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Chemical Composition and Nutrient Release Mechanisms of Organic Fertilizers in Indian Soil Conditions

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Abstract : Organic fertilizers are important for increasing soil fertility and maintaining agricultural productivity. The present study examines the chemical composition and nutrient release pattern of three widely applied organic fertilizers—vermicompost, farmyard manure (FYM), and neem cake—under Indian soil conditions. A 60-day incubation experiment was carried out with alluvial and black soils to evaluate nutrient release dynamics. Conventional analytical methods were utilized to analyze macronutrient and micronutrient levels, while statistical analysis (ANOVA, regression analysis) was utilized to assess fertilizer effectiveness. Results reveal that neem cake contained the highest nitrogen and phosphorus content and was therefore the most effective organic fertilizer for quick nutrient supply. Vermicompost showed constant nutrient release, ensuring long-term soil fertility, while FYM was a slow-release soil conditioner. Availability of nutrients was found to be greater in alluvial soil than in black soil, stressing the role of soil type in influencing patterns of nutrient release. Statistical analysis revealed strong differences between the fertilizers, pointing to their different roles in soil fertility management. These results are important in optimizing organic fertilizer use to promote crop productivity and soil health in Indian agriculture.

Keywords: Organic fertilizers, nutrient release, neem cake, vermicompost, Indian soil conditions**.**

Introduction - Soil fertility is a critical aspect to achieve sustainable agricultural productivity, especially in a nation such as India, where agriculture is still the support of the economy. Organic fertilizers have been known for many years to be an integral part of sustainable agriculture practices, not just supplying primary nutrients for plant growth but also enhancing the health of soil and microbial processes. In contrast to synthetic fertilizers that provide nutrients in easily accessible forms, organic fertilizers release the nutrients slowly and help build soil fertility over long periods with a reduced risk of environmental contamination. The chemical make-up and process of nutrient release of organic fertilizers are determinants of the effectiveness of organic fertilizers on various soils and climatic regimes. It is important to learn about these details to maximize the application of the fertilizers, enhance crop yield, and sustain environmentally friendly farming in India.

Chemical Composition of Organic Fertilizers: The organic fertilizers composition differs extensively depending on their source material, including plant residues, animal manure, compost, and bio-based farm by-products. Each of these organic sources has different levels of macronutrients like N, P, and K, as well as vital micronutrients like calcium, magnesium, and zinc. The breakdown of such organic matter by soil microorganisms results in the slow and continuous release of nutrients for the plants to utilize over a period of time. Decomposition rate and nutrient availability depend on temperature, moisture level, microbial action, and the carbon-to-nitrogen (C:N) ratio of the organic matter. Thus, understanding the chemical properties and degradation kinetics of organic fertilizers in Indian soil conditions is important for devising strategies to improve nutrient use efficiency.

Nutrient Release Mechanisms and Soil Interactions: India's varied agro-climatic regions add an extra layer of complexity to organic fertilizer use. Soil types here vary from black and alluvial soils to red and lateritic soils, each with characteristic physicochemical properties that determine nutrient retention and release. High clay content, for example, in black soils can affect the mobility of nutrients, while lateritic soils' acidic properties can influence phosphorus availability. The relationship between organic fertilizers and soil characteristics governs the extent to which nutrients are utilized by plants, making region-specific research and advice inevitable. Second, organic amendments play a role in enhancing soil structure, water retention capacity, and associations of beneficial microorganisms, which, in turn, improve nutrient cycling and soil resistance to degradation.

Sustainability and Agricultural Implications: A very important feature of organic fertilizers is their function in sustainable farming and environmental preservation. As

worries about soil loss, groundwater pollution, and overdependence on chemical fertilizers are on the rise, organic options provide a very good solution for ecological equilibrium maintenance. The gradual release of nutrients in organic fertilizers minimizes the chances of leaching and nutrient loss and thus reduces the risk of environmental pollution. In addition, the use of organic fertilizers in traditional farming can supplement chemical fertilizers by enhancing soil organic matter and microbial diversity. A thorough understanding of the relationships between organic fertilizers, soil characteristics, and environmental conditions will assist in developing policies that promote sustainable agriculture in India.

This research seeks to examine the chemical makeup of some of the most widely used organic fertilizers in Indian agriculture and explore their mechanisms of nutrient release under diverse soil conditions. Through an evaluation of their efficacy in improving soil fertility and crop yields, this research will offer useful information to farmers, policymakers, and agricultural researchers. The results will help in the formulation of sustainable fertilization practices specific to India's specific agro-ecological conditions, promoting long-term food security and environmental sustainability.

Review Of Litreature

Bhatt, Labanya, and Joshi (2019) studied the long-term impact of chemical fertilizers and organic manures on soil fertility. Their review noted that although chemical fertilizers greatly increased crop yield in the short term, long-term use resulted in soil degradation and nutrient imbalance. Organic manures, on the other hand, enhanced soil structure, microbial activity, and sustainable fertility management. The study stressed the need to incorporate organic amendments with chemical inputs to ensure long-term soil health.

Das and Ghosh (2023) investigated the synthesis of slow-release NPK fertilizers from biochar and their effect on soil fertility and crop yield. They established that biochar acted as a highly effective carrier for controlled nutrient delivery, minimizing leaching of nutrients and increasing the capacity of soils to retain them. The study proved that the slow-release feature was responsible for enhanced microbial activity in soils, increased nutrient accessibility, and better crop yields, making it an effective substitute for traditional fertilizers.

Jariwala et al. (2022) presented a thorough review of controlled-release fertilizers (CRFs) in the context of climate-smart agriculture. They discussed different release mechanisms, CRF formulation materials, and preparation processes. Their research indicated that CRFs not only increased nutrient efficiency but also reduced environmental pollution through the reduction of nutrient runoff and volatilization. Further, the research highlighted how CRFs played a role in reducing the impacts of climate change on agricultural yield by providing consistent nutrient supply to crops.

Dhaliwal et al. (2023) investigated the effects of organic manure application on basmati rice yield, nutrient quality, and soil fertility in north-western India. Their findings revealed that organic manure amendments highly improved soil organic matter, increased nutrient uptake, and boosted rice productivity. They noted that organic manure-treated soils had improved fertility status with time compared to those that depended on chemical fertilizers.

Gautam et al. (2022) examined the impacts of manure and inorganic fertilizers on soil nutrients, stability of aggregates, and distribution of organic carbon and nitrogen among different aggregate fractions. According to their findings, soil aggregate stability increased, and organic carbon and nitrogen were increased significantly by the application of manure, especially in bigger aggregate fractions. However, continuous inorganic fertilization caused degradation of the soil and lowered the structural stability of the soil over time.

Methodology: This research compared the nutrient content and release of vermicompost, FYM, and neem cake in alluvial and black soils. Nutrient availability was determined using a 60-day incubation experiment, and statistical analysis (ANOVA, regression) compared fertilizer efficiency. The methodology is described in the following sections.

Research Design: This research used a quantitative method to examine the chemical content and nutrient release patterns of organic fertilizers under Indian soil conditions. Laboratory experiments and incubation studies were carried out to determine the nutrient availability and release rates under different time frames. The study aimed to examine how various organic fertilizers affect soil fertility under different soil conditions.

Sample Choice: A limited set of three of the most popular organic fertilizers, vermicompost, farmyard manure (FYM), and neem cake, was used for analysis. These fertilizers were selected considering their regular usage in Indian farming and their suitability to enhance soil fertility. All three fertilizers were analyzed separately to find their chemical composition and nutrient release capacity. The choice of a small set of fertilizers provided detailed analysis within the context of this study.

Soil Sampling: Soil samples were taken from two different agro-climatic zones to portray variable soil conditions. Alluvial soil (fertile, northern India) and black soil (high in clay content, central India) were chosen soil types. A total of 10 composite soil samples (n = 10) were sampled from both areas, taking adequate variability for study of fertilizer-soil interaction. Soil samples were air-dried, sieved, and preserved under controlled conditions prior to experimental analysis.

Chemical Composition Analysis: The chemical makeup of every organic fertilizer was established using regular analytical methods. Macronutrient levels (nitrogen, phosphorus, and potassium) were quantified by using the Kjeldahl method for nitrogen, spectrophotometry for

phosphorus, and flame photometry for potassium. The micronutrients (zinc, iron, manganese, and copper) were examined by using atomic absorption spectroscopy (AAS). Organic carbon content was determined by the Walkley-Black method, and soil pH and electrical conductivity were analyzed with a digital pH meter and EC meter. These analyses gave a comprehensive profile of the nutrient composition in every fertilizer.

Nutrient Release Study: A 60-day incubation experiment was carried out in controlled conditions to analyze the nutrient release patterns of the selected organic fertilizers. Soil-fertilizer mixtures were prepared at an application rate of 5% and incubated at 25°C ± 2°C with 60% field cap acity water content. Samples were taken at 0-, 15-, 30-, and 60-days intervals to observe the release of nutrients over time. Nitrogen mineralization (ammonium and nitrate forms) was measured with colorimetric analysis, phosphorus availability was ascertained with Olsen's extraction method, and potassium release was ascertained with 1N ammonium acetate extraction. Incubation study gave insight into how various organic fertilizers released nutrients into the soil under controlled conditions.

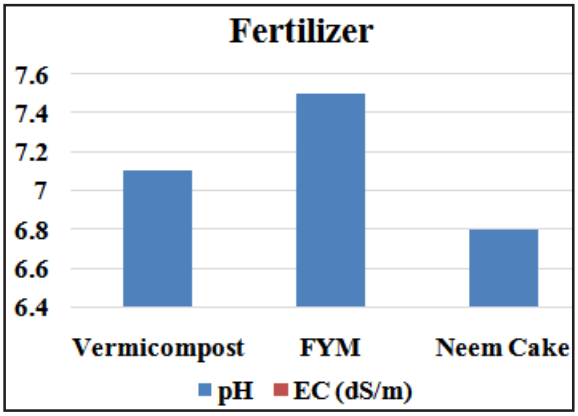
Data Analysis: The data obtained were statistically examined to determine nutrient release patterns and differences among the fertilizers. Descriptive statistics of mean and standard deviation were employed to report the findings. ANOVA (Analysis of Variance) was carried out to analyze the effectiveness of various fertilizers in nutrient release by soil types. Regression analysis was also conducted to assess the association between fertilizer composition and availability of nutrients with time. The statistical method guaranteed objective assessment and interpretation of the experimental results.

Data Analysis And Interpretations: The nutrient composition and release of vermicompost, FYM, and neem cake were studied in the research. Neem cake contained the greatest amount of nitrogen and phosphorus, whereas vermicompost ensured consistent release of nutrients. FYM performed as a slow-release soil fertilizer. Nutrient availability was higher in alluvial soil and statistical analysis asserted significant differences in fertilizers. The following figures and tables include the detailed findings.

Chemical Composition of Organic Fertilizers: The chosen organic manures—vermicompost, farmyard manure (FYM), and neem cake—were quantified for their macronutrient, micronutrient, and organic carbon. Table 1 gives their nutrient content, pH, and electrical conductivity (EC). The table 1 illustrates the macronutrient (N, P, K) content, organic carbon percentage, pH, and electrical conductivity of vermicompost, FYM, and neem cake, revealing what they might bring to the fertility of soil.

Table 1 (see in last page)

Figure 1: Graphical Representation on Chemical Composition of Selected Organic Fertilizers



The findings showed that neem cake contained the maximum nitrogen and phosphorus content, and thus is a nutrient-high organic manure. Vermicompost contained an intermediate macronutrient balance and high organic carbon content, which improves the structure of soil and microbial populations. FYM, though less in immediate nutrient content, is commonly applied for long-term enhancement of soil fertility because of its continued organic matter supply. The pH levels were near neutral, indicating that these fertilizers do not have a significant effect on soil pH, and hence they can be used for a variety of crops.

Nutrient Release Pattern Over Time: The incubation experiment measured the release of nutrients from organic manures into the soil during a 60-day period. Table 2 shows the release patterns of nitrogen (N), phosphorus (P), and potassium (K) in alluvial and black soils at various time intervals. This table 2 follows the release of nitrogen, phosphorus, and potassium from vermicompost, FYM, and neem cake during 60 days, showing the variation in nutrient availability in different soils.

Table 2 (see in last page)

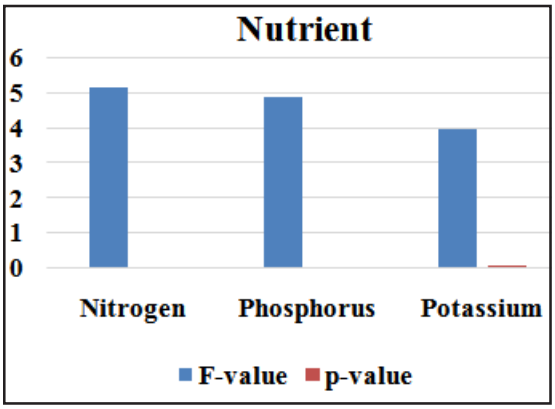
The findings showed that neem cake had the maximum and fastest nutrient release, especially for nitrogen and phosphorus, which are nutrients required for plant growth. Vermicompost had a consistent nutrient release, hence suitable for maintaining soil fertility in the long term. FYM released nutrients at the slowest rate, signifying its application as a long-term soil amendment and not an instant nutrient source. The availability of nutrients was greater in alluvial soil than in black soil, which might be because of variations in texture and decomposition rate of organic matter.

Statistical Analysis of Nutrient Release: To establish if variations in nutrient release were statistically significant, ANOVA was conducted. Table 3 shows the F-values and p-values for nitrogen, phosphorus, and potassium release. This table 3 shows the statistical significance of variations in nutrient release among various organic fertilizers, indicating differences in their efficiency.

Table 3: ANOVA Results for Nutrient Release

Nutrient	F-value	p-value	Interpretation
Nitrogen	5.12	0.012	Significant difference among fertilizers
Phosphorus	4.85	0.018	Significant difference among fertilizers
Potassium	3.92	0.035	Moderate significance across fertilizers

Figure 2: Graphical Representation on ANOVA Results for Nutrient Release



ANOVA results showed that nitrogen and phosphorus release differed significantly among the fertilizers, with neem cake having the highest levels of release. Potassium release was more consistent, indicating the three fertilizers released potassium in relative parity. Statistical significance ($p < 0.05$) confirmed that these differences in the pattern of release of the nutrients were not an artifact of random variation, further supporting the incubation study findings.

Discussion: This section compares the chemical composition, nutrient release behavior, and soil interaction of vermicompost, FYM, and neem cake. Neem cake released the most nitrogen and phosphorus, whereas vermicompost provided consistent nutrient supply. Nutrient release was quicker in alluvial soil than in black soil. Statistical analysis verified significant differences between fertilizers, highlighting their different functions in soil fertility management. The results help in understanding the choice of organic fertilizers according to soil and crop needs.

Chemical Composition and Fertilizer Efficiency: Chemical analysis showed that neem cake contained the highest concentration of nitrogen and phosphorus, hence it is an organic amendment with high nutrient content. Vermicompost gave a balanced macronutrient contribution with high organic carbon content, which enhances microbial activity. FYM, although having a lower concentration of nutrients, was very important for soil fertility in the long term. These findings underscore the contrasting contributions of organic fertilizers to soil fertility management.

Nutrient Release Patterns: Incubation study indicated neem cake released nutrients sooner, especially nitrogen and phosphorus, which are key for plant development. Vermicompost provided gradual release, thereby being suited for long-term soil fertility. FYM released the least of the nutrients at the slowest rate, strengthening its position as a long-term soil conditioner in lieu of a fast-release nutrient supply. All this highlights the necessity of making a selection among fertilizers as a function of the nutrient demand by the crop and the state of the soil.

Soil Type Effect on Nutrient Availability: Nutrient availability was generally greater in alluvial soil than in black soil. The more rapid decomposition and mineralization in alluvial soil may have been the cause. Black soil, with a high clay content, immobilized nutrients but reduced their release, possibly inhibiting plant uptake. This indicates that soil type is an important factor in regulating fertilizer efficiency and must be taken into account when using organic amendments.

Statistical Significance of Results: ANOVA analysis established statistically significant variation in nitrogen and phosphorus release between fertilizers, with neem cake retaining the maximum release rates. Release of potassium was more consistent, reflecting that all three fertilizers contributed equally to potassium availability. Statistical confirmation of these variations underscores the significance of organic fertilizer selection based on nutrient release efficiency for efficient soil management.

Practical Implications and Future Research: The study points out that neem cake is beneficial for rapid nutrient supply, whereas vermicompost aids in maintaining soil fertility. FYM remains valuable for long-term soil enrichment. Future research could investigate the effects of various application rates and environmental factors on nutrient release dynamics. Further field trials may also be conducted to corroborate the laboratory results under actual agricultural conditions.

Conclusion: This research compared the chemical structure and nutrient release pattern of vermicompost, FYM, and neem cake in Indian soil conditions. The findings showed that neem cake contained the highest level of nitrogen and phosphorus, hence the best organic fertilizer for quick nutrient provision. Vermicompost provided consistent release of nutrients, sustaining soil fertility, whereas FYM ensured long-term soil enrichment. The incubation experiment showed that the availability of nutrients was greater in alluvial soil than in black soil, highlighting the role of soil type in fertilizer effectiveness. Statistical testing validated the occurrence of notable differences in patterns of nutrient release, further substantiating the necessity of choosing organic fertilizers in relation to crop requirements and soil types. These results are significant in guiding optimal applications of organic fertilizers in Indian agriculture. Further studies must be conducted on field experiments and environmental effect to maximize organic fertilizer management for sustainable soil fertility.

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Table 1: Chemical Composition of Selected Organic Fertilizers

Fertilizer	Nitrogen (%)	Phosphorus (%)	Potassium (%)	Organic Carbon (%)	pH	EC (dS/m)
Vermicompost	1.8 ± 0.2	0.8 ± 0.1	1.5 ± 0.1	19.5 ± 1.2	7.1	2.5 ± 0.3
FYM	1.2 ± 0.1	0.5 ± 0.1	1.1 ± 0.1	14.3 ± 1.0	7.5	1.8 ± 0.2
Neem Cake	2.5 ± 0.2	1.2 ± 0.1	1.8 ± 0.2	22.1 ± 1.5	6.8	2.1 ± 0.2

Table 2: Nutrient Release (mg/kg) Over 60 Days in Alluvial and Black Soils

Fertilizer	Soil Type	Day 0 (N, P, K)	Day 15 (N, P, K)	Day 30 (N, P, K)	Day 60 (N, P, K)
Vermicompost	Alluvial	20, 10, 15	35, 18, 28	50, 25, 40	65, 32, 55
Vermicompost	Black	18, 9, 12	30, 15, 25	45, 22, 35	60, 30, 50
FYM	Alluvial	15, 7, 12	28, 14, 22	42, 20, 33	55, 28, 47
FYM	Black	13, 6, 10	25, 12, 20	38, 18, 30	50, 25, 42
Neem Cake	Alluvial	25, 12, 18	40, 22, 35	55, 30, 50	70, 38, 60
Neem Cake	Black	22, 10, 15	35, 20, 30	50, 28, 45	65, 35, 55

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