Field and Laboratory Study of Nitrogen Mineralization Dynamics in Four Tunisian Soils

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Abstract

Prediction of Nitrogen (N) mineralization from soil Organic Matter (OM) is important when we try to optimize N fertilization and assess adverse N impacts on the environment. The focus of this research study was to investigate throughout a field and laboratory approach, the influence of the pedoclimate and some soil properties on N mineralization dynamics in four non-amended soils of a semi-arid zone in North Tunisia. The aim was also to propose a classification according to their potential N mineralization and kinetics.

Keywords

Nitrogen • Mineralization • Fertilization • Potential nitrogen mineralization
Semi-arid region

1 Introduction

Nitrogen (N) is the most limiting nutrient in crop production and one of the most commonly applied fertilizers in greatest amounts (Perroni-Ventura et al. 2010), especially in arid and semi-arid regions. There, soils are already poor to very poor in N because of the naturally feeble organic restitutions, principal source of N in soil. Therefore, mineral nitrogenous fertilizers should be supplemented particularly in cultivated crops in these regions. Underestimation of mineral N released from soil Organic Matter (OM) mineralization results in the application of excess N fertilizer, leading to the potential for environmental contamination due to leaching as well as surface runoff losses (Mulvaney et al. 2001).

In arid and semi-arid regions, less is known about N mineralization dynamic as well as N availability. In northern Tunisia, for instance, some few laboratory studies were carried out on soil sampled from surface horizon of alluvial plain and amended with different organic residues (manure, composts…) (Saidi et al. 2015). These studies investigated the effects of different amendments on mineralization of N in soil and on chemical and microbial biomass soil properties. Other works from other regions have reported differences in N transformations when the same organic residues were incorporated into different soils collected from surface layers of Ruston (Sistani et al. 2008) and Alabama soils (USA) (Kpomblekou-A and Genus 2012). Observed differences may be attributed to adsorption capacity of the soil to bind organic N, increased aeration in sandier soil and different C:N ratios. Although these studies were important to complete an understanding of N mineralization, they were conducted under laboratory conditions, which often overestimate mineralization patterns occurring under normal field conditions. Indeed, the N mineralization process is often regulated by several factors such as the quantity and the quality of soil OM, soil temperature and water content, drying and rewetting events, soil texture, soil pH level and other soil characteristics (Bechtold and Naiman 2006). Thus, understanding N mineralization dynamic under different pedogenitic and bio-climate conditions could be important in managing N more efficiently.

In this context, the present study aims to better investigate throughout a fieldwork in a semi-arid zone, the influence of the pedo-climate conditions (soil temperature, soil moisture) and some physicochemical properties specific to the soil type on N mineralization rates in four non-amended Tunisian soils developed under contrasted pedogenetic conditions.

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The aim is also to propose throughout a laboratory incubation approach, a classification according to the potential N mineralization and kinetics of the different studied soils.

2 Material and Methods

In this study, we selected four non-amended soils developed under contrasted pedogenetic and bioclimatic conditions in North Tunisia (Fig. 1). We sampled a Luvisol (P1) in the Aïn Draham forest area (*Quercus ilex* and *Quercus suber*). The region has a humid bio-climate with tempered winter. We collected a Vertisol (P2) and a Fersialsol (P3) (Oued Zarga region) both from the Béja Governorate agricultural area. It is a very narrow zone with a significant bioclimatic variability ranging from a sub-humid bio-climate to a middle semi-arid bio-climate. The Vertisol and the Fersialsol were both cultivated (cereal crops). They were collected from agricultural field plots that had not received N fertilization during a long period. Finally, we sampled a Calcisol developed under forest species (*Pinus halepensis* and *Quercus ilex*) in the Kef area, which correspond to an upper semi-arid to middle semi-arid bio-climate. For all sites, we took soil samples from each horizon of the profile (from top to bottom).

All samples were analysed, according to international standards, for pH (ISO 10390), electrical conductivity (EC) (ISO 11265), soil texture (NF X31-107), Total Nitrogen (TN) (NF EN ISO 11261), Total Organic Carbon (TOC) (ISO 14235) and for lime ($CaCO_3$) contents (NF EN ISO 10693). The extraction of mineral N forms as ammonium (NH_4-N) and nitrate (NO_3-N) was with KCl (1 M) according to ISO standards (ISO/TS 14256-1). In the field, we followed, under natural conditions, the dynamic of mineral N evolution in the studied soils, as well as its depth distribution according to soil temperature and soil moisture variation during the experimental period from January to June 2015. We measured every month (with equal intervals) the mineral N forms (NH_4–N and NO_3–N), the soil temperature and moisture for soil samples taken from each horizon of the profile. In the laboratory, we followed, under controlled conditions (Temperature = 22 °C, Moisture = 2/3 field capacity), the quantity of mineral N evolution of the surface horizons of the studied soils according to the incubation time (six weeks).

3 Results and Discussion

3.1 Physicochemical Properties of Studied Soils

We present the main physicochemical properties of the studied soils in Table 1. Data show an important variability among horizons and soils. For instance, large differences in soil richness in OM were recorded as shown by TOC and TN contents, which ranged respectively from 0.17% in the Fersialsol (Oued Zarga) to 3.71% in the Calcisol (Kef) and from 0.24% in the Vertisol (Béja) to 3.4% in the Calcisol (Kef). Moreover, the various studied soils showed comparable

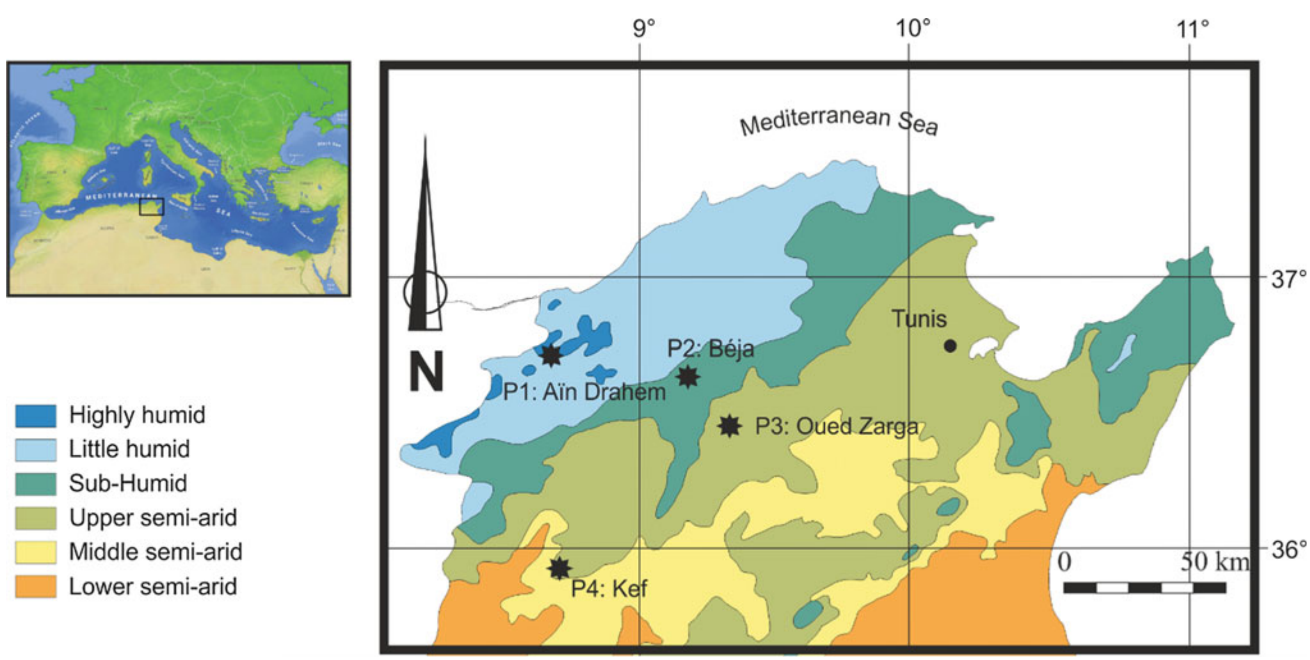

Fig. 1 Localization of the study sites according to bioclimatic stages (P1: Luvisol (Aïn Draham), P2: Vertisol (Béja), P3: Fersialsol (Oued Zarga), P4: Calsisol (Kef))

Table 1 Selected physicochemical properties of the studied soils

Soil	Depth (cm)	pH	EC (mS cm^{-1})	Sand%	Silt%	Clay%	$CaCO_3$%	TN‰	TOC%	C:N
Luvisol (Aïn Draham)	20	6.1 ± 0.1	0.2 ± 0.1	62.00 ± 1.4	17.00 ± 0.2	21.00 ± 1.2	1.0 ± 0.0	1.68 ± 0.01	2.43 ± 0.03	14.46 ± 0.09
	60	6.7 ± 0.2	0.1 ± 0.0	63.00 ± 1.5	21.01 ± 0.4	18.00 ± 0.1	6.5 ± 0.3	0.95 ± 0.10	1.00 ± 0.01	10.61 ± 1.23
	130	4.8 ± 0.1	0.1 ± 0.0	19.00 ± 1.0	10.00 ± 0.1	68.00 ± 2.4	1.0 ± 0.1	1.14 ± 0.04	0.69 ± 0.00	6.06 ± 0.21
	230	5.1 ± 0.4	0.1 ± 0.0	63.00 ± 1.3	2.00 ± 0.0	33.00 ± 1.4	3.2 ± 0.1	0.68 ± 0.08	0.41 ± 0.00	6.09 ± 0.72
Vertisol (Béja)	30	8.3 ± 0.3	0.3 ± 0.1	26.00 ± 1.2	42.00 ± 0.1	29.00 ± 0.6	30.5 ± 0.8	2.14 ± 0.10	2.58 ± 0.01	12.07 ± 0.52
	54	8.2 ± 0.1	0.3 ± 0.1	29.00 ± 1.1	49.00 ± 0.7	23.00 ± 0.3	28.2 ± 0.0	1.84 ± 0.07	1.52 ± 0.02	8.27 ± 0.21
	122	8.1 ± 0.2	0.9 ± 0.2	28.00 ± 1.0	53.00 ± 0.2	20.00 ± 0.5	77.6 ± 1.5	0.36 ± 0.03	0.24 ± 0.03	6.65 ± 0.28
Fersialsol (Oued Zarga)	26	7.9 ± 0.1	0.2 ± 0.1	47.00 ± 1.3	37.00 ± 0.2	17.00 ± 0.2	2.3 ± 0.1	1.49 ± 0.09	1.43 ± 0.02	9.62 ± 0.45
	102	7.8 ± 0.1	0.1 ± 0.1	18.00 ± 1.3	21.00 ± 0.0	60.00 ± 3.1	0.0 ± 0.0	1.18 ± 0.04	0.50 ± 0.00	4.24 ± 0.14
	222	8.2 ± 0.0	0.2 ± 0.0	42.00 ± 1.0	34.00 ± 0.4	24.00 ± 0.8	36.4 ± 0.4	0.54 ± 0.02	0.17 ± 0.00	3.15 ± 0.12
	326	7.9 ± 0.2	1.3 ± 0.2	41.00 ± 1.1	33.00 ± 0.5	24.00 ± 1.1	51.7 ± 0.7	0.39 ± 0.01	0.19 ± 0.01	4.88 ± 0.38
Calcisol (Kef)	20	7.9 ± 0.1	0.3 ± 0.0	19.17 ± 1.0	45.37 ± 0.1	36.90 ± 0.1	7.0 ± 0.1	3.40 ± 0.40	3.71 ± 0.07	11.03 ± 1.51
	45	8.2 ± 0.2	0.2 ± 0.1	20.00 ± 1.4	36.59 ± 0.1	44.23 ± 1.5	8.1 ± 0.1	2.80 ± 0.20	3.30 ± 0.30	11.77 ± 0.23
	115	8.4 ± 0.0	0.3 ± 0.0	25.32 ± 1.2	32.80 ± 0.1	39.40 ± 0.8	22.0 ± 0.5	2.40 ± 0.10	2.50 ± 0.10	10.42 ± 0.02

EC Electrical conductivity, *CaCO3* Lime, *TN* Total Nitrogen, *TOC* Total Organic Carbon

discontinuities between surface and deep horizons. This clearly appears in the vertical profile of OM characterized by a decrease in TOC and TN contents as soil depth increases.

Similar to OM distribution, the highest values of C:N ratio were recorded in surface horizons and decreased with depth in the majority of studied cases. Soil C:N ratio determines the decomposability of soil OM, therefore has an important impact on N deposition in soil. The pH values were around 8 in most studied soils. This is mainly due to the high lime content. Indeed, soil enrichment in calcium carbonate marked all studied soils from top to bottom of the soil profile. In the case of the Luvisol (Aïn Draham), pH values were feeble and decreased quickly with depth. The soil texture was dominated by silt and clay content (>60%) throughout the profile. These size fractions showed the highest quantities in almost all studied soils except the Luvisol, which recorded a big amount of sand fraction (63%) especially in surface horizons. The electrical conductivity (EC) values were very low and increased as we move from the surface horizons to the deep horizons for most studied soils. We noticed important EC values in depth particularly for the Fersialsol. EC varied from 0.2 mS/cm top to 1.3 mS/cm bottom.

Inherent soil properties such as clay content and OM content have been constantly shown to influence the process of N mineralization and N immobilization in the soil. Other soil characteristics, such as pH level, C:N ratio and salinity, may also affect soil OM decomposition and are expected to give an indication on N mineralization dynamics mainly in arid and semi-arid soils.

3.2 Field and Laboratory Study of N Mineralization

Our field results showed an enrichment in mineral N values in surface horizons of all studied soils. These amounts decreased with depth following different patterns according to soil type. The highest mean rate of mineralized N was recorded in the Calcisol (232.09 mg kg^{-1} dry soil) due to the high Total Organic Carbon (TOC) and Total N (TN) content and low C:N ratio. The lower concentration was recorded in the case of the Luvisol (<30 mg kg^{-1} throughout the profile) because of a high clay-silt content (>40%) and a low pH levels especially in depth (pH = 4.8).

Ammoniacal (NH_4–N) and nitric (NO_3–N) N production according to the depth showed marked monthly variations. During winter months (January, February), the decrease in inorganic N concentrations was attributed to lower soil temperature and higher water volumes causing the N to be more leached. Accordingly, the Calcisol and the Vertisol recorded respectively 203 and 66.19 mg kg^{-1} of NO_3–N in deep layers. Mineral N values reached their maximum in March, mainly in surface horizons of all studied soils due to higher temperature and greater soil moisture. In April, these values started to decrease gradually and regressed in May and June except the Vertisol, which recorded relatively high-mineralized N contents (≈20 mg kg^{-1}).

Data from the laboratory study showed wide dispersion of values concerning potential N mineralization and Kinetics. They presented the following decreasing order: Calcisol > Vertisol > Fersialsol > Luvisol. Two fractions constituting organic nitrogenous supplies were distinguished. An active fraction with high mineralization rate and a larger passive fraction slowed down by clays and resistant to microbial biodegradation.

Exploring our results help to understand the rate of N availability in relation with N requirement of the crops and thereby reduce the N fertilizer cost and loss to the environment.

4 Conclusion

Based on our field and laboratory results, N fertilization can be carefully managed in order to reduce harmful environmental impacts such as nitrate leaching mainly by avoiding excessive or unnecessary N fertilization. We believe that effort should continue to gain a better understanding of the complex process of N mineralization, which supplies a substantial, and in some cases most of the N need by crops. Further efforts to improve our ability to predict N mineralized essentially under field conditions will help to increase the efficiency of use of N fertilizers to achieve economically and environmentally sound crop production.

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