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Potential Nitrogen Mineralization Variability in Commercial Row Crop Fields

Abstract

Nitrogen (N) transformation in soils is crucial in determining N availability for plant growth. Row crop producers have widely adopted cover crops across the U.S. However, there is limited knowledge about N transformations in commercial fields with and without cover crops. Furthermore, there is lack of understanding about the spatial variability of potential N mineralization in row crops and how it varies within a field and between cropping systems. An in-situ mineralization study was conducted in two Alabama row crop farms to evaluate the variability of potential N mineralization across locations and within a farm. The results revealed the variability in N mineralization within farms at both the locations. It was reported that a farm with cover crop and residue retention history had a mineralization rate of 1.18 to 3.89 lb/acre/day. In contrast, another farm with no cover crop had a mineralization potential of 0.93 to 1.17 lb/acre/day. These findings underscore the importance of cover crops and residue retention for enhancing N mineralization potential.

Introduction

Nitrogen transformation in soils

Nitrogen (N) transformation refers to converting N from an unavailable form to a plant-available form and vice versa. Nitrogen, being the limiting nutrient, is required in higher quantities as it directly influences crop yield and productivity. It has various forms and can significantly impact agricultural productivity or contribute to environmental pollution.

Why is it important to understand N transformations?

Understanding N transformations are essential for several reasons. First, while the dominant component of soil N is organic N, plants primarily utilize inorganic forms such as ammonium and nitrate (NH_4^+, NO_3^-). Soil microbes primarily mediate the biological processes that convert unavailable or organic forms into available forms. Second, N often acts as a limiting factor for plant growth in most terrestrial ecosystems. Consequently, the productive capacity of an ecosystem, known as net primary production, can be regulated by the rates at which soil microbes transform N into forms that plants can utilize. The main concepts associated with N transformations in soil include mineralization, immobilization, volatilization, nitrification, and denitrification. Recognizing these transformations and understanding the various forms of N is crucial for comprehending N movement within the landscape and its environmental implications.

Soil mineralization and immobilization

Soil mineralization is the process by which organic N compounds are transformed into simpler inorganic forms, including nitrate and ammonium. According to various studies, the rate of N mineralization in the soil is not constant in time or space, and it depends on many factors, such as soil type, properties of organic matter, composition of soil microorganisms, and soil temperature and moisture (Robertson and Groffman, 2007, Liu et al., 2016, Buzin et al., 2019, Risch et al., 2020). These factors and their effect on mineralization are elaborated below:

1. Availability of organic N compounds: Organic N compounds are an energy source for microorganisms, facilitating mineralization.
2. The organic source's carbon-to-nitrogen ratio (C:N): A C:N ratio below 30 promotes mineralization.
3. Soil temperature: Optimal mineralization occurs at around 77°F (25°C), while temperatures below 68°F (20°C) slow the rate of mineralization.
4. Soil moisture: Soils that are poorly drained or too dry experience limited microbial activity, thus slow rates of microbial decomposition and mineralization (Curtin et al, 2012). The ideal moisture level for mineralization is at field capacity or approximately 75% of field capacity. Adequate moisture facilitates microbial activity and nutrient release.
5. Soil texture: Soil texture, such as sand or clay content, influences the stability of organic matter and its decomposition rate. Sandy soils have faster organic matter decomposition than heavy clay soils.
6. Biodiversity: Microbial biodiversity plays a crucial role in mineralization. Healthy soils, particularly those under conservation practices and cover crop systems, harbor a greater diversity of beneficial microbes that greatly influence the potential for mineralization.

Soil immobilization **i**s the opposite process of soil N mineralization and involves converting inorganic forms of N into organic forms present in soil microbes. This process is also termed "nitrogen robbing." In this process, soil microbes utilize the available inorganic N as a nutrient source, leading to its incorporation into their biomass. Immobilization of N reduces its availability for plant uptake, and it may limit plant growth. It occurs when the soil organic matter or amendments added to the soil contain relatively high amounts of carbon compared to N. Furthermore, N immobilization can intensify during periods of limited moisture availability, such as drought (Zheng et al, 2017).

Impact of conservation practices on N mineralization rates

Conservation practices (CP), especially residue retention and crop rotation are known to improve the amount and quality of soil organic matter (SOM), which in turn increases the soil N mineralization. Residue retention involves leaving crop residues, including stalks, leaves, and other plant materials on the field after harvest instead of removing them.

These residues, originating from previous crops or cover crops specifically planted for this purpose, contribute to soil health and fertility. On the other hand, crop rotation is a strategy where various crops are cultivated in a specific field over a series of seasons or years that optimizes soil fertility, mitigating pest and disease challenges, and ultimately improving overall crop yields. Cover crops have many excellent benefits and are essential to soil health. Cover crops provide advantages by protecting top fertile soil and adding organic substrate to improve soil beneficial microbes. Overall, it enhances soil aggregate stability, soil biological activity, soil biodiversity, and carbon sequestration (Ghosh et al., 2010). Munera et al., 2020 conducted a study to investigate the effects of CP on the amount and quality of soil organic matter (SOM) and potential N mineralization. Their results suggest that the CPs are more effective in increasing SOM and N mineralization than conventional agricultural systems. Another study by Restovich et al., 2022 highlighted the importance of incorporating legumes as cover crops in crop rotation. The experiment reported that the legume monoculture and legume-dominated mixtures maintained higher soil mineral N stocks at cover crop termination than the grass- or brassica-associated cover crops. Introducing a legume in a mixture with non-legumes enhances N cycling by maintaining biological N fixation and N retention of potentially leachable N in aboveground biomass of both the legume and the non-legume mixture component.

Understanding soil N immobilization is crucial for managing N dynamics in agricultural systems. By carefully considering the C:N ratios of organic inputs and ensuring adequate moisture conditions, farmers can mitigate the potential adverse effects of N immobilization and maintain a balanced nutrient supply for their crops.

Soil health and potential N mineralization

Soil health is intricately tied to soil organic matter (SOM). It is vital in soil fertility as it enhances nutrient absorption and release and creates a conducive environment for soil microbes (Geisseler et al. 2021). Soil microbes are key players in maintaining soil fertility as they break down organic residues, which either immobilize N, making it unavailable for plants or mineralize N, making it available for plant uptake. This article explores the advantages of conservation practices and the retention of residues on agricultural lands. More specifically, the focus is on the impact of potential N mineralization by soil microbes. Gaining a deeper understanding of N cycling in agriculture is crucial for improving fertilizer use efficiency and promoting sustainable food production in Alabama.

The N mineralization potential of soils is an estimate of the net production of inorganic N under given conditions, and it provides a means to assess soil N availability. To investigate the N mineralization potential of different soil types, a study was conducted in Alabama in 2022. The study aimed to observe the differences in N mineralization potential between two commercial farms, one with a cover crop adoption and the other without a cover crop history, and determine the within-field variability for mineralized N.

Materials and Methods

The study was conducted on two farmers' fields (Table 1) in Central (F40) and North Alabama (F11). An in-situ buried bag experiment protocol, as described by Sullivan et al. (2021), was followed.

Table 1. Field descriptions

Location	Area (Acres)	Soil type	Crops
F40	14.4	Loamy sand	2021 - Peanut 2022 - Cotton 2023 - Corn
F11	118	Silty loam	2021 - Soybean 2022 - Corn 2023 – Wheat-Soybean

Field F40 (Figure 1) was divided into seven locations: high, medium, and low-yielding zones based on multiple years of data collected at this farm (Table 2). The soil type is classified as loamy sand (Table 2).

Figure 1. Sampling locations at Field F40.

Table 2. Soil texture at all incubation locations in Field F40.

Location	Yield zone	Sand %	Silt %	Clay %	Soil textural class
3	High	81.6	12.16	6.20	Loamy sand
4	High	75.9	15.08	9.00	Sandy loam
5	Medium	75.9	16.04	8.04	Sandy loam
6	Medium	81.7	14.16	4.16	Loamy sand
7	Low	79.9	14.0	6.16	Loamy sand
8	Low	86.9	6.53	6.59	Loamy sand
9	High	81.9	10.0	8.08	Loamy sand

The cropping sequence observed in Field F40 involved a peanut-cover crop-cotton rotation. This experiment was conducted during cotton crop. At the beginning of the study, Field F40 had residues retained on its soil surface (cover crop residues –mixture of triticale planted @ 30 lb/acre, clover @ 5 lb/acre, and radish @ 5 lb/acre) and received an application of two tons per acre of chicken litter (35 days before planting) and recommended dose of urea (217 lb/acre) at the time of planting cotton (05/20/22). The total soil carbon content in Field F40 ranged from 1.0% to 1.8%. To assess the variability in N mineralization potential of the field, all seven locations were selected for the in-situ incubation experiment. The buried bags were collected four times starting in June and continued until the end of September (Table 3) to assess the N mineralization potential of the soil.

Table 3. Timeframes for buried bag installation and incubation period in Field F40.

Time period 1	06/06/23 to 06/27/23
Time period 2	06/27/23 to 07/21/23
Time period 3	07/21/23 to 08/29/23
Time period 4	08/29/23 to 09/20/23

Similarly, based on historical yield data, Field F11 (Figure 2) was divided into 4 locations: 1 and 2 into high-yielding and 7 and 8 into low-yielding zones. The farm has predominantly silty loam soils (Table 4). The farm employs a crop rotation system consisting of soybeans followed by corn. There are four months of fallow period (December - March) between soybean harvest in November and corn planting in April. Chicken litter (25 days before planting) and recommended dose of urea (420 lb/acre) was applied to corn (04/21/22). The study was conducted during corn period (Table 1). The total soil carbon content in Field F11 ranged from 1.2% to 1.6%. All four locations were chosen for the incubation experiment to capture the variability within the field. The buried bags were pulled twice during the growing season to assess the nitrogen mineralization potential (Table 5).

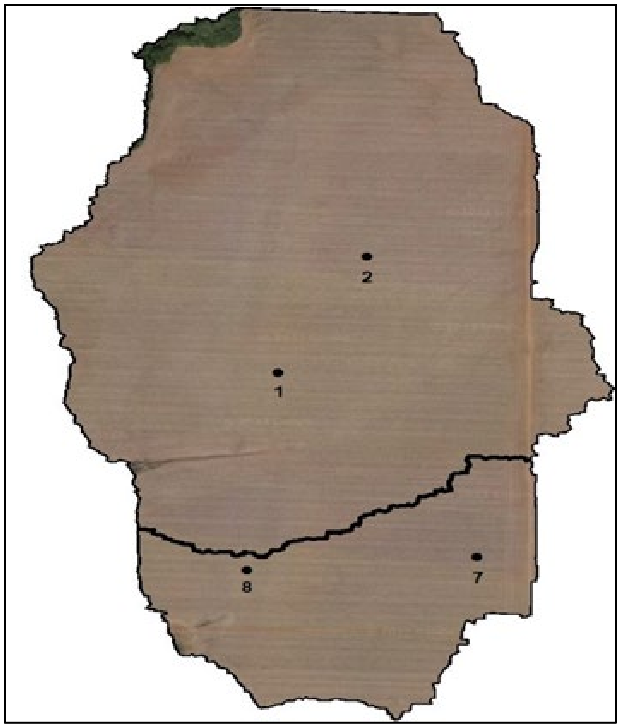

Figure 2. Sampling locations at Field F11.

Table 4. Soil texture variability at different incubation locations at F11

Location	Yield zone	Sand %	Silt %	Clay %	Soil textural class
1	High	23.6	54.1	22.4	Silt loam
2	High	33.4	46.4	20.3	Loam
7	Low	25.4	54.4	20.3	Silt loam
8	Low	23.6	50.0	26.4	Silt loam

Table 5. Field F11 incubation dates

Time period 1	05/01/22 to 07/07/22
Time period 2	07/07/22 to 09/05/22

***In situ* buried bag study**

This study used 8-inch-long Whirl Pak bags to perform infield incubation. These bags were sealed on one side and had a tie on the other end to secure their contents.

1. Soil samples were collected from the cotton field at various sampling locations at Field F40 and Field F11 (Figures 1 and 2) using an auger to extract soil from the top 2 inches of the soil profile. The collected soil from the replicates was combined and passed through a 6 mm sieve to create composite samples. The soil collection and sieving steps are shown in Figure 3.

2. No additional water was added to the soil samples during collection to maintain similar moisture conditions as surrounding soils. The soil moisture presents at the sampling time, referred to as "as-is" soil moisture, was retained within the samples. At the time of collection, the moisture status of soils was near field capacity to provide adequate moisture availability and promote better aeration within the bag.

3. Subsequently, 100 grams of the sieved soil was tightly packed into the labeled Whirl Pak bags and securely sealed for incubation. The bags were buried near the crop rows to ensure that the soil inside the bags experienced similar temperatures as the surrounding field soil. This in-situ placement allowed for the estimation of N mineralization under natural conditions. The incubation steps are shown in Figure 4.

4. At burial, the soil samples were analyzed for bulk density, gravimetric water content, nitrate, and ammonium to provide initial N concentration (T0).

5. The bags remained buried for a minimum incubation period of 21 days at various periods, as specified in Table 2 and Table 4.

6. The bags were carefully retrieved from the field after incubation. The soil contents were analyzed to determine gravimetric water content and the concentrations of nitrate and ammonium, referred to as the final N concentration (T1).

7. Following the first incubation period, a new set of bags was buried, and steps 1 to 6 were repeated to collect mineralization data multiple times during the cropping period, allowing for multiple measurements and a more robust assessment of N mineralization over time.

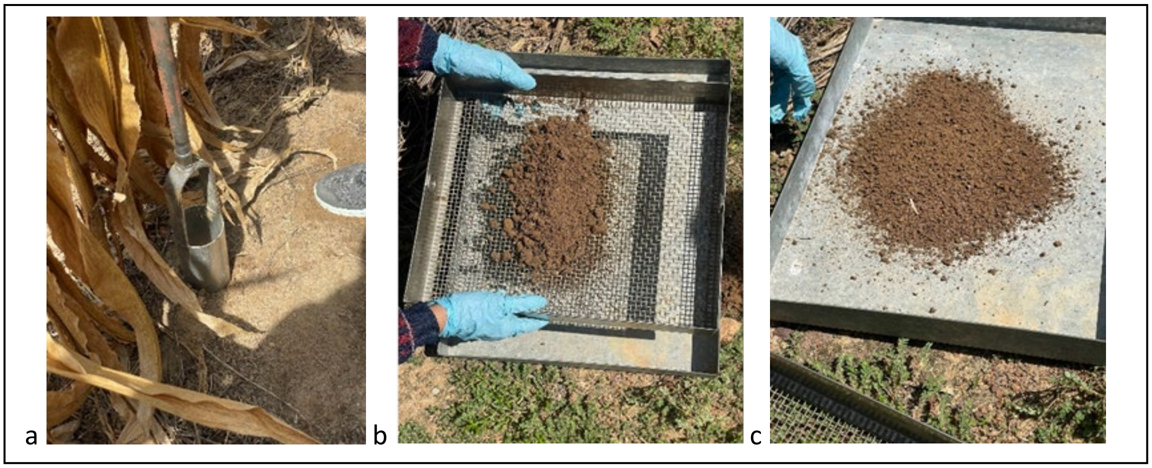

Figure 3. Sample collection. Soil sample collection near the row (a), combined sample is sieved using 5 mm mesh (b), and sieved sample (c).

Figure 4. Sample incubation. Weighing for uniform sample size (a), packing and labeling soil in a Whirl Pak bag (b),and sealing and burying the bag parallel to the crop row (c).

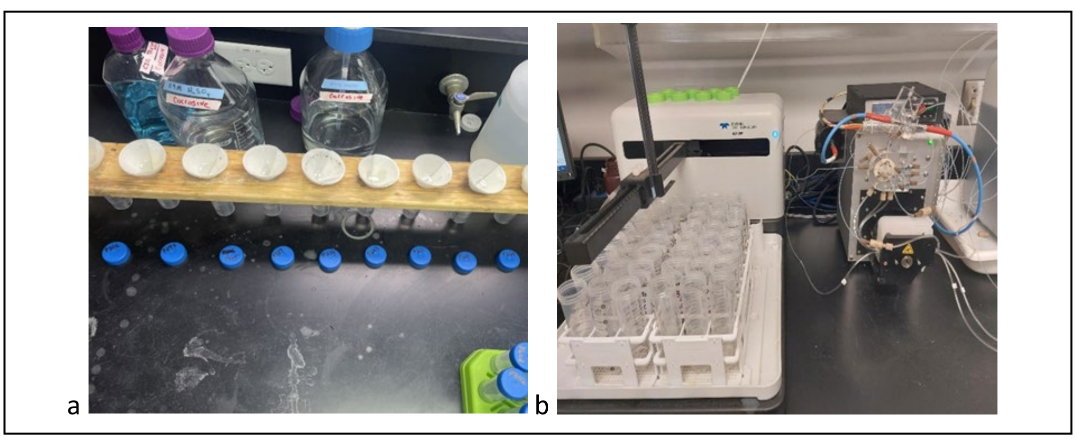

Figure 5. Sample analysis. KCl extraction of soil followed by filtration (a) and nitrogen analysis using flow injection analyzer (b).

Nitrogen analysis

The soil retrieved from bags was used to determine inorganic N accumulation. The soil was extracted at "as-is" moisture to avoid the flush of mineralization that often accompanies soil drying and rewetting. The gravimetric water content of the soil was also calculated to adjust the soil weight on an oven-dried basis for the final N (kg/ha) estimation (Figure 5). Ammonium + nitrate-N were determined by using 5 g soil (weight later adjusted using gravimetric water content calculations) and 2M KCl extraction, followed by analysis in flow injection analyzer (Nitrate-EPA 353.2- FIAlyzer 1000, Greiss method with cadmium reduction and Ammonium - EPA 350.1-FIAlyzer 1000, salicylate method)

Calculations

T0 is when the bag was buried, and T1 is when the bag was retrieved from the soil.

<u>Net nitrification</u>

= ([nitrate on T1] – [nitrate on T0]) / incubation days

<u>Net ammonification</u>

= ([ammonium on T1] – [ammonium on T0]) / incubation days

<u>Net mineralization</u>

= ([nitrate + ammonium on T1] – [nitrate + ammonium on T0]) / incubation days

Results and Discussion

By conducting this experiment at Field F40 under actual farming conditions, valuable insights into the N dynamics and mineralization potential were obtained. Mineralization rates were higher at F40, ranging from 1.18 to 3.89 lb/acre/day during the start of the experiment, and declined to 0.93 to 1.77 lb/acre/day during later periods (Figure 6). In contrast, the mineralization rate in Field F11 (Figure 7) ranged from 0.40 to 0.47

lb/acre/day during the first incubation period (33-days) and increased from 0.93 to 1.17 lb/acre/day during the second incubation period (55-days). The initial high mineralization rate at F40 can be attributed to the availability of organic substrate in the form of cover crop residues (Nov – Mar). The presence of organic substrate and a favorable carbon-to-nitrogen ratio promoted microbial population and mineralization. Conversely, F11 lacked cover crops; thus, a low organic substrate for microbes led to low mineralization rates and immobilization at locations 7 and 8 during the first incubation.

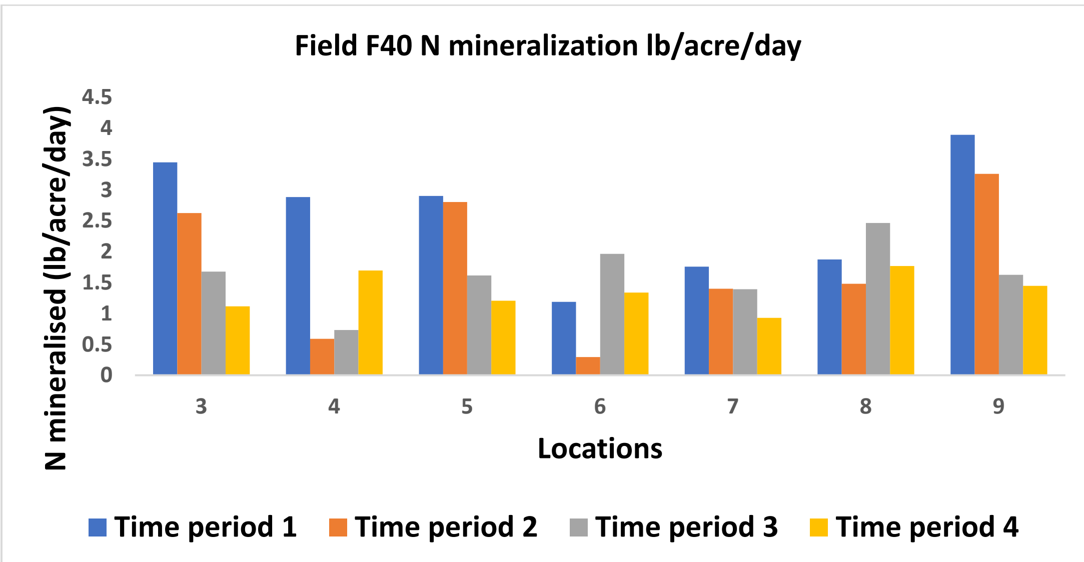

Figure 6. N mineralization during different time periods at Field F40.

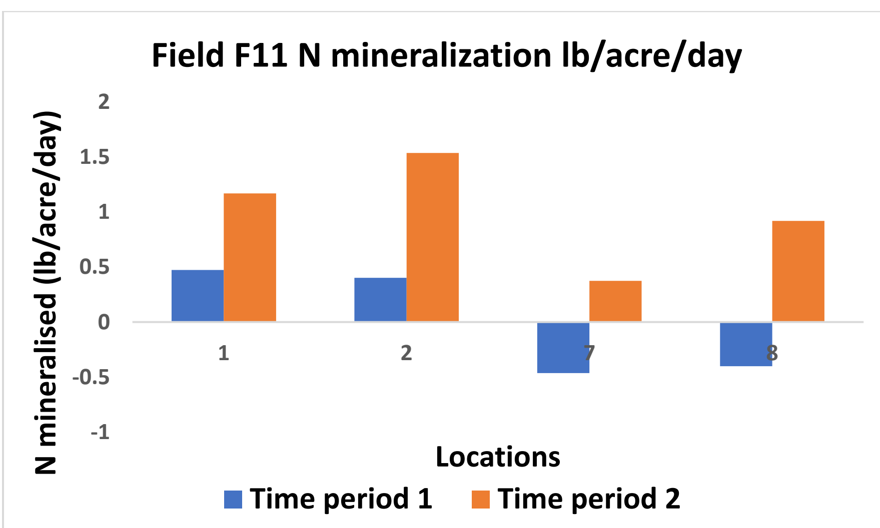

Figure 7. N mineralization during different time periods at Field F11.

Another crucial consideration is the influence of topography, hydrology, and weather on the results. The favorable topography with slopes of less than 6% and the loamy sand texture of soils facilitated adequate drainage and less surface runoff at F40. A total of 20 inches of rainfall was recorded during this experiment with an average T_{max} of 89 °F (Figure 8), which favored the decomposition of cover crop residues on the soil surface and the decomposition of poultry litter applied before planting. Conversely, F11, with heavy textured soils and a slope around 10%, experienced hot and dry conditions during the study period with an average T_{max} of 88 °F and only 10 inches of rain (Figure 9). Before planting corn, the field was fallow from November 2021 to April 2022. During this fallow period, 28.1 inches of rainfall were recorded, leading to surface runoff, which could have carried away topsoil and accumulated inorganic N. This phenomenon likely resulted in decreased beneficial microbial activity in the soil. This theory is supported by results observed at location numbers 7 and 8 (which falls under steeper slope areas compared to location 1 and 2), (Figure 2) which experienced immobilization at first incubation and could be attributed to slower rate of decomposition of organic substrate-poultry litter (applied 25 days before planting).

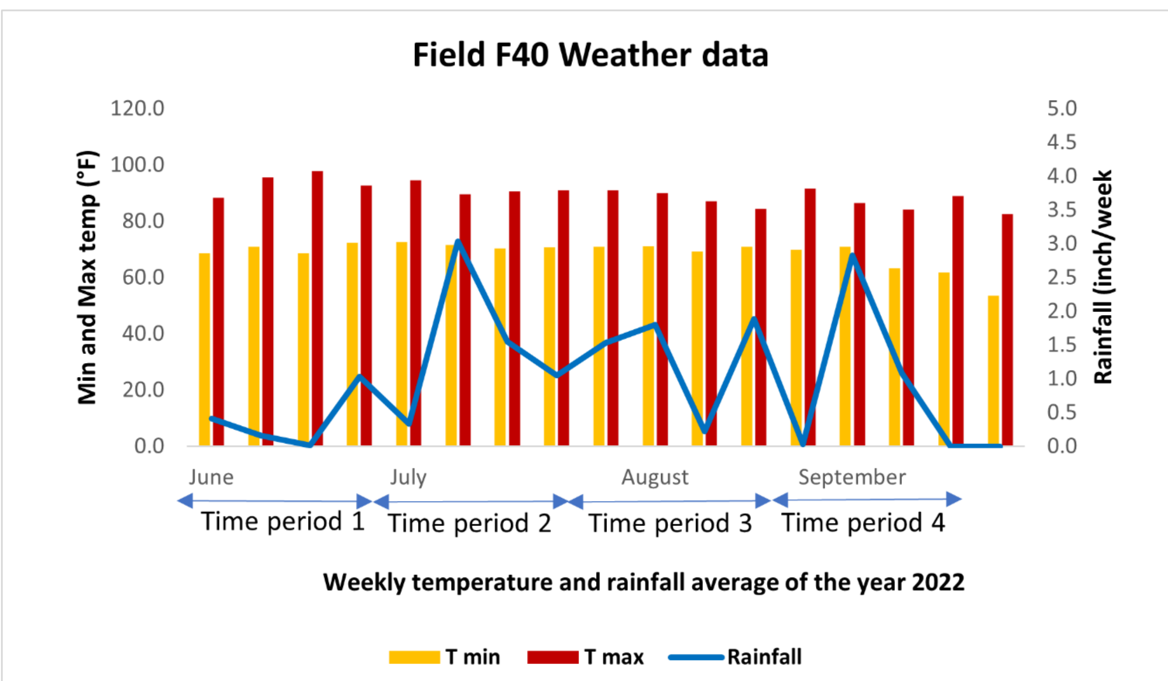

Figure 8. Weather data during the study period at Field F40.

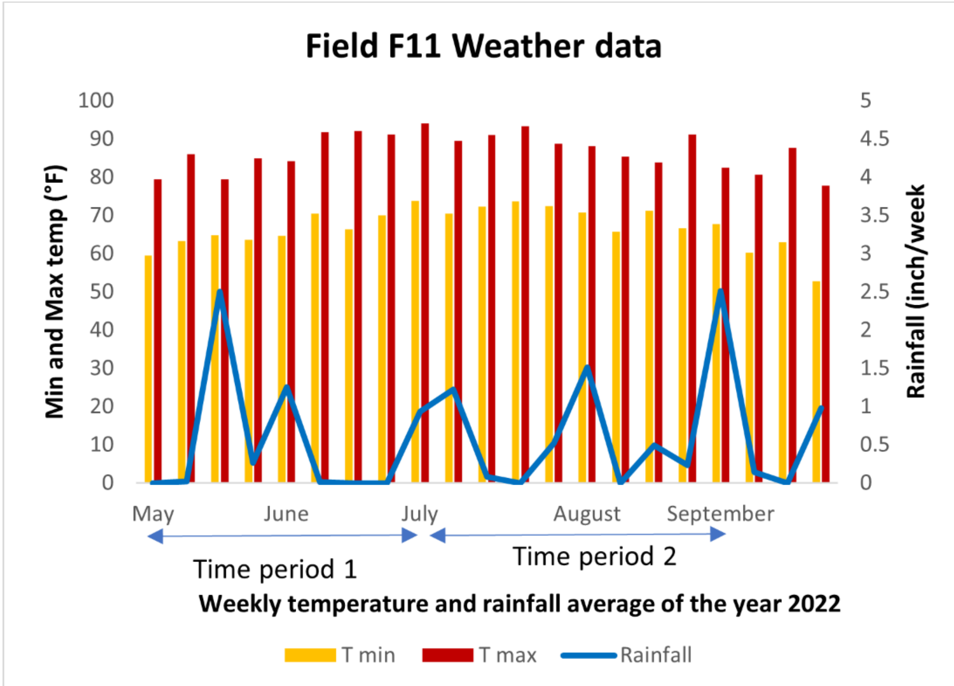

Figure 9. Weather data during the study period at Field F11.

The results also exhibited variation among different locations within both experimental sites. The variation in mineralization followed a similar trend as the yield-based zone delineation. At F40 (Figure 6), the highest mineralization rate was recorded at locations falling under high-yielding zones (3,4,9) compared to the lowest at low-yielding zones (7 and 8). The variation was predominantly due to differences in hydrology. The soil texture for all the locations did not vary significantly at the surface layer. Similarly, at F11, high mineralization rates were reported at locations 1 and 2 (high-yielding zones). The mineralization potential at these locations ranged from 0.40 to 0.47 lb/acre/day during the first incubation and 1.17 to 1.54 lb/acre/day during the second incubation compared to locations 7 and 8 that experienced immobilization at first, followed by mineralization (0.38 to 0.89 lb/acre/day) during the later incubation period (Figure 7).

This experiment was conducted to collect baseline data from farmer-managed fields to understand the contribution of mineralized N in the total N inputs in commercial row crop system. There are a few limitations to this experiment. The protocol followed can only make relative comparisons in N mineralization rate and amount among soils sampled from different parts of the fields having variable texture, slope, and hydrology.

Under farmers' field conditions, it is difficult to maintain uniform conditions like temperature and soil moisture conditions (e.g., moisture near field capacity) when using soils that vary in texture and water holding capacity. For an in-depth understanding of soil N mineralization, the protocol should be replicated under laboratory conditions of similar soil temperature and moisture.

Conclusion

This study emphasizes the variability of N mineralization within a field and between two commercial agricultural farms with dissimilar management practices. Overall, the experiment findings underline the intricate relationship between soil properties, climatic conditions, and organic inputs in shaping the mineralization processes within agricultural systems. F40, with a cover crop history, had enhanced N mineralization potential compared to F11, with no crop during the fallow period. The comparison between F40 and F11 also highlights the importance of adequate moisture conditions and implementing conservation practices and residue retention on agricultural lands. The within field variability emphasizes the heterogeneity in topography and hydrology, indicating varying N dynamics within the field. The applied inorganic N fertilizer is short-lived due to its complex nature and associated losses. However, organic matter provides a slow but steady source of plant nutrients. By comprehending the intricacies of N cycling and field variability, we can improve fertilizer efficiency and foster sustainable agricultural practices for enhanced food production.

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Conflict of Interest

The authors declare no conflict of interest.

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