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Nitrogen release dynamics from organic and inorganic sources in a tropical Alfisol: Implications for synchronizing nutrient supply in rainfed sorghum systems

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Abstract

Nitrogen release synchrony between soil amendments and crop requirements is essential for enhancing nitrogen use efficiency in rainfed agroecosystems. A laboratory incubation experiment was carried out for 112 days to determine the dynamics of nitrogen release from organic and inorganic sources in a tropical Alfisol. Farmyard manure (FYM), vermicompost (VC), poultry manure (PM) and urea were applied at the same rate of 30 mg N kg⁻¹ soil under controlled aerobic conditions. The changes in ammonium-N (NH₄⁺-N), nitrate-N (NO₃⁻-N) and total mineral nitrogen were determined periodically. Urea was found to mineralize at a faster and continuous rate, releasing nearly 95% of the applied N by the end of incubation. Poultry manure also continued to mineralize, releasing 67% of the applied N. In contrast, FYM and VC initially immobilized N up to 28 days, followed by gradual mineralization, releasing 33% and 29% of the applied N, respectively. Nitrate-N was found to dominate the mineral N pool throughout incubation. Although no crop was grown during incubation, the findings of this study would help to understand the patterns of nitrogen availability, which would be useful for synchronizing nutrient supply in rainfed sorghum systems. The study highlights the need for source-specific nitrogen management strategies to improve nitrogen use efficiency and sustainability in rainfed agriculture.

Keywords: Nitrogen mineralization, organic manures, poultry manure, vermicompost, Alfisol, aerobic incubation

1. Introduction

Rainfed agriculture covers almost 55% of the cultivated area in India and contributes around 40% of the total food grain production in the country, which sustains a major portion of the human and animal population in the arid and semi-arid areas (Gopinath *et al.*, 2013) [7]. These areas are marked by irregular rainfall, hot climate and poor soil quality with low organic carbon and available nutrients, especially nitrogen (Srinivasarao *et al.*, 2012) [13]. Alfisols are found in large areas of the semi-arid tropics and are inherently low in soil organic carbon and available nitrogen, leading to low productivity and efficiency of nitrogen use in crops. Sorghum (*Sorghum bicolor* L. Moench) is one of the principal cereals in rainfed areas because of its drought resistance and ability to grow under low-input conditions. But the productivity of sorghum is still much below its potential, mainly because of improper use of nitrogen and its timing in relation to crop requirements. Nitrogen in chemical fertilizers is readily available, but the recovery efficiency of fertilizers in rainfed areas is generally low due to volatilization, leaching and uneven distribution of rainfall (Dobermann, 2005) [6]. Organic manures like farm yard manure (FYM), vermicompost (VC) and poultry manure (PM) are commonly employed in rainfed ecosystems as an alternative or supplementary source of nitrogen. Organic manures like farmyard manure (FYM), vermicompost (VC) and poultry manure (PM) are commonly employed in rainfed ecosystems as an alternative or supplementary source of nitrogen, and their application method significantly influences plant population and growth attributes in sweet corn (Banoth *et al.*, 2025) [3]. These organic manures enhance the soil's organic carbon, microbial biomass and overall health (Venkateswarlu and Srinivasarao, 2004; Melero *et al.*, 2006) [14, 10].

However, the nitrogen in organic manures is mainly in organic form and becomes available to plants only after microbial mineralization. The rate and extent of nitrogen release are dependent on the chemical composition, C:N ratio and level of decomposition of the organic manure (Agehara and Warncke, 2005; Abbasi *et al.*, 2007) ^[2, 1]. Even in soils categorized as nutrient-sufficient based on soil tests, crop response may still occur due to limited nutrient availability in the rhizosphere and microbial mediation of nutrient release (Kundu *et al.*, 2023) ^[9].

However, fertilizer guidelines tend to assume equal nitrogen availability from different organic manures, resulting in the incorrect estimation of plant-available nitrogen and a lack of synchronization with crop demand (Chadwick *et al.*, 2000) ^[5]. Controlled incubation experiments carried out in the absence of plants enable the separation of soil nitrogen processes from plant uptake and offer a precise method for estimating the dynamics of nitrogen mineralization and immobilization (Keeney and Nelson, 1982) ^[8]. Though crop growth is not an objective of incubation, the data are often used to guide nutrient management in the target cropping system. In this regard, the current study was conducted to describe the dynamics of nitrogen release from organic and inorganic sources of nitrogen in a tropical Alfisol and to interpret the implications of the data for synchronizing nutrient supply in rainfed sorghum.

2. Materials and Methods

2.1 Soil

The soil samples (0-15 cm depth) were collected from the Gunegal Research Farm of the Central Research Institute for Dryland Agriculture (CRIDA), Hyderabad, India. The soil was identified as a sandy clay loam Alfisol with pH 6.78, electrical conductivity 0.09 dS m⁻¹, organic carbon 0.50% and available nitrogen 210 kg ha⁻¹. The soil samples were air-dried, crushed and sieved through a 2mm sieve.

2.2 Nitrogen sources

The nitrogen sources used were urea (inorganic), farm yard manure (FYM), vermicompost (VC) and poultry manure (PM), with a control treatment in c. The organic manures varied in total nitrogen content and C:N ratio, with poultry manure having the lowest C:N ratio.

2.3 Incubation experiment

An aerobic incubation experiment was carried out for 112 days. Nitrogen sources were well mixed with soil at an equivalent rate of 30 mg N kg⁻¹ soil. Soil water content was kept at field capacity throughout the incubation. The average bi-weekly incubation temperature varied from 26.4 to 30.2 °C. Soil samples were taken at 0, 7, 14, 28, 56, 84 and 112 days after incubation (DAI). Samples were extracted with 2 M KCl and NH₄⁺-N and NO₃⁻-N were determined according to standard procedures (Keeney and Nelson, 1982) ^[8]. Total mineral nitrogen was calculated by summing the concentrations of NH₄⁺-N and NO₃⁻-N.

2.4 Statistical analysis

The data obtained from incubation experiments were statistically analyzed using the ANOVA procedure of SAS 9.2 (SAS Institute Inc. 2009) ^[15]. The Duncan multiple range test at $p \leq 0.05$ was used to establish the significance of

the difference between the means. The combined (pooled) analysis of the means was carried out using formulae described by McIntosh (1983) ^[16] for split plot design.

3. Results and Discussion

In control soil, during the incubation study (Table. 1) an increase in the total mineral nitrogen content was recorded even with low organic carbon and nitrogen content representing the potential for nitrogen mineralization in Alfisols (Keeney and Nelson, 1982; Srinivasarao *et al.*, 2012) ^[8, 13]. An increase in mineral nitrogen content might be due to microbial decomposition of innate organic matter, which acted as a nitrogen source (Gopinath *et al.*, 2013) ^[7]. The addition of urea resulted in a rapid increase in total mineral nitrogen content, which mineralized 95% by day 112. The rapid increase is attributed to hydrolysis of urea and subsequent nitrification in aerobic soils can leverage the immediate crop demand for nitrogen but should meet the crop nutrient requirement period (Keeney and Nelson, 1982; Dobermann, 2005) ^[8, 6]. The immobilization of nitrogen released from urea was not observed. The temporal changes in total mineral nitrogen (NH₄⁺-N + NO₃⁻-N) across all nitrogen sources during the incubation period are detailed in Table 2 and Figure 1. In case of poultry manure, FYM, and vermicompost, by 112 days a total of 67%, 33% and 29% nitrogen was released, respectively. The rapid release with poultry manure is attributed to narrow C:N ratio and availability of labile organic nitrogen, for FYM and vermicompost immobilization of nitrogen during the initial days of (approx 28 days) incubation was observed, which later followed by mineralization, attributed to assimilation of organic compounds in FYM by microbes during the initial days of application. These results were in accordance with those presented by Chadwick *et al.* (2000) ^[5] and Agehara and Warncke (2005) ^[2], stating that FYM can be used for long term nitrogen supply source. For vermicompost, the declined release of nitrogen might be due to the formation of recalcitrant organic products which do not undergo further microbial decomposition (Agehara and Warncke, 2005; Abbasi *et al.*, 2007) ^[2, 1].

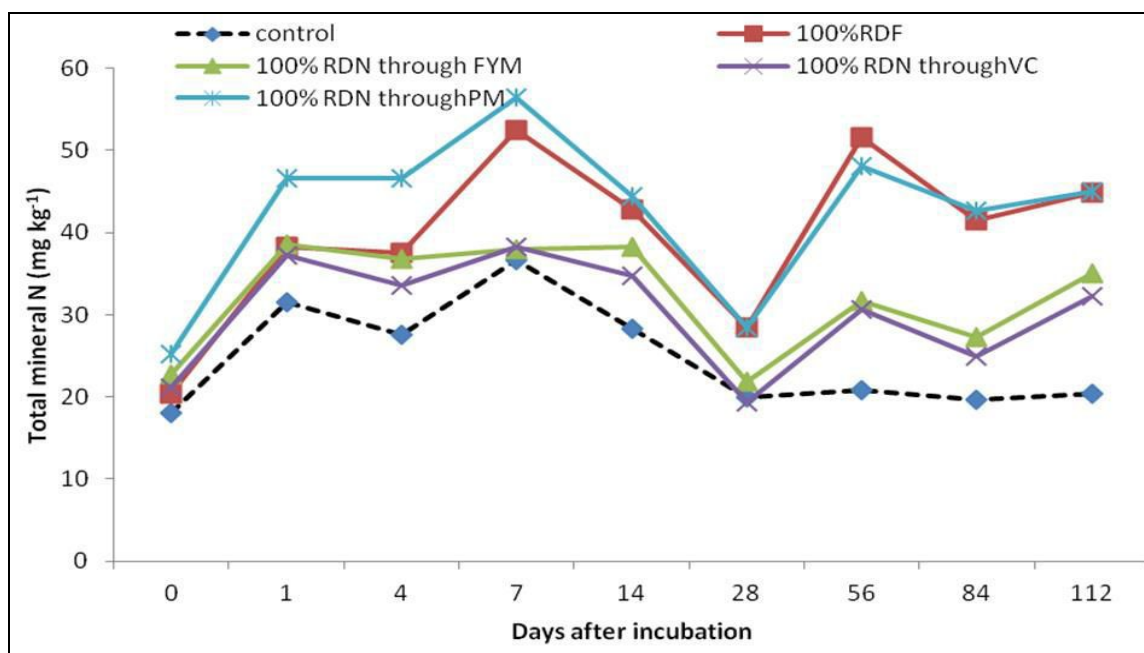
Nitrogen immobilization was observed approximately 28 days after incubation with organic manures which was previously reported as a common phenomenon related to organic amendment studies with wider C:N ratios. This immobilization is attributed to microbial immobilization. During the incubation study, predominance of nitrate-N was recorded. Though the ammonical-N was high during the initial days of incubation, the microbe mediated conversion of ammonical-N to nitrate-N under aerobic conditions was favoured, which agrees with the findings of (Keeney and Nelson, 1982) ^[8] in tropical Alfisols. The nitrogen release pattern of organic manures obtained from the incubation study implies practical difficulty, which can be faced due to improper and untimely application of nitrogen sources. Application of rapid nitrogen releasing sources can be considered for immediate leverage of sorghum demand for nitrogen (Ostmeyer *et al.*, 2022) ^[11]. Combining organic manures with inorganic fertilizers enhances synchronization between nitrogen supply and crop demand, leading to improved nitrogen uptake and efficiency in rainfed sorghum systems (Bayu *et al.*, 2006; Srinivasarao *et al.*, 2013) ^[4, 12].

Table 1: Amendment effect on total mineral nitrogen over 112 days (mg kg^{-1} soil)

Amendment	Total mineral N over 112 days (mg kg^{-1} soil) (average)
Control	24.7 ^D
100% RDF	39.8 ^B
FYM	32.2 ^C
VC	30.2 ^C
PM	42.6 ^A
SEd($\pm$)	1.0
P $\leq$ 0.05	*
CV(%)	4.2

*Significant at $p \leq 0.05$ Means in the same column with different superscript letters are significantly ($p \leq 0.05$) different.**Table 2:** Total mineral N ($\text{NH}_4\text{-N} + \text{NO}_3\text{-N}$) mg kg^{-1} soil with and without added organic manures incubated under controlled laboratory conditions for 112 days

Treatments	Days after incubation								
	0	1	4	7	14	28	56	84	112
Control	18.1 ^D	31.5 ^C	27.5 ^D	36.7 ^C	28.3 ^D	19.9 ^B ^C	20.8 ^D	19.6 ^D	20.4 ^D
100% RDF	20.4 ^C	38.3 ^B	37.5 ^B	52.5 ^B	42.8 ^A	28.5 ^A	51.6 ^A	41.5 ^A	44.9 ^A
FYM	22.8 ^B	38.6 ^B	36.8 ^B	37.6 ^C	38.2 ^B	21.8 ^B	31.6 ^C	27.3 ^B	35.1 ^B
VC	21.1 ^C	37.3 ^B	33.6 ^C	38.2 ^C	34.9 ^C	19.4 ^C	30.7 ^C	24.8 ^C	32.2 ^C
PM	25.2 ^A	46.6 ^A	46.6 ^A	56.4 ^A	44.4 ^A	28.4 ^A	48.1 ^B	42.6 ^A	45.0 ^A
SEd(±)	0.5	1.1	1.0	1.6	1.3	0.9	1.2	1.0	1.2
P≤0.05	*	*	*	*	*	*	*	*	*
CV(%)	3.1	4.1	4.0	5.1	4.8	5.5	4.6	4.5	4.6

*significant at $p \leq 0.05$ Note: Nitrogen was applied at the rate of 30 mg kg^{-1} soil in each amended treatment.Means in the same column with different superscript letters are significantly ($p \leq 0.05$) different**Fig 1:** Mineralization pattern of nitrogen from its different sources

4. Conclusions

The results showed the existence of marked differences in nitrogen release patterns between organic and inorganic materials in a tropical Alfisol. Urea had a fast nitrogen mineralization process, releasing almost all the applied nitrogen in 112 days, which is ideal for meeting immediate demand but is a potential loss in rainfed situations. Poultry manure released about two-thirds of the nitrogen due to its favourable C:N ratio and higher mineralizable nitrogen. Conversely, farmyard manure and vermicompost immobilized nitrogen at first and then released less than one-third of the total nitrogen at the end of the incubation period, which can act as a slow-release material for long-

term soil fertility. Nitrate-N was the predominant form of mineral nitrogen, which indicates potential leaching in rainfed situations.

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