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DOI: https://doi.org/10.64388/IREV9I5-1712359

Assessment of the Potential of Fruits and Vegetable Dumpsite Soils and Poultry Litter to Enhance N Mineralization in Girei Local Government Area of Adamawa State

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Abstract- ***This study investigated the effectiveness of fruits and vegetable dumpsite soils (FDS and VDS) and poultry litter (PL) in enhancing nitrogen mineralization and improving soil fertility in soils from Modibbo Adama University Teaching and Research Farm, Yola, Adamawa State, Nigeria. A 9 × 9 factorial completely randomized design was used, including nine treatments MAU soil alone, NH_4NO_3, FDS, VDS, PL, and their combinations incubated for 60 days under controlled moisture and aeration conditions. Soil samples were periodically analyzed for pH, organic carbon, total nitrogen, ammonium (NH_4^+-N), nitrate (NO_3^--N), cumulative mineralized nitrogen, bulk density, porosity, and water-holding capacity. The results indicated that organic amendments initially increased soil pH, which decreased gradually due to ongoing ammonification and nitrification. Organic carbon and total nitrogen content rose steadily, reflecting enhanced nutrient availability and microbial activity. Ammonium and nitrate concentrations were significantly higher in amended soils, with the FDS + VDS + PL combination showing the greatest nitrogen mineralization. Cumulative mineralized nitrogen data revealed sustained nitrogen release throughout the incubation period. Additionally, soil physical properties improved with amendment application, evidenced by lower bulk density, greater porosity, and higher water-holding capacity, indicating improved soil structure and moisture retention. The study demonstrates that incorporating locally available organic residues such as dumpsite soils and poultry litter offers a practical, environmentally sustainable, and cost-effective approach to enhance soil fertility, reduce reliance on synthetic fertilizers, and support climate-smart agricultural practices.***

Keywords: Nitrogen Mineralization, Poultry Litter, Fruit and Vegetable Dumpsites, Organic Amendments, Soil Fertility, Sustainable Agriculture

I. INTRODUCTION

The exploration of fruits and vegetable dumpsite soils and poultry litter as potential enhancers of nitrogen mineralization has become increasingly relevant within the broader discourse on sustainable soil fertility management. In many low- and middle-income regions, persistent nutrient depletion, escalating fertilizer prices, and environmental concerns associated with chemical fertilizer misuse have intensified the search for alternative and locally accessible nutrient sources. Organic residues from fruits and vegetable dumpsites constitute a rich repository of biodegradable materials characterized by high moisture content and readily decomposable carbon substrates, which foster accelerated microbial decomposition and the conversion of organic nitrogen into plant-available mineral forms (Amoakwah et al., 2020; Singh & Shah, 2021). Over time, these dumpsite soils become enriched with organic matter, microbial biomass, and mineralizable nitrogen pools, thereby functioning as unconventional yet potentially valuable nutrient reservoirs for surrounding agricultural landscapes.

Poultry litter represents another organic resource of considerable agronomic value, particularly in regions where poultry production is rapidly expanding. It contains substantial quantities of nitrogen in both organic and inorganic fractions primarily uric acid, ammonium, and urea that undergo mineralization and nitrification to supply crops with essential nitrogen throughout the growing season (Adekiya et al., 2019; Hassan et al., 2022). In addition to its nitrogen contribution, poultry litter improves soil structure, enhances cation exchange capacity, stimulates microbial activity, and supports the long-term accumulation of soil organic matter, all of which play critical roles in sustaining soil fertility and productivity (Ch'ng et al., 2020; Liang et al., 2023). As a result, integrating poultry litter into soil management strategies aligns with climate-smart and resource-efficient agricultural practices.

The recycling of these organic waste materials into farmland offers a dual advantage: it mitigates the environmental threats posed by unmanaged waste accumulation while simultaneously enriching the soil with essential nutrients (Okoro et al., 2022; Agyeman et al., 2023). However, the rate and extent of nitrogen mineralization from dumpsite soils and poultry litter are influenced by several biophysical factors, including the chemical composition of the materials, soil microbial community structure, prevailing environmental conditions, and the carbon-to-nitrogen ratio of the amendments (Somda et al., 2020; Wanjiru et al., 2021). Understanding these complex interactions is fundamental to optimizing nitrogen release patterns, minimizing nutrient losses through volatilization, leaching, or immobilization, and enhancing nitrogen-use efficiency within cropping systems.

Given these considerations, a comprehensive assessment of the nitrogen mineralization potential of fruits and vegetable dumpsite soils and poultry litter is essential for establishing evidence-based guidelines that support sustainable nutrient recycling. Such an evaluation not only advances scientific knowledge on organic nitrogen dynamics but also offers practical implications for farmers seeking cost-effective and environmentally responsible approaches to soil fertility improvement. Consequently, this study investigates the capacity of these organic materials to enhance nitrogen mineralization in the soils of the study area, contributing to broader efforts to integrate locally sourced organic resources into sustainable soil fertility management frameworks.

II. MATERIALS AND METHOD

Location and Climate of the Study Area

The study was conducted in MAU Yola Teaching and Research Farm in Girei LGA, Adamawa State, Nigeria, located between latitudes 9°34'9°36'N and longitudes 11°1'11°56'E at an elevation of about 150 m. The area covers 1,848 km² with a population density of 93.89 km² (Census, 2016) and is bordered by Song to the north, Fufore to the east, and the Benue River to the south (Adebayo et al., 1999). The region experiences a semi-arid climate with distinct wet (May–October) and dry (November–April) seasons (Adebayo et al., 1999; Dent & Young, 1981). Annual rainfall averages 1000 mm, most of which falls between July and September, while temperatures peak in April (40.6°C) and decline in December–January (Mirchaulum, 1999). The landscape forms part of the Benue Valley, characterized by gently undulating to nearly flat terrain underlain by Bima Sandstone and recent alluvial deposits (Mamza et al., 2018).

Sample Collection and Preparation

Fruits and vegetable dumpsite soils were collected from two dumpsites in Kasuwan Gwari Market, Jimeta (Yola North LGA), situated between latitudes 9.171'9.288'N and longitudes 12.226'12.433'E. Samples were taken at 0–20 cm depth. Poultry litter was obtained from a deep-litter layer unit in Ganye LGA. All materials were air-dried, cleaned of debris, ground, and passed through a 2 mm sieve.

Treatment and Experimental Design

The experiment followed a 9 × 9 factorial completely randomized design with three replications, consisting of nine amendment treatments and nine sampling times. Amendments included MAU soil alone, ammonium nitrate, fruits dumpsite soil, vegetable dumpsite soil, poultry litter, and various combinations thereof at equivalent field rates. Each treatment was mixed with 250 g of air-dried soil and incubated for 60 days at 60% water-holding capacity under aerated conditions. Moisture was maintained by periodic weighing and watering. A total of 243 incubation units were sampled destructively on days 0, 2, 5, 7, 14, 21, 35, 49, and 60. Samples were analyzed for ammonium, nitrate, mineralized nitrogen, pH, EC, and organic carbon following Musa et al. (2021), with additional post-incubation analyses of physical and chemical properties.

Laboratory Analysis

Soil physical properties were analyzed using the Bouyoucos hydrometer method and bulk and particle densities determined according to Jaiswal (2003). Chemical properties including pH, EC, organic carbon, total nitrogen, available phosphorus, exchangeable bases, and effective cation exchange capacity were measured using standard procedures (Nelson & Sommers, 1982; Olsen & Dean, 1965; Bray No. 1; Jaiswal, 2003; Anderson & Ingram, 1994). Poultry litter pH, EC, moisture, organic carbon, total nitrogen, and extractable nutrients were determined using established wet chemistry and AAS methods.

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Data Analysis
Data were subjected to ANOVA using SAS 9.4 in a two-factor CRD, and treatment means were separated using Tukey's HSD at $P < 0.05$. Percentage changes in selected soil properties were calculated, and cumulative nitrogen mineralization trends were visualized graphically.

III. RESULT AND DISCUSSION

The interaction between treatments and incubation time on soil pH is presented in Figure 1. Across all treatments, the highest pH values were recorded at day 0, with MAU soil amended with fruit dumpsite soil (FDS) and poultry litter (PL) showing the maximum pH of 7.78, although this did not differ significantly from other treatments at the same time. The initially elevated pH likely reflects the alkaline nature of the amendments. Fluctuations and gradual decreases in pH over time can be attributed to simultaneous ammonification and nitrification processes, as well as interactions between heavy metals in dumpsite soils and the soil matrix. Increased microbial activity from high organic matter content in FDS and vegetable dumpsite soil (VDS) may have produced organic acids, contributing to the decline in pH. These findings are consistent with Orimisan et al. (2024) and Roy and Kashem (2014), who observed declining soil pH over incubation irrespective of organic amendment type, and Musa et al. (2021), who linked pH reduction to the conversion of ammonium to nitrate.

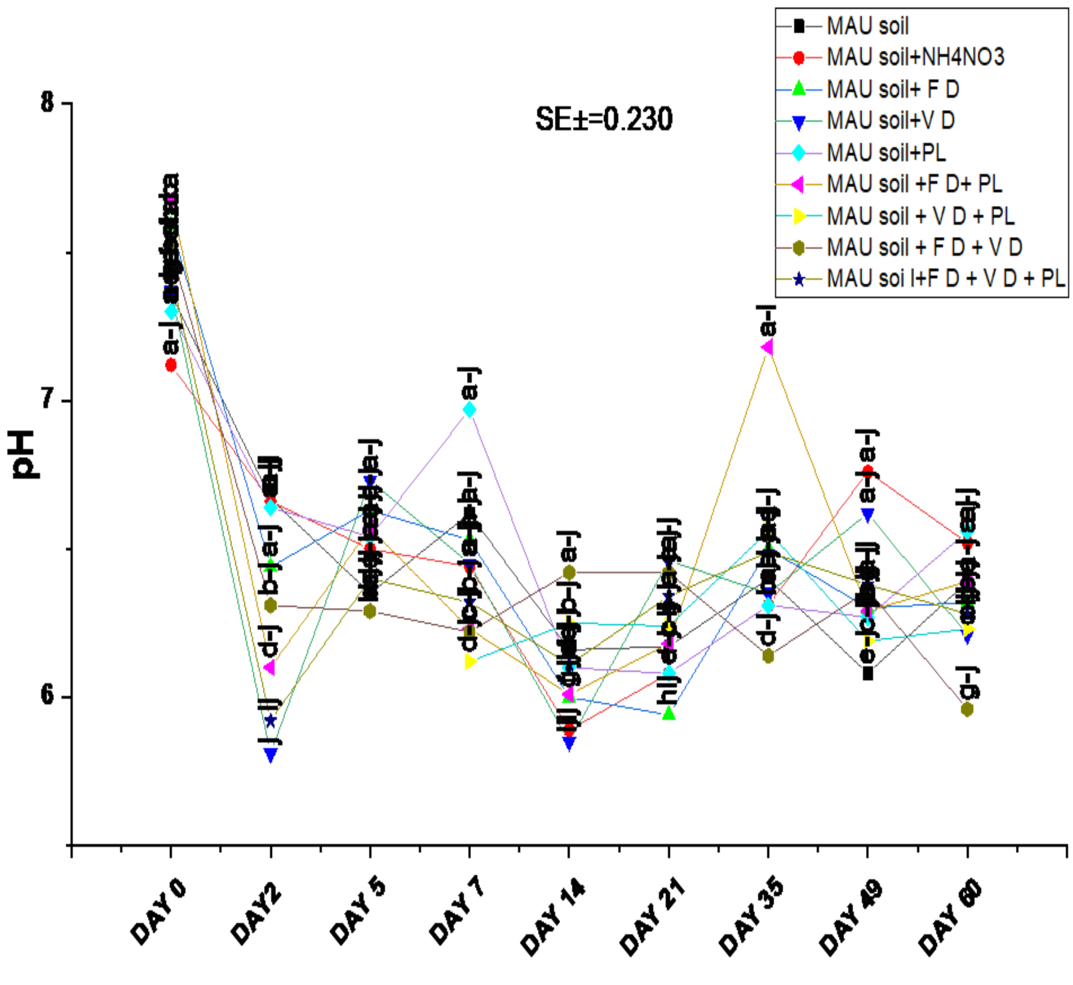

Figure 1: Interaction between Treatments and Time of Incubation on pH

(MAU soil= Soil from Modibbo Adama University Teaching and Research Farm, Yola, FDS=fruit dumpsite soil, VDS= Vegetable dumpsite soil, PL= Poultry litter)

Figure 2 illustrates the effect of treatment and incubation time on soil organic carbon. The highest organic carbon content (14.06 g kg^{-1}) was observed in MAU soil amended with NH_4NO_3 at day 21, followed by MAU soil + FDS + VDS at day 49 (13.84 g kg^{-1}) and MAU soil + PL at day 35 (13.67 g kg^{-1}). The increase in organic carbon over time may reflect accumulation of stable carbon fractions despite microbial activity. Abbasi and Khaliq (2016) reported reductions in organic carbon due to microbial decomposition, whereas Syarif (2018) observed increases over prolonged incubation as labile carbon is transformed into stable humic substances.

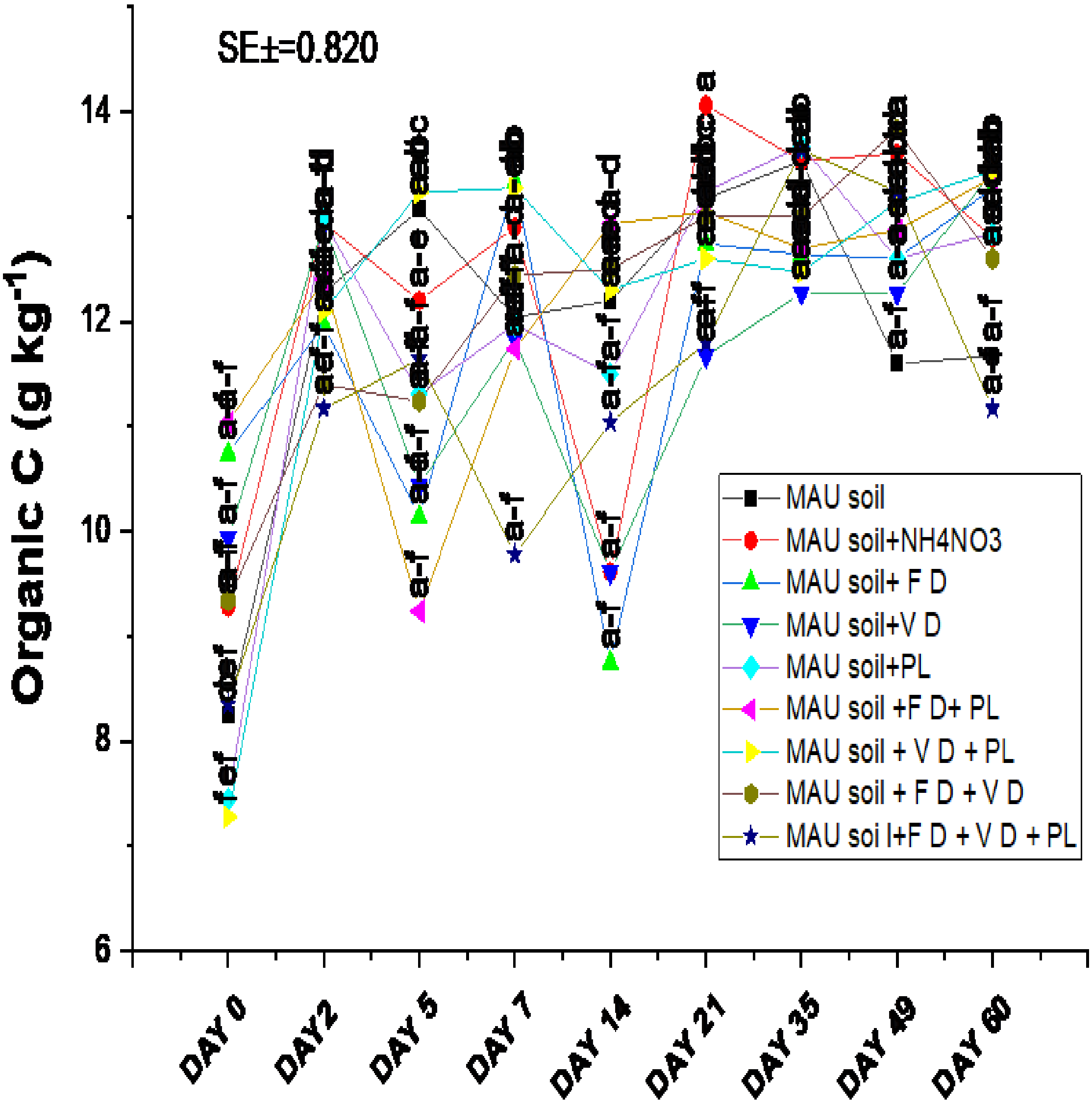

Figure 2: Interaction between Treatments and Time of Incubation on Organic Carbon

(MAU soil= Soil from Modibbo Adama University Teaching and Research Farm, Yola, FDS=fruit dumpsite soil, VDS= Vegetable dumpsite soil, PL= Poultry litter)

As shown in Figure 3, total nitrogen (TN) content varied significantly ($P<0.05$) among treatments and incubation times. On day 0, MAU soil + FDS + PL recorded the highest TN (0.013%). By day 2, the amended control (NH_4NO_3), MAU soil + VDS, and MAU soil + PL exhibited higher TN compared to other treatments. At day 49, MAU soil + FDS + VDS released the highest TN, with the maximum overall TN (0.16%) observed in MAU soil + FDS + VDS at day 45 and in NH_4NO_3-amended control at day 21. Elevated TN values are attributed to the high soluble nitrogen content of the amendments and enhanced microbial mineralization, consistent with Zhao et al. (2023) and Musa et al. (2021).

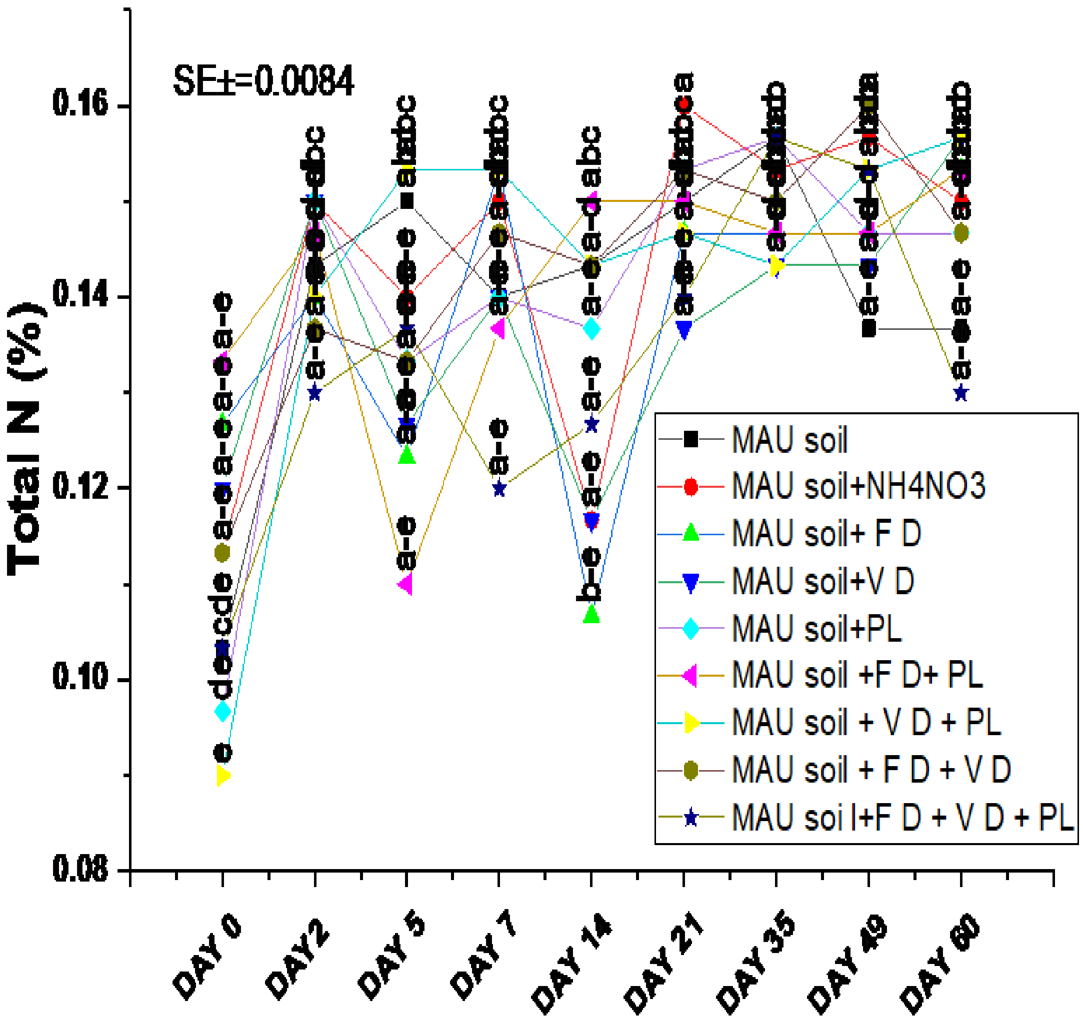

Figure 3: Interaction between Treatments and Time of Incubation on Total N

(MAU soil= Soil from Modibbo Adama University Teaching and Research Farm, Yola, FDS=fruit dumpsite soil, VDS= Vegetable dumpsite soil, PL= Poultry litter)

Figure 4 presents the effect of treatments on NH_4^+-N mineralization. Significant differences ($P<0.05$) were observed among treatments and incubation times. The unamended control consistently exhibited the lowest ammonium content (0.0004% on days 2 and 7), whereas MAU soil + FDS + VDS + PL showed the highest NH_4^+-N (0.0019%) on day 35. This reflects the abundance of easily mineralizable nitrogen in organic amendments and higher microbial activity, as reported by Azeez and Van Averbeke (2012). Ammonium levels declined toward day 60 due to microbial immobilization and reduced ammonification.

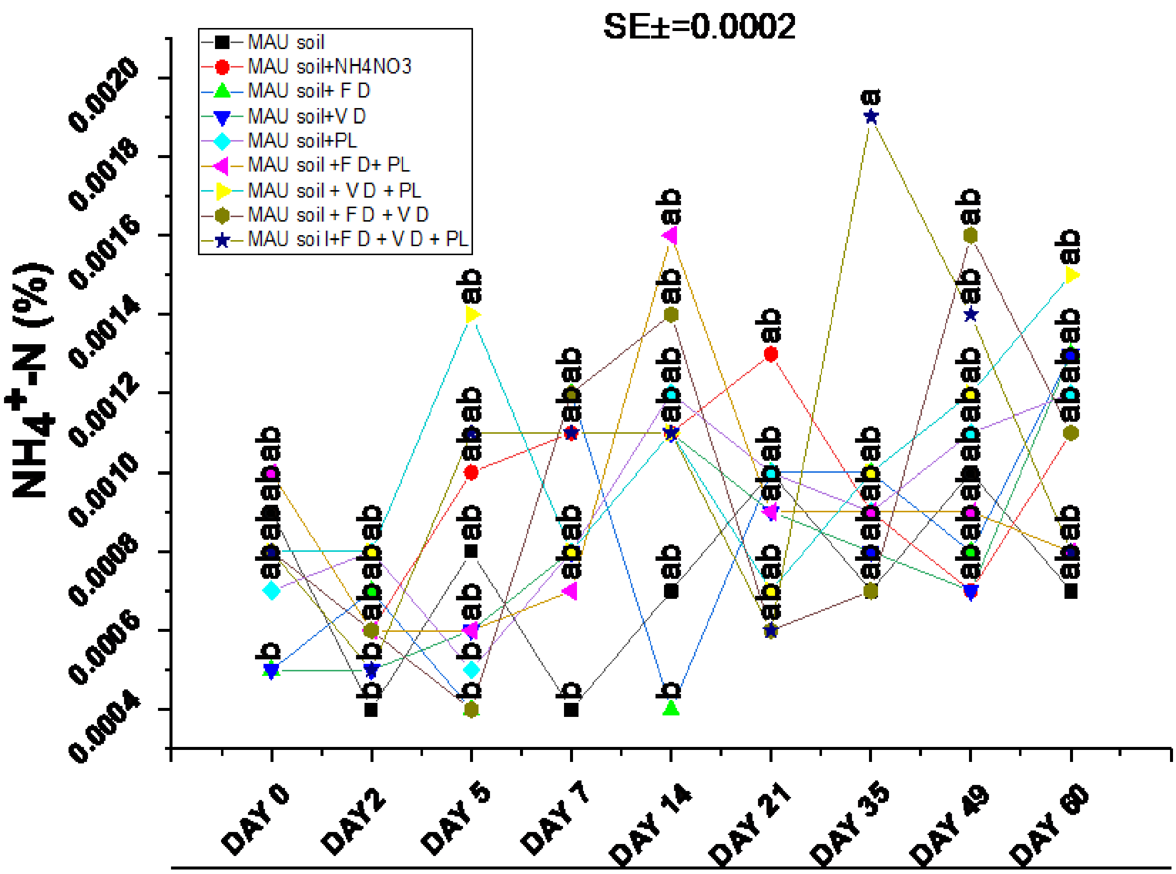

Figure 4: Interaction between Treatments and Time of Incubation on Ammonium

(MAU soil= Soil from Modibbo Adama University Teaching and Research Farm, Yola, FDS=fruit dumpsite soil, VDS= Vegetable dumpsite soil, PL= Poultry litter)

The interaction of treatments and incubation time on nitrate (NO_3^--N) is shown in Figure 5. Initial nitrate concentrations were higher in MAU soil + FDS + PL (0.0008%) than in the control (0.0006%). MAU soil + FDS + VDS recorded the highest nitrate values on day 7, while the NH_4NO_3-amended control achieved the peak nitrate concentration (0.0013%) on day 35. Increased nitrate at later stages results from ammonium oxidation by Nitrosomonas and Nitrobacter, consistent with Escudero et al. (2012) and Tratsch et al. (2019).

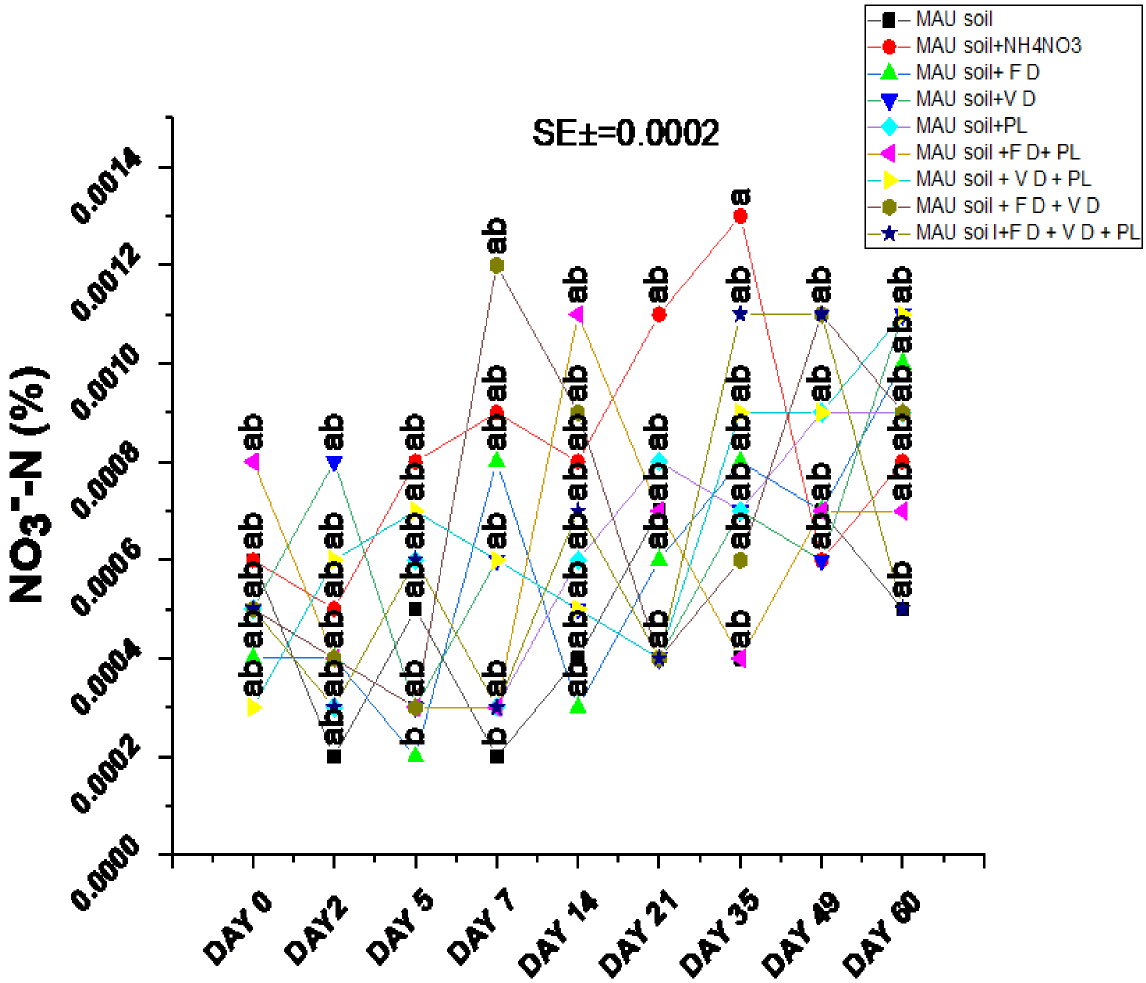

Figure 5: Interaction between Treatments and Time of Incubation on Nitrate

(MAU soil= Soil from Modibbo Adama University Teaching and Research Farm, Yola, FDS=fruit dumpsite soil, VDS= Vegetable dumpsite soil, PL= Poultry litter)

Figure 6 shows total mineralized nitrogen (NH_4^+-N + NO_3^--N) across treatments and incubation time. Mineralized N was significantly higher in amended soils than in the control, following trends similar to ammonium release. The maximum mineralized nitrogen (MAU soil + FDS + VDS + PL) was observed on day 35, with subsequent reductions by day 60. These results align with Musa et al. (2021), highlighting the high mineralizable nitrogen content of fruit and vegetable waste–amended soils.

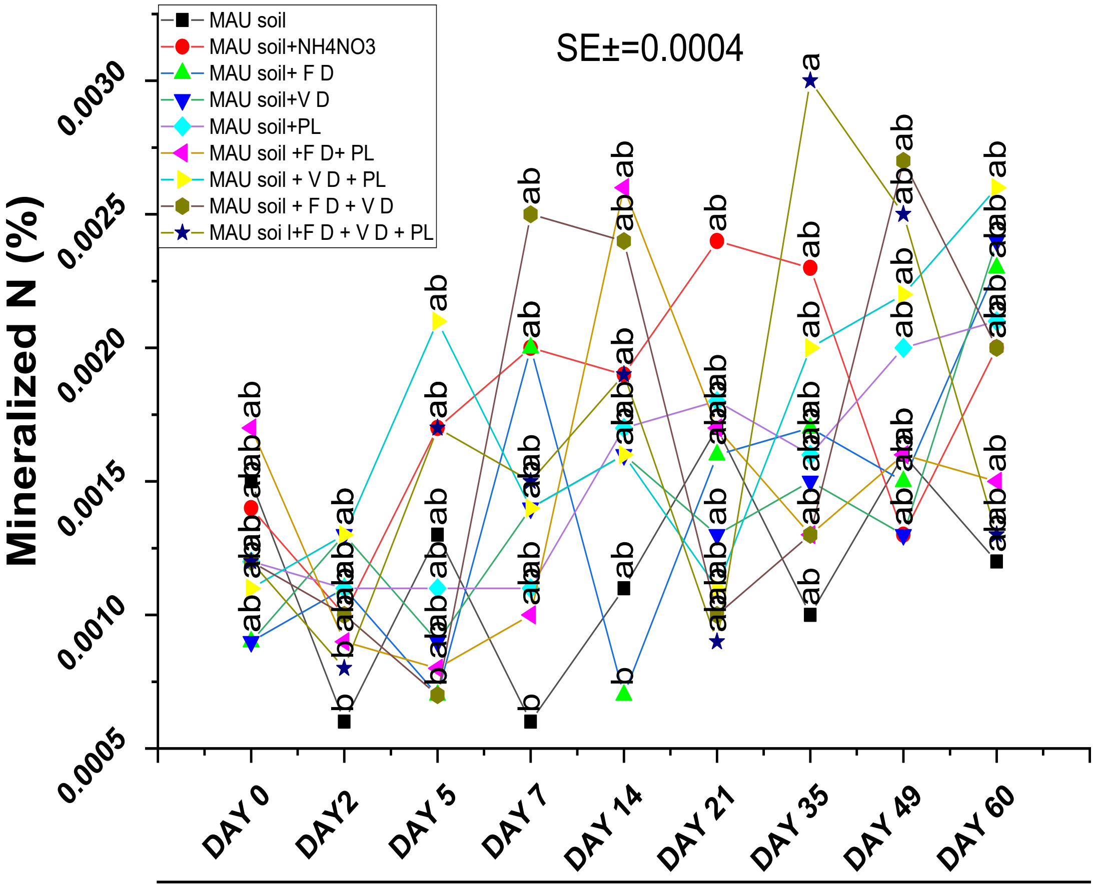

Figure 6: Interaction between Treatments and Time of Incubation on Mineralized N

(MAU soil= Soil from Modibbo Adama University Teaching and Research Farm, Yola, FDS=fruit dumpsite soil, VDS= Vegetable dumpsite soil, PL= Poultry litter).

Cumulative mineralized nitrogen over the 60-day incubation (Figure 7) increased progressively with time. The unamended control exhibited the lowest cumulative N, whereas the NH_4NO_3-amended control showed the highest. These patterns are consistent with Musa et al. (2021) and Masunga et al. (2016), who reported elevated cumulative nitrogen release in organic residue–amended soils due to their high labile nitrogen content.

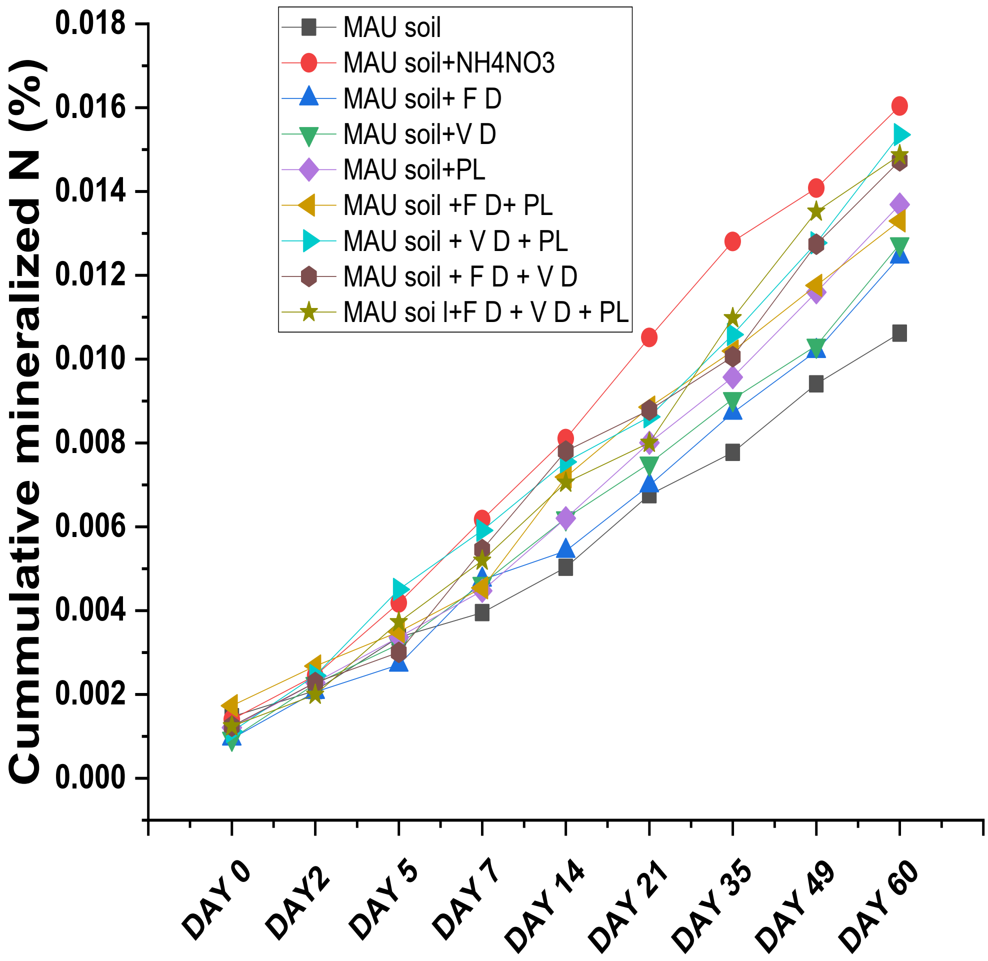

Figure 7: Treatment Effect on Cumulative Mineralized N for the Duration of the Experiment

(MAU soil= Soil from Modibbo Adama University Teaching and Research Farm, Yola, FDS=fruit dumpsite soil, VDS= Vegetable dumpsite soil, PL= Poultry litter)

Changes in Some Soil Properties with Incubation Time

Figure 8 shows that bulk density decreased with organic amendments, particularly in MAU soil + FDS + PL on day 2, consistent with Angin et al. (2013). The increase in bulk density observed in MAU soil + FDS (day 35) and MAU soil + FDS + VDS + PL (day 21) may reflect decomposition-induced structural changes. The “fluff effect” described by Layman (2010) explains the reduction in bulk density due to increased pore space from organic matter incorporation.

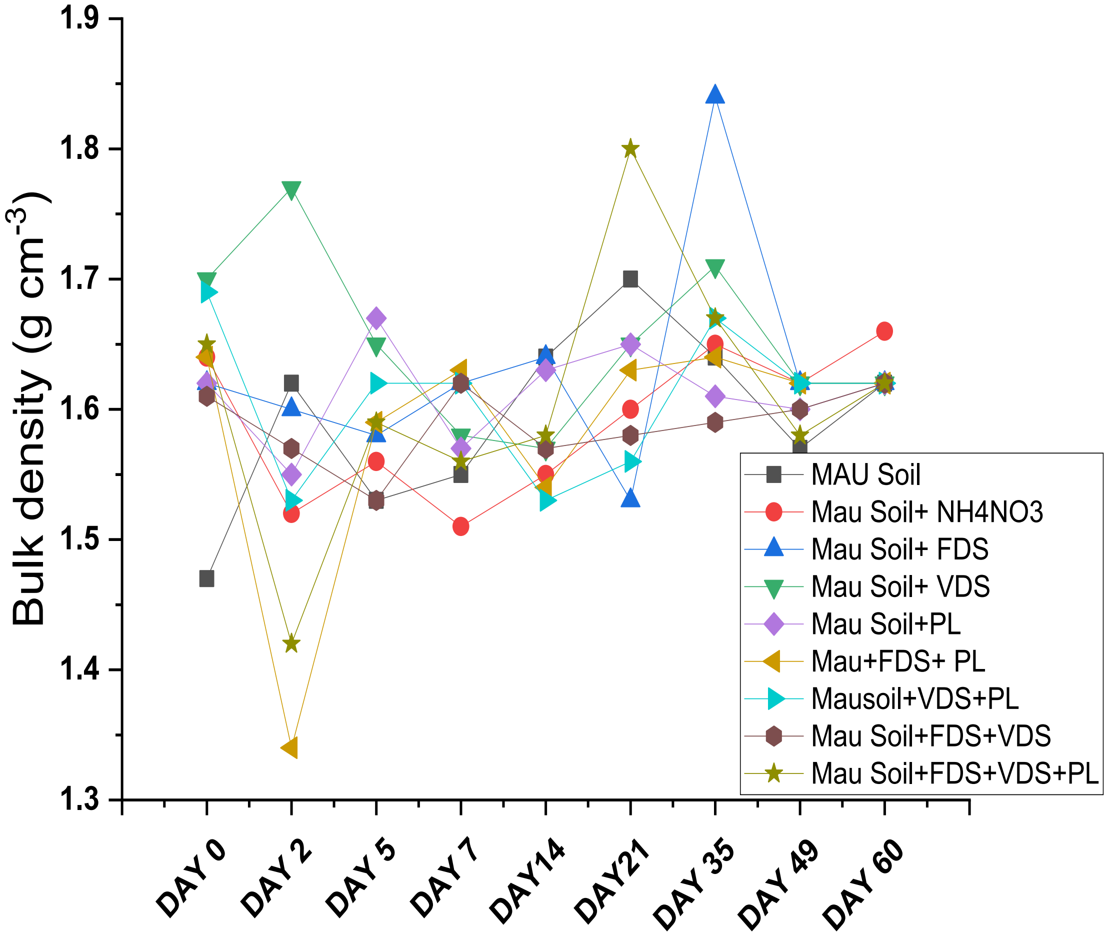

Figure 8: Soil Bulk Density during 60 Days Incubation Studies

(MAU soil= Soil from Modibbo Adama University Teaching and Research Farm, Yola, FDS=fruit dumpsite soil, VDS= Vegetable dumpsite soil, PL= Poultry litter)

As shown in Figure 9, porosity increased significantly ($P<0.05$) across all amended treatments, with the largest increases in MAU soil + FDS + PL and MAU soil + FDS + VDS + PL at day 2. The positive relationship between organic amendment application and soil porosity is consistent with the findings of Marinari et al. (2000).

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DOI: https://doi.org/10.64388/IREV9I5-1712359

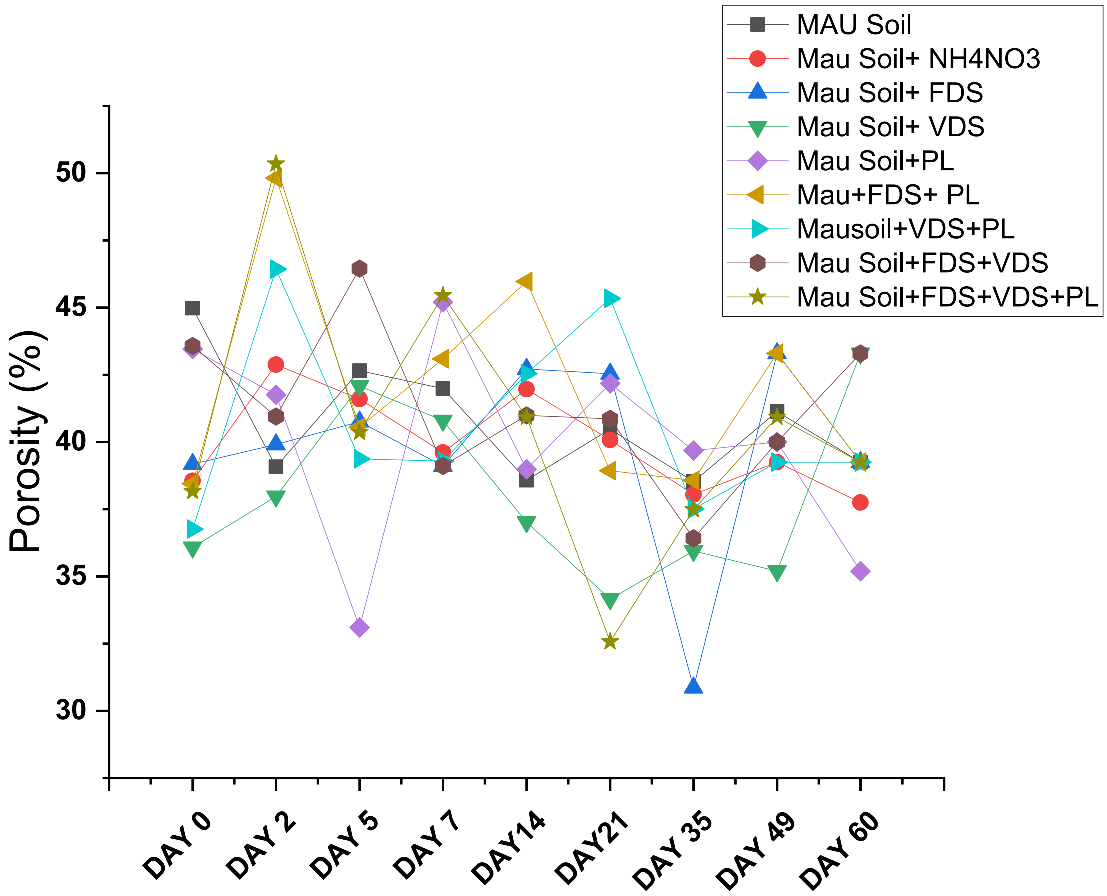

Figure 9: Percentage Soil Porosity during 60 Days of Incubation Studies

(MAU soil= Soil from Modibbo Adama University Teaching and Research Farm, Yola, FDS=fruit dumpsite soil, VDS= Vegetable dumpsite soil, PL= Poultry litter)

Figure 10 shows that all treatments significantly ($p<0.05$) increased soil water holding capacity (WHC) over time. MAU soil + VDS + PL had the highest WHC at day 0, followed by minor fluctuations before reaching maximum values at day 60, while MAU soil + NH_4NO_3 remained the lowest. The increase in WHC is attributed to organic amendments improving soil structure, porosity, and water retention due to their hydrophilic nature, consistent with previous studies (Agboola, 1998; Reicosky, 2003; Nawara et al., 2017; Smith, 2018).

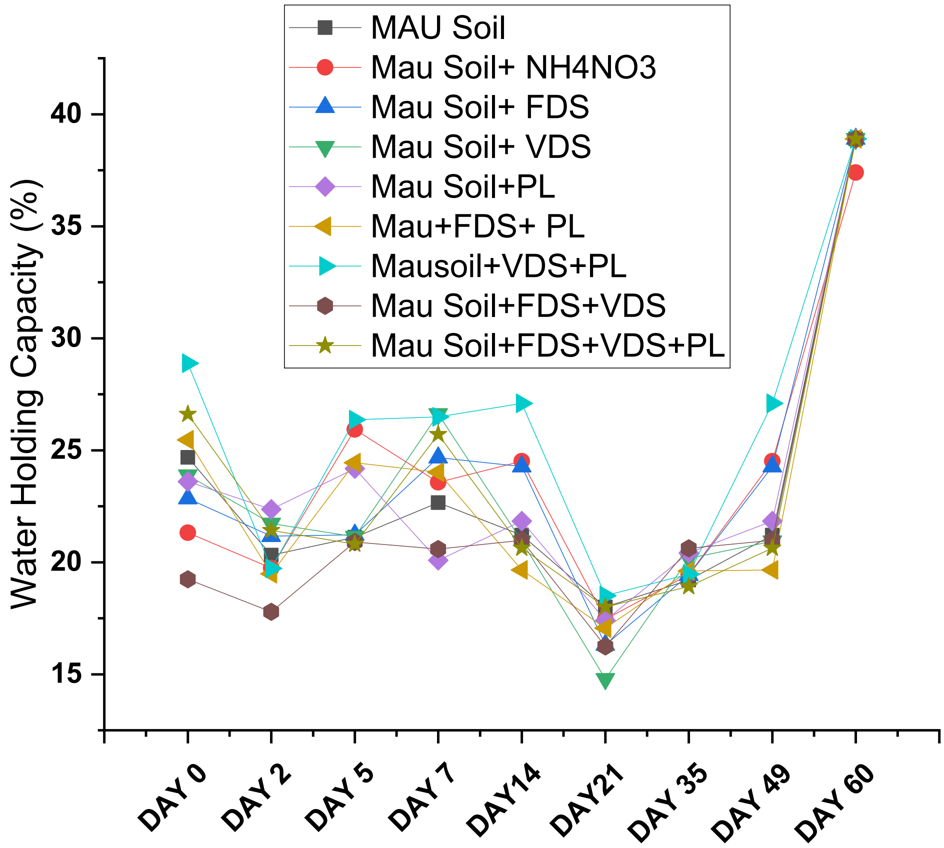

Figure 10: Percentage Soil Water Holding Capacity during 60 days of Incubation Studies. (MAU soil= Soil from Modibbo Adama University Teaching and Research Farm, Yola, FDS=fruit dumpsite soil, VDS= Vegetable dumpsite soil, PL= Poultry litter)

IV. CONCLUSION

In conclusion, the study demonstrates that organic wastes from fruit and vegetable dumpsites and poultry litter are effective in enhancing soil nitrogen availability and improving soil physical properties. Fruits and vegetable dumpsite soils and poultry litter substantially enhance nitrogen mineralization and improve key soil properties, including organic carbon content, porosity, and water-holding capacity. The combination of FDS, VDS, and PL provided the greatest benefit, suggesting that integrated application of locally available organic residues can serve as an effective, sustainable, and environmentally friendly strategy for improving soil fertility in the study area. These organic amendments offer a viable alternative to chemical fertilizers, contributing to resource-efficient and climate-smart agricultural practices.

REFERENCES

[1] Abbasi, M. K., & Khaliq, A. (2016). Soil organic carbon dynamics under different organic amendments: Implications for carbon sequestration. Environmental Science and Pollution Research, 23(22), 22994–23005.

[2] Abdallah, M., El-Hady, M., & Abdel-Gawad, A. (2019). Role of soil organic matter in improving water retention and crop productivity. Journal of Soil Science and Plant Nutrition, 19(2), 456–468.

[3] Adebayo, A. A., Ibrahim, A., & Yusuf, M. (1999). Climate, soils, and land use in Adamawa State, Nigeria. Nigerian Journal of Soil Science, 9, 1–12.

[4] Adekiya, A. O., Agbede, T. M., Olayanju, A., Ejue, W. S., Dunsin, O., Aboyeji, C. M., & Adesola, O. O. (2019). Poultry manure and NPK fertilizer effects on soil properties and performance of cucumber. Scientific Reports, 9, 15936.

[5] Agboola, A. A. (1998). Organic matter and soil fertility management in the tropics. Ibadan University Press.

[6] Agyeman, P. C., Amoah, N., & Alhassan, M. (2023). Organic waste recycling and soil fertility improvement in tropical agroecosystems. Environmental Sustainability, 6(2), 175–187.

[7] Amoakwah, E., Frimpong, K. A., & Asiedu, E. K. (2020). Biodegradable market waste as a soil amendment: Effects on soil nutrient dynamics. Waste Management, 118, 610–618.

[8] Anderson, J. M., & Ingram, J. S. I. (1994). Tropical soil biology and fertility: A handbook of methods (2nd ed.). Wallingford, UK: CAB International.

[9] Angin, I., Kizilkaya, R., Gunes, A., & Inal, A. (2013). Influence of organic amendments on soil bulk density and porosity. Soil Science and Plant Nutrition, 59(3), 415–425.

[10] Azeez, J. O., & Van Averbeke, W. (2012). Ammonium and nitrate release from organic amendments in tropical soils. Nutrient Cycling in Agroecosystems, 92(2), 203–214.

[11] Bray, R. H., & Kurtz, L. T. (1945). Determination of total, organic, and available forms of phosphorus in soils. Soil Science, 59(1), 39–46

[12] Ch'ng, H. Y., Ahmed, O. H., & Majid, N. M. A. (2020). Nitrogen mineralization from poultry litter and its effect on soil chemical properties. Agronomy Journal, 112(3), 1971–1984.

[13] Dent, D., & Young, A. (1981). Soil survey and land evaluation. London: George Allen & Unwin.

[14] Dent, D., & Young, A. (1981). Soil survey and land evaluation. London: George Allen & Unwin.

[15] Escudero, A., González-Moro, M. B., & Martínez-Ros, E. (2012). Nitrogen transformations and availability in soils amended with organic residues. Soil Biology and Biochemistry, 47, 1–10.

[16] Hassan, M. A., Chen, Q., Liu, G., & Zhang, Z. (2022). Poultry manure application improves soil nitrogen dynamics and microbial functioning. Soil Systems, 6(3), 46.

[17] Ikeh, M. N., Onwukwe, J. C., & Udoh, B. A. (2013). Effects of organic amendments on soil water retention and structure in degraded soils. International Journal of Agriculture and Forestry, 3(5), 220–227.

[18] Jaiswal, A. K. (2003). Soil physical and chemical analysis methods. New Delhi: Agrobios Publishers.

[19] Layman, R. (2010). Soil physical properties and the "fluff effect" of organic matter. Soil Science Review, 44(2), 105–112.

[20] Liang, Q., Xie, J., & Wang, J. (2023). Organic amendments and nitrogen cycling in agricultural soils: A microbial perspective. Frontiers in Soil Science, 3, 1159084.

[21] Mamza, J., Ali, A., & Bala, A. (2018). Geomorphology and soil-landscape relationships in the Benue Valley, Northeast Nigeria. Journal of African Earth Sciences, 145, 193–204.

[22] Marinari, S., Masciandaro, G., Ceccanti, B., & Grego, S. (2000). Influence of organic and mineral fertilizers on soil biological and physical properties. Bioresource Technology, 72(1), 9–17.

[23] Masunga, T. L., Kutu, F., & Sileshi, G. W. (2016). Nitrogen mineralization from organic residues in tropical soils. Agriculture, Ecosystems & Environment, 218, 68–77.

[24] Mirchaulum, M. (1999). Climatic characteristics of Adamawa State, Nigeria. Nigerian Journal of Meteorology, 4(2), 25–33.

[25] Musa, A., Azeez, J. O., & Van Averbeke, W. (2021). Organic amendments and nitrogen mineralization in tropical soils. Soil Use and Management, 37(3), 441–454.

[26] Nawara, S., Adam, B., & Kowalski, P. (2017). Effects of organic matter addition on soil-available water and crop yields: A meta-analysis. Soil Use and Management, 33(2), 147–156.

[27] Nelson, D. W., & Sommers, L. E. (1982). Total carbon, organic carbon, and organic matter. In A. L. Page (Ed.), Methods of soil analysis: Part 2, Chemical and microbiological properties (pp. 539–579). Madison, WI: ASA and SSSA.

[28] Okoro, C. C., Nwankwoala, H. O., & Mbah, G. B. (2022). Effects of urban organic waste dumpsite soils on soil fertility and heavy metal dynamics. Environmental Challenges, 7, 100510.

[29] Olsen, S. R., & Dean, L. A. (1965). Phosphorus. In C. A. Black (Ed.), Methods of soil analysis, Part 2: Chemical and microbiological properties (pp. 1035–1049). Madison, WI: American Society of Agronomy.

[30] Orimisan, S., Adeyemi, F., & Oluwaseun, A. (2024). Effects of organic amendments on soil

pH and microbial activity. Journal of Agricultural Science, 16(1), 55–68.

[31] Reicosky, D. C. (2003). Organic amendments and soil water relations: Effects of compost and manure. Soil Science, 168(9), 655–667.

[32] Roy, S., & Kashem, M. A. (2014). Dynamics of soil pH under organic amendments. Communications in Soil Science and Plant Analysis, 45(18), 2370–2382.

[33] Singh, S., & Shah, S. (2021). Biodegradation of fruit and vegetable waste and its impact on soil properties. Journal of Environmental Management, 287, 112333.

[34] Smith, P. (2018). Soil organic matter and hydrological properties: Implications for water retention and storage. Global Change Biology, 24(1), 27–35.

[35] Somda, Z. C., Sanon, A., & Somé, K. (2020). Nitrogen mineralization from organic residues under varying soil and climatic conditions. Nutrient Cycling in Agroecosystems, 117, 297–309.

[36] Syarif, A. (2018). Dynamics of organic carbon and nutrients after organic waste addition in an acid soil. International Journal of Agriculture, Environment and Biotechnology, 11(1), 55-64.

[37] Tratsch, W., Müller, H., & Hoffmann, C. (2019). Organic residue application and nitrogen mineralization in temperate soils. Nutrient Cycling in Agroecosystems, 115(2), 183–197.

[38] Udoh, A., Udo, E. J., & Essien, J. P. (2005). Organic matter amendments and soil water retention in Nigerian ultisols. Nigerian Journal of Soil Science, 15, 20–28.

[39] Wanjiru, J., Kihara, J., & Sommer, R. (2021). Organic resource quality influences nitrogen release and soil fertility improvement. Agriculture, Ecosystems & Environment, 306, 107200.

[40] Zhao, X., Li, R., & Wang, Y. (2023). Microbial influence on nitrogen dynamics in soils amended with organic residues. Applied Soil Ecology, 190, 104750.