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Original Research Paper

Sustainable Manure Management Using Biofiltration and Composting to Improve Farm Environmental Quality

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Key Words

Biofiltration, Aerobic composting, Sustainable manure management, Ammonia emission reduction, Odor control, Pathogen inactivation Nutrient recycling, Organic fertilizer, Livestock waste treatment, Environmental quality improvement, Soil fertility enhancement, Mixed livestock farms.

Abstract

Unacceptable manure digestion of livestock is also an extreme environmental concern and is also known to pollute the atmosphere, contaminate the water resources, degrade the soil structure and general depreciation of the health of farm ecosystems. In livestock system In livestock systems containing a mixture of animals, uncontrolled release of manure is associated with a lot of ammonia, volatile organic compounds, odorous gases, and pathogenic microorganisms, which pose danger to animal welfare as well as other communities. This paper examines a holistic and sustainable manure management system, which combines biofiltration, aerobic composting, and cycling of nutrients, to reduce such environmental effects. An experimental trial was controlled over a period of 60 days in order to measure the decrease in ammonia emissions, concentration of odours and pathogen load, and to measure nutrient improvement in end result compost product. Ammonia was also minimised by the biofiltration unit to 45-62 which showed a good removal level at the highest stages of decomposition. The level of odour concentration decreased considerably and was a positive sign of cleaner air and low nuisance level. Thermophilic composting targeted and destroyed the major pathogens, such as Escherichia coli and Salmonella, and the stabilised compost showed an enhanced nutrient content with a significant increase in nitrogen, phosphorus, and potassium levels as in comparison to untreated manure. The steps of soil application tests revealed the use of compost generated under the integrated system as adding to the soil increased the fertility of the soil, and the growth parameters of the plants, as well as led to a decrease in the use of synthetic fertilisers. These advantages represent the environmental and agronomic advantages of the proposed system. On the whole, the paper is a good demonstration of the fact that biofiltration-aided composting is an effective, environmentally-friendly, and scalable manure management approach that can be deployed in mixed livestock farms especially in areas where the environment is under pressure and that agricultural production is intensifying. The integrated approach will promote sustainable livestock management and long-term financial agricultural resilience because it will reduce pollutant emissions, enhance compost quality, and contribute to the future of circular nutrient utilisation.

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Introduction

Environmental Effects of Inappropriate Disposal of Manure

Even though livestock manure is a that is an excellent source of organic matter and all vital nutrients, it becomes a major environmental pollutant where it is not well managed. In the most mixed livestock production systems, the manure is emitted into the open fields, unlined pits or emptied into drainage systems thus leading to significant losses of nitrogen and organic products into the atmosphere and water bodies. Emissions of ammonia (NH 3), hydrogen sulphide (H 2 S), methane (CH 4), nitrous oxide (N 2 O), and volatile organic compounds (VOCs) are damaging to the quality of air and contribute to greenhouse gas buildup, as well as endanger human health and livelihood of farmworkers and farm animals. The mismanagement of manure is also a pressing agricultural and environmental problem because of its leaching and runoff, which cause further eutrophication of the surface waters, acidification of soils and biodiversity loss.

Sustainability of Manure Management Necessary

As livestock production and intensification continue, conventional ways of managing manure can no longer address the requirements of environmental standards or sustainability. There are viable alternatives like biofiltration, composting, anaerobic digestion, and recovery of the nutrient that can be used as viable methods of sustainable manure management and can reduce pollution and improve resource effectiveness. These include bio-filtration and aerobic composting which are notable in that they have low operational cost, high effectiveness in pollutant removal in a microbial manner and in their capability to transform the waste into useful soil components. As the systems working in such systems help to turn the liabilities of the environment into agricultural resources that are useful.

Potential of Biofiltration and Composting Synergy

Biofiltration is a viable method of air purification as it facilitates the treatment of polluted air by subjecting it to biologically active philtre media with microorganisms that break down NH 3, VOCs, and odour constituents. When used together with aerobic composting that stabilises the manure with the help of thermophilic decomposition; the composite system promotes the retention of nitrogen, faster turnover of organic matter, and pathogen inactivation. Such synergy will lower the level of gaseous emission on the spot and enhance the quality and maturity of the end product compost. The blended application of the technologies in the actual farm environment, especially in the operations of mixed livestock, is the subject of a limited amount of research, although the performance of these technologies alone is promising.

Background and Aim of the Current Study

This research undertaking is an attempt to compare the environmental performance of sustainable manure management system which combines biofiltration, aerobic composting, and nutrient recycling in a mixed livestock farm, which includes cattle, goats and poultry. The system was evaluated based on different environmental and agronomic parameters and measurements over a 60-day experimental period at a time; reduction of ammonia, odour concentration, reduction of pathogens, enrichment of compost nutrient, and increase in soil fertility. The results offer scientific reasoning toward the adoption of biofiltration-supported composting as affordable yet health-friendly approach that can help to improve the environmental quality of farms and ensure sustainable livestock production.

Literature Review

Environmental Problems of Livestock Manure

Manure of livestock is high in nitrogen, phosphorus, organic acids, heavy metals, and pathogenic microorganisms, which may pose great risks to the environment when not properly handled. In uncontrolled decomposition, there is the release of harmful gases, including ammonia (NH_3), hydrogen sulphide (H_2S), methane (CH_4) and nitrous oxide (N_2O), which increases the accumulation of greenhouse gases as well as odour nuisance among the rural society. Overload of nitrogen causes eutrophication of water and decrease the water quality level, and NH_3 airborne contamination negatively influences the soil acidity and animal health (Akdeniz et al., 2011; Cao et al., 2019). These ecological outcomes underscore the need to have sustainable manure treatment technology that could be effective in reducing gaseous emission and enhance nutrient stabilisation.

The Biofiltration of Gaseous Emission

Biofiltration has become one of the most cost-effective and environmental friendly technology of controlling the emission to gases and water vapours produced by animal manure. Biofilters make use of porous media, organic or inorganic whose colonies comprise microbes which oxidise pollutants to less harmful compounds. Research has shown large removal efficiencies such as 40-80% reduction of ammonia, up to 95% reduction of volatile organic compounds and influencing large quantities of deactivating air pathogens (Chu et al., 2024; Chen et al., 2005). Good surface area and moisture-holding capability of biofilter media like pine nuggets, coconuts cors, lava rocks, peats, and wood chips support the growth of the microbes (Akdeniz et al., 2011; Du et al., 2024). The operation of biofilers in the long term has also been indicated to be stable in terms of performance and therefore can be used in continuous application on a farm environment (Pergola et al., 2020).

Composting as a Strategy of Stabilisation of Manure

It is widely accepted that aerobic composting is a good way of stabilising livestock manure by thermophilic microbial decompositions. Composting can improve the process of organic matter conversion, extinguish pathogens at high temperatures of more than 55 ^{o}C, and nitrogen fixation when additives in the form of bulking agents that include rice straw and sawdust are added (Yang et al., 2019; Sánchez et al., 2015).

Many studies point to the possibility of composting to lower the emission of greenhouse gases, through uncontrolled anaerobic degradation minimization (Mu et al., 2017; Pane et al., 2015). Besides the environmental advantage, compost generated by agricultural and organic waste has been found to have a greater favourable biological activity on the soil and also boost crop yield when it is used as a fertiliser (Halder & Vijaykarthigeyan, 2025; Prabhakar, 2025).

Biofiltration–Composting Biosensors

Recent studies reveal that biofiltration is a manure management system that can be used in synergy with aerobic composting and achieve the objective of even further decreasing the amount of pollutants emitted and enhancing the end product of the compost. Treatment with biofilters has been demonstrated to reduce first range capital ammonia, decrease odour emissions and save nitrogen throughout the thermophilic composting phases (Chu et al., 2024; Margono, 2025). Such integrated systems have also succeeded in transforming the organic waste into high valued fertilisers with low environmental footprints. Nevertheless, there is a lack of field-based research on mixed-livestock farms especially in tropical climates, and this means that there is a huge gap in research. An integrated system of agronomic and environmental assessment is almost essential to allow large scale adoption.

Methodology

System Development and Experimental Design

Design of the Experiment and Treatment Architecture

Six experimental control trial was done on a mixed livestock farm with cattle, goats and poultry to evaluate the effectiveness of sustainable manure management technologies. To compare the growth of two treatment systems, T1 (Control) was composed of standard manure department, where newly produced manure was piled in heaps and left to decompose naturally under the influence of the environment with no aeration, temperature regulation, and odour-control measures. T2 (Treatment) had an incorporated biofiltration-assisted composting system, in which manure was first passed through a biofiltration system, which was designed to eliminate gaseous pollutants before being subjected to aerobic composting. This two-phase experiment was adopted with the aim of testing the reduction of emission, support compost, and nutrient increase of the experiment compared to the conventional management methods.

Bio-Philtre System Design and Suicide

An up-flow biofilter was designed in the form of a rectangle (1.5 m 1.0 m 1.0 m) next to the manure handling space to wash the contaminated polluted air flowing forth due to the decomposition of manure. The biofilter had three active layers: a coconut coir (20 cm) layer that gave the biofilter a high degree of porosity and good location sites in which microbes could proliferate; a wood-chip (25 cm) layer that gave the biofilter mechanical stability and an additional surface area where aerobic microbes could thrive; and finally, a charcoal and gravel mix (25 cm) which enhanced high adsorption of gases, water control and drainage efficiency. The airflow in the system was forced through the system by a 0.5 hp variable-speed blower, with airflow kept at 0.8–1.2 m 3 -min -1, to maximise contact between the gas and biofilm. This design contributed to the fact that there was constant oxidation of ammonia and odour compounds by microbes before composting.

Operation Conditions and Aerobic Composting Process

After the biofiltration, rice straw was added to the manure in a 3:1 ratio to obtain the optimal combination of C:N ratio of 2530:1, which makes the thermophilic composting in ratio 3:1 ideal. Piles of compost were the ones built with the dimensions of 1.2 m x 1.0 m x 0.8 m and kept under the controlled aerobic conditions Figure 1. The mechanical turning was carried out after every five days so that oxygen levels are maintained at above 12 and to ensure the even distribution of heat and microbial decomposition. A moisture level was kept within 5060%, protected with the help of a digital moisture probe to avoid anaerobic foci and insufficient metabolic processes. All these operational parameters facilitated quick stabilisation process, inactivation of pathogens and development of better nutrient preservation in the end compost product.

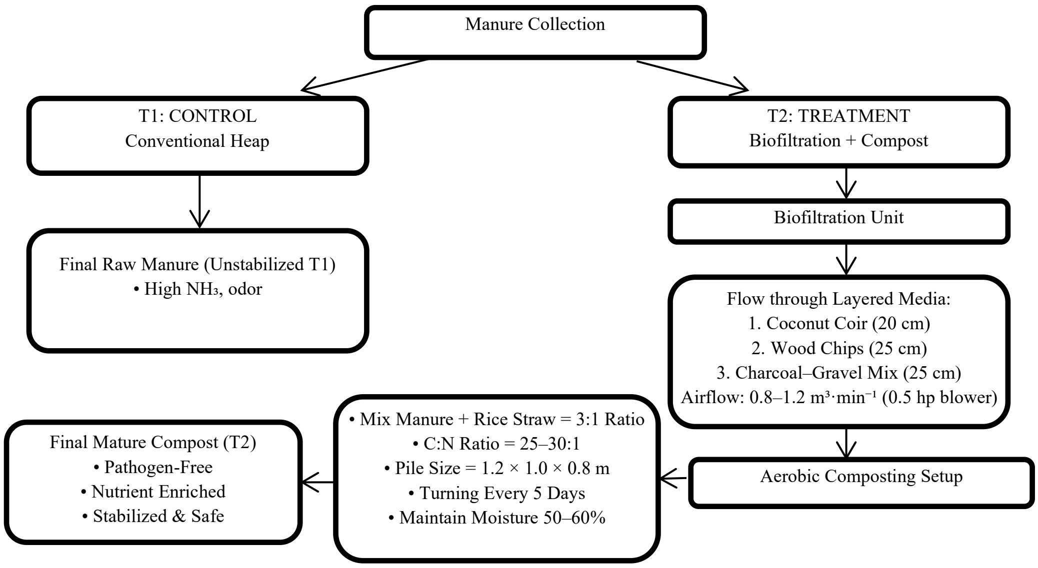

Figure 1: Process Flow Diagram of the Integrated Biofiltration–Composting Manure Management System

Monitoring of Environmental and Compost Quality Parameters

Air Quality and Monitoring of Emission

To examine the usefulness of the integrated manure management system in the minimization of gaseous emissions, intensive air-quality screening was done during the entire timeframe of the experimental period, which lasted 60 days. A portable electrochemical analysis of ammonia (NH 3) was monitored at 3-day intervals with a NH 3 detector of a range of 0-500 ppm with sample collection at 30 cm above the manure piles to detect the peaks of emissions at the source. The intensity of the odour was determined according to the EN 13725 standard of dynamic olfactometry, results in factors of odour units (OU /m 3), which were calculated using the threshold detection response of a trained panel. At the same time, the ambient temperature and relative humidity were measured with the help of a digital thermo-hygrometer in order to estimate the impact of environmental changes on gaseous release patterns. The joint measurements were a credible estimate of the emission dynamics during both conventional and those in the presence of biofilter under composting conditions.

Maturity and Stabilisation Indicators of Compost

Several physicochemical indices were followed in order to determine the maturity of compost, rate and efficiency of decomposition. Reading of temperature was done each day in compost piles; thermocouples were placed 20 cm deep, and this allowed the identification of mesophilic and thermophilic regimes which are necessary in reduction of pathogens and degradation of organic matter. Compost pH and electrical conductivity (EC) were determined by extracting compost 1:10 using distilled water, which gives an insight into the changes in nutrient mineralization and salinity. The ratio of carbon-to-nitrogen (C: N), which is a significant maturity factor, was calculated by estimating the total carbon, as determined by WalkleyBlack method, and total nitrogen, determined through Kjeldahl digestion. Also, the germination index (GI) was determined by a lettuce seed bioassay on phytotoxicity and to determine maturity of compost as more GI value is an indication of stabilised material that may be used in agriculture.

Analysis of The Microbial and Pathogen

Microbial analysis was observed in order to identify the sanitary level of compost and to confirm the effectiveness of reducing pathogens of the integrated system. Serial dilution, selective plating and colony enumeration procedures were employed to quantify Escherichia coli and Salmonella spp. in order to monitor the inactivation of the pathogens in the case of thermophilic composting. The presence of faecal coliforms was testified through membrane filtration in order to determine the general level of contamination of microbes. In addition, the dynamics of microbial communities, such as the total aerobic bacteria and actinomycetes count were observed to appreciate the dynamics of biological activity in the biofilter and composting system Figure 2. All these microbial indicators worked together to guarantee that the end product of the compost, biosafety standards, and information concerning the biological processes underlying improvements in manure stabilisation.

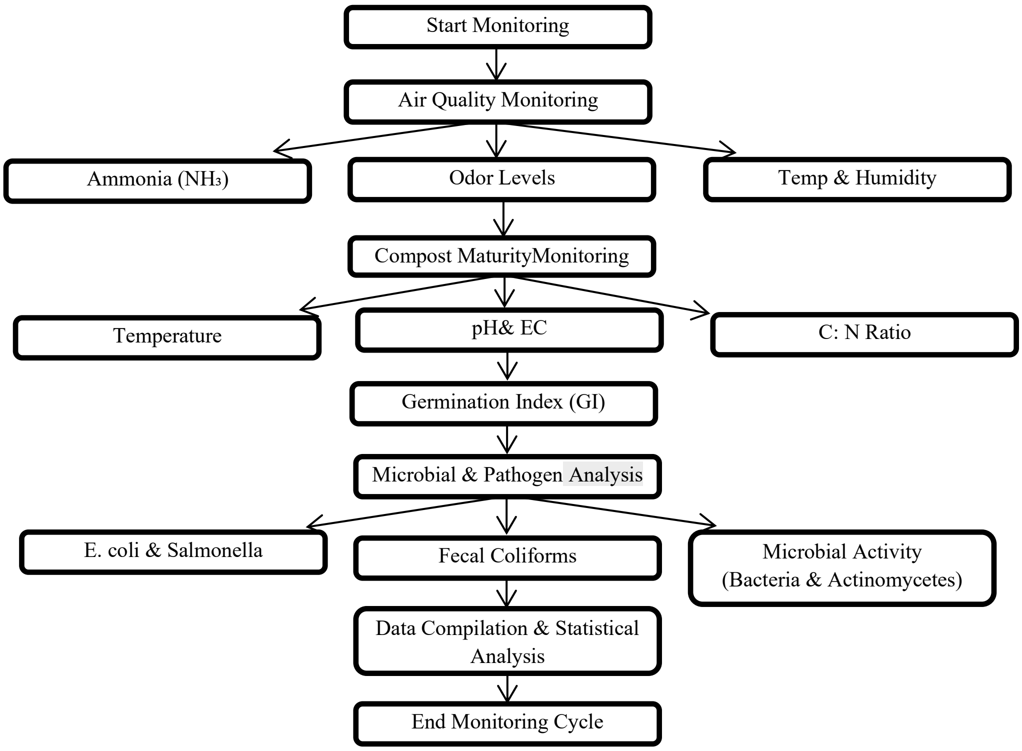

Figure 2: Workflow Diagram for Environmental and Compost Quality Monitoring Procedures

Data Processing, Statistical Analysis, and Soil Application Study

Statistical Validation

All the experimental data were analysed statistically to provide a scientific rigour and measure the importance of the effects of the treatment. The one-way Analysis of Variance (ANOVA) was used in order to make comparative analysis of the main environmental and compost quality parameters between the control (T1) and the biofiltration assisted composting system (T2). In cases of significant differences as shown by ANOVA, Tukey, Honestly Significant Difference (HSD) post-hoc test was used to determine particular pairwise variations at the significance level of $p = 0.05$. All the measurements were repeated 3 times ($n = 3$ per treatment) to guarantee data reliability and minimise the sampling error. Variability was interpreted and consistency across replicates were accepted by calculating standard deviations and 95 percent confidence intervals and providing them. This statistical model gave strong statistical data of the performance of the manure management treatments which were compared.

Analysis of Nutrient Composition

In order to determine the effect of integrated biofiltration-assisted composting on the nutrient enrichment of final composts, the samples were dried and mixed using a standardised method and a standard laboratory protocol was used to determine the nutrient level. The amount of total nitrogen was reported as results of the Kjeldahl digestion technique and available phosphorus of the soil was reported as the results of the Olsen P extraction technique to determine the available forms of phosphorus to plants. Potassium, and organic carbon, both have been estimated through the use of Walkley-Black hydrate oxidation process and a calibrated flame photometer respectively. These parameters of nutrients were determined in comparison to the nutrient parameters of the control compost to determine the amount of nutrient retention and stabilisation that was achieved with the assistance of biofiltration. The analysis developed allowed determining the quality improvement of compost and its applicability as an organic fertiliser.

Assessment of Soil and Growth of Plants

The soil application trial with the maize (Zea mays L.) was done to identify the agronomic value of the compost products. Three soil treatments were put up; the control compost amended soil (T1), biofiltered compost amended soil (T2), and an amended soil which got a standard chemical fertiliser (NPK) to give some standard baseline. Table 1 provided the important characteristics of plant growth such as plant height; chlorophyll content as determined with SPAD metre and total biomass accumulation during the growth cycle. The analysis of soil samples was performed on levels of organic carbon and nutrients after the harvest, in order to determine the degree of improvement in soil fertility after its application. The outcomes of the given pot experiment proved the improved agronomic performance behind the compost produced by the integrated biofiltration-composting system and indicated its possible use as the sustainable alternative to the use of chemical fertilisers.

Table 1: Summary of Data Processing, Statistical Methods, Nutrient Analysis, and Soil Application Study

Category	Parameter / Activity	Method / Instrument Used	Purpose / Output
Statistical Validation	Experimental replication	n = 3 per treatment	Ensures data reliability and reduces sampling error
	Variance analysis	One-way ANOVA	Determines statistically significant differences between T1 and T2
	Post-hoc comparison	Tukey's HSD test ($p \leq 0.05$)	Identifies pairwise treatment differences
	Variability reporting	Standard deviation & 95% CI	Evaluates consistency and precision of measurements
Nutrient Composition Analysis	Total Nitrogen (N)	Kjeldahl digestion method	Determines nitrogen retention and compost maturity
	Available Phosphorus (P)	Olsen P extraction	Measures plant-available phosphorus in compost
	Potassium (K)	Flame photometer	Quantifies exchangeable potassium level
	Organic Carbon (OC)	Walkley–Black method	Evaluates organic matter content and compost stabilization
Soil Fertility & Plant Growth Assessment	Soil Treatments	T1: Soil + Control Compost T2: Soil + Biofiltered Compost NPK: Soil + Chemical Fertilizer	Compares agronomic performance across treatments
	Plant Height	Scale measurement at growth intervals	Indicates vegetative growth response
	Chlorophyll Content	SPAD meter	Assesses photosynthetic activity & plant health
	Biomass Accumulation	Fresh & dry weight measurement	Evaluates plant productivity
	Soil Organic Carbon	Walkley–Black method (post-harvest)	Measures improvement in soil fertility
	Soil Nutrient Levels	Standard soil NPK tests	Determines nutrient enhancement due to compost

Results and Discussion

Ammonia Emission Reduction and Air Quality Improvement

The biofiltration-composting system was shown to have a high ammonia emission reduction when compared to the traditional management of the manure. It was found that biofiltration was effective in reducing the concentration of NH 3 by 45-62 percent, although the most significant reduction was attained within the first 15 days when the activity of manure decomposition was the most active. The concentration of ammonia shot up in the control treatment (T1), peaking at 185 ppm but the new system (treatment T2) emitted similar levels (65-95 ppm) all the time. This contrast shows the capacity of the biofilter to oxidise ammonia biologically to reduce its release to the atmosphere and this enhances air quality in the areas surrounding livestock facilities. These cuts correspond with the literature of moderate to high NH 3 removal efficiencies with biofilter systems. The quality of air is not only improved thus betterment of the environment but also helps to ameliorate the health of the animals and the safety of the workers in the farms.

Smell Minimization and Clean Air Effects

Odour emission was much reduced in the biofiltration-assisted composting system where T2 had an average of 780 OU/m 3 as opposed to 2410 OU/m 3 in T1 which is an approximate of 68 percent. This significant reduction indicates that the biofilter can be used to reduce the volatile organic compounds and gases that cause odours and, thus, reduce the widespread nuisance problems of manure management. Odour mitigation is specifically critical when farms are situated in the vicinity of residential neighbourhoods where complaints raised by the communities and regulatory limitations are common practises. The findings reveal that biofiltration-based system integration in manure management systems is useful in overriding odour-emission as well as ensuring that environmental air-quality standards are met.

Inactivation of Pathogens and Bio Safety Assurance

The T2 system showed thermophilic composting (5763 0 C) which is adequate to destroy pathogens and sanitise the compost. Consequently, the treated compost showed 99 percent reduction in Escherichia coli and total inactivation of Salmonella spp up to day 25 with the control compost (T1) still being within the acceptable biosafety limits. This increase in the destruction of pathogens can be explained by the prolonged thermophilic conditions and improved aeration which is provided by the composting design. This proves the integrated system achieves the task of stabilising manure and at the same time yielding a final product with hygienic safety levels enough to be of agricultural use as global standards require pathogen-free compost.

Soil Fertility, Nurtrient Enhancement and Agronomic Performance

The final compost of the treated system recorded significant increase in nutrient content (18% increase in nitrogen, 22% in phosphorus and 15% in potassium) over the control and a lower C:N ratio of 13.5:1 which showed better compost maturity. Pot trials also confirmed the agronomic potential of T2 compost and had a 32 percent increase in plant height, 28 percent increase in chlorophyll content and a 25 percent increase in soil organic carbon Figure 3. It is worth noting that although an initial growth of plants was supported by chemical fertiliser (NPK), T2 compost was reported to support the survival of soil fertility and improve soil health in the long run Table 2. Those findings are in line with the idea that biofiltration-based composting does not only mitigate environmental pollutants, but produces nutrient-rich organic amendment, which could improve crop growth and foster sustainable nutrient recovery.

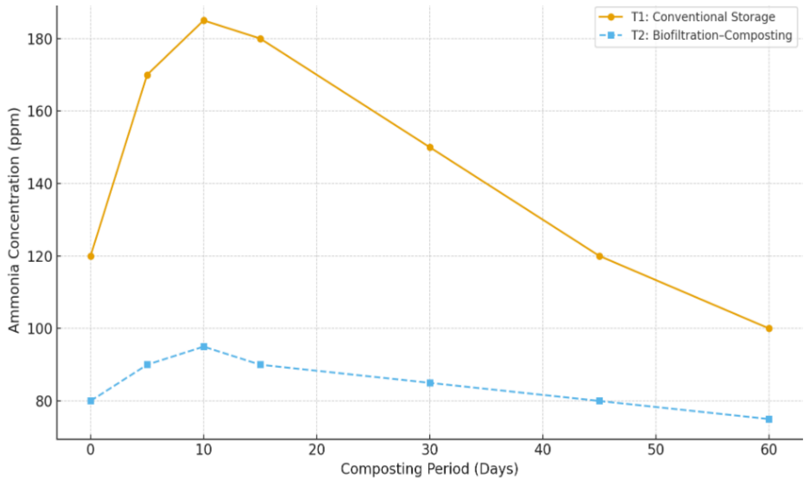

Figure 3: Ammonia (NH_3) Emissions Over A 60-Day Treatment Period Under Conventional Manure Storage (T1) And Biofiltration-Assisted Composting (T2), Showing Consistently Lower NH_3 Concentrations in the Treated System

Table 2: Ammonia (NH_3) Emissions During 60-Day Treatment Period

Day	T1: Conventional Storage (ppm)	T2: Biofiltration–Composting (ppm)
0	120	80
5	170	90
10	185	95
15	180	90
30	150	85
45	120	80
60	100	75

Conclusion

This research validates that biofiltration coupled with aerobic composting offers a novel and effective scaleable and eco-friendly method of managing manure of livestock. The joint system was effective in the aforementioned areas of significantly lowering the quantity of ammonia emissions and the degree of odour intensity, which proved that there were evident positive changes in the quality of the farm air and labour protection. Improved thermophilic composting helped in large proportional inactivation of pathogens which yielded hygienically safe and mature compost product rich in valuable nutrients. Experiments on soil application also showed that treated compost enhanced the growth of plants, the organic carbon of the soil and the overall soil health, thus eliminating the need to use chemical fertilisers and promoting long term soil performance. All these results underscore the possibility of biofiltration-aided composting as an effective plan towards furthering circular-based nutrient use, reduced environmental harm, and enhancement of sustainable livestock-based farming systems, especially in dual-species agricultural systems.

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