Optimizing Composting Ratios of Cassava Peels and Pig Manure for Enhanced Compost Quality

Victoria F. Ediene and Otobong B. Iren
Department of Soil Science
Faculty of Agriculture
University of Calabar, Calabar
Corresponding author's email: victoriaediene@gmail.com

ABSTRACT

The management of agro-processing has become an environmental issue in many developing countries. This study investigated the composting of cassava peels and pig manure to produce a nutrient-rich organic amendment for enhancing soil fertility. Seven composting ratios, by weight (w/w), of cassava peels and pig manure (cassava + pig manure: 1:1, 2:1, 3:1, 1:2, 1:3, and cassava peel and pig manure alone) were examined. Composting temperatures, moisture content, pH, nutrient composition, and microbial activity were monitored over 12 weeks to determine the optimal combination for optimizing nutrients in the compost. The results showed that moisture content, pH value, C:N ratio, total nitrogen, organic carbon, Ca^{2+}, Mg^{2+}, K^{2+}, Na^{2+}, bacterial and fungal colony-forming units varied among the seven composts. The cassava peel-to-pig manure ratio of 1:1 provided the most favourable conditions, with slightly higher terminal pH values of 6.6, moisture content of 30%, C:N ratio: 11.85, total nitrogen: 0.6%, organic carbon: 7.34%, Ca^{2+}: 8.8 cmol/kg, Mg^{2+}: 13.87 cmol/kg, K^{2+}: 0.18 cmol/kg, Na^{2+}: 0.14 cmol/kg, and bacteria and fungi counts of 1.88 x 106 CFU and 1.7 x 103 CFU, respectively. The compost maturity of the cassava peel-to-pig manure ratio at 1:1 ratio indicated effective decomposition. This research findings support composting these agricultural wastes, not only to reduce environmental pollution but also to provide a viable manure for soil fertility management.

Keywords: Cassava peels, compost, pig manure, nutrient retention, fertility

INTRODUCTION

One of the main environmental problems of today's society is the continuous increase in agro-processing wastes. In many developing countries, sustainable management of these wastes have become major issues due to their degradable nature and lack of profitable technique and adequate methodology to convert these 'wastes' to better manure quality or other useful means such as energy (Effa *et al.*, 2022; Sharma *et al.*, 2024; Elemi *et al.*, 2024). With increase in population, and agricultural operations, greater waste production is eminent. Composting is a useful method to help the environment gets rid of these wastes (Manea *et al.*, 2024). A composting system confines the organic materials, often of plant and animal origin, in the presence of microbes, thereby accelerating the breakdown of these materials (Sayara, 2020). It is an efficient and economical way of utilizing waste and provides plants and soil with multiple benefits.

Composting is an aerobic process in which microorganisms, under controlled conditions, convert a mixed organic substrate into carbon dioxide (CO_2), water, minerals, and stabilized organic matter (humus) (Mironov *et al*., 2021; FAO, 2021). It is also called a solid-state fermentation process, which exploits the phenomenon of microbial degradation and mineralization (McKinley and Vestal, 1984; Beffa, 2002). Controlled environmental conditions, particularly of moisture and aeration required to yield temperatures (49^0C–60^0C), conducive for microorganisms involved in the composting process distinguishes composting from natural rotting or decomposition (Zucconi and de Bertoldi, 1987, Chen and Inbar, 1993). Temperature is one of the main factors that control microbial activity during composting (Boulter *et al*., 2000).

Globally, cassava is the sixth most important food crop in terms of annual production (FAOSTAT, 2010), and is a staple food for approximately 800 million people (FAO/IFAD, 2009; Lebot, 2009). Cassava peel is a by-product of processing the roots for starch, flour, "fufu and garri" (fermented cassava product) which constitute 11% of the root, with approximately 400,000MT (dry matter basis) of it produced annually (FAOSTAT, 2012). According to FAO (2001), about 250 to 300 kg of cassava peels are produced per tonne of fresh cassava root processed. Currently, there is an increase in campaign for enlarging the cassava production scale in Nigeria. The implication of this is increased waste production from cassava processing. This suggests that huge amount of cassava peels waste will be generated in the process, hence, the need to design and adopt a system capable of handling these huge anticipated waste problems. Cassava peels which are regarded in many areas in Nigeria as waste are rich in N (1.60%), P (0.16%), K (1.14%), Ca (0.88%), Mg (31.37 mg/kg) , Zn (32.29 mg/kg) and Cu (39.22 mg/kg) (Akanbi *et al*. (2007). It is also rich in crude protein (5.29%) and fat (1.18%), contains 10-30% crude fibre, 87.4% dry matter, 5.2% crude protein, 1.4% ether extract and 5.8% ash (Oyenuga, 1968; Akanbi *et al*. 2007). Several researchers have attested to the use of cassava peel waste in restoring organic matter level in the soils thus boosting crop production (Adediran *et al*., 2006; Akanbi *et al*., 2007; Iren *et al.*, 2015, 2016).

Pig production on the other hand is on the increase for meat consumption. Its manure contains nutrient elements that can equally support crop production and enhance the physical and chemical properties of the soil (Iren *et al*., 2013; Iren *et al*., 2014). Daily pig manure production has been put at 4.67 kg per day per animal (ASABE, 2005). Thus, the total amount of swine manure generated annually is approximately, 110 million metric tons. Traditionally, land application of swine manure is considered the most common practical and economical utilization method. However, land application of excessive volumes of swine manure is reported to create environmental issues (Choudhary *et al*., 1996; Riaño *et al*., 2014). Swine manure is a valuable source of nutrients, particularly nitrogen (N), phosphorus (P), and potassium (K), when utilized in an environmentally sustainable manner

(Keener *et al.*, 2001, Hodgkinson *et al.*, 2002; Iren *et al.*, 2013; Iren *et al.*, 2014).

Mature compost have been noted to provide more stable forms of organic matter and enhance nutrient release in the soil (Zainudin *et al.*, 2022) Finished compost is generally more concentrated in nutrients than the initial raw organic waste and can stabilize the soil as well as serve as an effective means of building soil fertility (Brady and Weil, 1999; Fagundes *et al.*, 2021; Carricondo-Martínez *et al.*, 2022; Gao *et al.*, 2023). This has prompted a research into the composting of cassava peels and pig wastes either solely or in combination as soil amendments and also as a useful solution to eliminate the problem of waste disposal.

This study, therefore, evaluates the manurial value of composting varied ratios of cassava peels and pig manure with a view to recommending the use of these wastes in compost making and the appropriate ratio to use in soil fertility maintenance.

MATERIALS AND METHODS

Experimental site

The experiment was conducted at the Teaching and Research Farm of the University of Calabar, Calabar, South-east Nigeria. Calabar lies between latitude 5° 32' and 4° 27' N and longitude 7° 15' and 9° 28' E in Nigeria. The town is characterized by a bimodal rainfall pattern with a long rainy season (March- July) and a short rainy season from September to early November after a very short dry spell in August. The total amount of rainfall within this period ranges from 2000 to 3500 mm annually while the mean temperature ranges between 23 and 33°C. The relative humidity ranges between 60 to 90%.

Materials preparation and layout

Cassava peels and pig manure for the experiment were sourced from rural farms. Cassava peels and pig manure were sorted to remove debris and non-degradable materials. Compost was prepared using cassava peels and well cured pig manure in different ratios wet (weight basis). Cassava peels and pig manure alone were also composted separately. Composting was carried out in compost bin bags (Plate 1). The experiment was laid out in a completely randomized design with three replications per treatment.

Treatments

The experiment consisted of seven treatments (Plate 1) of 25 kg/portion of each component, mixed in the following ratio: one portion of cassava peels + one portion of pig manure (1:1), two portions of cassava peels+ one portion of pig manure (2:1), three portions of cassava peels + one portion of pig manure (3:1), one portion of cassava peels + two portions of pig manure (1:2), one portion of cassava peels + three portions of pig manure (1:3), cassava peels alone and pig manure alone.

Composting process

Composting was done following the procedure as described by Adediran *et al.* (2006). The compost bins were watered and turned once weekly for two weeks and then fortnightly till the end of the composting process which lasted for 12 weeks. Temperature and pH of the pile were measured with a thermometer and pH meter respectively, on a daily basis for the first three days and afterwards weekly.

At the end of the compositing process, the composts were removed from the compost bins, air dried under shade to reduce the moisture content. Forty percent(40%) moisture content was obtained. Compost samples were taken for nutrient analysis after composting.

Laboratory studies
Physicochemical Analyses

Moisture content of the compost was determined by the weight difference by oven drying at 105°C until there was no further change observed in dry weight. Compost samples for organic matter (OM) determination were dried and ground, OM was determined by weight difference after 2 hours of combustion in a muffle furnace at 600°C (Irshad*et al*., 2013); pH was measured as a 1:5 (w/v) water soluble extract using a pH meter (Haug, 1993), organic carbon (OC) and total nitrogen (TN) were determined by freeze-drying and ball-grinding samples to sizes < 0.1 mm, with an Vario EL cube elemental analyzer(Haug, 1993; Gershuny and Rodale 2018). Exchangeable Na and K were determined after liquid extraction from the various compost extractants (Haug, 1993). The Na and K extractants were mixed with 1 *M*KCl and 1*M* sodium acetate respectively, in the ratio 1:10 (w/v) at room temperature for 1 hour and centrifuged and read using an atomic absorption spectrophotometer (Haug, 1993; Gershuny and Rodale 2018). Moisture contents of the compost were reported as percentage of fresh weight while other analyses were reported on a dry matter basis**.**

Microbial Analyses

Enumeration of Total Heterotrophic Bacteria and Fungi population

Compost samples were serially diluted in ten folds. Dilution factors of 10^{-6} and 10^{-3} were used for bacteria and fungi cultures, respectively. Total viable heterotrophic aerobic counts were determined using the pour plates technique for bacteria and fungi accordingly as outlined by Alef (1995) and Zuberer (1995). Colony counts were taken after incubating the plates at 30°C for 24 and 48 hours for bacteria and fungi, respectively.

RESULTS AND DISCUSSION

Temperature of cassava peels and pig manure based compost

The highest temperature at week 1, was obtained from compost ratio of 2:1 (42.^{o}C) while the least was obtained from 1:3 (31 ^{o}C). Comparatively, 1:2 compost mixture had the highest temperature in weeks 2-5 (49 ^{o}C, 59.5 ^{o}C, 44 ^{o}C, 69.5 ^{o}C) and in weeks 9-11(39.5 ^{o}C, 41 ^{o}C, 29 ^{o}C), while pig manure (PM), had the highest temperature at weeks 7 (59.5 ^{o}C), 8 (49 ^{o}C) and 12 (29.5 ^{o}C), respectively. It was observed that temperature generally followed a similar trend across the various treatment combinations (Fig.1). The temperatures steadily increased within 1-3 weeks and declined in week 4. However, after the initial decline observed at week 4, there was an increase with temperatures reaching its peak at week 5. The heating phase lasted for 5 weeks this was followed by subsequent slight increase and decrease in temperature and finally declined to < 29.5 ^{o}C at week 12. The increase and decrease pattern observed in temperature could be attributed to the turning process and the activities of favourable micro-organisms in the mixture. Micro-organisms are reported to release enzymes into the composting mixture as they carry on metabolic processes, resulting in decomposition and consequently accelerating a rise in temperature within the mixture (Olamiyi and Akanbi, 2008). The high temperature in phase one could also be attributed to the breaking down of the complex and tough fibrous materials of the compost as reported by Inckel *et al*. (2005).Although, the temperature range reported in the heating phase of this research was slightly below the 60-70^{o}C reported by Nickel *et al*. (2005), temperatures in the second (50-30^{0}C) and third (15-25^{o}C) phases were in line with their report. These temperature ranges, according to Nickel *et al*. (2005), were attributed to decomposition without much heat generation (in phase two) and the slow dropping of temperature due to maturation phase at the end of decomposition (phase three). The results obtained herein are equally close to the value of 60^{o}C reported by Ngeze (1998) as the ideal temperature for compost heap and in agreement with the report of Olaniyi and Akanbi (2008) who reported the range of 25-41%. Nonetheless, the high temperature observed during the composting process was essential to accelerate decomposition, kill pathogens, eliminate weed seeds, reduce harmful organisms and break tough plant materials.

The pH of cassava peels and pig manure based compost

The pH values varied from week one among the seven composts with mean values of 5.4, 5.1, 5.0, 6.2, 6.7, 5.3 and 6.8 for ratios 1:1, 2:1, 3:1, 1:2, 1:3, CP and PM, accordingly. All the pH values steadily increased from week one to weeks 9 and peaked at week 9 (Fig. 2) with values reaching 7.2, 6.9, 6.8, 8.2, 8.4, 6.7, and 7.8 and declined in weeks 10 and 11 with slightly higher terminal pH values 6.6, 6.8, 6.7, 7.8, 7.9, 6.1 and 7.5 observed at the twelfth week for compost ratios of 1:1, 2:1, 3:1, 1:2, 1:3, CP and PM, respectively. The highest pH was obtained for 1:3 mixing ratio, closely followed by 1:2 while the least was from the sole compost of CP. The final compost products were slightly acidic to slightly alkaline(6.6 - 7.3) and slightly alkaline (7.4 - 7.8), except for the cassava/pig manure ratio of 1:3 which was moderately alkaline (7.9) and CP which was slightly acid in reaction. However, the ranges obtained indicate the presence of plant nutrients as pH of 6 to 7 is generally favourable for nutrient availability. Most finished composts have pH between 5.0 – 8.5, this depend on the compost materials used (Chang *et al.*, 2006).

Moisture contents of cassava peels and pig manure compost

The moisture content (Fig. 3) of compost prepared with cassava peels (CP) and pig manure (PM) with mixing ratios of 1:1, 2:1, 3:1, 1:2 and 1:3 were examined. From the results obtained, there were no much variations in moisture content among the different mixing ratios. However, the initial average moisture content for the different mixing ratios in week 1 were 40% for 1:1 mixing ratio, 45.3% for 2:1 mixing ratio, 45.99% for 3:1 mixing ratio, 39.0% for 1:2 and 1:3 mixing ratios, 41.0% for cassava peels and 48.1% for pig manure. The values however were within the range (40-65%) recommended by Seyedbagheri

(2010). In the second week, there was an increase in moisture content as a result of the addition of water which had triggered an increase in temperature. The moisture content were observed for the different mixing ratios and sole composting as follows 53.9% for 1:1, 49:9% for 2:1, 46% for 3:1, 58.1% for 1:2, 59.0% for 1:3, 46% for CP and 48.2% for PM. In the third and fourth weeks, similar trends were observed as temperature and moisture increased with addition of water and turning of the compost pile. The average moisture content for the different ratios at the 3rd week were 70.14% for 1:1, 57.3% for 2:1, 49.1% for 3:1, 60.5% for 1:2, 62.15 % for 1:3, 60.5% for 1:2, 62:1% for 1:3, 56% for CP and 56% for PM. Whereas, the moisture content for the fourth week were 60.45% for 1:1, 63.8% for 2:1, 49% for 3:1, 60.5% for 1:2, 62.1% for 1:3 and 56% for CP and PM respectively. Similar moisture trends were reported by Seyedbagheri (2010).In the 5th week, the moisture content dropped slightly and continued in that trend till the 6th week. The moisture content further dropped during the 7th week and continued decreasing as the weeks went by due to non addition of water. The non addition of water was as a result ofthe soggy nature of the compost in week six. Continuous turning of the compost piles without adding water resulted in a tremendous drop in moisture content to an almost uniform values observed during the 8th to 12th weeks. Twenty eight percent(28%) moisture content was obtained for each composting ratios of 2:1, 3:1, 1:2, C.P and P.M. Whereas, 1:1 and 1:3 had moisture content of 30% and 29% respectively. The tremendous drop of moisture content of the compost piles during the 7th week turning could be attributed to the non addition of water earlier reported and the relatively high temperature observed during the 4thand 5thweek could have contributed to rapid vaporization of water thus resulting in drying of the compost. Similar observations were made by Finstein *et al*. (1992).

Carbon /Nitrogen (C/N) ratio of cassava peels and pig manure compost

The C/N ratio of all seven treatments at the final stage were low and ranged between 8.57- 12.26 (Fig. 4) with no significant difference among the various composting ratios except for CP. Poultry manure composthad the highest C/N ratio while CP had the least. However, these low C/N ratios have several implications. The low C:N ratio of < 20 suggests that the compost is rich in nitrogen relative to carbon. It indicates that the compost is nutrient dense and could be beneficial to leafy vegetables. However, if applied in large quantities could lead to nutrient overload. Compost with low C/N will release N rapidly when applied to soil and may require additional carbon rich material.

Nutrient content of cassava peels and pig manure compost

The organic carbon contents of the compost were generally high (>5 %) with the highest value obtained from 1:1 compost mixture (Fig. 4), however there were no significant differences among the various treatments except for CP. Magnesium (Mg) was high (3.8 - 8.0 cmol/kg) to very high (>8 cmol/kg) (Fig. 5) in rating with each compost combination differing from each other except for 3:1 and 1:2 and 2:1 and CP which were similar in ranking. Sodium (Na) was low (< 0.2 cmol/Kg)) (Fig. 5) in rating with each compost combination differing from each other except for 3:1 and 1:2 and across the sole compost and different combinations ratios. The Nitrogen contents of the composts were moderate (0.59 % - 2.26 %)(Fig. 4) in rating with each compost combination differing from each other except for 3:1 and 1:2. The highest potassium (K^{2+}) (Fig. 5) in rating with each compost combination differing from each other except for 3:1 and 1:2 was obtained from 1:1 compost mixture. The composting ratio of 1:3 had the least magnesium (Mg^{2+}) content while PM was least in K^{2+}.The highest available phosphorus content was obtained from 1:2 ratio while 2:1 had the least value. Cassava peel (CP) recorded the highest calcium content (11.87 cmol/kg) followed by 1:3 (10.00 cmol/kg) ratio while 1:2 was least (7.07 cmol/Kg) in Ca contents. Base saturation was highest in cassava peels compost while 1:2 mixing ratio and pig manure had the least. Hydrogen (H^+)was highest in pig manure compost. The results obtained in this study are comparable with the report of Olamiyi and Akanbi (2008) and Akanbi *et al.* (2007). The composting ratios of the cassava peels and pig manure had significant effects on the organic carbon, calcium, sodium, hydrogen, and base saturation of the final compost product while total nitrogen, available phosphorus, Mg^{2+}, K^{2+} Al and ECEC were not significantly influenced by the mixing ratios (FIG. 2).

Microbial population of cassava peels and pig manure compost

The total bacterial counts for the twelve week duration were 22.6 x 10^6,18. 4, 23.9 x 10^6, 15.6 x 10^6, 29.7 x 10^6, 17.3 x 10^6, 25.9 x 10^6 with mean colony forming unit values of 1.88 CFU, 1.53 CFU, 1.99 CFU, 1.30 CFU, 2.47 CFU, 1.44 CFU and 2.16 CFU or samples 1:1, 2:1, 3:1, 1:2, 1:3, CP and Pig manure respectively. The cassava peels and pig manure compost at the ratio of 1:3 had the highest bacterial counts while the ratio of 1:2 had the least bacterial population. Generally the bacterial population was observed to steadily increase with increase in pH and temperature and peaked at 3 weeks and steadily decreased with increase in temperature paving way for increase in fungal population. The mean fungi counts for the twelve week duration were 1.7x 10^3 CFU, 1.56 x 10^3 CFU, 1.6 x 10^3 CFU, 1.4x 10^3 CFU, 1.17 X 10^3 CFU, 1.21 x 10^3 and CFU, 1.48x 10^3 CFU, for samples 1:1, 2:1, 3:1, 1:2, 1:3, CP and Pig manure respectively. Results for the fungal counts indicates that cassava peels and pig manure based compost at a ratio of 1:1 had the highest count (1.7 X 10^3) while the ratio of 1:3 had the least count (1.17 X10^3). The microbial counts result suggests that these compost treatments are at varying stages of decomposition. The disparity in the microbial counts despite the same climatic condition and same time of composting may also be attributed to the differences in compost materials composition as well as their varied ratios. The pattern observed for bacteria and fungi population suggests that microbes evolve or disperse with response to stimuli, available substrate, moisture, temperature and pH. According to Bass *et al*. (2016) moisture content of <30% reduces microbial activity in compost and has significant influence on microbial activity in compost.

From the results, it was observed that there was more bacterial colony forming units than fungi. The increased fungal population observed at week 10 could be attributed to favourable pH and the ability of fungi to degrade more recalcitrant substances than bacteria. Fungi tend to be more in the later stages of composting because their preferred substrates which include decay-resistant materials such as waxes, complex proteins, hemi-celluloses, lignin, and pectin were available (Hoitink *et al*., 1991). The moisture regime (21% to 29%) and a pH (6.70 -7.20) across the treatments favoured the proliferation of fungi, since they are less sensitive to environments with low moisture and pH than bacteria.

Conclusion

The research demonstrates that the composting of cassava peels and pig manure is an effective method for managing agricultural waste towards enhancing soil fertility. Among the different ratios tested, the 1:1 ratio of cassava peels to pig manure yielded the best results in terms of microbial activity and nutrient content, This method presents a sustainable solution for reducing environmental pollution while improving nutrient retention for better soil health, particularly in regions with high agricultural activity like Nigeria.

Recommendations

1. Farmers and agro-processors should adopt composting of cassava peels and pig manure in a 1:1 ratio for optimal nutrient retention and soil enhancement.

2. Further research should explore the long-term effects of this compost on different crops and soil types.

3. Governments and agricultural organizations should promote composting as a sustainable waste management practice in farming communities.

4. Training programmes should be developed to educate farmers on the benefits and methods of composting agro-wastes to improve soil health

REFERENCES

Adediran, J. A, Taiwo, L. B., Akande, M. O. & Lawal, B. O. (2006).Working manual on compost making and use: A guide for extension agents, farmers, compost makers and users. Institute of Agriculture and Training (IAR&T), Ibadan, Nigeria, pp 1-20.

Akanbi, W.B., Adebayo, T.A., Togun, O.A., Adeyeye, A.S. & Olaniran, O. A. (2007).The use of Compost Extract as Foliar Spray Nutrient Source and Botanical Insecticide in *Telfairiaoccidentalis*.*World Journal of Agricultural Sciences*, 3 (5): 642-652.

Alef, K. (1995). Nutrient Sterilization, Aerobic and Anaerobic Culture Techniques, Enrichment and Isolation of Microorganisms. In Alef, K. and Nannipieri (Eds.), Methods in Applied Soil Microbiology and Biochemistry (pp. 45-50). London: Academic Press Limited.

ASABE (American Society of Agricultural and Biological Engineers) (2005).Standard D384.2-Manure Production and Characteristics.(Standard).America n Society of Agricultural and

Biological Engineers. New York. 400 pp.

Bass, A.M., Bird, M.I., Kay, G. &Muirhead, B. (2016). Soil Properties, Greenhouse Gas Emissions and Crop Yield Under Compost, Biochar and Co-Composted Biochar in Two Tropical Agronomic Systems. *Science of the Total Environment*, 550:459–470. Doi: 10.1016/j.scitotenv.2016.01.143.

Beffa, T. (2002).*The Composting Biotechnology: A Microbial Aerobic.*Institute of Agriculture and training (IAR&T), Ibadan, Nigeria, pp 1-20.

Boulter, J. I., Boland, G. J. &Trevors, J. T. (2000). Compost: a study of the development process and end-product potential for suppression of turfgrass disease,*World Journal of Microbiology and Biotechnology*, (16), 2, 115–134.

Brady, N.C. & Weil, R.R. (1993).The nature and properties of soils. 14th ed. Pearson Education, Inc. Upper Saddle River, New Jersey.

Carricondo-Martínez, I., Falcone, D., Berti, F., Orsini, F. & Salas-Sanjuan, M. D.C. (2022).Use of Agro-Waste as a Source of Crop Nutrientsin Intensive Horticulture System.*Agronomy*, 12, 447.

Chang, J.I., Tsai, J.J. & Wu, K.H.(2006).Composting of vegetable waste. *Waste Management and Research*, 24, 354-362.

Chen, Y. &Inbar, U. (1993). Chemical and spectroscopical analyses of organicmatter transformation during composting in relation to compost maturity, in *Science and Engineering of Composting*, H. A. J. Hoitink and H. M. Keener, Eds.,pp. 550–600,Worthington, Ohio, USA. 320 pp.

Choudhary, M., Bailey, L.D. & Grant, C. A. (1996) Review of the Use of Swine Manure in Crop Production: Effect on Yield and Composition and on Soil and Water Quality. *Waste Management and Research*, 14, 581-595.

Elemi, E. D., Effa, E. B., Ukatu, P. O., Uwak, G. E., Agah, L. J. & Eyong M. E. (2024). Conjugal Effect of D. I Grow Bio-Organic Fertilizer and Organo-Mineral Fertilizer on the Growth and Yield of Cucumber (Cucumis sativus L.) in South Eastern Rain Forest Zone. In Proceedings of the first Faculty of Agriculture International Conference , (pp. 370-378). ASUU Secretariat. ISBN: 978-978-773-798-9.

Effa, E. B., Elemi, E. D., & Eja, D. E. (2022). Synergistic effects of poultry and goat manures on the growth and yield of groundnut (Arachis hypogaea L.) in humid Ultisol. *Journal of Agriculture, Forestry & Environment*, 6(1), 85-94.

Fagundes, P., Castro, F., Santos, L., Castro, S. & Lange, L. (2021).Study of the Nutritional Increase in Organic Composts Obtained by Aerobic Biostabilization in the Management of Food Wastes. *Journal of Management and Sustainability*, 11, 15–26.

FAO (2001).Strategic environmental assessment.An assessment of the impact of cassava production and processing on the environment and biodiversity. Proceedings of the validation forum on the global cassava development strategy, Volume 5. FAO, Rome, 26-28 April 2000

FAO/IFAD (Food and Agriculture Organization of the United Nations and International Fund for Agricultural Development), (2009).*The World Cassava Economy; Facts, Trends and Outlooks*, Food and Agriculture Organization of the United Nations and International Fund for Agricultural Development, Rome, Italy.

FAOSTAT (Food and Agriculture Organization of the United Nations Statistics), (2010). *Food and Agricultural Commodities Production*, Food and Agricultural Organization of the United Nations Statistics Database.*Volume II.Camden House Publishing Ltd. p. 145.*

FAOSTAT (Food and Agriculture Organization of the United Nations Statistics) (2012). *Food and Agricultural Commodities Production*, Food and Agriculture Organization of the United Nations Statistics Database.http://faostat.fao.org/site/339/default.aspx.

Finstein, M.S., Miller, F.C., Mac Gregor, S.J. & Psarianos, K.M. (1992). The Rutgers Strategy for Composting: Process Design and Control. *Acta Horticuturae,* 302, 75-85

Food and Agriculture Organization (FAO) (2021). Composting Process and Techniques; Martínez, M.M., Pantoja, A., Eds.; Food Organization (FAO): Rome, Italy.

Gao, Y., Wang, S., Tan, W. & Xi, B. (2023). Dynamics of nutrient elements and potentially toxic elements during composting with differentorganic wastes. Front. *Sustainable Food Systems*, 7, 118-139.

Gershuny, G. & Rodale I. (2018). The Rhodale book of composting (2nded.). Rodale Books. Emmaus, PA

Hodgkinson, R.A., Chambers, B.J., Withers, P.J.A. & Cross, R. (2002) Phosphorus Losses to Surface Waters Following Organic Manure Applications to a Drained Clay Soil. *Agricultural Water Management*, 57, 155-173.

Hoitink, H., Chen,W., Trillus-Gray, M. &Chung.Y.R.(1991). Compost for control of plantdiseases.*Agronomy*, 414-9.

Haug, R. T. (1993). The practical handbook of compost engineering. Lewis Publisher. Boca rato, FL

Inckel M, Smet PD, Termette, T.&Veldkamp, T, (2005). The preparation and use ofcompost. Agromisa Foundation, Wageningen, the Netherlands.

Iren, O. B., John, N. M. & Imuk, E. A. (2013). Influence of rates of pig manure and NPK (15:15:15) fertilizer on soil chemical properties and dry matter yield of Fluted Pumpkin (*Telfairia occidentalis*, Hook f.). *Nigerian Journal of Soil and Environmental Research*, 11: 55-59.

Iren, O. B., John, N. M. &Imuk, E. A. (2014).Effect of varying rates of pig manure and NPK (15:15:15) fertilizer on growth, nutrient uptake and yield of fluted pumpkin (*Telfairiaoccidentalis* Hook f.). *Nigerian Journal of Soil and Environmental Research*, 12: 75-81.

Iren, O. B., Akpan, J. F..Ediene V. F. & Asanga, E. E. (2015). Influence of cassava peels and poultry manure-based compost on soil properties, growth and yield of waterleaf (*Talinum triangulare* Jacq) in an *ultisol* of south-eastern Nigeria. *Journal of Soil Science and*

Environmental Management, 6 (7): 187-194.

Iren,O. B., Ediene, V. F., Uwah, I. D. & Ekpenyong, V. E. (2016). Influence of varied ratios of cassava peels and pig manure - based compost on soil properties and yield of okra (*Abelmoschus esculentus (l) Moench*). *Proceedings of 50th Annual Conference of Agricultural Society of Nigeria* (ASN), Abia, Umudike, 1061 – 1064.

Irshad, M, Eneji, A.E, Hussain, Z.& Ashraf, M. (2013). Chemical characterization of fresh and composted livestock manures. *Journal of Soil Science and Plant Nutrition*, 13:115-121.

Keener, H.M., Elwell, D.L., Ekinci, K. & Hoitink, H. A. J. (2001). Composting and value-added utilization of manure from a swine finishing facility.*Compost Science and Utilization*. (9) 4:312-321.

Lebot, V. (2009).*Tropical Root and Tuber Crops: Cassava, Sweet Potato, Yam and Aroids*, CABI,Wallingford,UK. 230pp.

Manea, E.E., Bumbac, C., Dinu, L.R., Bumbac, M. & Nicolescu, C. M. (2024). Composting as a SustainableSolution for Organic Solid WasteManagement: Current Practices andPotential Improvements.Sustainability 16, 6329.https://doi.org/10.3390/su16156329

McKinley, V. L. & Vestal, J. R.(1984). Bio-kinetic analyses of adaptation and succession: microbial activity in composting municipal sewage sludge. *Applied and nvironmental Microbiology*, 47, (5). 933–941.

Mironov, V., Vanteeva, A. & Merkel, A. (2021). Microbiological Activity during Co-Composting of Food and Agricultural Waste for Soil Amendment. *Agronomy*, 11, 928-938.

Ngeze, P. B, (1998).Learn how to make and use compost manure in farming. Stantex Publisher, Westland, Nairobi, Kenya.58 pp

Olaniyi, J. O. & Akanbi, W. B. (2008). Effects of cultural practices on mineral compositions of cassava peel compost and its effects on the performance of cabbage (*Brassica oleracea* L.). *Journal of Applied Biosciences*, 8(1), 272–279. https://www.biosciences.elewa.org

Oyenuga, V.A. (1968). Nigeria's food and feeding stuffs: their chemistry and nutritive value. 3rd Edn. University of Ibadan Press, pp: 15-22.

Riaño, B. & García-González, M.C. (2014). On-Farm Treatment of Swine Manure Based on Solid-Liquid Separation and Biological Nitrification-Denitrification of the Liquid Fraction. *Journal of Environmental Management*, **132**, 87-93.

Sayara, T., Basheer-Salimia, R., Hawamde, F. & Sánchez, A. (2020). Recycling of Organic Wastes through Composting: Process Performance and Compost Application in Agriculture. *Agronomy*, 10, 1838.

Seyedbagheri, M. M. (2010). Compost: Production, quality, and use in commercial Agriculture. University of Idaho Extension, College of Agricultural and Life Science, CIS 1175, pp. 1-6.

Sharma, A., Soni, R. & Soni, S. K. (2024). From waste to wealth: exploring modern composting innovations and compost valorization. *Journal of Mater Cycles Waste Management*, 26, 20–48.

https://doi.org/10.1007/s10163-023-01839-w

Zainudin, M.H.M., Zulkarnain, A., Azmi, A.S., Muniandy, S., Sakai, K., Shirai, Y. & Hassan, M. A. (2022). Enhancement of Agro-IndustrialWaste Composting Process via the Microbial Inoculation: A Brief Review. *Agronomy*, 12, 198-209.

Zuberer, D. A. (1995).Recovery and enumeration of viable bacteria. In: Mikelson, S. H. (Ed.), Methods of soil Analysis Part 2. Microbiological and Biochemical Properties. Washington DC: Soil Science Society of America. pp. 365-373.

Zucconi, F & de Bertoldi, M. (1987). Compost specifications for the production and characterization of compost from municipal solid waste, In:*Compost Production, Quality and Use*, M. de Bertoldi, M. P. Ferranti, P. L'Hermite, and F. Zucconi, Eds., Elsevier Applied Science, London, UK. pp. 30–50.

Plate 1: Experimental layout showing the placement of the different compost mixtures