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The potential of Plant Residues and Industrial Sewage Sludge as Organic Fertilizers, and their Effect on Soil pH and Moisture of Acid Sulfate Soil

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ABSTRACT
Intensive farming is expanding rapidly, making organic fertilizer development vital to achieve sustainable agriculture. Thus, the purpose of this study is to understand the potential of decaying plants and industrial sewage sludge as organic soil amendments. This study was conducted from December 2019 to May 2021 in Ho Chi Minh City. Decaying plants and sewage sludge from wastewater treatment enterprises were collected. Manure and probiotics were also added according to the semi-fermentation method to develop different composting formulas. The quality of fertilizer was evaluated based on national standards. The last step was to observe the compost applications potential in improving acidic soil moisture and soil pH. The study found that the composts containing 70% plant waste + 20% cow manure + 10% dried sludge + microbial (0.25 liters/1m3) met the nutrient criteria of the Vietnamese Government on fertilizer management as follows: pH 6.7, total organic matter 31.08%; total N 2.37%; 5.67% P2O5, 8.97% K2O; humic acid 2.59%; fulvic acid 1.24%; and C:N ratio 11.03. After applying the compost fertilizer (10,000 kg/ha), a significant improvement in acidic sulfate soil pH and moisture-holding capacity was recorded compared to the conventional methods of farming.

Keywords: decayed plants, sewage sludge, organic fertilizer, acidic sulfate soil

INTRODUCTION
Conventional agriculture that frequently uses chemical fertilizers and pesticides has been known to cause hazardous residues in agricultural products, jeopardizing both environmental and human health. Thanks to the benefits of organic farming, innovative and environmentally friendly methods of producing organic fertilizers are gradually being developed. In 2018, the Prime Minister of Vietnam stated that “Fertilizers and soil amendments must be produced from materials and methods that conform to organic agricultural standards”. Therefore, Vietnam is focused on identifying organic fertilizer sources that meet the requirements of state regulations.

To achieve sustainable agriculture, diverse types of organic fertilizers from different sources of biological waste should be utilized. Based on the current agricultural land area in Vietnam, about 10 million hectares of cultivated land, and about 200 million tons of organic fertilizer are needed each year. However, the total organic fertilizer from domestic production and importation is only about 3 million tons per year (MARD, 2018).

Organic raw materials are needed to produce organic fertilizers. Sources of materials include by-products from farming, animal husbandry, food production and manufacturing. Pöykiö *et al.* (2019) analyzed that the concentrations of nutrients (P, Ca, Na, K, Mg, and Zn) in Finnish sludge were relatively high. This supports the production of fertilizer from sludge. Faozi *et al*. (2018) have proved that compost from banana stem can be used as a soil conditioner as well as a source of nutrients to increase the growth and yield of soybean crops. Banana stem is a potential material of compost because it is rich in minerals and organic materials: C (21.85%), N (0.28%), P (0.98%), K (3.30%), and C: N (78). Applying compost from banana stem at a dose of 15 tons/ha for *Artemisia vulgris* provides an average yield of 18 tons per ha, while increasing soil pH from 5.26 to 6.77 (Quyen and Bao, 2021). Thus, organic fertilizer can to improve the physical and chemical properties of soil.

This study was conducted to determine the feasibility of producing and using organic fertilizers from plant residues and industrial sewage sludge through the decomposition mechanism of microorganisms. The study also evaluates the effect of organic fertilizers on soil pH and soil moisture.

MATERIALS AND METHODS

Sampling

The study was carried out from December 2019 to May 2021 at the laboratory of the Faculty of Environment and Biotechnology, Van Lang University, and Sen Viet Farm. The materials in this research were collected from different areas of Ho Chi Minh City, Vietnam. The sewage sludge was gained from municipal wastewater treatment plants. The sludge was analyzed and determined to be free of hazardous substances (pH=8.8; Pb = 0.67 mg/kg; Cd = 0.075 mg/kg; As = 0.018 mg/kg), which was dried at 105ºC for 8 hours. Banana stems and fruits, and vegetable remains were collected from markets in Ho Chi Minh City. They were chopped and dried to have a moisture content of 20%. Cow manure purchased from free-range cow farms contained total organic matter (68.6%), nitrogen (1.57%), P_2O_5 (2.29%), and K_2O (1.08%). Microbial (*Bacillus subtilis, Streptomyces* spp) for agriculture usage were provided by the Southern Research Centre for Soil, Fertilizer and Environment, Institute of Soil Agro-chemistry. Acidic soil was taken from the basil cultivation area of Senviet Farm (pH-KCl 3.2; OC=3.69%; N total=0.177%; P_2O_5 total=107mg/kg; K_2O_5 total = 813 mg/kg).

Compost treatments preparation

The fertilizer formulas were established as shown in Table 1. After the fermentation process, the materials were kept in semi-aerobic incubation conditions at room temperature. The moisture content was periodically checked and maintained at 50%. The compost was mixed every 7 days.

Table 1. The compost compositions

Formula	Decayed plants	Cow manure	Dried sewage sludge	Microbial
F1	80%	20%	0%	0.25 liters/1m^3 mixture
F2	75%	20%	5%	0.25 liters/1m^3 mixture
F3	70%	20%	10%	0.25 liters/1m^3 mixture
F4	65%	20%	15%	0.25 liters/1m^3 mixture
F5	60%	20%	20%	0.25 liters/1m^3 mixture

The indicators of fertilizer quality according to Vietnam's National technical regulation include pH_{KCl}, OM (%); N_{total} (%); P_2O_5; K_2O; fulvic acid; humic acid; lead (Pb); cadmium (Cd); arsenic (As); mercury (Hg); presumptive *E. coli* and *Salmonella* spp. The most optimal formula was selected to be used in the experiment of improving acidic soil.

Effect of organic compost on soil moisture and soil pH

The experiment was conducted in pots containing 5 kg of soil. The amount of fertilizer for each pot was calculated using the formula: weight (Db) x depth of an acidic soil (20cm) = soil mass of 1 ha/20cm. Each treatment was replicated 3 times. After fertilizing, the fertilizer was mixed evenly into the soil and 3.75 liters of water was added. The pots for the trail were arranged outdoors but protected from rainwater. The pots have a depth of 30cm and the soil contained in them with a thickness of 20cm. Table 2 shows the composting dosage of organic compost used.

Table 2. Composting dosage for different treatments

Treatment	Dosage
T1 (control)	Normal farmer's process: lime: 10,000 kg/ha + phosphorus 600 kg/ha
T2	Composting 8000 kg/ha
T3	Composting 10,000 kg/ha
T4	Composting 12,000 kg/ha
T5	Composting 14,000 kg/ha

National standard TCVN 6651:2000 was applied to determine the moisture saturation: A metal tube (D = 100cm, H = 10cm) was used to collect the soil samples. In the laboratory, the soil mass from the tube was gently removed and weighed from the tube to prevent the soil from breaking and losing its texture, then weigh the soil mass and proceed to put the soil into a plastic tube with D = 100 cm and H = 20 cm, one end is sealed by a thin cloth, hang the plastic tube on the holder. Use the measuring glass to measure the correct amount of water, pour slowly into the plastic tube containing the soil to allow the water to penetrate evenly into the soil, stop for about 5 minutes for the water to penetrate, and pour again when the water is clear. If the surface overflow occurs, stop for 5 minutes for the water to absorb completely and continue pouring until the first drop of water is seen through the thin film covering the bottom, at this time the soil has reached saturated moisture; determine the amount of water poured into the soil (the soil has the maximum moisture capacity). Thereby, determining the amount of water used to saturate the experimental soil is 3.75 liters per 5 kg of soil.

Experimental follow-up:

Determination of soil moisture in experimental treatments: determine soil moisture before the experiment and after 14 days of incubation with manure. Using a moisture meter to determine the moisture content of soil samples for testing and taking soil samples for drying also follows the drying method in an oven. The method is to mix the soil, pick up all the roots. Then take 20g into a cup and dry it at 105^0C, in 8 hours take it out and put it in a desiccator to cool, reweigh the weight, this job is repeated 2 to 3 times when the soil mass is not double. Calculate the complete dried moisture content of the soil (%) (National standards TCVN 5979:2007).

Determination of soil pH was done before and 14 days after composting treatments, done by glass electrode in soil suspension - 1M KCl solution (National standards TCVN 5979:2007). The collected data were analyzed for variance (ANOVA) and the mean values were tested according to LSD (least significant differences) with a level of $p \leq 0.05$ using Stagraphic 15.0 software.

RESULTS AND DISCUSSION

Effect of dried sewage sludge on time and quality of compost

After 5 weeks, the moisture content of compost in the incubator was always maintained at 50%. The changes in pH and incubation temperature are shown in Table 3. When fermentation occurs, the enzymes of microorganisms and fungi consume organic compounds and release organic acids. During the early stages of composting, these acids accumulate and result in a decrease in pH (after 2-3 weeks) (Quyen and Bao, 2021). The change in pH in this study was due to the organic matter in the plant waste being decomposed by enzymes and the influence of sewage sludge. All treatments with decayed plants and dried sludge had increased pH, from 6.5 to 6.7 (higher values received in formula F3, F4, F5). All of these treatments were higher than the control treatment (pH = 6.0). However, there is no significant statistical difference was observed. The above results of pH increase in formula F3, F4, and F5 can be explained due to being supplemented with dried sludge (the initial pH of dried sludge is 8.8).

Table 3. Effect of the dried sludge on the pH of the compost

Formula	Composting duration				
	1 weeks	**2 weeks**	**3 weeks**	**4 weeks**	**5 weeks**
F1 (control)	6.0	5.5	5.6	6.0	6.0
F2	6.5	5.6	5.9	6.0	6.5
F3	6.8	5.6	6.0	6.5	6.7
F4	7.0	5.6	6.0	6.7	6.7
F5	7.0	5.6	6.4	6.7	6.7
CV, %	0.65	1.23	3.67	1.86	3.33
α	0.676 (> 0.05)	0.868 (> 0.05)	0.001 (< 0.05)	0,543 (> 0,05)	0,623 (> 0,05)

Table 4. Effect of dried sludge content on compost mass temperature

Formula	Composting duration					
	1 weeks	**2 weeks**	**3 weeks**	**4 weeks**	**5 weeks**	**6 weeks**
F1	30.5	43.5	50.5	51.5	43.0	33.5
F2	32.6	52.5	53.5	45.0	33.2	
F3	33.3	52.7	50.7	44.5	30.0	
F4	33.3	53.2	51.5	43.5	29.0	
F5	33.3	53.5	50.5	45.5	28.7	
CV, %	0.55	1.02	5.72	1.53	2.22	
α	0.8859 (> 0.05)	0.4539 (> 0.05)	0.008 (< 0.05)	0.2539 (> 0.05)	0.2356 (> 0.05)	

The formulas with the addition of dried sludge gave the composting time up to 5 weeks. The result had a statistically significant difference compared to the control. This explains the effect of the dried sludge as a buffer, serving both as a habitat and as a source of nutrients for microorganisms. The decay time of compost in this experiment is similar to that of compost from banana stems and biochar in the research of Quyen and Bao (2021). In terms of organoleptic, formulas F3, F4, and F5 gave a well-balanced and smooth compost, with a dark brown color. This can be explained by the impact of the sludge content on the quality of the compost as well as the ripening time of the compost materials.

Analysis results of nutritional indicators in compost after composting

Table 5 shows that pH_{KCl} of organic fertilizer after composting get highest in treatment F4 and lowest in treatment F1, this difference was statistically significant ($p<0.05$). The results were noted, when composting plant wastes supplemented with manure and sewage sludge in the ratio of 60:20:20, improved the pH of organic fertilizer better than the remaining treatments. The drying sludge has an initial pH of 8.8 - This is also an important scientific basis for the research team to include this material as a research object and experimentally has demonstrated its ability to increase the pH of the sludge when added to the composting mixture.

Total organic matter (OM) content: OM content was highest in treatment control (F1), followed by treatment F2, and lowest in treatment F4. The results of the lowest humification rate in treatment F1 (control - without the addition of sludge) show that the role of supporting the decomposition of organic matter in the sludge material is quite clear. The highest rate of humification in the composting process belonged to treatment F4 (mixing 15% of sludge), followed by treatment F3 (10% sludge) and treatment F5 (20% sludge). However, according to Duncan's ranking in statistical analysis, all 3 treatments F3, F4, and F5 did not have a clear difference in this indicator at statistically significant; therefore, in terms of economic efficiency, treatment F3 will be selected in this experiment.

Table 5. Results of analysis of nutrients in compost

Criteria	Results					
	Unit	Formula				
		F1 (control)	**F2**	**F3**	**F4**	**F5**
pHKCl		6.14	6.25	6.7	7.23	7.4
Total nitrogen	%	2,23	2,32	2,37	2,34	2,35
P_2O_5	%	4,27	4,03	5,67	5,73	5,76
K_2O	%	5,11	7,25	8,97	8,99	8,99
Acid humic	%	1,41	2,06	2,59	2,72	2,61
Acid fulvic	%	0,17	0,94	1,24	1,21	1,21
C:N	-	12,34	11,49	11,03	12,54	12,68
E. coli	MPN/g	Not detected	Not detected	Not detected	Not detected	Not detected
***Samonella* spp**	/25g	Not detected	Not detected	Not detected	Not detected	Not detected
Total organic matter	%	34,8	33,91	31,08	30,61	30,76

Total nitrogen was highest in treatment F3 and lowest in treatment F1, this difference was not statistically significant. This shows that the total nitrogen content in organic fertilizer through the composting process does not change significantly. Total potassium content was highest in treatments F4 and F5; lowest in treatment F1, this difference is statistically significant; This could explain the source of potassium added from the sludge material. The highest total phosphorus content in treatments F4 and F5, followed by treatment F3 and lowest in treatment F1, this difference was statistically significant. However, compared with the control, the remaining treatments had the total phosphorus content gradually increase with the mixed biochar content, the biochar control improved the phosphorus content in the manure.

Humic acid content was highest in treatment F4, followed by treatments F3 and F5; lowest in the control treatment. The humic acid content in the post-experiment treatments was improved as compared to before experiment. According to Decree 108/2017/CP of the Government, it is required that bio-organic fertilizers must have a humic acid content greater than 2.5%. Thus, treatments F3, F4, and F5 all had humic acid content that met the standards of bio-organic fertilizers. In terms of economic efficiency, treatment F3 will be selected for production.

Furthermore, fulvic acid content was found to be highest in treatment F3, followed by treatments F4 and F5 with the lowest level of fulvic acid was found in treatments F1 and F2.

C:N ratio, which is one of the important criteria to assess the quality standards of organic fertilizers according to the Government's Decree 108/2017/CP: organic or bio-organic fertilizers must have a C:N ratio of less than 12. According to this regulation, only two treatments F2 and F3 met the requirements of organic fertilizer standards according to TCVN.

The results in Table 5 showed that *E.coli and Samonella spp*. in all treatments were not detected in this experiment.

The results of the analysis of quality indicators of organic fertilizers based on the standards of the Government's Decree 108/2017 ND-CP on fertilizer management showed that treatment F3 met the standards of bio-organic fertilizers. And treatment F3 with the composition: plant waste (70%) + cow manure (20%) + dry sludge (10%) + microbial (0.25 liters/1m^3) will be selected to be included in the efficacy assessment for improving the pH of acid soil in Binh Quoi area, Binh Thanh District, Ho Chi Minh City, Viet Nam (Senviet Farm).

The ability of organic compost to improve soil pH and soil moisture holding capacity

The results in Table 6 shows that organic fertilizer produced from plant residues in combination with manure and sewage sludge had a higher effect on improving the pH of acid soil than the method of using lime and phosphorus of the farm (treatment T1-control); however, there was no statistical difference in the level of additional application of 8000 kg/ha compared with the control. With application from 10,000 kg to 16,000 kg per ha, there was a statistically significant difference ($p<0.05$) in the experimental treatments T3, T4, and T5 compared with the control (T1). Besides, the soil moisture was also improved most clearly in the organic fertilizer treatments. This shows the important role of organic matter in maintaining soil moisture. Treatments T3, T4, and T5 gave the best moisturizing results and was a statistically significant difference compared with NT1 and control ($p<0.05$). This result can be compared with the study of Faozi et al. (2018) when applying compost from banana stem to soybean plants in coastal sandy areas, the authors also noted: compost from banana stem makes increased organic matter content in coastal sandy soils, improved soil water and nutrient storage capacity; at the same time, the level of fertilization from 20 to 60 tons/ha increased the yield of experimental soybean varieties. From the results obtained, treatment T3 with a fertilizer application rate of 10,000 kg/ha was selected as optimal when applied to improve the acid soil of SenViet Farm.

Table 6. Soil pH and moisture holding capacity of acidic soil after treatment

Treatment	pH-KCl	Moisture
T1 (control)	4,97c	10,68c
T2	5,50b	17,50b
T3	6,10a	20,14a
T4	6,12a	20,32a
T5	6,20a	20,27a
$LSD_{0.05}$	0,48	2,13
CV%	3,8	6,6

Note: CV% stands for coefficient of variation, unit is percent

CONCLUSION

The organic fertilizer that made from plant waste (70%) + cow manure (20%) + dry sludge (10%) + microbial (0.25 liters/1m^3) are composted in 5 weeks reach the standards of the Vietnam Government's Decree 108/2017 ND-CP on fertilizer management. Applying organic fertilizer (compost) to acidic soil has had a significant impact on improving soil pH and moisture holding capacity in the soil compared to the method of liming and phosphorus application of the people; the level of additional fertilizer application for acidic soil of Senviet Farm is recommended 10,000 kg per ha. It is necessary to popularize the process of composting agricultural by-products and non-hazardous industrial wastes to make fertilizers for sustainable agricultural production. Also, further studies and evaluation of the compost on the effectiveness for specific plants is needed.

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