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NITROGEN MINERALIZATION RATE IN COMBINED APPLICATION OF ORGANIC AND INORGANIC NITROGEN FERTILIZERS ON INCEPTISOL'S BENGKULU

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ABSTRACT

Inceptisol is characterized by poor soil chemical properties, particularly a deficiency of nitrogen (N), one of the essential macronutrients required by plants in large amounts but typically present in soil at low availability. This study aimed to determine the rate of N mineralization resulting from the combined application of ZA fertilizer (21% N) and cow manure on Inceptisol soil from Bengkulu. The experiment was conducted from November 2023 to March 2024 at the Soil Science Laboratory, Faculty of Agriculture, University of Bengkulu, using a single-factor Completely Randomized Design (CRD) with four treatments: 100% ZA fertilizer (400 kg ha^{-1}), 50% ZA + 50% organic fertilizer, 30% ZA + 70% organic fertilizer, and 100% organic fertilizer (25,000 kg cow manure ha^{-1}), each replicated three times across five incubation intervals (7, 14, 28, 42, and 70 days after incubation/DAI), producing 60 experimental units. Ammonium ($NH4^+$) and nitrate ($NO3^-$) concentrations were measured periodically, and the mineralization rate was calculated using a first-order kinetic model. The results showed that the combination of 50% ZA and 50% organic fertilizer produced the highest $NO3^-$ mineralization rate (2.37 ppm day^{-1}), while 100% organic fertilizer produced the highest $NH4^+$ mineralization rate (0.93 ppm day^{-1}). Sole application of ZA fertilizer resulted in a negative $NH4^+$ mineralization rate (-2.96 ppm day^{-1}), indicating rapid conversion of $NH4^+$ into $NO3^-$ through nitrification. These findings suggest that the combination of inorganic and organic N fertilizers provides a more sustained and balanced N mineralization pattern than either fertilizer applied alone, offering a practical strategy for improving N availability in Inceptisol soils.

Keywords: Ammonium; Inceptisol; Nitrogen mineralization; Nitrate; ZA fertilizer

INTRODUCTION

Inceptisol is one of the most extensively distributed soil orders in Indonesia, covering approximately 70.52 million hectares or about 37.5% of the country's total land area, making it highly potential for agricultural cultivation. Despite its wide distribution and considerable potential, the utilization of Inceptisol in the field is not free from constraints. This soil order exhibits variable texture, ranging from coarse to very fine, and is classified as an immature soil with weak profile development that still closely resembles its parent material. Such characteristics result in generally low natural fertility, which requires careful management to improve productivity.

One of the major chemical limitations of Inceptisol is its poor soil chemistry, reflected in low organic carbon content, acidic pH, and nutrient deficiency, particularly nitrogen (N). Nitrogen is among the essential macronutrients most abundant in the Earth's atmosphere (78%) and plays a critical role in plant growth, including protein and amino acid synthesis, vegetative development, chlorophyll formation, and the biosynthesis of cytokinin and auxin hormones. Plants absorb nitrogen mainly in the form of ammonium ($NH4^+$) and nitrate ($NO3^-$). Although required in large quantities, nitrogen availability in soil is consistently low because N is highly mobile and prone to losses through leaching, volatilization, and denitrification.

Nitrogen mineralization is the process by which inorganic N is formed from organic N through the sequential stages of aminization, ammonification, and nitrification. The mineralization rate of organic N into inorganic N is a key factor determining the amount of N available for plant uptake in soil. This process is influenced by several factors, including the carbon-to-nitrogen (C/N) ratio of the organic material, soil fertility, temperature, moisture content, and fertilizer management practices. Organic materials with a low C/N ratio decompose more readily and tend to produce a higher mineralization rate than those with a high C/N ratio.

To address nitrogen deficiency, farmers commonly apply inorganic fertilizers such as ZA (ammonium sulfate), which contains 21% N and 24% sulfur (S) and is readily soluble, providing nitrogen quickly to the root zone. However, because inorganic N is released rapidly, it is also highly susceptible to loss through leaching and volatilization, which can reduce the efficiency of N utilization by plants. As an alternative or complement, organic fertilizers such as cow manure are widely used. Cow manure contains approximately 0.33% N, 0.11% P, and 0.13% K, and besides supplying nutrients gradually, it also improves soil physical, chemical, and biological properties, increases cation exchange capacity, and stimulates the activity of soil microorganisms responsible for decomposition and nutrient cycling.

Combining inorganic and organic nitrogen sources is considered a promising strategy because it may provide an immediately available N supply from the inorganic component while organic matter supports a slower, more sustained release of nutrients and enhances microbial activity in the soil. However, information on how different proportions of ZA fertilizer and cow manure affect the dynamics and rate of N mineralization specifically in Bengkulu Inceptisol remains limited. Therefore, this study was designed to evaluate the rate of nitrogen mineralization under various combinations of ZA fertilizer and cow manure applied to Inceptisol soil, with the aim of identifying the combination that provides the most favorable and sustained N mineralization pattern for plant nutrition.

MATERIALS AND METHODS

Time, location, and soil sampling

This research was conducted from November 2023 to March 2024 at the Soil Science Laboratory, Faculty of Agriculture, University of Bengkulu. Composite soil samples of Inceptisol were collected from Pasar Pedati Village, Pondok Kelapa Sub-district, Central Bengkulu Regency, at an elevation of 7 m above sea level (coordinates 03°35.485′ S and 102°08.006′ E), at a depth of 0–20 cm. Soil samples were air-dried, crushed, cleared of roots, plant debris, and gravel, and sieved through a 2 mm mesh prior to use.

Experimental design

The experiment used a single-factor Completely Randomized Design (CRD), with treatments consisting of combinations of inorganic N fertilizer (ZA, 21% N) and organic fertilizer (cow manure), as follows: N1 = 100% ZA fertilizer (400 kg ha^{-1}); N2 = 50% ZA (200 kg ha^{-1}) + 50% cow manure (12,500 kg ha^{-1}); N3 = 30% ZA (120 kg ha^{-1}) + 70% cow manure (17,500 kg ha^{-1}); and N4 = 100% cow manure (25,000 kg ha^{-1}). Each treatment was incubated and sampled at five time intervals (7, 14, 28, 42, and 70 days after incubation/DAI) and replicated three times, resulting in a total of 60 experimental units.

Incubation procedure

Soil samples equivalent to 300 g (oven-dry weight basis) were placed into PVC incubation cylinders (17 cm height, 3-inch diameter) lined with gauze at the base to retain the soil. Fertilizers were weighed according to the assigned treatment dose and thoroughly mixed with the soil. Soil moisture was maintained by adding 97 mL of water for N1, 100 mL for N2, 102 mL for N3, and 105 mL for N4. Incubation was performed aerobically under open, room-temperature conditions, with ambient temperature ranging from 28–31°C and relative humidity ranging from 68–76% throughout the incubation period.

Observed variables and analytical methods

The variables observed were soil ammonium ($NH4^+$) and nitrate ($NO3^-$) concentrations, measured periodically at 7, 14, 28, 42, and 70 DAI. Ammonium concentration was determined using the Indophenol Blue method with a spectrophotometer at a wavelength of 660 nm, while nitrate concentration was determined using the Derivative Spectrophotometry method (brucine method) at a wavelength of 392.4 nm. Prior to analysis, soil extracts were obtained by shaking 10 g of soil with 50 mL of 1 N KCl solution for 60 minutes, followed by filtration.

Mineralization rate calculation and statistical analysis

The nitrogen mineralization rate was estimated using a first-order kinetic model, expressed as:

$$y = a\,(1 - e^{-kt})$$

where y is the cumulative mineralized N (ppm), a is the maximum potential mineralizable N (ppm), e is Euler's number (2.71828), k is the N mineralization rate constant, and t is the incubation time (days). Data were analyzed using Analysis of Variance (ANOVA), and treatments showing significant effects were further analyzed using the Least Significant Difference (LSD) test at the 5% significance level.

RESULTS AND DISCUSSION

Initial soil characteristics

Initial soil analysis revealed that the Inceptisol used in this study had a sandy loam texture, comprising 73.16% sand, 12.42% clay, and 14.41% silt. The soil exhibited a low organic carbon content (2.10%), low total N content (0.21%), and slightly acidic pH (4.92). The cow manure used as the organic fertilizer source had an organic carbon content of 20.55% and a total N content of 2.04%. These baseline characteristics confirm that the soil was indeed deficient in both organic matter and nitrogen, supporting the rationale for fertilizer amendment in this experiment.

Effect of fertilizer combination on $NH4^+$ and $NO3^-$ concentrations

Analysis of variance indicated that the combination of organic and inorganic N fertilizers significantly affected $NO3^-$ concentration at 14, 42, and 70 DAI, and significantly affected $NH4^+$ concentration at 42 and 70 DAI (Table 1), while no significant differences were observed at earlier observation times (7 and 28 DAI). This pattern suggests that the effect of fertilizer combination on N transformation becomes more pronounced as incubation progresses, once microbial decomposition and nitrification processes are fully underway.

Table 1. Analysis of variance for soil $NO3^-$ and $NH4^+$ concentrations at each observation time

Observation time (DAI)	F-calculated	F-table (5%)	CV (%)
Nitrate ($NO3^-$)			
7	3.12 ns	4.07	15.03
14	5.57 *	4.07	12.22
28	2.07 ns	4.07	18.12
42	6.35 *	4.07	6.96
70	7.73 *	4.07	7.20
Ammonium ($NH4^+$)			
7	2.90 ns	4.07	20.13
14	2.19 ns	4.07	19.22
28	1.01 ns	4.07	19.09
42	4.42 *	4.07	14.01
70	15.52 *	4.07	9.19

Note: * = significant effect; ns = not significant, at the 5% level.

Regarding $NH4^+$ dynamics (Table 2), the combination of 30% ZA + 70% organic fertilizer produced the highest concentration at both 42 DAI (62.90 ppm) and 70 DAI (63.41 ppm), significantly higher than the other treatments. In contrast, sole application of ZA fertilizer (N1) showed a marked decline in $NH4^+$ concentration over time, from 44.49 ppm at 42 DAI to only 38.51 ppm at 70 DAI. This decline reflects the rapid conversion of $NH4^+$ to $NO3^-$ through nitrification, since ammonium-based inorganic fertilizers are readily transformed once nitrifying bacteria become active. The treatments incorporating organic fertilizer (N2, N3, N4) instead exhibited an increasing trend in $NH4^+$ over time, attributable to the slow, continuous release of nitrogen from decomposing organic matter combined with enhanced heterotrophic microbial activity (ammonification), which steadily replenishes the $NH4^+$ pool.

Table 2. Effect of ZA and cow manure fertilizer combinations on soil $NH4^+$ concentration

Treatment	42 DAI (ppm)	70 DAI (ppm)
100% ZA	44.49 b	38.51 c
50% ZA + 50% organic fertilizer	46.96 b	59.42 ab
30% ZA + 70% organic fertilizer	62.90 a	63.41 a
100% organic fertilizer	46.43 b	50.27 b

Note: numbers followed by the same letter within the same column are not significantly different based on the LSD test at the 5% level.

A comparable pattern was observed for $NO3^-$ concentration (Table 3). At 42 and 70 DAI, the combination of 30% ZA + 70% organic fertilizer and 50% ZA + 50% organic fertilizer produced the highest $NO3^-$ concentrations, reaching 102.18 ppm and 102.58 ppm at 70 DAI, respectively, both significantly higher than the sole ZA treatment (79.34 ppm at 70 DAI). The sole ZA treatment exhibited a declining $NO3^-$ trend from 14 to 70 DAI, which is consistent with the lowering of soil pH commonly associated with ammonium sulfate application; the resulting acidification can inhibit nitrifying bacteria such as Nitrosomonas and Nitrobacter, thereby suppressing nitrate accumulation. Conversely, treatments with a higher proportion of organic fertilizer showed a continuous increase in $NO3^-$ over the incubation period, indicating that organic matter addition supports sustained nitrification by supplying energy substrates and maintaining microbial activity.

Table 3. Effect of ZA and cow manure fertilizer combinations on soil $NO3^-$ concentration

Treatment	14 DAI (ppm)	42 DAI (ppm)	70 DAI (ppm)
100% ZA	91.38 a	83.44 b	79.34 b
50% ZA + 50% organic fertilizer	75.65 ab	83.71 b	102.58 a
30% ZA + 70% organic fertilizer	90.84 a	100.79 a	102.18 a
100% organic fertilizer	63.54 b	82.16 b	93.07 a

Note: numbers followed by the same letter within the same column are not significantly different based on the LSD test at the 5% level.

Nitrogen mineralization rate

The first-order kinetic model was applied to estimate the mineralization rate constant (k), the potential mineralizable N (a), and the resulting mineralization rate (ppm day^{-1}) for both $NH4^+$ and $NO3^-$ across all treatments (Tables 4 and 5).

Table 4. Nitrogen mineralization rate ($NH4^+$) under different fertilizer combinations

Treatment	Rate constant (k)	Potential mineralization (a)	Mineralization rate (ppm day^{-1})
100% ZA	-0.0077	4.13	-2.96
50% ZA + 50% organic fertilizer	0.0010	3.92	0.27

30% ZA + 70% organic fertilizer	0.0012	4.04	0.33
100% organic fertilizer	0.0039	3.59	0.93

Table 5. Nitrogen mineralization rate ($NO3^-$) under different fertilizer combinations

Treatment	Rate constant (k)	Potential mineralization (a)	Mineralization rate (ppm day^{-1})
100% ZA	0.0034	4.24	0.96
50% ZA + 50% organic fertilizer	0.0103	3.95	2.37
30% ZA + 70% organic fertilizer	0.0056	4.31	1.49
100% organic fertilizer	0.0082	4.01	1.97

For $NH4^+$, the highest mineralization rate was recorded under the 100% organic fertilizer treatment (0.93 ppm day^{-1}), whereas the sole ZA treatment produced a negative rate (-2.96 ppm day^{-1}). This negative value indicates that $NH4^+$ was consumed faster than it was generated, consistent with rapid nitrification converting $NH4^+$ into $NO3^-$ under conditions where readily available inorganic N dominates. The application of organic fertilizer alone provided a more gradual but positive supply of $NH4^+$, likely because the organic substrate offers a continuous carbon and nitrogen source that sustains heterotrophic microbial decomposition over the incubation period.

For $NO3^-$, the highest mineralization rate occurred under the combination of 50% ZA + 50% organic fertilizer (2.37 ppm day^{-1}), while the lowest rate was found under sole ZA application (0.96 ppm day^{-1}). The combined treatment likely benefits from the immediate availability of inorganic N from ZA fertilizer together with the additional substrate and improved microbial habitat provided by organic matter, thereby accelerating the nitrification process. Sole ZA application provided inorganic N without supporting organic matter, which limited the overall growth of the nitrifying microbial community despite the immediately available N source. These results align with previous findings indicating that mineralization rates are strongly influenced by the quality of organic material, particularly its C/N ratio, with low C/N organic materials generally producing higher mineralization rates than those with high C/N ratios.

Overall, the combination of inorganic and organic nitrogen fertilizers, particularly at moderate-to-high proportions of organic fertilizer (50–70%), produced more favorable and sustained N mineralization patterns compared to either fertilizer type applied alone. These results support the practice of integrated nutrient management, in which inorganic fertilizers supply an immediate nitrogen source while organic amendments such as cow manure sustain microbial activity and gradual nutrient release, ultimately improving the efficiency and duration of nitrogen availability in Inceptisol soils. In addition to fertilizer type and proportion, environmental factors such as soil temperature and moisture are known to strongly influence mineralization dynamics; mineralization generally increases with temperature within an optimal range of 25–35°C and is also enhanced under adequate soil moisture, which favors microbial decomposition activity. Future studies incorporating direct measurement of soil organic carbon, temperature, and moisture throughout the incubation period are recommended to further elucidate the mechanisms underlying these mineralization patterns.

CONCLUSION

The combined application of ZA fertilizer and cow manure significantly affected the rate of nitrogen mineralization in Bengkulu Inceptisol soil. The highest $NO3^-$ mineralization rate (2.37 ppm day^{-1}) was achieved with the combination of 200 kg ha^{-1} ZA fertilizer and 12,500 kg ha^{-1} cow manure (50% ZA + 50% organic fertilizer), while the highest $NH4^+$ mineralization rate (0.93 ppm day^{-1}) was achieved with 25,000 kg ha^{-1} cow manure applied alone (100% organic fertilizer). Sole application of ZA fertilizer resulted in a negative $NH4^+$ mineralization rate, reflecting rapid nitrification under inorganic-only fertilization. These findings indicate that combining inorganic and organic nitrogen sources provides a more balanced and sustained nitrogen mineralization pattern than either source alone, supporting the use of integrated fertilization strategies to improve nitrogen availability in Inceptisol soils. Further research analyzing soil organic carbon, temperature, and moisture during incubation is recommended to obtain a more comprehensive understanding of the factors governing nitrogen mineralization.

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