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Quality Assessment of the Anaerobic Composting of Dehydrated Sludge from Wastewater Treatment Plant for Agriculture Application

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ABSTRACT

Recycling biodegradable waste is one of the crucial stages in sustainable waste management. Recycling them for agricultural purposes can have a beneficial impact on environmental protection, with more organic amendment and fewer chemical fertilizers contaminating farmland and groundwater. This will support food production of the right nutritional quality, by increasing yields. The aim of this research was the biotechnological valorization of dewatered sludge as compost for agricultural soil fertilization. Compost was applied using the windrow method. The materials used for composting are dewatered sludge from the wastewater treatment plant, mixed with fillers, such as green and brown waste. The obtained results suggest that the finished products from heaps A, B and C show a significant level of stability. These results reinforce the viability of composting products as soil improvers, highlighting their stability, effective disinfection and compliance with environmental standards. This study showed that the compost from dewatered sludge can be a promising alternative to the use of chemical fertilizers in agricultural crops, with a view to improving yields.

Keywords: agricultural, environmental, fertilizers, biotechnological, compost, cultivation.

INTRODUCTION

Faced with ever-increasing waste production and the challenges of waste management, national and European environmental policies are focusing not only on the need to reduce waste production, but also on waste recovery (Crovella et al., 2024). This involves reuse, recovery, recycling or any other action aimed at producing secondary primary materials (Directive 2006/12/EC). In this sense, the reuse of organic matter in agriculture appears to be an interesting way of managing organic and biodegradable waste. However, increasing problems of nitrogen pollution of water resources as well as the emergence of health crises and epizootics have led the agricultural (Nafez et al., 2015) world and legislators to restrict the possibilities of direct spreading of organic waste on agricultural soils (Mejías et al., 2021). Moreover, the spreading and storage of such waste can cause nuisances for local residents, such as odor emissions (Rincón et al., 2019) due to unstabilized organic matter. The socio-political context therefore favors (Lü et al., 2021) composting, the effects of which will lead to the stabilization and hygienization of initial waste as well as the biosynthesis of humic matter necessary for the agronomic quality of soils. Composting (Han et al., 2020) is generally described in two phases. The first, known as "fermentation", mainly develops aerobic reactions for the biological consumption of the most biodegradable organic matter, the addition of which to the soil could block the transfer of nitrogen to plants, and the storage of which under anaerobic (Banegas et al., 2007) conditions could lead to the emission of malodorous molecules. The biological activity and stabilization of organic matter associated with this stage of treatment may nevertheless prove incomplete due to limiting conditions of oxygenation, temperature and substrate humidity, or the disappearance of nutrients required by micro-organisms. The second phase of treatment, known as "maturation" (Kujawa et al., 2020), continues the stabilization of organic matter via biosynthesis reactions of organic macromolecules known as humic matter, the soil conditioning properties of which are sought after. The stability of organic matter is an essential quality criterion for ensuring the safety of compost (Rékási et al., 2019) and its subsequent use. More specifically, stability can be described as the degree of biodegradation beyond which biological activity is significantly slowed down and does not restart, even in the presence of the conditions favorable to this activity. The term maturity is often superimposed on stability. For the composting practitioner, compost maturity defines a product that is ready for use, in terms of the degree of decomposition, the absence of phytotoxicity and its amending qualities. Therefore, maturity encompasses the notion of stability, which the authors prefer to use when referring to the evolution of organic matter (Tremier et al., 2007).

The aim of this research was the biotechnological valorization of dewatered sludge as compost for agricultural soil fertilization.

MATERIALS AND METHODS

Sewage sludge and bulking agents

Dewatered sewage sludge was collected at the wastewater treatment plant, which mainly treats domestic and industrial wastewater. At the same time, plant waste, including materials such as fresh grass, foliage and wood cuttings, was collected from parks and gardens. It should be noted that this waste included both green and brown components, including dry leaves and tree and shrub pruning residues. The application of these vegetation-based materials was seen as a stop-gap measure, not only because of their easy availability in the region, but also because of their economical nature.

Experiment set-up and sample collection

Three composting treatment trials were carried at the agricultural land between May and October 2023: the experiment was conducted during the spring-summer season with different proportions of sludge and bulking agents, green and brown waste for heap A contains 25% dehydrated sludge with 75% bulking agents, and for heap B contains 50% dehydrated sludge and 50% bulking agents, whereas the third heap C contains 75% dehydrated sludge and 25% bulking agents (Table 2). After the treatment, the samples of final composts were dried at room temperature. Testing focused on heavy metals, pH and electrical conductivity EC. This approach was adopted to ensure representative sampling, covering various areas of the heap and ensuring an accurate assessment of the characteristics of the final compost. This approach reinforces the reliability of the results by taking into account the possible variability within each compost heap.

Physicochemical analyses

The organic material was obtained by heating the crucibles in a muffle furnace at the following temperature of 550±25 °C. The difference in mass between the plug before and after the heating process is used to calculate the organic matter. The heavy metal content was measured by mineralizing the samples according to standard procedures after using ICP (Inductively Coupled Plasma Spectrometry). The pH is determined by the pH meter by diluting a portion of the slurry in distilled water, and EC is determined by extracted the sludge sample with water at 20±1 °C, to dissolve the electrolytes. The specific electrical conductivity of the filter extract is measured and the result corrected to a temperature of 25 °C.

Bacterial indicator determination

Biological analyses were carried out to determine pathogenic micro-organisms, in particular total coliforms, faecal coliforms, enterococci, and Escherichia coli, both in the raw material and in the compost obtained during each heap. For bacterial analysis, compost samples were mixed with sterile distilled water, checking that bacteria were evenly distributed throughout the samples. A dilution by a factor of ten was then carried out, and the bacteria enumeration method, conformed to compost evaluation guidelines and current standards.

Table 1 shows the characteristics of sewage sludge, whereas Table 2 shows different proportions of sludge and bulking agents, green and brown waste for heap.

Table 1. The characteristics of sewage sludge

Parameter	Sewage sludge
Organic matter (%DW)	53.24%
Total nitrogen (%DW)	3.06%
C/N	11.44
pH	7.6
Electrical conductivity (mS/cm)	1.52
Cadmium (mg/kg DW)	1.03
Chromium (mg/kg DW)	55.00
Copper (mg/kg DW)	186.91
Nickel (mg/kg DW)	25.40
Lead (mg/kg DW)	62.10
Zinc (mg/kg DW)	2627.15
Enterococci (CFU/100ml)	4.10^4
Total coliforms (CFU/100ml)	5.10^5
Fecal coliforms (CFU/100ml)	35.10^4
Eschrichia coli (CFU/100ml)	15.10^4
Micro-organismes revivifiables (37°C) (CFU/100ml)	16.10^4

RESULTS AND DISCUSSION

Final compost characteristics

The mature compost from heaps A, B and C had a dark appearance, favorable physicochemical characteristics, and adequate organic matter and nutrient content, see Table 3. The addition of fillers and sewage sludge to heaps A, B and C resulted in an improvement in the composition and moisture content of the original product. The carbon/nitrogen ratio is often applied as an indicator of the degradation of compost mixtures, as it can indicate the degree of maturity of compost. Various studies have proposed different ideal ranges for the C/N ratio, from less than 12 to less than 25 (Rihani et al., 2010) for composted materials. On the basis of this recommendation, the final composts in this study had a satisfactory C/N ratio below 17, qualifying them as good quality and suitable for use on agricultural land (Table 3).

Reporting initial and final organic matter content is of particular importance in the context of composting, as it provides insight into the extent of biodegradation (Chazirakis et al., 2011). The initial organic matter of the heaps was higher than that produced at the end of treatment, due to the degradation of organic matter by microbes (Table 3). This reduction in organic matter content can be achieved mainly through mineralization of sludge OM, as the fillers would be made up of a more structured fraction, less susceptible to microbial attack (Topal et al., 2016).

The total decrease in organic matter was 42%, 28% and 13% for heaps A, B and C, respectively. The greatest reduction in organic matter was observed in heap C, i.e. 63% of the initial value, indicating more intense degradation of organic matter in heaps B and C, which are more suitable for composting due to their ability to achieve more extensive degradation of organic matter and maintain an active process in the heap. On the other hand, there is no perfect organic matter content for compost quality, and the results underline the importance of careful monitoring of biodegradation in order to adjust the process accordingly.

Evolution of temperature

Temperature is an important parameter of the thermophilic fermentation phase. The temperature rise time varies from 3 to 8 days for all heaps (Figure 1, 2 and 3). Temperature generally reached is between 55 and 75 °C, an average of 65 °C for the three co-compost heaps. The duration of this thermophilic phase varies from 10 to 67 days.

Aeration

The objective of turning is to mix the materials and maintain aeration, compaction reduces aeration. Daily turning of the heap is done manually throughout the thermophilic phase.

pH and EC

The pH and EC are two essential parameters to measure when considering a material for use as an organic amendment, as they influence the physicochemical and biological reactions taking place in the soil. After the treatment, the pH of heaps achieved

Table 2. Different proportions of sludge and bulking agents, green and brown waste for heap

Heap A	Heap B	Heap C
25% dehydrated sludge with 75% bulking agents	50% dehydrated sludge and 50% bulking agents	75% dehydrated sludge and 25% bulking agents

Table 3. Physicochemical and bacteriological characteristic of the sewage sludge composting process

Parameter	A (25%SS + 75% GW.BW)		B (50 SS + 50% GW.BW)		C (75%SS + 25% GW.BW)		Standard (USEPA)[a]	Standard (WHO)[a]
	First	Final	First	Final	First	Final		
Organic matter (%DW)	54%	42.82%	59%	28%	63%	13.73%	-	-
C/N	20.77	1.528	19.34	1.88	17.45	0.52	15	-
pH	7.30	7.176	7.80	7.236	7.92	6.519	6–8.5	6–9
EC (mS/cm)	7.22	6.78	7.42	5.59	7.81	5.19	<8	-
Enterococci (CFU/100 ml)	4.10^{2}	ND	2.10^{3}	ND	3.10^{4}	3.7	-	-
Total coliforms (CFU/100 ml)	3.10^{2}	ND	2.10^{3}	1.4	3.10^{5}	2.2	-	-
Fecal coliforms (CFU/100 ml)	11.10^{2}	ND	25.10^{3}	ND	32.10^{4}	ND	<1000	<1000
Escherichia coli (CFU/100 ml)	6.10^{2}	ND	10.10^{3}	ND	13.10^{5}	ND	-	-
Micro-organismes revivifiables 37°C (CFU/100 ml)	7.10^{5}	ND	13.10^{6}	1.1	14.10^{7}	ND	-	-
Cadmium (mg/kg DW)	0.61	0.27	0.48	0.44	0.93	0.72	39	15–40
Chromium (mg/kg DW)	20.25	10.98	30.98	20.25	26.66	24.03	1200	-
Copper (mg/kg DW)	65.23	35.02	88.56	54.59	160.27	140.76	1500	1000–1750
Nickel (mg/kg DW)	11.33	5.49	9.92	7.89	14.73	12.36	420	300–400
Lead (mg/kg DW)	16.82	8.24	20.23	15.1	24.88	22.31	300	750–1200
Zinc (mg/kg DW)	1700	180	830	300	640	450	2800	2500-4000

Note: CFU – colony forming unit, DW – dry weigh, ND – no detectetd, USEPA – U.S. Environmental Protection Agency, [a] Standard limits for agricultural use, SS – Sewage sludge; GW, BW – green waste, brown waste.

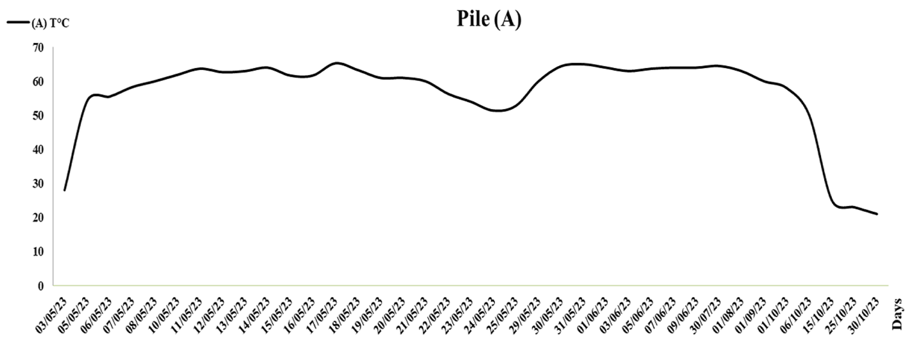

Figure 1. Temperature change during the co-composting in heap A

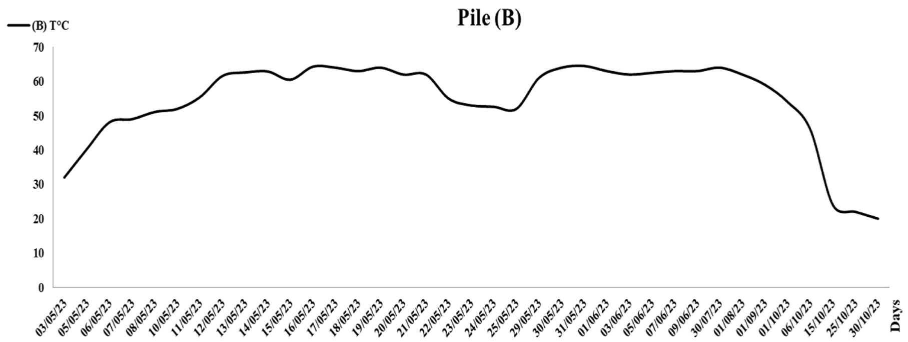

Figure 2. Temperature change during the co-composting in heap B

the values of 7.17, 7.23 and 6.51 for heaps A, B and C, respectively, see Table 3. These pH values for the final product indicate that the compost is of high quality from the point of view of its agricultural use, falling within the recommended range of 6 to 8.5, as suggested in several previous studies (Nikaeen et al., 2015). The EC value of compost, which reflects the concentration of soluble salts in compost, is of

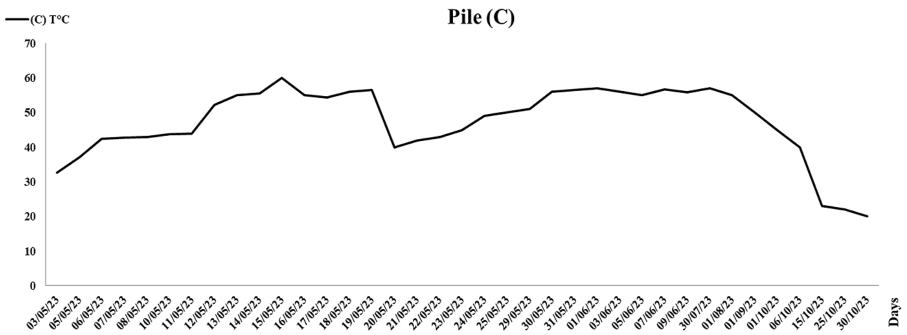

Figure 3. Temperature change during the co-composting in heap C aeration

great importance from an agricultural perspective, as it can influence the germination and growth of plants as well as seeds when applied to soil (AL-Saedi et al., 2019). The initial EC value of the heaps decreased to 6.78, 5.59 and 5.19 mS/cm at the end of the treatment for heaps A, B and C, respectively. The initial content of soluble salts in the mixtures was very high for heaps B and C. As desired, EC decreased throughout the experiment.

Compost sanitization

In this study, coliforms were chosen as indicators of the presence of pathogens. An overriding observation revealed that most coliforms were inactivated after being exposed to a temperature of 55 °C for 1 hour or 60 °C for 15–20 minutes (Silva et al., 2009). A significant reduction in the number of coliforms was noted in all heaps, as shown in Table 3. Salmonella was considered absent in all samples with fecal coliform. The results indicated a significant reduction in the presence of Salmonella in composted sewage sludge. The final composts were sanitized, as the presence of Salmonella was not detected. At the end of composting, the levels of micro-organisms detected lower than those measured before treatment (Ibrahim et al., 2015).

The microbial counts consistently registered higher levels in heaps B and C. However, in all instances, the results align with the guidelines for the safe reuse of sewage sludge (Victor et al., 2008). The destruction of pathogens in composts depends on the temperature rise in the heap, as well as on the frequency with which the heap is turned. The thermophilization phase depends on the structure of the compost raw material and its biodegradability. The thermophilization phase persisted for approximately 2 to 10 weeks, followed by a maturation period lasting at least 3 to 5 weeks. The duration of thermophilization in the various piles exceeded the necessary time frame to meet health standards. Most pathogens were effectively eradicated at the temperatures reached during composting, ensuring that the final products pose no harm for agricultural use.

Phytotoxicity analysis

In order to evaluate the suitability of compost as a crop growth stimulator, a germination test was conducted on cucumber seeds. The objective was to demonstrate the effectiveness of the composting process in eliminating phytotoxic compounds and to evaluate the degree of compost maturity. Germination test results indicated that cucumber seeds germinated favorably when exposed to the compost and soil mixtures. Furthermore, even with the presence of toxic metals at low concentrations, as shown in Table 1, no phytotoxic effects were observed. A germination index GI above 80% suggests the absence of phytotoxicity in mature compost, while a value below 50% indicates a significant degree of phytotoxicity. In this study, the results obtained after the composting treatment demonstrated that all the composts produced had a GI above 80%, indicating that the phytotoxic substances had lost their harmful effect or had been eliminated.

Heavy metals

Metal concentrations in the initial product and final composts A, B and C were evaluated as shown in Table 3. These values are within the standard limits established by USEPA. The conducted study shows that all heavy metals in used sludge have low concentrations, which makes the agricultural application of sewage sludge possible. This compliance with established standards underlines the viability of using composted sewage sludge as an amendment for soil fertilization.

CONCLUSIONS

The study presented that concentrations of heavy metals after composting decrease and meet standards for spreading biosolids on agricultural land. On the other hand, the volume ratio between sludge (75%) and bulking agents (25%) is the most effective, because these mixtures reached the highest level of degradation of organic matter. This reinforces the viability of composting products as soil amendments, highlighting their stability and effectiveness. The composts which present a significant level of stability, have a germination index close to 80, which indicates non-phytotoxicity and have reached maturity after 75 days and have been effectively disinfected due to the high temperatures reached during treatment composting.

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