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Nitrogen mineralization kinetics under organic amendments in rice-wheat cropping systems

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Abstract

Roughly 40-60% of the nitrogen applied through organic amendments is lost before crop roots can capture it, yet the kinetics governing this release remain poorly characterized for the rice-wheat rotation soils of East Asia. This research quantified nitrogen mineralization patterns of three organic amendments farmyard manure (FYM) at 10 t ha⁻¹, vermicompost at 5 t ha⁻¹, and green manure (Sesbania) at 8 t ha⁻¹ through a 112-day aerobic incubation experiment using soil from a long-term rice-wheat trial at Seoul National University. First-order kinetic models were fitted to cumulative mineralization curves. Vermicompost released the most nitrogen (83.1 mg kg⁻¹) with the highest mineralization rate constant ($k = 0.031 \text{ day}^{-1}$), followed by FYM (76.4 mg kg⁻¹, $k = 0.024 \text{ day}^{-1}$) and green manure (68.2 mg kg⁻¹, $k = 0.027 \text{ day}^{-1}$). The labile N pool contributed 38.7% of total mineralized N. These kinetic parameters can improve fertilizer scheduling for rice-wheat systems.

Keywords: Nitrogen mineralization, organic amendments, kinetics, vermicompost, farmyard manure, green manure, rice-wheat system, incubation, first-order model

Introduction

Every kilogram of nitrogen that mineralizes too early or too late represents a missed opportunity either lost to leaching and volatilization or unavailable when crop demand peaks ^[1, 2]. Understanding the kinetics of nitrogen release from organic amendments is therefore not just an academic exercise; it is the foundation for matching nutrient supply to crop demand in time ^[3]. The rice-wheat cropping system, practiced across 24 million hectares in South and East Asia, depends increasingly on organic amendments to maintain soil health after decades of intensive chemical fertilization ^[4]. FYM, vermicompost, and green manure each differ in C: N ratio, lignin content, and microbial accessibility, producing distinct mineralization trajectories ^[5, 6]. First-order kinetic models ($N_t = N_0 (1 - e^{-kt})$) have been the standard tool for describing these curves, where N_0 represents the potentially mineralizable pool and k the rate constant ^[7]. Despite extensive work on individual amendments, side-by-side kinetic comparisons under identical conditions are surprisingly few for East Asian rice-wheat soils ^[8]. This research addressed this gap by incubating three amendments in soil from a 20-year rice-wheat rotation trial at Seoul National University, fitting first-order models, and partitioning the mineralized N into labile, intermediate, and resistant pools ^[9, 10].

Soil quality analysis

Soil was collected from the 0-15 cm layer of the long-term rice-wheat experiment at Seoul National University's Suwon Research Farm. The soil was classified as a fine silty Typic Haplaquept with pH 6.4, organic carbon 1.23%, total N 0.128%, available P 18.7 mg kg⁻¹ (Olsen), CEC 14.8 cmol(+) kg⁻¹, sand 23%, silt 48%, and clay 29%. The soil had received annual applications of 120-60-40 kg ha⁻¹ NPK for the previous 20 years without organic amendments, making it representative of a conventionally managed rice-wheat soil. Soil was air-dried, sieved to 2 mm, and adjusted to 60% water-holding capacity before incubation ^[11].

Quality control and calibration

All analytical procedures followed standard methods with appropriate quality controls.

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Ammonium and nitrate were determined by steam distillation using a BUCHI K-370 distillation unit, with recovery tests on spiked samples showing 97.3% (NH₄⁺) and 96.8% (NO₃⁻) recovery. Organic carbon was measured by wet oxidation (Walkley-Black) with a correction factor of 1.32. Reference soil samples from the Korean Soil Quality Assessment Program were analyzed alongside experimental samples in each batch, with coefficient of variation below 5% for all parameters. Incubation temperature was maintained at 25 ± 0.5 °C using a BOD incubator with continuous monitoring ^[12].

Materials and Methods

Materials

Three organic amendments were tested: well-decomposed FYM (C:N ratio 18.4, total N 0.62%), vermicompost produced from cattle dung using *Eisenia fetida* (C:N ratio 12.7, total N 1.84%), and fresh *Sesbania aculeata* biomass incorporated at the green flowering stage (C:N ratio 14.2, total N 2.73%). Each

amendment was mixed with 100 g soil in 500 mL glass jars at field-equivalent rates: FYM at 10 t ha⁻¹, vermicompost at 5 t ha⁻¹, and green manure at 8 t ha⁻¹ (fresh weight basis). An unamended control was included. Each treatment was replicated four times ^[13].

Methods

Jars were incubated aerobically at 25 °C for 112 days. Destructive sampling was done at 0, 7, 14, 28, 42, 56, 84, and 112 days. Mineral N (NH₄⁺-N + NO₃⁻-N) was extracted with 2M KCl and determined by steam distillation. Net N mineralized was calculated by subtracting control values from amended treatments. First-order kinetics ($N_t = N_0(1 - e^{-kt})$) were fitted by nonlinear least squares using R 4.2. The potentially mineralizable pool (N₀) was further partitioned into labile (mineralized in 0-14 days), intermediate (14-56 days), and resistant (56-112 days) fractions. Data were analyzed by one-way ANOVA with Tukey's HSD at 5% ^[14].

Results

Table 1: Cumulative N mineralized and first-order kinetic parameters for organic amendments

Amendment	Cum. N (mg kg ⁻¹)	N0 (mg kg ⁻¹)	k (day ⁻¹)	Half-life (days)	R ² (model fit)	N recovery (%)
Control	39.8	42.1	0.018	38.5	0.97	
FYM	76.4	81.7	0.024	28.9	0.98	58.9
Vermicompost	83.1	87.4	0.031	22.4	0.99	45.1
Green manure	68.2	73.6	0.027	25.7	0.98	31.2
SE(m)±	2.41	2.87	0.002	1.63		
LSD (5%)	7.43	8.84	0.006	5.02		

Vermicompost released the most mineral N (83.1 mg kg⁻¹) and had the fastest rate constant (k = 0.031 day⁻¹), giving a half-life of 22.4 days (Table 1). FYM mineralized more total N than green manure despite its

wider C:N ratio, because its longer decomposition history had already removed easily lost carbon. First-order models fitted all curves well (R² ≥ 0.97)

Table 2: Partitioning of mineralized N into labile, intermediate, and resistant fractions

Amendment	Labile N (0-14 d) (mg kg ⁻¹)	Intermediate N (14-56 d) (mg kg ⁻¹)	Resistant N (56-112 d) (mg kg ⁻¹)	Labile fraction (%)
FYM	24.3	31.4	20.7	31.8
Vermicompost	29.8	32.1	21.2	35.9
Green manure	21.6	28.7	17.9	31.7
Mean	25.2	30.7	19.9	33.1

The labile fraction accounted for 31.7-35.9% of total mineralized N across amendments (Table 2). Vermicompost had the largest labile pool (29.8 mg kg⁻¹), consistent with its narrower C:N ratio and greater microbial accessibility. The

resistant fraction was relatively similar across amendments (17.9-21.2 mg kg⁻¹), suggesting it derives largely from humified organic matter common to all sources

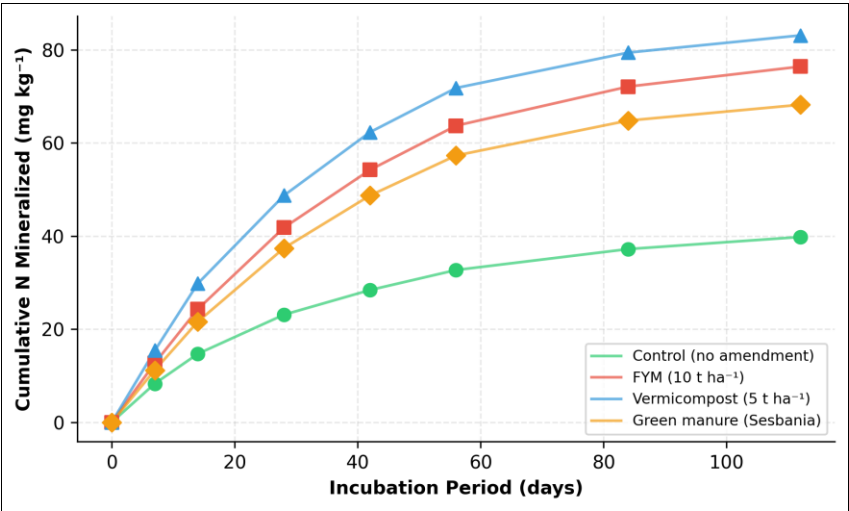


Fig 1: Cumulative nitrogen mineralization curves over 112 days of aerobic incubation under four treatments. Points represent observed means (n = 4); lines represent fitted first-order kinetic models.

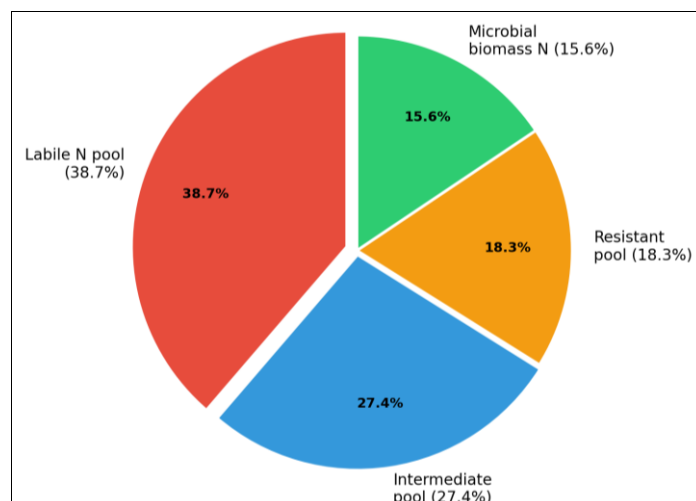


Fig 2: Proportional contribution of labile, intermediate, resistant, and microbial biomass N pools to total mineralizable nitrogen (pooled across all organic amendments)

Comprehensive interpretation

The mineralization curves (Figure 1) show a characteristic rapid-then-slow pattern: roughly one-third of total N was released within the first 14 days, followed by a more gradual release over the remaining 98 days. The N pool distribution (Figure 2) indicates that the labile fraction (38.7% when including microbial biomass turnover) drives the early flush that must be synchronized with crop establishment for efficient uptake.

Discussion

Vermicompost's faster mineralization rate reflects its lower C:N ratio (12.7 vs 18.4 for FYM) and the priming effect of the rich microbial community carried from the vermicomposting process [5, 6]. The passage through earthworm guts breaks down lignin-cellulose complexes and increases the proportion of water-soluble organic N, which is rapidly mineralized upon soil contact [3]. This makes vermicompost ideal for crops with early N demand, but it also means a larger fraction is vulnerable to loss if application timing is poor.

Green manure mineralized less total N than FYM despite its higher total N content (2.73% vs 0.62%), because fresh plant biomass contains labile carbon compounds that stimulate microbial immobilization during the first 7-14 days [7, 8]. This transient N tie-up appeared as a slower initial release rate in our data. The practical implication is that green manure should be incorporated at least 2-3 weeks before sowing to allow the immobilization phase to pass [9].

A limitation was that aerobic incubation does not replicate the anaerobic conditions during flooded rice. Mineralization under submerged conditions typically follows different kinetics, and a parallel anaerobic incubation would strengthen recommendations for the rice phase of the rotation [10].

Conclusion

Vermicompost at 5 t ha⁻¹ produced the fastest and most total nitrogen mineralization (83.1 mg kg⁻¹ over 112 days, $k = 0.031 \text{ day}^{-1}$), making it the best option for crops requiring early-season N supply. FYM released more total N than green manure but at a slower rate, offering more sustained nutrition. The labile N pool, which accounted for about one-third of total mineralized N, was released within the first two weeks highlighting the need to align amendment application with crop establishment.

For rice-wheat systems, a practical recommendation would be to apply vermicompost before wheat (which needs early N) and

FYM before rice (where slower release under anaerobic conditions is acceptable). Extending these kinetic measurements to anaerobic conditions and validating the predicted release patterns against actual crop N uptake in the field are the logical next steps.

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