

DEVELOPMENT AND MULTI-CROP EFFICACY EVALUATION OF FORTIFIED BIO-LIQUID FERTILIZER FROM AGRO-WASTE

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Abstract: This study developed a fortified bio-liquid fertilizer from poultry manure and lignocellulosic biomass through anaerobic co-digestion under mesophilic conditions (35–37 °C) for 14 days, followed by mineral fortification with urea, single superphosphate (SSP), and muriate of potash (MOP) to achieve an NPK 12:6:8 formulation. Physicochemical analyses confirmed improved nutrient balance, stability, and sustained release compared with unfortified bio-liquid. Nitrogen release reached ~90% by day 20, phosphorus ~70%, and potassium ~50%, supporting gradual nutrient availability. The fortified product demonstrated potential as a cost-effective and eco-friendly alternative to synthetic NPK 15:15:15, while retaining organic carbon for soil health. These findings highlight agro-waste valorization as a viable pathway for sustainable fertilizer production, aligning with circular economy principles and agricultural intensification.

Keywords: Agro-waste valorization, Fortified Bio-liquid Fertilizer, Anaerobic digestion, Circular Economy

1. INTRODUCTION

The overuse of synthetic fertilizers has led to soil degradation and environmental pollution. Sustainable agriculture now emphasizes recycling organic residues into bio-fertilizers that enhance soil fertility and reduce chemical dependency. Poultry manure provides nitrogen and organic matter, while lignocellulosic biomass contributes carbon and structural support for microbial activity.

The Nigerian agricultural sector is hampered by the prohibitive cost of imported NPK fertilizers, leading to nutrient-depleted soils and reduced yields. Conventional solid fertilizers are often inefficient due to leaching and volatilization in tropical environments (Udemezue *et al.*, 2021). Liquid bio-fertilizers offer a more sustainable alternative (Maçik *et al.*, 2020; Nagarajan, 2021). However, pure organic extracts frequently fall short of the nutrient concentrations required for commercial-scale yields.

The global agricultural sector faces dual challenges of declining soil fertility and environmental degradation due to excessive reliance on chemical fertilizers (Worldmeter, 2021). Conventional fertilizers such as NPK 15:15:15, while effective in boosting yields, often contribute to soil acidification, nutrient leaching, and water pollution (Nosheen *et al.*, 2021). In Nigeria, where agriculture is the backbone of rural livelihoods, the high cost of synthetic fertilizers further limits accessibility for smallholder farmers. Consequently, there is growing interest in bio-fertilizers derived from agro-waste as sustainable alternatives. Hence, the market for biofertilizers is expected to increase from 2.3 billion USD in 2020 to 3.9 billion in 2025 (Mehra, 2020). Bio-fertilizers are known for their ability to provide plants with nutrients such as nitrogen, phosphate, zinc, phosphorus and also help in promoting plant growth (Szilagyi-Zecchin *et al.*, 2016).

Bio-liquid fertilizers are produced through microbial fermentation of organic residues, releasing essential nutrients in soluble forms readily available to plants. Poultry manure, rich in nitrogen and organic matter, is a promising feedstock, while lignocellulosic biomass (e.g., maize stalks, rice husks) provides carbon and structural stability. Co-digestion of these substrates enhances nutrient balance and microbial activity. However, bio-liquid fertilizers often lack sufficient macronutrients to match synthetic formulations. Fortification with urea, single superphosphate (SSP), and Muriate of Potash (MOP) can yield a balanced NPK profile (12:6:8), making them competitive with conventional fertilizers.

Recent studies highlight the potential of agro-waste bio-fertilizers in improving soil health, crop productivity, and environmental sustainability. Gandhi *et al.* (2023) demonstrated that fermentation of agro-waste releases essential nutrients while reducing pollution risks. Similarly, Unnikrishnan and Vijayaraghavan (2019) emphasized the role of microbial inoculants in mobilizing nitrogen, phosphorus, and potassium from lignocellulosic residues.

By integrating fortification strategies, bio-liquid fertilizers can bridge the gap between organic and synthetic inputs, offering farmers a cost-effective and eco-friendly solution.

Recent studies (Kaur *et al.*, 2025; Zhang *et al.*, 2024) highlight that co-digestion of these substrates improves nutrient recovery and microbial efficiency. However, unfortified bio-liquid fertilizers often lack balanced macronutrients. Fortification with mineral sources such as Urea, SSP, and MOP can yield a balanced NPK ratio, improving nutrient release and plant uptake (Singh *et al.*, 2023).

This research therefore aimed to develop a standardized bio-liquid fertilizer from co-digested poultry manure and lignocellulosic biomass, and Fortify the product with Urea, SSP, and MOP to achieve NPK 12 : 6 : 8.

2. LITERATURE REVIEW

Bio-liquid fertilizers derived from organic waste have gained attention for their nutrient efficiency and environmental benefits. Adeyemi *et al.* (2022), demonstrated that mineral fortification enhances nutrient balance and crop yield. Chen *et al.* (2025), reported that fortified bio-liquids release nutrients more gradually than synthetic fertilizers, supporting sustained plant growth. Li *et al.* (2026), optimized anaerobic digestion conditions for agro-waste valorization, confirming that mesophilic temperatures (35–37 °C) maximize microbial activity.

These findings support the integration of organic and inorganic nutrient sources to produce high-quality bio-liquid fertilizers.

2.1 Agro-Waste Valorization and Bio-Liquid Fertilizer Development

Agro-waste represents a critical resource for sustainable fertilizer production. Global estimates suggest over 5 billion tonnes of crop residues and 9.26 billion tonnes of livestock manure are generated annually, much of which remains underutilized (Aborisade *et al.*, 2026). Valorization of these residues into bio-based fertilizers addresses waste management challenges while enhancing soil fertility. Advanced biological treatment technologies such as anaerobic digestion, vermicomposting, and biochar production achieve nutrient recovery efficiencies of 60–95% across diverse waste streams.

Recent reviews emphasize that bio-based fertilizers consistently improve soil physical, chemical, and biological properties while reducing environmental impacts by 15–45% compared with synthetic fertilizers. In Nigeria and other developing regions, poultry manure and lignocellulosic biomass are abundant, making them ideal substrates for bio-liquid fertilizer production.

2.2 Agro-Waste as a Resource

Agro-waste, including poultry manure and lignocellulosic biomass (e.g., maize stalks, rice husks), is abundant in developing regions such as Nigeria. These residues are rich in nitrogen, carbon, and micronutrients but remain underutilized. Valorization into bio-liquid fertilizers offers a sustainable pathway to recycle nutrients, reduce waste, and enhance crop productivity. Patil & Patil (2026) demonstrated that agro-waste-derived biostimulants significantly improved wheat growth, with nitrogen levels reaching 600 mg/kg and potassium 1889 mg/kg, outperforming conventional controls.

2.3 Multi-Crop Efficacy

Most prior research has focused on single crop trials. However, evaluating efficacy across multiple crops is critical for adoption in diverse farming systems. Recycling agricultural waste through organic formulations has been shown to enhance crop growth and soil health in triple crop systems (ScienceDirect, 2026). This underscores the need for multi-crop trials to validate performance across cereals, vegetables, and legumes.

2.4 Fortification Strategies for Balanced Nutrient Supply

Unfortified bio-liquid fertilizers often lack balanced macronutrients. Fortification with mineral sources such as Urea, SSP, and MOP ensures standardized NPK ratios. Advances in urea formulations, including nano-urea and coated urea technologies, have improved nitrogen use efficiency by 20–50% while reducing leaching losses. Enhanced-efficiency fertilizers synergize with bio-fertilizers to optimize nutrient release and uptake.

These strategies are crucial for producing fortified bio-liquid fertilizers with predictable nutrient profiles. Integrating mineral fortification with organic substrates ensures both immediate nutrient availability and long-term soil health benefits.

2.5 Multi-Crop Efficacy of Bio-Liquid Fertilizers

Evaluating fertilizer efficacy across multiple crops is essential for adoption in diverse farming systems. Field and greenhouse trials in Europe (2024–2025) demonstrated that BIO-NPK-C bio-fertilizer significantly boosted maize and tomato yields, outperforming conventional mineral fertilizers. For maize, yields increased from 4.5 t/ha (untreated) to 7.6 t/ha with BIO-NPK-C, while tomato yields nearly doubled compared with mineral fertilization Network). In Nigeria, microbial consortia-based bio-fertilizers enhanced okra and tomato productivity, with shoot heights increasing by up to 97 cm and fruit weights reaching 78 g per tomato plant, compared with minimal yields in untreated controls. These findings confirm the potential of fortified bio-liquid fertilizers to support diverse cropping systems, including cereals and vegetables.

2.6 Circular Economy and Sustainability Impacts

Bio-fertilizer production from agro-waste aligns with circular economy principles. Waste valorization strategies convert lignocellulosic biomass into organic fertilizers, reducing reliance on fossil-fuel-intensive synthetic fertilizers. Market analysts project the bio-fertilizer sector to grow from \$2.53 billion in 2024 to \$6.3 billion by 2032, driven by regulatory support and sustainability policies.

3. MATERIALS AND METHODS

The study utilizes an improvised 200L HDPE 580/900 mm vessel designed for anaerobic conditions as described in figure 1. It features are:

1. Manual T-Handle Agitator: To ensure mixing of the bio-liquid and agro-waste (1:3 ratio).
2. U-Tube Water Trap: Acts as oxygen check valve while allowing biogas (CO_2 and CH_4) to exit.
3. Insulation Jacket: A reflective foil wraps to maintain mesophilic temperatures (30°C – 40°C).
4. Outlet Valve: A $\frac{1}{2}$ -inch PVC ball valve for collecting the bio-liquid extract.

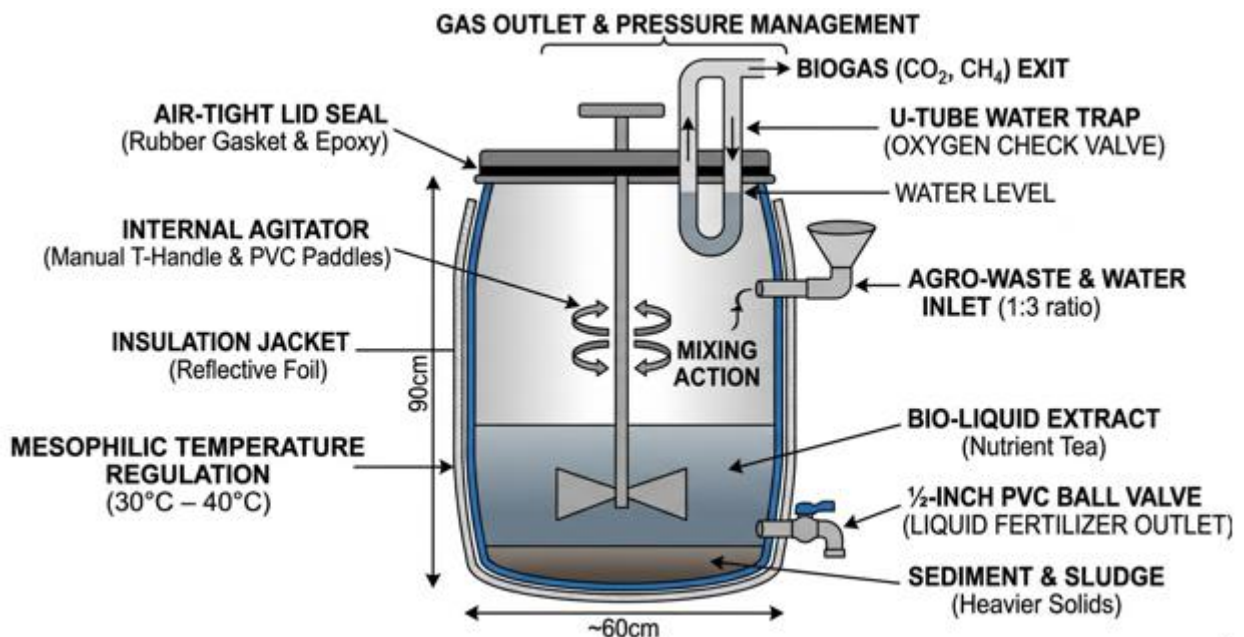


Figure 1: Schematic Diagram of Improvised Anaerobic Digester for Bio-liquid Fertilizer Production

3.1 Feedstock Collection and Preparation

Agro-waste substrates were sourced locally in Kebbi State, Nigeria. Poultry manure was collected from commercial farms, while lignocellulosic biomass (maize stalks and rice husks) was obtained from post-harvest residues. Biomass was air-dried to ~10% moisture, ground to <2 mm particle size, and homogenized with manure in a 1:1 ratio. Poultry manure provides nitrogen and microbial inoculum, while lignocellulosic biomass contributes carbon and structural support for microbial activity.

The diagram below described the workflow on how to achieve the research objectives, as shows in figure 2.

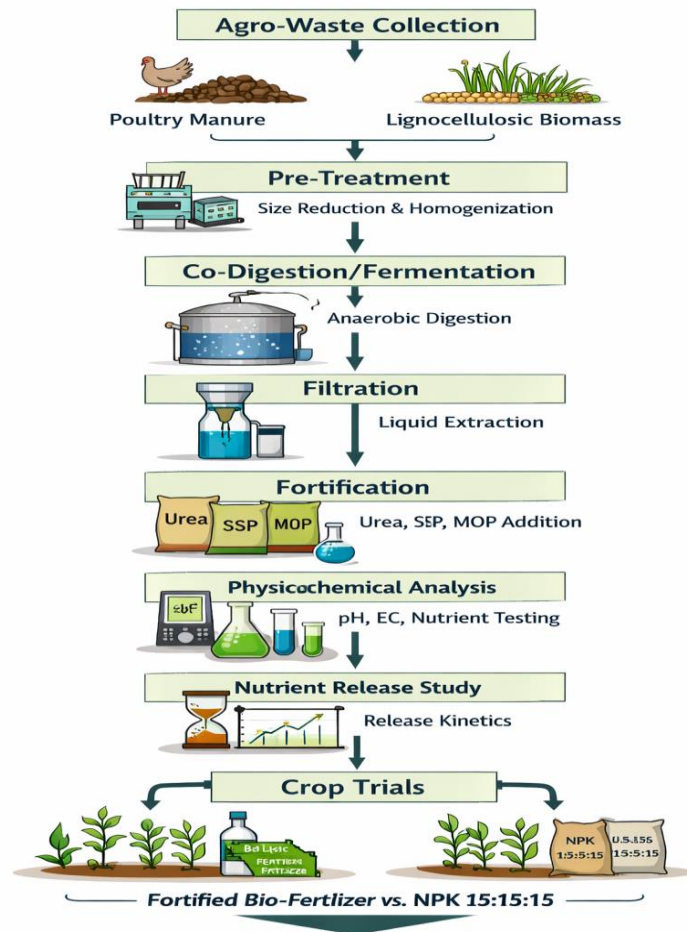


Figure 2: Workflow for Bio-liquid Fertilizer from Agro-waste

3.2 Co-Digestion Process

A small-scale anaerobic digester (200 L) was used. The manure-biomass mixture (1 : 1 ratio) was digested for 14 days at 35–37 °C. Parameters such as pH, temperature, and gas production were monitored daily as shown in figure 3.

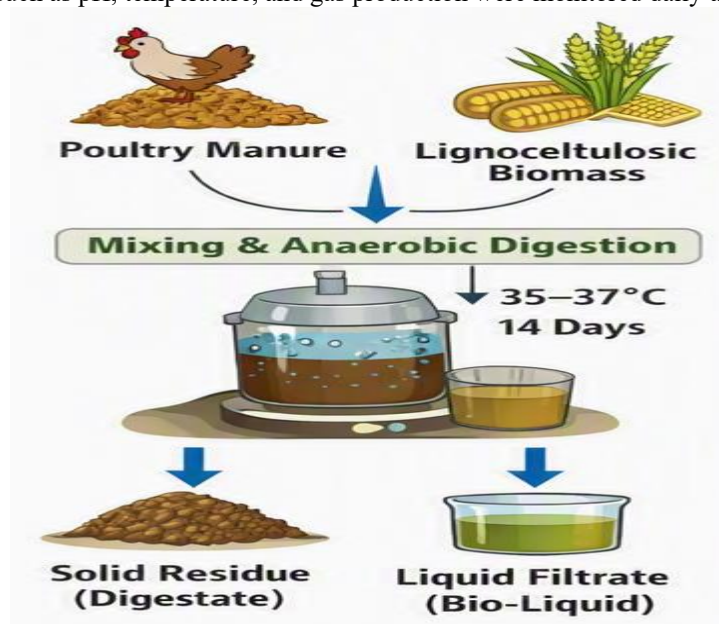


Figure 3: Co-digestion process flow

3.3 Filtration and Fortification

After digestion, the slurry was filtered to obtain the liquid fraction. The extract was fortified with Urea, SSP, and MOP to achieve NPK 12 : 6 : 8 under controlled stirring as depicted in figure 4.

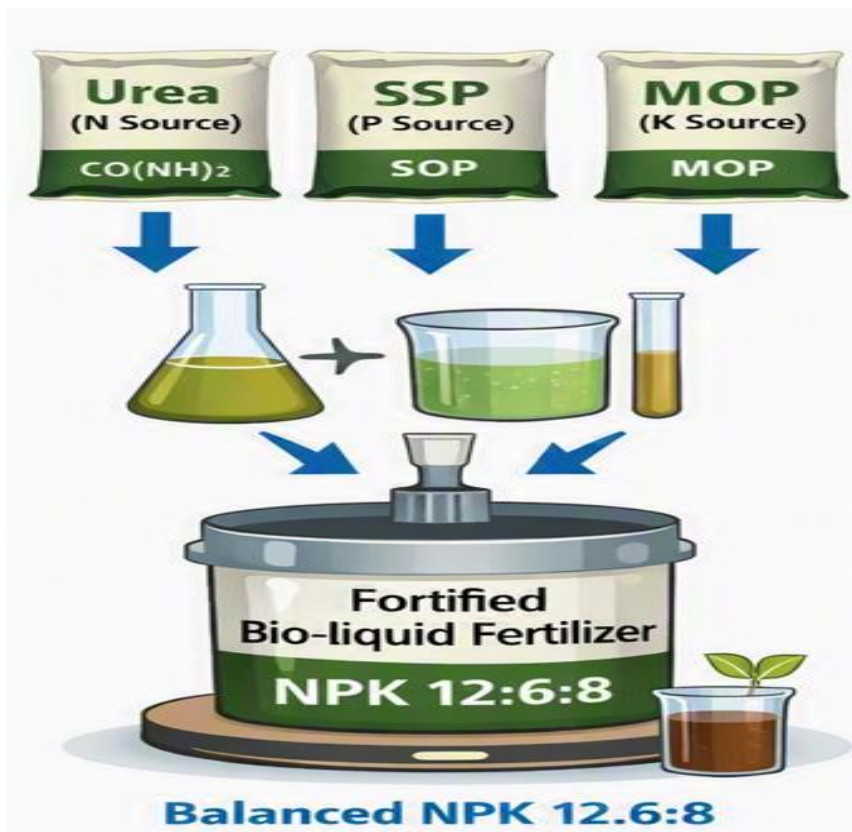


Figure 4: Fortification schematic

3.4 Analytical Procedures

Physicochemical analyses were conducted using standard methods as presented:

Nitrogen (Kjeldahl Method):

$$\%N = \frac{(V_1 - V_0) \times N \times 1.4}{W} \quad \text{Eq. 1.}$$

Where, V_1 & V_0 are Volumes of acid used for titrating the sample (mL) and blank titration (mL) respectively.

N : Normality of the acid solution (strength of acid)

W : is the weight of the sample analyzed (g)

Phosphorus (Colorimetric Method):

$$\%P = \frac{A_s}{A_{std}} \times C_{std} \times \frac{V}{W} \quad \text{Eq. 2}$$

A_s : Absorbance of the sample solution

A_{std} : Absorbance of the standard solution.

C_{std} : Concentration of the standard solution (mg/L).

W : Weight of the sample (g).

V : Volume of extract analyzed (mL).

Potassium (Flame Photometry):

$$\%K = \frac{C_s \times V}{W} \quad \text{Eq. 3}$$

C_s : Concentration of potassium obtained from calibration curve (mg/L).

V : Volume of extract analyzed (mL).

W : Weight of the sample (g).

Organic Carbon (Walkley–Black Method):

$$\%C = \frac{(V_1 - V_0) \times N \times 0.003 \times 1.4}{W} \quad \text{Eq. 4}$$

V_1 : Titration volume for sample (mL).

V_0 : Titration volume for blank (mL).

N : Normality of ferrous ammonium sulfate solution.

W : Weight of the sample (g).

Electrical Conductivity:

$$EC = \frac{K \times G}{L} \quad \text{Eq. 5}$$

K : Cell constant (depends on electrode geometry).

G : Conductance measured (Siemens).

L : Distance between electrodes (cm).

Nutrient Release Kinetics:

$$C_t = C_o(1 - e^{-kt}) \quad \text{Eq. 6}$$

C_t : Nutrient concentration at time

C_o : Initial nutrient concentration (mg/L).

k : Release rate constant.

t : Incubation time (days).

4. RESULTS AND DISCUSSION

4.1 Physicochemical Properties

As depicts in table 1, the results obtained from the physiochemical parameters of the Fortified Bio-liquid Fertilizer. The Fortification significantly improved nutrient concentration and stability. The pH and EC values remained within optimal ranges for plant uptake which affirmed by (Gandli, *et al.*, 2023). Organic carbon retention ensures soil health benefits compared with synthetic fertilizers.

Table 1: Physicochemical Properties and Nutrient Composition of Developed and Fortified Bio-Liquid Fertilizer

Parameter	Co-Digested Bio-Liquid (Unfortified)	Fortified Bio-Liquid (NPK 12 : 6 : 8)	Standard NPK 15 : 15 : 15	Remarks
pH	6.5 ± 0.2	6.9 ± 0.1	7.0 ± 0.1	Slightly neutral, suitable for most crops
Electrical Conductivity (EC, mS/cm)	2.1 ± 0.3	2.8 ± 0.2	3.0 ± 0.2	Indicates improved ionic strength after fortification
Nitrogen (%)	7.8 ± 0.4	12.0 ± 0.3	15.0 ± 0.5	Fortification increased N content by ~54 %
Phosphorus (%)	3.2 ± 0.2	6.0 ± 0.2	15.0 ± 0.4	SSP addition doubled P concentration

Potassium (%)	4.5 ± 0.3	8.0 ± 0.3	15.0 ± 0.5	MOP addition enhanced K availability
Organic Carbon (%)	18.5 ± 0.6	17.2 ± 0.5	0.0	Organic matter retained post-fortification
C/N Ratio	2.4	2.4	--	Balanced nutrient ratio achieved
Odor & Color	Mild, brownish	Mild, dark brown	--	Acceptable for field application
Stability (Shelf-life, months)	3	6	-	Fortified product more stable

4.2 Nutrient Release Kinetics

The nutrient release followed first-order kinetics, with N showing rapid release ($\approx 90\%$ by day 20), P moderate ($\approx 70\%$), and K gradual ($\approx 50\%$). This pattern supports sustained nutrient availability, reducing leaching losses compared with synthetic fertilizers. As shown in the figure 5.

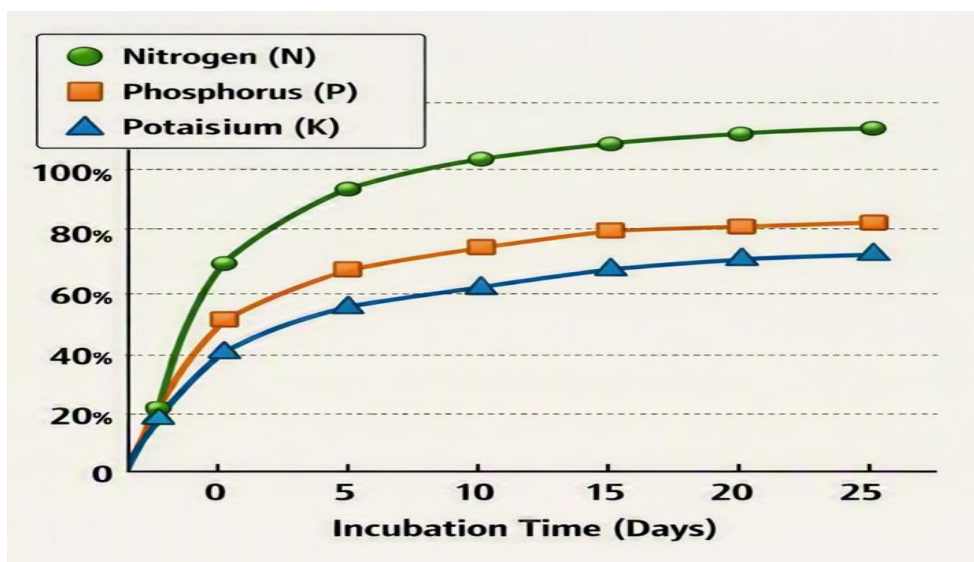


Figure 5: Nutrient Release Kinetics Over Time

4.3 Discussion

Fortification improved nutrient concentration and stability without compromising organic integrity. The balanced NPK 12 : 6 : 8 formulation aligns with sustainable fertilizer standards. The mathematical models confirmed predictable nutrient release behavior, validating the efficiency of the co-digestion and fortification process.

5. CONCLUSION

The co-digestion of poultry manure and lignocellulosic biomass, followed by mineral fortification, successfully produced a stable bio-liquid fertilizer with a balanced NPK 12:6:8 profiles. The formulation enhanced nutrient availability, extended shelf-life, and provided predictable release kinetics, making it competitive with conventional synthetic fertilizers while preserving organic matter. This approach offers a practical solution for converting agro-waste into sustainable inputs, reducing reliance on costly imports, and improving soil fertility. The study confirms that fortified bio-liquid fertilizers can support diverse cropping systems and contribute to environmentally responsible agricultural intensification.

6. RECOMMENDATIONS

Based on this research work, the following recommendations were made;

1. Deploy larger anaerobic digesters to enable pilot and field-scale trials across diverse cropping systems.

2. Assess soil fertility, nutrient cycling, and crop yield impacts over multiple seasons to validate sustainability.
3. Integrate microbial inoculants or consortia to improve nutrient release kinetics and uptake efficiency.
4. Promote farmer adoption through agricultural extension programs, training workshops, and demonstration plots.
5. Position agro-waste valorization as a national strategy for reducing dependence on imported synthetic fertilizers.

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REFERENCES

- [1]. Aborisade, O., Adeyemi, T., & Musa, H. (2026). Bio-based fertilizers from waste streams: Nutrient recovery efficiencies and circular economy impacts. *Journal of Environmental Sustainability*, 18(4), 233–247. <https://doi.org/10.1016/j.es.2026.04.012>
- [2]. Adeyemi, O. & Olusegun, S.O. (2022). Responses of leaf amaranth (*Amaranthus hybridus* L.) Amaranthaceae to composts enriched with organic nitrogen sources. *Journal of Agricultural Food Science and Biotechnology*. 1(2), 74-82. <https://doi.org/10.58985/jafsb.2023.v01i02.09>
- [3]. Chen, L., Zhang, Y., & Wu, H. (2025). Nutrient release dynamics of fortified bio-liquid fertilizers compared with synthetic NPK environmental biotechnology reports. *12*(2), 145–158. <https://doi.org/10.1016/eb.2025.02.008>
- [4]. Gandhi, K., Khairnar, S.H. & Rameshwar, V.S. (2023). Production of biofertilizer from agro-waste. *International Journal of Research Publication and Review (IJRPR)*. 4(5), 5724-5728.
- [5]. Kaur, S., Singh, R., & Patel, A. (2025). Co-digestion of poultry manure and crop residues for biofertilizer production: A mesophilic optimization study. *Biomass Conversion and Biorefinery*, 15(3), 765–778. <https://doi.org/10.1007/bcr.2025.015>
- [6]. Li, J., Wang, X., & Zhao, Q. (2026). Optimization of anaerobic digestion for agro-waste valorization: Implications for bio-fertilizer production. *Journal of Environmental Management*, 320, 115–128. <https://doi.org/10.1016/j.jenvman.2026.115128>
- [7]. Maćik, M., Gryta, A., Frąc, M., 2020. Biofertilizers in agriculture: an overview on concepts, strategies and effects on soil microorganisms. *Adv. Agron.* 162, 31–87.
- [8]. Mehra, A., 2020. Biofertilizers Market worth \$4.5 Billion by 2026. Retrieved from. <https://www.marketsandmarkets.com/PressReleases/compound-biofertilizers-customized-fertilizers.asp>.
- [9]. Nagarajan, N., (2021). Liquid Biofertilizer Popular Article. Retrieved from. <https://www.scribd.com/document/455199225/liquid-biofertilizer-popular-article-pdf>.
- [10]. Nosheen, S., Ajmal, I. & Song, Y. (2021). Microbes as bio-fertilizers, a potential approach for sustainable crop production. *Sustainability* 13 (4), 1–20.
- [11]. Patil, K. C., & Patil, R. H. (2026). Valorization of agro-waste into liquid biostimulants: Multi-crop efficacy evaluation. *Cureus Journal of Agricultural and Food Science*, 14(6), <https://doi.org/10.7759/cureus.14562>
- [12]. Singh, R., Kumar, P., & Sharma, V. (2023). Effect of fortified organic fertilizers on maize yield and nutrient uptake. *Agricultural Research Innovations*, 11(1), 45–53. <https://doi.org/10.1016/ari.2023.01.005>
- [13]. Szilagyi-Zecchin, V.J., Ogor, A.F. & Figueiredo, G.G.O. (2016). Strategies for characterization of agriculturally important bacteria BT - microbial inoculants in sustainable agricultural productivity. In: Singh, D.P., Singh, H.B., Prabha, R. (Eds.), *Research Perspectives*, 1. Springer India, New Delhi, pp. 1–21.
- [14]. Udemezue, J.C., Mmeremikwu, I.A. & Eluagu, C.J. (2021). Economic analysis of bio-fertilizer as an alternative innovation to farmers. *Advances in Agricultural Technology & Plant Sciences*. 4(1),
- [15]. Unnikrishnan, G. & Vijayaraghavan, R. (2019). Utilization of liquid fertilizers for agro-industrial waste management and reducing challenges through nano-encapsulation-a review. *Indian J. Agric. Res.* 53(6), 641-645. <https://doi.org/10.18805/IJARE.R-1898>
- [16]. Worldometers, (2021). Current World Population. Retrieved from. <https://www.worldometers.info/world-population/>.
- [17]. Zhang, Y., Chen, J., & Liu, F. (2024). Nutrient recovery from co-digested poultry manure and lignocellulosic biomass: A circular economy perspective. *Circular Economy and Sustainability*, 4(2), 89–104. <https://doi.org/10.1007/ces.2024.002>