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Characterization and Utilization of Sludge from a Wastewater Treatment Plant for the Production of Organo-mineral Fertilizer

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ABSTRACT

There is a global crusade for increased agricultural production to alleviate food security challenges due to the expanding world population. The growing population in Nigeria, contributes to increase in the volumes of sewage sludge wastes generated. Sludge are created when wastewater is treated and a large amount of the nutrients accumulate in the sludge. Many studies focus on basic chemical properties but lack deep analysis of micro- and macro-nutrients and heavy metal determination. This research investigated the production of an organo-mineral fertilizer by combining sewage sludge from a wastewater treatment plant with chemical fertilizer. The experimental approach involved collection and processing of sewage sludge, formulation and characterization of organo-mineral fertilizer. The moisture content was 21.5% - 35.7%, pH (4.0-8.2), total organic matter (22.2-50.0%), bulk density (1.0-2.1g/cm3) and water holding capacity (42.0-54.5 g water/g dry sample). The chemical composition shows the presence of K_2O (5.49-10.27%), P_2O_5 (18.27-35.30%) and N (4.99-9.26%). Other elements present are Ca (4.61-33.89 g/kg), Mg (4.61-18.86 g/kg), Zn (0.91-5.0 g/kg) and Fe (8.28-10.97 g/kg). The findings highlight the importance of sludge-based organo-mineral fertilizer in reducing reliance on synthetic fertilizers while providing an effective waste management solution. The results also demonstrate that sludge from water treatment plants is a potential candidate for formulating organo-mineral fertilizer for use in crop production.

Keywords - *Crop production; Formulation; Organo-mineral; Sewage-sludge; wastewater*

I.INTRODUCTION

Continued growth in the global population, along with rising demand for food and energy, is projected to intensify reliance on fertilizer inputs. In recent years, the cost of mineral fertilizers has risen steadily, with particularly acute impacts in developing countries such as Nigeria, where import dependency and high market prices constrain farmer access. Fertilizer production and availability remain heavily dependent on finite natural resources principally nitrogen (N), phosphorus (P), and potassium (K) which are subject to global supply constraints and price volatility. Improving the quality and use of organic-based fertilizer materials offers a promising alternative that can reduce dependency on costly mineral fertilizers while enhancing nutrient cycling and environmental sustainability. Meta-analyses have shown that partial substitution or addition of organic fertilizers can increase crop yields and improve nitrogen and water use efficiency, while reducing nitrogen losses and greenhouse gas emissions compared with exclusive use of mineral fertilizers. These organic inputs also contribute to enhanced soil health, microbial activity, and long-term fertility, providing economic and ecological benefits, especially in low-input agricultural systems (Farooq *et al*. 2024)

Most countries face the challenge of optimal waste reuse, treatment and disposal due to its quantity. Sewage sludge, also known as bio-solids, is an obligatory by-product of wastewater recovered after its proper treatment. It is characterized by high concentrations of solid and organic matter, with a significant presence of pathogens, nutrients, organic and inorganic pollutants. Due to its characteristics, sludge represents both a problem and an opportunity. While sludge can be used as fertilizer, in most cases it must first be stabilized to decrease its potential as a pollutant. The application of biosolids is expected to increase structural nutrients (C, H, and O) and macro-nutrients (N, P, K, Ca, S, and Mg) coupled with balance of micro-nutrients (Zn, Cu, Fe and Mn) and other trace elements. There are several advantages of supplementation of sewage sludge to crop cultivation soils in the form of range of nutrients being added to the soil, decreasing soil acidification, less need for pesticides and fertilizers, preventing soil erosion, increase in the number of beneficial soil organisms, physical, chemical and biological properties of soil get improved (Zafar *et al.* 2021).

Application of sewage sludge for fertilizers production leads to reduction in the amount of waste, ensures recycling of nutrients and organic matter to the soil and improves usage of natural resources, which is in line with sustainable development goals. However, not all the sewage sludge can be used as a component of fertilizers, it depends on its quality. The low content of nutrients in sewage sludge in comparison with mineral fertilizers is one of the timely drawbacks. In view of this fact, it becomes pertinent to note that the addition of alternative sources of phosphorus and potassium in the form of animal manures and biomass as well as mineral fertilizers increases the nutrient content of sewage sludge-based fertilizer (Kominko, *et al*. 2019).

Various technologies have been developed for removing heavy metals from sewage sludge such as chemical extraction, bioleaching, electrokinetic remediation, immobilization techniques, etc.
Sewage sludge (biosolids) has long been explored as a soil amendment because it supplies key nutrients—particularly nitrogen and phosphorus—and organic matter that can improve soil structure and fertility. However, its reuse in agriculture is regulated to mitigate risks from contaminants such as heavy metals, antibiotic resistance genes, pathogens, and other emerging pollutants, and must comply with quality standards set by national and international guidelines before land application such as limits on heavy metals and pathogen reduction to ensure safety (Buta *et al.*, 2021).

Biofertilizer can be produced through composting of sewage sludge with organic co-substrates such as sawdust and plant biomass, and that amendments with microbial agents like Effective Microorganisms can enhance organic matter degradation, humification, and nutrient dynamics during the composting process (Li *et al.*, 2024).

Jastrzebska and Kostrzewska (2019), produced an innovative suspension fertilizer (SSAB) from sewage sludge ash with addition of phosphorus-solubilising *bacteria Bacillus megaterium.* Jia *et al.* (2023) combined use of biochar and microbial agent (including EM) enhanced lignocellulose degradation and compost quality during sewage sludge-plant biomass composting. This study shows that the addition of EM improved the composting process and humic acid formation in organic waste composting. Recent studies have advanced the development of sewage sludge-based organo-mineral fertilizers by integrating organic waste with inorganic nutrient sources to improve nutrient content and agronomic performance. For example, multicomponent organo-mineral fertilizers have been successfully formulated by combining dried sewage sludge with poultry litter ash and mineral fertilizers, yielding products with total nutrient contents exceeding 20% that meet regulatory standards for heavy metal content and are optimized for crops such as maize and sunflower (Adelodun *et al.,* 2021; Kominko *et al.,* 2019).

Additionally, research has demonstrated that organomineral fertilizers derived from sewage sludge can enhance soil fertility and crop production such as increased soil organic carbon and improved chickpea yields when applied in granular or powdered forms (Soares Viana *et al.*, 2024). More recently, amendments of sludge-based organomineral fertilizers with mineral phosphate sources have been shown to improve phosphorus use efficiency in *Urochloa brizantha*, indicating their potential as alternatives to conventional soluble P fertilizers

(Espinoza *et al.,* 2025). The purpose of using sludge in agriculture is partly to utilize nutrients such as phosphorus and nitrogen and partly to utilize organic substances for soil improvement. Therefore, there is need to develop a technology for bio fertilizer production based on wastes, especially on sewage sludge. The agricultural sector needs supply of alternative nutrients and organic matter (humus) to compensate for losses through harvest, grazing, erosion, bush burning etc. In principle, all types of sludge can be spread on farmland if they fulfil the quality requirements (heavy metals and pathogens pre-treatment) laid down by the legislation of the relevant country. Biosolids used for fertilizer production can reduce the costs of sewage sludge disposal and reliance on mineral fertilizers. It is a step towards a Circular Economy policy focused on environmentally-friendly and resource-efficient society by re-using and recycling materials and making a closed-loop system. Therefore, the research seeks to find solution for the utilization of sludge from wastewater to produce organo-mineral fertilizer. This project is aimed at eradicating environmental pollution associated with sewage sludge disposal and to develop a product that will serve as an alternative to mineral fertilizer which is expensive and unaffordable by many local farmers in Nigeria. The aim of this research will be achieved through determining the physical properties and analysing the chemical composition of the organo-mineral fertilizer.

II. MATERIALS AND METHODS

2.1 Sample Collection and Preparation

The sludge sample was obtained from municipal waste water treatment Plant in Calabar, Cross River State, South-South, Nigeria. The cow dung was collected from a farm at the Department of Animal Science, Faculty of Agriculture, University of Uyo, Uyo, Akwa Ibom State. The sludge sample was sundried on a flat wooden board during the summer season for five (5) days to reduce the moisture content and smell. The samples were then dried in an oven at 110ºC for 1 h and allowed to cool. After drying, the sample was pulverized, digested and filtered (APHA, 2005). The cow dung was also sundried for five days then oven dried at 65ºC and allowed to cool.

2.2 Formulation of organon-mineral fertilizer

Organo-mineral fertilizers were formulated using the pulverized sewage sludge, cow dung and mineral fertilizer at different amount generated through the application of Design Expert 11 as shown in Table 1. These formulation materials were all blended by adding little quantity of water. The mixtures were continuously stirred and oven dried at 50ºC to a constant weight. The dried samples were pulverized and sieved using 250 µm sieve size.

Table 1: Composition of organo-mineral fertilizer obtained from Design Expert

Runs	Sample	Quantity (g)		
		Sludge	Cow dung	Mineral fertilizer
2	OMF 1	20.9	20	9.1
4	OMF 2	19.3	17.1	13.6
5	OMF 3	15	15	20
12	OMF 4	15	19.1	15.9
13	OMF 5	19.3	17.1	13.6
14	OMF 6	21.4	15	13.6

2.3 Characterization of organo-mineral fertilizer

The formulated organo-mineral fertilizer was characterized for elemental composition by XRF machine. Properties such as pH, moisture content, water holding capacity, bulk density and total amount of organic matter were also determined using standard procedures.

2.3.1 X-ray fluorescence of samples

The chemical composition of the Organo-mineral fertilizer was determined using energy-dispersive X-ray fluorescence machine, model Genius-IF Xenometric EDXRF, Skyray Instruments, USA. The sample in a powdered form was placed firmly in a waxed and gold-plated sample holder and attached on both sides with a scotch tape. The energy dispersive patterns were obtained with the help of a computer attached to the instrument and each compound recorded in percentage.

2.3.2 Moisture content

The moisture content is defined as the total weight-loss of a sample after it has been dried to 105ºC. Six foil papers each containing 5g of the different Organo-mineral fertilizer were placed in an oven for 2 h. The foil papers were removed, desiccated, and weighed. The weight loss was measured and the moisture content (%) was determined using Equation 1.

$$\text{Moisture (\%)} = \frac{\text{Loss in weight of sample}}{\text{Weight of sample}} \text{ X } 100 \qquad 1$$

2.3.3 Sample pH

pH was determined using a digital pH meter. 0.5 g of each sample was taken into the beaker and 40 mL of deionized water was added to the beaker. The solution was stirred with a glass rod and the pH recorded after 30 min using a pH meter.

2.3.4 Water holding capacity

Water holding capacity was determined by weighing 5g of each of the samples was placed on a filter paper that is fitted in a measuring cylinder and 250ml of deionized water was added into the sample. The volume of the filtrate was taken and the mass of the filtrate determined using calculated using equation 2,

$$\text{Holding Capacity} = \frac{\text{mass of water}}{\text{Total mass of saturated fertilizer}} \text{ X } 100\% \qquad 2$$

2.3.5 Bulk density

The true density measurement was performed using Archimedes principle. 1.0g of dried sample wrapped in a polyethene was immersed in water. The water level before and after immersion was recorded. The density was evaluated by dividing dried weight and the difference in water level before and after immersion.

2.3.6 Total Amount of Organic Matter

This was determined by igniting the oven dried samples at a temperature of 350 ºC. The total of organic matter was determined from equation 3,

$$W_1 = W_2 - W_3 \qquad 3$$

Where:

W_1= Total weight of organic matter
W_2 = weight of oven dried sample
W_3 = weight of ignited sample

III. RESULTS AND DISCUSSION

3.1 Chemical composition of samples

The chemical composition of macro elements in the formulated organo-mineral fertilizer samples is presented in Table 2. Nitrogen (N) ranges from 4.99 to 9.26 %, P_2O_5 (18.2-35.30 %) and K_2O (5.49-10.277%). Sample OMF 3 has the highest amount of P_2O_5 (35.30%) while OMF 6 has the lowest P_2O_5 (18.27%), highest nitrogen (9.26 %) and K_2O (10.277%) content. The macro elements were dictated in significant amount in all the samples and are very important nutrients required by plant for their growth and yield. Phosphorus is essential for strong root formation, seedling establishment, and early plant vigor. Adequate phosphorus promotes blooming, fruit set, and seed production (Jiang, *et al.* 2024). Therefore, sample OMF 3 with higher phosphorous content will improve the fruit and seed formation in plants. Nitrogen promotes leaf and stem development while potassium enhances disease resistance and improves plant tolerance to drought, salinity and cold. Combined use of N and K can optimize the asynchronous filling of superior and inferior spikelets and, in particular, enhance inferior spikelet weight with higher cereal yield (Xu *et al*. 2023). Sample OMF 6 with high nitrogen and potassium will be suitable for crops such as rice, maize, corn, etc.

Table 2: Chemical compositions of macro components in organo-mineral fertilizer

Samples	**Components composition (%)**		
	N	**P_2O_5**	**K_2O**
OMF I	4.99; σ=0.56	31.09; σ=0.85	9.07; σ=0.01
OMF 2	7.81; σ=0.78	32.98; σ=0.75	6.67; σ=0.43
OMF 3	5.60; σ=0.45	35.30; σ=0.83	7.02; σ=0.08
OMF 4	5.67; σ=0.56	30.84; σ=0.30	5.49; σ=0.12
OMF 5	5.59; σ=0.91	33.68; σ=0.16	9.34; σ=0.03
OMF 6	9.26; σ=01.4	18.27; σ=0.20	10.27; σ=0.12

The presence of micro elements and heavy metals are summarized in Table 3. The micro elements like Ca, Mg, Zn, Fe and Cu are required in small amount by plants for healthy growth. The moderate amount of these elements in all the samples implies their application in crop protection while heavy metals such as Cd, Pb, Cr and Ni in high concentration may cause adverse effect to plants (Jock *et al.* 2018). Generally, the chemical analysis indicates that the weight percentage of different elements like nitrogen, phosphorus, potassium, and calcium are within the required range and this suggested that the formulated fertilizers are good sources of nutrition and can promote plant growth (Majee *et al*. 2020).

Table 3: Elemental compositions of micro, trace and heavy Metal in formulated Organo-mineral Fertilizer

Component (g/kg)	**Sample composition (g/kg)**					
	OMF I	**OMF 2**	**OMF 3**	**OMF 4**	**OMF 5**	**OMF 6**
Ca	4.61; σ=0.48	11.09; σ=0.61	23.19; σ=0.12	15.00; σ=0.03	28.41; σ=0.74	33.89; σ=0.01
Mg	4.61; σ=0.54	4.84; σ=0.89	16.17; σ=0.96	5.82; σ=0.32	17.71; σ=1.6	18.86; σ=0.08
Zn	5.00; σ=0.046	0.91; σ=0.007	1.98; σ=0.056	1.17; σ=0.046	2.21; σ=0.038	2.25; σ=0.055
Fe	10.07; σ=0.39	8.91; σ=0.01	9.95; σ=0.09	10.97; σ=0.43	10.26; σ=0.04	8.28; σ=0.06
Cu	0.45;σ=0.009	0.112; σ=0.0012	0.280; σ=0.0003	0.147; σ=0.0004	0.243; σ=0.0016	0.309; σ=0.0024
Cd	13.56; σ=0.75	10.32; σ=0.43	13.03; σ=1.2	12.68; σ=0.39	14.62; σ=0.15	1.60; σ=0.059
Pb	20.39; σ=0.75	18.88; σ=0.36	26.16; σ=1.7	24.59; σ=1.3	24.15; σ=0.58	12.67; σ=0.87
Cr	196.78; σ=2.6	167.9; σ=0.17	228.8; σ=14.2	210.5; σ=4.7	26.0; σ=6.9	81.5; σ=0.26
Ni	40.0; σ=0.12	31.24; σ=0.55	50.20; σ=0.06	35.42; σ=0.56	55.21; σ=0.50	47.72; σ=0.06

3.2 Physical Composition of Organo-Mineral fertilizer

The physical properties of the samples are presented in Table 4. The physical properties determined on the samples were moisture content, bulk density, pH, water holding capacity and total organic matter. The moisture content in all the samples (20.5 to 35.7 %) is relatively high and this could be due to the addition of mineral fertilizer which is hygroscopic and might have absorbed moisture from the air when exposed to the surrounding.

The pH of samples range between 4.0 and 8.2. This shows that samples OMF 1 and OMF 4 are acidic in nature while other samples are basic with a relatively weak degree of alkalinity. This also indicates that sample OMF 4 can easily neutralized a basic soil than sample OMF 1 while samples OMF 2, 3, 5 and 6 can be effective in an acidic environment.

Sample OMF 1 has the maximum water holding capacity (54.5 g water/g dry sample) and sample OMF 4 (42.0 g water/g dry sample) has the minimum. This implies that OMF 4 with lower water holding capacity has pores with larger diameter and is considered very important for both soil-water-plant relationships and maintenance of good soil structure. The application of organic materials increases soil water retention, especially in soil having lower surface tension (Jock and Ilechukwu,. 2023)

The bulk density values ranged from 1.0 to 2.1 g/cm^3. Sample OMF 4 also has the highest bulk density (2.1 g/cm^3) and sample OMF 6 the lowest (1.0 g/cm^3). Bulk density somehow reduces with decreased in the amount of cow dung and mineral fertilizer in the sample. This could be due to the decrease in the total weight of the formulated components.

The total organic content ranges between 22.2 and 50.0%. Higher total organic content is expected when the manure presents high dry matter content and higher C:N ratio. Increased in soil organic matter also increases the degree of aggregation and pores volume (Loss et al., 2019).

Table 4: Physical properties of organo-mineral fertilizer

Sample	Parameters				
	Moisture content (%	**pH**	**Water holding capacity (g water/g dry sample)**	**Bulk density (g/cm^3)**	**Total organic matter (%)**
OMF 1	25.6	6.9	54.5	1.1	22.2
OMF 2	30.2	7.5	42.0	1.2	30.1
OMF 3	28.2	8.2	50.2	1.5	27.4
OMF 4	35.7	4.0	49.3	2.1	50.0
OMF 5	20.5	7.2	52.8	1.3	30.0
OMF 6	21.5	7.1	51.9	1.0	28.2

IV.CONCLUSION

The following conclusions were drawn from the study:

1. The study showed that sludge from the water treatment plant can be effectively utilized in the production of organo-mineral fertilizer.
2. The sludge contained useful nutrients and organic matter that contribute to soil fertility.
3. Treatment and blending reduced potential environmental and health risks, making the fertilizer safe for agricultural use.
4. The produced organo-mineral fertilizer improved nutrient availability and supported plant growth, demonstrating its potential as a sustainable alternative to conventional fertilizers.
5. Overall, this approach provides an environmentally friendly and cost-effective solution for sludge management and agricultural nutrient supply.

AUTHOR(S) CONTRIBUTIONS

A. A. Jock conceptualization, designed the study, supervised the fertilizer formulation experiments and reviewed the manuscript critically for intellectual content. P. M. Kamtu resource provision, statistical analysis and editing of the manuscript. S.C. Ubani collected sludge samples, conducted laboratory investigation and prepared the first draft of the manuscript..

AI DISCLOSURE

References search were aided by the used of AI (ChatGPT)

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DECLARATION OF CONFLICT OF INTEREST

Authors have no conflict of interest to declare.

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