

Co-composting of Dried Sludge Types and Food Waste Using Compost Barrel

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Co-composting of dried sludge types and food waste using compost barrel

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Abstract: *Biodegradable waste is the most significant percentage in the overall waste generation, which has become a challenging environmental problem, as does sewage sludge, which requires further treatment before agricultural use. This study aimed to evaluate the supplementing effect of the two types of dry sludge on the composting of food waste using a composting barrel. Results showed the significance ($p < 0.05$) of adding either natural dried sludge (NDS) or polymer-infused dried sludge (PIDS) in achieving thermophilic condition needed for pathogen inactivation. Moreover, the addition of PIDS met the standard criteria for soil conditioners. The potentially toxic elements (PTEs) like Pb, Zn, and Cu, falls into threshold limits, while other elements, such as Ca, S, K, and Mn, reached the standard range for plant nutrients, which can be essential for ideal plant growth. The morphological aid of scanning electron microscopy (SEM) confirmed by X-ray fluorescence (XRF) analysis provided alternative evidence of heavy metal reduction due to greater charge build-up in the specimen.*

Keywords: food waste; dried sludge; co-composting; macro-micro elements; potentially toxic elements; plant nutrients

1. INTRODUCTION

The treatment and management of biowaste is still a prevalent issue, especially for developing countries. Modern treatment methods such as microbial fuel cell with food waste solution [1] and anaerobic digestion [2] are few examples. Nonetheless, composting is a cost-effective method for recycling biowaste which improves soil characteristics and promote crop growth [3]. An upland city in the Philippines has biodegradable waste as the largest portion (41.67%) of its municipal solid waste, which could harm the environment if not treated well [4]. On the other hand, little information is available about the elemental composition of sewage-dried sludge also known as biosolids, which is generated from wastewater treatment plants. Baguio city is a highland metropolitan area in the Philippines, is continuously battling its garbage disposal, which is aggravated by a lack of wastewater facilities. The city has only one wastewater treatment plant, which produces two types of dried sewage sludge: naturally dried sludge (NDS) and polymer-infused dried sludge (PIDS). NDS is the product of the old activated sludge treatment process and is typically dried under normal ambient conditions for approximately three to four months. At the same time, PIDS comes from the newly introduced technology known as a volute dewatering press, wherein sludge is fed into a rapid mixing tank with an infusion of polymer flocculants that speeds up the drying time by approximately 3 to 5 days. The problem is that these dry sludges contains heavy metals and pathogens, which could be one of the main reasons why it is not recommended for agricultural purposes [5]. This could be an additional waste that is transported to its nearest available sanitary landfill, especially when no private entity will haul for various purposes such as soil amendment.

According to the Grgas et al. [6], composting is a biological treatment process for ensuring the safe application of sewage sludge in agriculture. Previous

studies have shown that co-composting biowaste and dried sludge could significantly reduce the extractability and exchangeability of heavy metals [7, 8]. Moreover, a recent study concluded that co-composting sewage sludge resulted in up to 90% reduction of pharmaceutical content [9]. Despite the numerous studies conducted on co-composting sludge and its complexity, the effects of cost-effective composting methods such as compost barrels on macro-micro elements and other composting parameters need further investigation, as suggested by Guzman et al. [5] and Geng et al. [10]. Additionally, no studies have been conducted in the locale using these two types of sludge in biowaste composting. Hence, this study aimed to assess the two types of dried sludge on the composting of food waste. With the burgeoning uncontrolled accumulation of garbage, which has become a worldwide phenomenon, this research study hopes to offer practical alternative mechanisms for managing dried sludge and biowaste byproducts.

2. METHODS

2.1 Material Preparation

Biodegradable waste was collected from the Men's Dormitory of Saint Louis University (Baguio City, Philippines). A waste characterization study (WACS) was conducted to determine the total amount of waste generated per day, wherein waste was collected for seven consecutive days from the five-story building. Bags and containers tagged with a specific type of waste (e.g., biodegradable, recyclable, or residual waste) were provided on each floor to collect various waste and weighed accordingly. Sawdust was obtained at the university's carpentry shop and was used as a carbon-rich material. The two types of sewage sludge: NDS and PIDS were collected at the only wastewater treatment plant in the city.

2.2 Morphological and Elemental Characterization Analysis

Scanning electron microscopy (SEM) was used to characterize the substrate morphology, while the heavy metal concentration and elemental composition was detected through X-ray fluorescence (XRF). SEM micrographs were obtained at magnifications of 500x and 100x (JSM-6010LV, JEOL, Japan) [11]. The 3D image in Figure 9 was captured using Gwyddion software. The XRF Vanta M Series was used to determine the elemental composition of the final compost. These techniques are nondestructive, cost effective, and time saving. Moreover, they can estimate the metal concentration present in the sample, and the results are consistent with those of atomic absorption spectroscopy (AAS)[12, 13]. Figure 1 shows a morphological image of the dried sewage sludge taken by scanning electron microscopy (SEM) at x500 and x100 magnification, respectively.

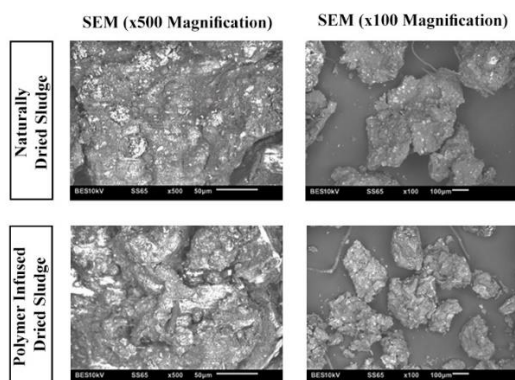


Fig. 1. SEM images of the two types of dried sludge

2.3 Experimental Set-up

Three 30-gallon recycled composting barrels were constructed, as shown in Figure 2. There are holes, 0.8 cm in diameter that were drilled on both sides, and the bottom part for leachate outlet drainage. A wood frame with rollers is assembled to support the weight and ensure proper turning. Compost Barrel 1, which contains kitchen waste and sawdust at a mixing ratio of 1:2, was used as the control. The content of compost in barrel 2 was similar to that in the control barrel but with the addition of 2 kg of NDS (1:2:2 mixing ratio). Compost Barrel 3 also had the same composition as the control but was supplemented with 2 kg of PIDS (1:2:2 mixing ratio). All three barrels had an initial carbon to nitrogen (C/N) ratio of 30:1. The three barrels were turned five times daily to ensure proper and sufficient aeration [14].



Fig. 2. The three composting barrels (Compost Barrel 1-left, Compost Barrel 2-middle, and Compost Barrel 3-right)

2.4 Data Collection and Physico-Chemical Analysis

Daily temperature measurement was done by inserting the standard thermometer device at three different points inside the compost for at least 5 minutes [15]. The daily pH was measured using a pH meter, where one hundred milliliters of distilled water was then used to dissolve a 10-gram sample of compost in a beaker. The weekly moisture content of the compost was measured by drying the samples at 110°C for 24 hours in an oven to ensure that all the water was removed [16]. The yield of the compost was analyzed using the following methods: total nitrogen was measured by Kjeldahl method, total phosphorous was determined through Vanadomolybdate method, total potassium was analyzed by Flame atomic emission spectroscopy, and total organic matter was measured by gravimetric method. For the statistical data analysis, real stat 2010 add-in was installed in Microsoft Excel for the determination of the p-value.

3.RESULTS AND DISCUSSION

3.1 Waste generation from the dormitory

Figure 3 showed that biodegradable waste accounts for eighty percent (80%) of the total waste generated, which is consistent with available literatures, stating that biowaste is the largest portion of the total solid waste. The biowastes are collected mainly from kitchen and dining areas. Plastic bags, Styrofoam, and polystyrene foams constitute thirteen percent (13%) of the collected waste while the remaining 7% is recyclable waste composed of plastic bottles, glass bottles, used papers, and metal.

Percentage Composition of Generated Waste

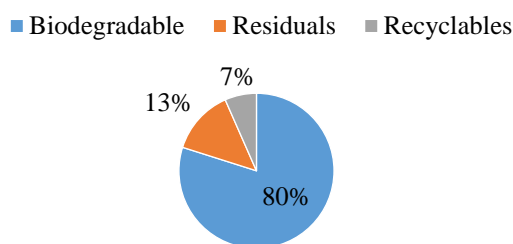


Fig. 3. Percentage composition of waste.

3.2 Effect of NDS and PIDS on the composting process

Figure 4 shows the temperature variation of the three composting barrels, which reflects the composting process stages: the mesophilic, thermophilic, and cooling stages. Temperature variation is essential in ensuring the destruction of pathogens and enhancing an efficient composting process [17]. The start of the degradation showed an increase of temperature because of the degradation of an adequate biowaste substrate that initiated microorganisms' activity. The results showed that compost barrels 1, 2, and 3 increases temperature reaching the thermophilic stage and registering the highest temperatures of 45°C, 57°C, and 62°C, respectively. The optimum temperature range for thermophilic phase is 45-65°C [18]. Additionally, a temperature of 55 to 60°C is favorable for the pasteurization of pathogens [19–21], while exceeding 70°C can inhibit the need for good bacteria and can increase the risk of ignition during the composting process [17, 19]. With these, the revealed that the addition of NDS and PIDS have led to a significant

increase in temperature (with p values of 0.043 and 0.041, respectively) from the 2nd to 6th day of composting. These temperature results also met the above criteria for the destruction of pathogens. After the thermophilic phase, all barrels exhibited a gradual decrease in temperature until they returned to ambient temperature due to minimal microbial activity, as seen in the studies of Meena et al. and Medina et al. [20, 22]. The cooling stage took 14 days from the 7th to 21st day for the three barrels to return to ambient temperature. The composting duration ranged from 20 to 21 days, after which fresh samples were harvested from the composting barrel to be air-dried for further curing and maturation.

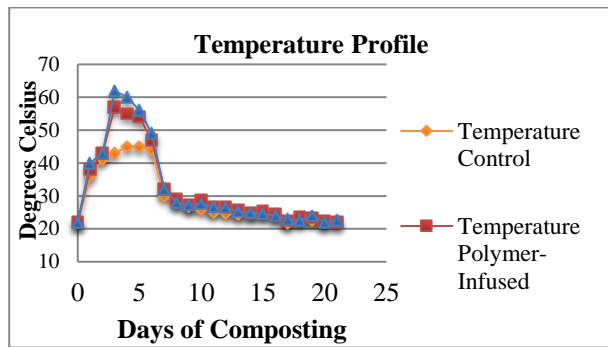


Fig. 4. Temperature variation during composting.

In terms of the pH variations, the results conform to the aerobic decay process range, as shown in Figure 5. All barrels had a measured pH of 5 lower than the standard range during the initial decomposition stage due to the presence of organic acid, similar to the results of [23]. After one week of degradation, the pH inside the three compost barrels increased to approximately six due to the biodegradation of lactic and acetic acids, which was caused by the transition from the mesophilic to the thermophilic stage, as supported by [24, 25]. pH is a good indicator of the extent of decomposition. The usual pH range is approximately 5.5 to 8 for the best operation of compost microorganisms [22]. Hence, the pH of the three barrels conformed to the standard operating procedure for composting.

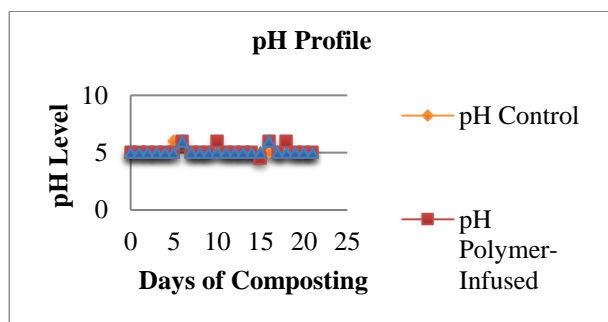


Fig. 5. pH variation during composting.

The optimum range of moisture in the composting process ranges from 40-60% [21], with 50% as the most ideal [26]. Figure 6 shows the reduction of moisture content for composts 1, 2, and 3, which conformed to the optimum moisture range. Compared with those in the compost barrels 2 and 3, the moisture content in the compost barrel 1 (control) was greater due to less dissipation of moisture linked to lower temperature levels. Compost barrel 2 had the lowest moisture after one week because it yielded a higher temperature, causing greater

moisture loss. Lunag et al. [14] reported that turning the barrels increases temperature and rapidly reduces the moisture content. The addition of NDS and PIDS caused the increased the temperature, resulting in a lower moisture than that of the control Barrel 1, with only the addition of PIDS reached the ideal level of 50% moisture after one week of composting. Moreover, a moisture of less than 40% will slow the degradation process [27] and greater than 65% will lead to anaerobic and acidic conditions, causing leachate and foul odor [22]. The study showed that there was no leachate or foul odor during the duration of the whole process since all three barrels yielded optimum pH and moisture ranges.

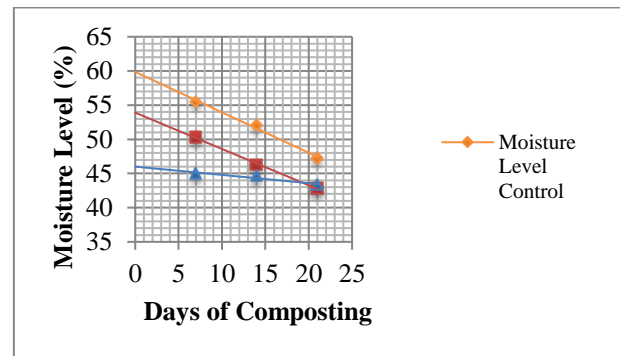


Fig. 6. Moisture variation during composting.

3.3 Qualitative SEM analysis of the initial and final stages of composting

Comparisons of the initial and final SEM microscopic morphologies of compost 1 (control), compost 2 (w/NDS), and compost 3 (w/PIDS) are shown in Figures 7, 8, and 9, respectively. SEM analysis requires the sample to be conductive to avoid specimen charge build-up, which might cause unexpected phenomena such as image deformation and abnormal contrast [11, 28]. Nonconductive specimens must have metallic coatings such as gold, platinum, and carbon to improve the surface conductivity, which increases image quality [28, 29]. The application of a gold coating to overcome charging is expensive, so an alternative method was used, such as decreasing the voltage to 10 kV and reducing the magnification to 100×.

Samples 1, 2, and 3 were nonconducting; hence, the presence of charge build-up (light) is evident at a magnification of 500× for the initial stage and the final stage of composting. Conversely, there was no charge build-up at lower magnification x100 for the control and NDS treatments, except for the final stage of compost 3 (w/PIDS), as shown in Figure 9. The researcher took advantage of charge build-up areas at 500× magnification and compared the images of the initial and final stages of composting. The results showed that all three samples had greater charge build-up areas at the final composting stage than at the initial composting stage because of the continuous degradation resulting in the reduction of metallic elements present in the barrels, which can be seen in the XRF analysis results shown in Table 1. The effects of the addition of two types of dried sludge on the final stages of compost samples 2 and 3 resulted in a greater charge build-up area than that of compost sample 1 (control).

Moreover, the compost from barrels 2 and 3 became more nonconducting than the control, as evidenced by the amount of their % organic matter (OM) (see Table 1 and Table 2). The addition of NDS and PIDS makes the sample more nonconducting, which leads to more charged built-up areas, as reinforced by a better degradation process during the thermophilic stage. The charged built-up areas result from abnormal contrast, which tends to flatten the sample surface and distort the image. Figure 10 shows that a larger charged size, which flattens the surface of composts 2 and 3, supports the claim of charged built-up regions in Figures 7, 8, and 9. Hence, the higher the metallic content of the sample is, the more conductive it is. In contrast, the lower the metallic content is, the more nonconductive the material is. The NDS and PIDS have solid stone-like features in the initial stages in terms of structure, as shown in Figure 1, but in the final stages, the three barrels have similar stretched-like structures. These results have the same and consistent findings with other authors who used SEM [30, 31]

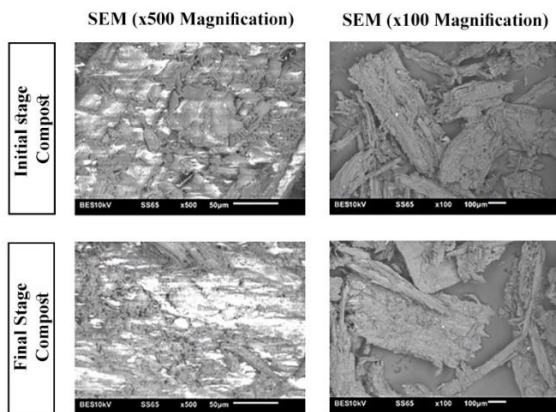


Fig. 7. SEM micrograph of Compost 1 (Control).

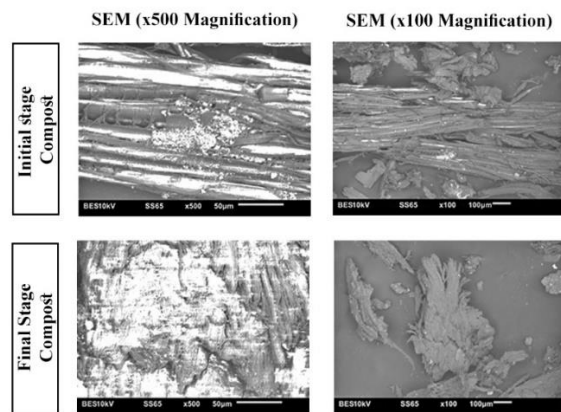


Fig. 8. SEM micrograph of Compost 2 (w/NDS).

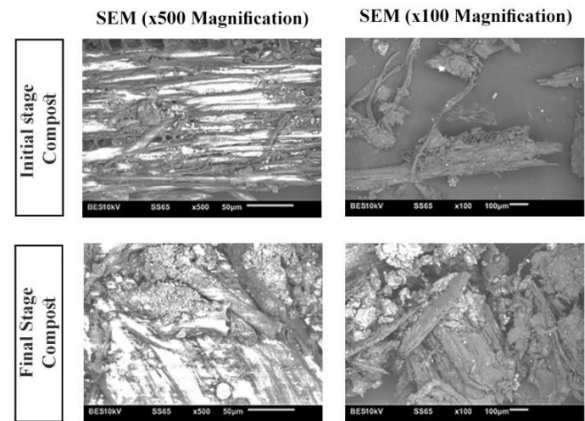


Fig. 9. SEM micrograph of Compost 3 (w/PIDS).

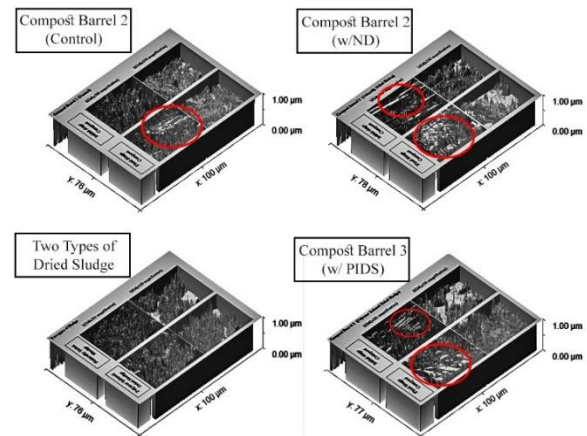


Fig. 10. Charge built-up areas at 500x magnification.

3.4 Quantitative XRF analysis of the final compost

Fig. 11. below presents the detected elements that are present in the final compost with the use of X-ray fluorescence (XRF). The elements are classified as potentially toxic elements (PTEs), macronutrients, micronutrients, and other elements. The concentrations of potentially toxic elements, also known as trace elements, or heavy metals, such as As, Cr, Cd, Pb, Zn, Ni, and Cu, were detected. This result is supported by published papers [8, 32, 33]. The concentrations of Pb, Zn, Ni and Cu were below the threshold limit, except for Cd, which did not meet the standard limit instead showed a stagnant concentration, as shown in [34]. This is because the pH was steady at approximately 4.5 to 6 and according to Hanc et al. [35], which was later confirmed by Boniecki et al. [36], increasing pH appears to be a fundamental cause of the observed decreases in available cadmium throughout the composting process. Generally, for heavy metals such as Cd, none have been identified to be associated with their biological properties [37]. Compared with the control treatment, the addition of NDS and PIDS significantly increased the Zn and Cu concentrations, which is found to be most influential element [38]. Although Zn and Cu are essential elements for plant growth, they both exceeded the acceptable range for optimum crop growth. Nevertheless, they are below the limit for possible phytotoxicity [39].

The micro-elements that are present in the compost in large quantities are Ca, Mg, S, P, K, and LE (the light element is abundant from air and water), which are

essential mineral nutrients that assist in plant growth and reproduction [40]. The concentrations of Ca, S, P, and Fe significantly decreased due to the degradation and dilution effects mentioned by Bertocini et al. [41]. The results showed that the Mg and K levels increased, which was also observed in Moretti et al. [32], except that the Mg concentration remained the same in the Moretti study. The addition of sludge met the nutrient range needed for optimum crop growth for Mn, while the concentrations of Mg, Zn, Cu, Fe, and Mo exceeded the adequate range.

SEM analysis of compost provides morphological surface image analysis while XRF detects the elemental composition of the yield compost. Combining SEM and XRF analysis showed a complimentary and comprehensive understanding to the compost that undergoes aerobic degradation process [13, 42].

Fig. 11. Elemental Characterization of Compost Output

*Elements Classification	Compost-Final product after 30 days			PTEs	Significant Differences between barrels:		
	Compost Sample				Standard	1&2	1&3
	1(Control)	2(w/NDS)	3(w/PIDS)	Threshold Limit	P value<0.05	P value<0.05	P value<0.05
PTE (Potentially Toxic Element)							
As	nd	nd	nd	20	—	—	—
Cr	nd	nd	nd	150	—	—	—
Cd	17.33***	25.5***	18.25***	5	0.547309	0.343434	0.547309
Pb	21.67	20	15.75	50	0.753316	0.966046	0.547853
(toxic if exceeded)							
Zn	16.5	201	263	500	0.00015**	0.00728**	0.20135
Ni	nd	nd	nd	60	—	—	—
Cu	nd	29	31	150	0.003646**	0.014878**	0.788495
Macro-Nutrients				Nutrient Sufficient Range			
Ca	2973.5***	8050***	7705***	2000-10000	0.001273**	0.000694**	0.705946
Mg	8800***	11300***	10050***	1500-5000	0.867172	0.469208	0.607792
S	825.5	2196.5***	2370.5***	1500-4000	0.033773**	0.016066**	0.767821
P	980.5	1702.5	1735	2600-5000	0.009225**	0.000603**	0.865068
K	3371.25	2814.75**	2769.75****	1500-3000	0.499498	0.435004	0.944267
LE(H, Li, Be, B, C, N, O, F, Na)	986375***	970450***	969625****	>95000	0.009448**	0.031806**	0.878204
Micro-Nutrients				Nutrient Sufficient Range			
Zn	16.5***	201***	263***	15 - 70	0.00015**	0.00728**	0.20135
Cu	nd	29***	31***	2.5 - 25	0.003646**	0.014878**	0.788495
Fe	244***	4760***	3135***	20 - 250	0.003272**	0.00907**	0.482825
Mn	nd	44.7***	48.75***	15 - 100	0.086012	0.019797**	0.405624
B	nd	nd	nd	5 to 25	—	—	—
Cl	nd	nd	nd	—	—	—	—
Mo	8.8***	16.3***	9.25***	.03 - 5	0.166119	0.721587	0.188393
Ni	nd	nd	nd	—	—	—	—
Co	nd	nd	nd	—	—	—	—
Notes:							
Results expressed as the mean ±SD.							
* Values are in mg/kg							
Nd: Not Detected. Levels are below the detection limit.							
** With significance(p<0.05)							
LE (Light Elements)							
*** Exceeded standard limit/range							
PTE's (As, Cr, Cd, Pb) limit-(Bureau of Product Standards, 2012)							
PTE's (Zn, Ni, Cu) limit - Austrian Class A standard (Hogg et al., 2002)							
Nutrients sufficient range- (McKenzie, 1998)							
**** Sufficient for plant nutrient							

3.5 Yield Compost Quality

Table 1 presents the total Nitrogen, Phosphorous, Potassium (NPK), total organic carbon (OC), and total organic matter (OM). All three composts were in accordance with the standard for soil conditioners or compost concerning percent OM, which indicate maturity and stability as supported by Ameen et al.

(2016). The results from Barrel 1 and 2 have lower NPK percentage compared to barrel 3. Only the addition of PIDS (barrel 3) meets the requirements for a soil conditioner stated by the Philippine National Standard for Organic Materials. Hence, this study recommends PIDS should be used as a bulking agent in composting biodegradable wastes.

Table 1. Physio-chemical analysis of the final compost

Parameters	Compost		
	Barrel 1 (Control)	Barrel 2 (w/NDS)	Barrel 3 (w/PIDS)
	Mean	Mean	Mean
Total Nitrogen(N),%	1.19	0.69	1.99
Total Phosphorous (P2O5), %	0.13	0.43	0.49
Total Potassium (K2O),%	0.23	0.20	0.22
Organic Carbon (OC),%	15.44	15.55	15.58
Organic Matter(OM),%	26.56	26.75	26.92
Total NPK, %	1.55	1.32	2.70

Notes: Standard values based on Philippine National Standard (PNS/BAFS 183:2016)-[43]
Total NPK (2.5 to 5%)
Organic matter > 20%

4.CONCLUSION

This study demonstrated the effect of co-composting two types of dewatered dried sewage sludge in biodegradable waste in the composting process on the end products of the process. Composting process parameters such as temperature, pH, and moisture content showed that the addition of dried sewage sludge enhanced the degradation process, especially in terms of achieving optimum pathogen elimination. After 30 days, the concentrations of potentially toxic elements (PTEs), such as As, Cr, Pb, Zn, Ni, and Cu, present in the compost output were lower than the standard parameters, except for Cd. The qualitative analysis of scanning electron microscopy (SEM) confirmed by the XRF quantitative results showed that the greater charge build-up areas were due to the improved composting process and significant reduction in metallic elements. The addition of polymer-infused dried sludge achieved the standard for soil conditioners while naturally dried sludge met the acceptable range for plant nutrition for Ca, S, K, and Mn. Moreover, the contents of Mg, Zn, Cu, Fe, and Mo exceeded the nutrient range of the plants. The importance of knowing the amount of macro, micronutrients, and other elements is an exciting and challenging starting

point for more research endeavors to tap into the potential beneficial effects of compost products in agriculture. This study recommends further analysis of the fate of macro and microelements used to maintain soil fertility.

5. ACKNOWLEDGEMENT

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