackish brown, the temperature was 30-35 °C.

Vermicomposting was done in duplicates, so there were 16 reactors of 4 reactors for SRA composting and 4 reactors for SRB composting. Watering and stirring process were done during vermicomposting. Watering was done to keep 50-60% moisturecontent, whereas stirring was to prevent the substrate from drying out and clumping (Tchobanoglous *et al.,* 1993). At the vermicomposting step there were BSF larvae appearing in the reactor. The number of larvae was not as much as at the time of pre-composting. Gradually, the BSF larvae appear out of themselves from the bottom of the reactor. So at the beginning of the vermicomposting process, there was an influence from BSF larvae. On the 20th day, there was a BSF fly inside the reactor. This indicates BSF larvae have done metamorphosis into a fly BSF. It was advantageous because the larvae could separated themselves from the reactor. Therefore, all napkins that closed the reactor were opened and flies left the reactor and then closed again. In the reactor tray, there were no *E.eugeniae* species found left the reactor. Therefore, the *E.eugeniae* from the acclimation process was able to survive and accept environmental conditions in the reactor.

Changes in Moisture Content, pH, Temperature, and C/N Ratio

Moisture content must be maintained within the range of 50-70% during composting to obtain an effective vermicomposting process. It is because the water in the substrate was used by microorganisms and worms to process metabolism in cells. Moisture content less than 40% will result in slow composting, on the contrary if the moisture content exceeds 70%, it will disrupt oxygen movement and create anaerobic conditions (Tchobanoglous *et al.*, 1993).

The average moisture content of the substrate in the SRA reactor was 61.84%. The highest moisture content was 67.47% measured in the SRA-10 reactor on the 15th day. The average moisture content of the substrate in the SRB reactor was 59.81%. The highest moisture content was measured in the SRB-20 reactor,i.e., 67.93% on the 50th day. Most of the lowest moisture content was measured in the SRA-0 and SRB-0 (as a compost reactor control without the addition of worms), i.e.,51.02% on the 55th day and 50.59% on the 40th day, respectively. This was due to the absent of respiration activity of worms observed in the control reactor. Low moisture content can also be explained by the occurrence of water consumption activities by microorganisms and worms during composting and evaporation. While the high moisture content was resulted from the activity of respiration (Coulibaly and Zoro, 2010). The relative SRA moisture content was higher than in the SRB. This can be explained by the differences in the composition of initial waste materials which was more food waste mixed in the case of SRA.

The initial pH of food waste was 5.3 and BSF larvae residual pH was 7.9. The pH value of the raw material is one of the considerations to make SRA and SRB composition. The composition of SRA and SRB was expected to create the pH received by the worm, which was 7.0-7.5. Although earthworms can survive at pH 5.9, but the ability of degradation will be slow (Anwar, 2013).

The pH increased on the 30th day and then tends to be stable. The SRB reactor showed adecrease in pH for the first 20 days due to the breakdown of polysaccharides and cellulose to organic acids by microorganisms (Xueling, 2006). After wards, the pH increased on the 30th day because of the use of organic acids as substrates as well as the formation of ammonia. This ammonification generates OH^- ions which increases the pH. The pH was then constant in the circumneutral pH due to the presence of CO_2 and water from the metabolism of worms and microorganisms. The reaction between water and CO_2 produces bicarbonate compounds (H_2CO_3), thus maintaining the pH condition.

Temperature was dependent on the metabolic activity, growth, and respiration of worms. A good temperature for the type of *E. eugeniae* is 21 °C-29 °C. However, the worm is still able to survive up to 35°C. If it exceeds that temperature, the worm will die and the microorganism cannot metabolize properly (Anwar, 2013). Then pre-composting was done in order to reduce and stabilize the temperature of raw materials. The temperature of the raw material during pre-composting was decreased by ± 8 °C. Initially, all materials have a temperature of 37 °C-40 °C. Then, it decreased with increasing time until the 10th day. The temperature did not reach the thermophilic phase because it was stirred during the pre-composting. Stirring waste can reduce high temperature (Tcobanoglous *et al.,* 1993).

Temperature analysis on vermicomposting shows a fluctuative trends until the final day. The increase occurred in several reactors on the 30th day and a decrease in almost all reactors after the 40th day. Then, the temperature tends to be stable. The increase in temperature was influenced by the moisture content of the material. The higher the moisture content of the material resulted in higher water consumption by microorganisms, so the moisture content was decreased. It caused the temperature to increase. The decrease was caused by a decrease in the activity of microorganisms because there was less of organic matter (Munroe, 2003). Then on the 40th day to the 60th day the temperature tends to be stable because the energy produced by the metabolism of the worms was too small so it has no impact on the substrate.

The biodegradation process requires C-organic for energy sources and nitrogen for protein synthesis as a building agent for bacterial cells. N-organic will be converted into ammonia and oxidized to nitrite and nitrate. Increasing the concentration of nitrate, causing microorganisms and worms to be more active in carbon degradation. Carbon is used as an energy source for metabolism and respiration. The results of this process produce worm excreta containing N-organic converted into ammonia, and finally the amount of carbon decreases. The C/N ratio is a key parameter of vermicompost quality because of it is related to the nutrient availability.

The initial Organic C/N ratio was fixeddue to the absence of worms at the pre-composting step. Then, during the vermicomposting process, organic C/N tends to decrease. Organic C/N ratio showed the amount of organic material that can be degraded by microorganisms and worms as organic compounds. The organic C/N ratio was strongly influenced by ammonium concentration. Ammonium concentration affects the amount of N-organic as a comparison of C-organic.

Based on the Regulation of the Minister of Agriculture of the Republic of Indonesia No.70/PERMENTAN/SR.140/10/2011, the C/N ratio used as a parameter of the stability of the organic fertilizer is the ratio of organic C/N. It was characterized by a total C/N ratio in the range of 15-25. The total C/N ratio range of 15-25 occured at the SRA reactor on the 40th day. In addition, nitrates was still increased in the SRA reactor on day 50 and 60. So the vermicompost was considered not stable as there might be further degradation process occurred. In order to overcome the low C/N ratio is by adding a bulking agent (Tripathi and Bhardwaj, 2004). The function of adding bulking agent is to maintain the composition of organic material, in this case bulking agent as a buffering agent.

Determination of Vermicompost Quality as Fertilizer

The determination of vermicompost quality was based on the quality standards of organic fertilizers that apply in Indonesia i.e., the Regulation of the Minister of Agriculture No.70/PERMENTAN/

SR.140/10/2011. The parameters that were reviewed in determining the quality of organic fertilizer were moisture content, pH, temperature, C, N, and C/N ratio. Determination of the quality of vermicompost that meets the quality of organic fertilizer can be seen in Table 2.

The results of the analysis of moisture content in the range of 50-70%. This moisture content was maintained in this range so that the substrate conditions remain moist. According to Anwar (2013), humidity is one of the important factors that influence vermicomposting. Worms need moisture in the range of 50-70%.

Based on the above mentioned Regulation, the pH value was in the 4-9 range and the temperature was in the range of 25-30 °C. Then all the compositions in the reactor was met the quality standards of organic fertilizer in terms of these parameters.

C-organic content in the quality standard of organic fertilizer is at least 15%. Then, the composition that qualified was SRA-0 and all SRB reactors. All control reactors qualify these standards. It can be clearly implied that the role and influence of worms was as an effective decomposer. The C-organic content of at least 15% aims to ensure that the content of organic matter in the soil does not decrease rapidly over time due to decomposition.

The results of N-organic content from all reactors with substrate composition ratio and variations in the amount of worms have fulfilled the regulated standard (i.e., > 0.4%).

The quality of vermicompost is determined by the C/N ratio because it is related to nutrient availability. The ratio of C/N that was not met the standards was not recommended for application as organic fertilizer because plants are susceptible to disease, disturbed metabolism, and even death in plants (Munroe, 2003). Based on the standard, the C/N ratio is 15-25. The minimum limit of C/N 15 ratio is expected that nutrients can be more absorbed by plants easily. It is caused by the availability of sufficient nitrogen so as to prevent competition between microorganisms and plants. Plant growth will not be disrupted due to competition for nitrogen consumption. While the maximum limit of C/N 25 is expected that organic fertilizer does not lose N levels in the form of ammonia. So that the C/N ratio is maintained within the 25. The higher the C/N ratio, the lower the N content.

The composition that qualified the C/N ratio of 15-25 was SRB. It has C/N in the range of 15-25 because of higher BSF larvae residues than food waste. BSF larvae residue as a provider of carbon needs in the process of vermicomposting. So, the amount of carbon and nitrogen was proportional during the process. Availability of the amount of carbon over a lot owned by the composition of the SRB, the composition of the SRB was preferable than SRA for vermicomposting. In SRB, the addition of worms that qualified was 10 g/kg substrate (16.62) and 20 g/kg substrate (15.35). Then, in terms of variations in the addition of worms, the lowest C/N ratio was chosen as the best quality, i.e., SRB-20. The C/N ratio that closed to 15 means that the availability of nutrients was sufficient and the content of organic matter was good for plant growth. The C/N ratio that smaller than 15 indicates organic fertilizer with high agronomic value (Verstappen *et al.*, 2017).

The SRB composition with the addition 20 g/kg of worms substrate produced the best quality or-

Table 2. Vermicompost Quality Determination

Reactor	Parameter						Result
	Moist. Cont.	pH	Temp.°C	C-org.	N-org.	C/N ratio	(Q/NQ)
Standard	-	4-9	25-30	> 15%	> 0.4%	15-25	
SRA-0	59.31	7.5	28	20.31	0.956	21.24	Q
SRA-10	61.09	7.4	27	*10.50*	1.076	*9.76*	NQ
SRA-15	61.33	8.0	27	*9.83*	1.051	*9.35*	NQ
SRA-20	62.43	7.7	27	*10.38*	1.141	*9.10*	NQ
SRB-0	59.44	7.5	27	25.53	1.068	23.90	Q
SRB-10	60.52	7.2	26	19.83	1.193	16.62	Q
SRB-15	60.08	7.3	26	15.07	1.226	*12.29*	NQ
SRB-20	59.47	77	26	18.07	1.177	15.35	Q

Note: (*italic*): less / more than the quality standard
Q : Qualify
NQ: Not Qualify

ganic fertilizer. This is related to the lowest ammonium concentration of it. Ammonium is produced from the excretion of worms and microorganisms. Then it should be the lowest ammonium concentration in the composition of SRB-0 because the organisms in the reactor were few. But the results showed that SRB-20 had the lowest ammonium concentration. This happened because the worms produce mucous fluid which could increase the activity of microorganisms that play a role in the conversion of ammonium to nitrite and nitrate (Anwar, 2013). Therefore, the more worms, the amount of mucus produced and ammonium is reduced because it is converted into nitrites and nitrates. According to Tripathi and Bhardwaj (2004), earthworm fragments and organic material are digested through the intestine. In the process of digestion this is assisted by enzymes and produced mucous so that it increases the surface area of microbial activity. Microbes conduct biochemical degradation of organic matter and provide several extracellular enzymes in intestinal worms to aid digestion. Thus,the intestinal mucus of worms and microorganisms has symbiotic mutualism interaction.

Ammonium concentration will affect the amount of N-organic. The lower the ammonium concentration, the N-organic concentration will be. Likewise, since organic N will affect the C/N ratio, the higher the N-organic, the lower C/N ratio will be. In this case, the SRB-20 composition showed the lowest ammonium and N-organic concentration, i.e., 0.023% and 1.177%, respectively.

Degradation Rate and Vermicompost Production

The degradation rate of the substrate was reviewed based on the level of substrate reduction and vermicompost production. The substrate reduction rate was analyzed from the dry weight of the substrate at the beginning and end of composting. Then vermicompost production was analyzed to determine the degree of degradation of the substrate. Fertilizer production was determined based on the results of sieve analysis.

The reduction rate was obtained from the difference between the initial substrate (day 0) and the final substrate (day 60). The reduction rate of the substrate showed the amount of organic compounds that could be degraded during the composting process. The results of the reduction rate can be seen in Figure 1 and 2. Figure 1 shows that substrate degradation (dry weight basis) was observed in all reactors.

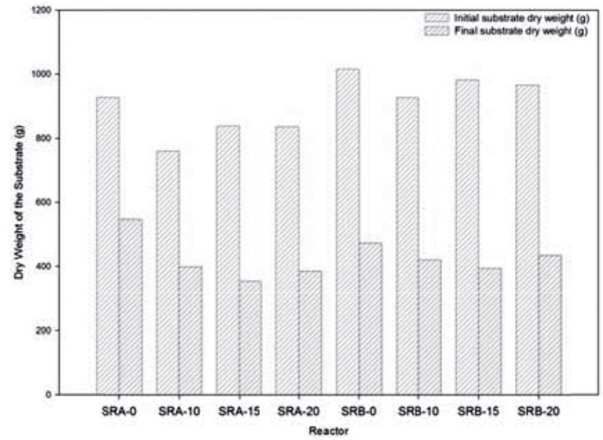

Fig. 1. Dry Weight of the Substrate

Figure 2 shows reduction rate (%) from all reactors. In the composition of SRA the addition of worms gave a reduction of 12%, whereas in the composition of SRB was around 3.1%. It seems that waste degradation by worms during vermicomposting was lower in the case of SRB (with more BSF larvae residue).

However, the average level of substrate reduction was greater in the SRB i.e., 56.5%. The high reduction was influenced by the amount of moisture content and low volatile solid. The highest reduction that was 59.9% in the reactor SRB-15. The addition worms of 15 g/kg substrate led to a slight increase of waste degradation by the worm to do the metabolic activity and respiration.

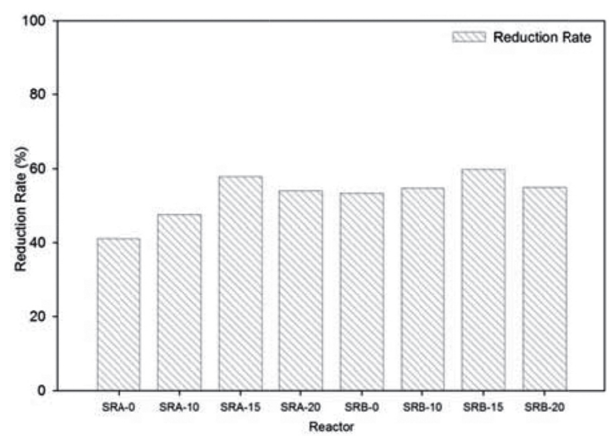

Fig. 2. Reduction rate

Vermicompost production has increased every 15 days as can be seen in Figure 3. The production of vermicompost in the reactor with the addition of worms was higher than in the control reactor. Vermicompost was formed due to the degradation by microorganisms and worms. In the beginning of the composting process, the average of vermicompost was 21.97% of all reactors. The SRB vermicompost production was more than the SRA. Production of vermicompost from the SRA and SRB waste composition was 70.25% and 71.03%, respectively.

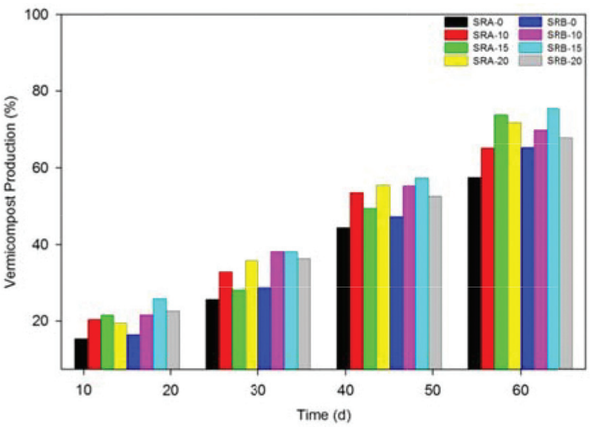

Fig. 3. Vermicompost Production

The low production of vermicompost SRA was influenced by the activity of microorganisms and worms and the higher moisture content. On the early days of composting, microorganisms and worms are adapting to the adjusted conditions so that they have not done much activity. Secondly, the moisture content held by the SRA was higher than in the SRB. The moisture content also affect the sieve analysis. Many of vermicompost are attached to the screen and close the sieve hole so that a few escape the sieve.

The vermicompost production related to the rate of substrate reduction. The average production of vermicompost was mostly produced from SRB composition. The highest vermicompost production was 75.47% obtained in the SRB-15 reactor.

Conclusion

The SRB waste composition (i.e., ratio of food waste: BSF larvae residue was 1:2) showed higher waste reduction although the contribution of worms in the degradation process was smaller than in the case of SRA. The average reduction was 56.5% and the vermicompost produced was 71.03%. Based on the composition, the highest reduction was 59.9%, produced by the addition of 15 g *E.eugeniae*/kg substrate. Vermicompost production obtained in the SRB-15 was 75.47%. Based on the regulated standard of vermicompost, SRB had better quality than SRA for organic fertilizer. The best quality of vermicompost was produced by the addition of 20 g *E. eugeniae*/kg substrate. The results obtained were pH 7.7, temperature 26ºC, moisture content 59.47%, C-organic 18.07%, C-total 23.34%, N-organic 1.17%, N-total 1.53%, organic C/N 15.35, and total C/N 15.18.

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