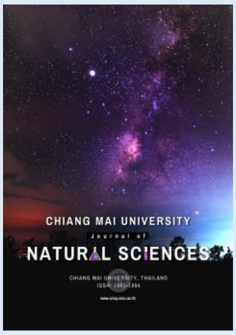

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Research article

Variability of Nitrogen Mineralization from Organic Matter in Agricultural Soils in the North of Colombia

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Abstract Variation of Nitrogen mineralization (Nm) and its relationship to physicochemical factors in soils of an irrigation district in the North of Colombia was evaluated. Physicochemical parameters were measured in topsoil (0–30 cm) samples taken from 22 points in agricultural lands (10 in the dry season, 12 in the wet season). Nm was estimated from organic matter (OM) content. Soil parameters in the study area are suitable for crop development, although they present variations between the dry and wet season, where the soil pH varies of slightly acidic to neutral and the OM content decreases. Additionally, in the dry season there was a positive correlation with pH, OM and C/N ratio and, during wet season between OM, sand, clay and bulk density. In both seasons, a negative correlation between silt and Nm was common. Environmental and soil conditions in the study area are favourable for Nm because during the dry season the accumulation of OM is favoured. Understanding how physicochemical factors influence Nm is essential for agricultural activities and the development of sustainable ecosystem services.

Keywords: N transformation, Physicochemical properties, Physicochemical interactions

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INTRODUCTION

Nitrogen (N) is one of the most critical elements in agricultural soils. It is considered a limiting nutrient due to its direct effect on plant growth and net primary productivity (Ma et al., 2017). Most world soils have less than required available N and applications of this nutrient have shown an increase in crop yield. However, in most cases, N is applied at a higher rate than recommended. Excess nitrogen fertilizers causes economic losses, water and air pollution, and can have an adverse impact on ecosystems and biodiversity (Santiago-Arenas et al., 2020).

Between ~92 and ~98% of soil N is present in organic form, therefore, not available for the plant. Nitrogen mineralization (Nm) plays an important role, as the mineralized fraction becomes available to the plant, where it can be used to increase crop yield (Rivera-González et al., 2012). Likewise, enhancing its use efficiency is also essential, particularly in areas where fertilizers are rather costly and their efficiency is limited by low water availability (Martínez et al., 2018).

Mineralization is the biochemical process through which the soil microorganisms transform the organic molecules of the residues of the plants (litter, microbial necromass and root organic exudates) into low molecular weight inorganic molecules (Monsalve et al., 2017). For carbon assimilation to occur in microbial biomass, N must also be assimilated in amounts determined by the ratio C/N of the microbial biomass. So if the amount of N present in the decomposition of organic waste is higher than that required by microorganisms, a net mineralization occurs, with inorganic N release. If the amount of N in the residue is equal to or less than the amount required by the microorganisms, there will be no net mineralization (immobilizing) (Kruse et al., 2004). On the other hand, the quantify Nm from the amount of OM (organic matter) in the soil is an indicative value of the microbial activity and estimates the organic C that can be mineralized in the soil in a certain time (Zhao et al., 2016).

In most soils, water content and temperature are the most important environmental factors controlling the net mineralization of N from OM (Kruse et al., 2004). The water deficit of the soil significantly reduces the productivity of the crops due to the lack of availability of nutrients in the soil solution, which are subsequently absorbed and assimilated for the production of dry matter (Ullah et al., 2019). Temperature influences the microbial biomass, at higher temperatures the proliferation of microorganisms increases. Optimal temperature for nitrification varies depending on the geographical location, due to the adaptation of bacteria to the environment (Monsalve at al., 2017). Additionally, other factors that control the net Nm, such as soil use, physicochemical properties of soil (texture, pH, among others), the present of functional microorganisms and the type of vegetation (organic composition) may negatively (immobilizing) or positively (mineralizing) contribute to the N supply in the soil. Some of these factors affect directly N transformation, whereas others mediate the process (Cabrera et al., 2005; Zhang et al., 2010).

Li et al. (2018) evidenced that on a global scale, soil microbial biomass regulates and determines the changes in Nm. Thus Nm is among the biological indicators of the soil due Nm represents the nutrient capture and soil OM dynamics. Additionally, at the microbiological level is the primary role in soil processes with spatial and temporal variability (Bünemann et al., 2016). Nm is a very slow process, performed by microorganisms (between 1 and 3% of total soil nitrogen), and sensitive to natural and anthropogenic changes (Li et al., 2012). Mainly due to the indiscriminate use of nitrogen fertilizers that can alter the biogeochemical nitrogen cycle, through its effects on pH and microbial activity (Martínez-Mera et al. 2016; Martínez-Mera et al. 2017b).

Nitrogen mineralization (Nm) commonly is evaluated either in the field or laboratory. The field incubation in a cylinder collected at local scales constrained by site climatic conditions or laboratory incubations use homogenised soil samples incubated under optimised and controlled temperature and moisture conditions (Risch et al., 2019). Neither method provides an accurate estimate of the N availability due in laboratory techniques can not consider variations in conditions field between sampling sites. Thus, any method should be considered as an indicator of Nm availability instead of actual current availability (Celaya-Michel and Castellanos-Villegas 2011). The results of the quantifications provide information and that can be of great help to improve practices that increase the efficiency of use of N and decrease the N losses in the environment (Dridi and Gueddari, 2019). Furthemore, in ecosystem studies are sensitive and ecologically relevant. Consequently, the Nm is a process highly variable and fluctuating with applications in different areas and is considered an indicator of the status or soil health (Bünemann et al., 2016).

Data on the distribution of Nm is of great importance for planning productivity in agricultural soils. In the same way, increased knowledge of the relationships between Nm and the physicochemical properties of agricultural soils might widely improve the capacity to predict the status of N and its metabolic pathways. This issue is fundamentally relevant for agricultural soils highly impacted by anthropogenic activity (Kader et al., 2010). In Colombia, most of the studies that have estimated the mineralization of soil organic matter based on the C-CO_2 released in incubations (Sanclemente-Reyes et al., 2013; Meriño-Cabrera et al., 2014; Gonzalez-Briceño, 2016) or studies related to the rate of Nm in organic materials as a source of fertilization (Figueroa-Barrera et al., 2012). The municipality of Repelón is considered as the agricultural pantry of the North of Colombia, it presents studies of characterization of soils (Martinez-Mera et al. 2017a), contamination of water by heavy metals (Torregroza-Espinosa et al., 2018), contamination of soils by heavy metals (Martínez-Mera et al., 2019) and nitrogen fixing bacteria in soils (Martinez-Mera et al. 2017b). Taking into account that there are no studies of Nm in agricultural soils, this work was developed in agricultural soils of an irrigation district in the North of Colombia, aiming to: (*i*) Determine Nm from the N content of OM, (*ii*) Describe the spatial patterns of Nm, and (*iii*) Relate Nm content with the physicochemical properties of the soil, and analyze the implications on sustainable management.

MATERIALS AND METHODS

Study area

This research was conducted in the Repelón irrigation district (RID) (10º 29 'N and 75º 08' O), located at the southern part of the Atlántico Department, Colombia (Figure 1). The RID has an extent of 4,200 ha, of which 3,750 ha are usable land and are destined for irrigation and drainage areas. Water supply is provided by El Guájaro reservoir (10º 42 'N y 75º 6' W) by an abduction channel (1 km) to the pump room (with a capacity of 5 m3 s-1), which raises water up to two distributary channels, upper channel (15 km) and lower channel (12 km). Distributary channels provide irrigation both by spraying and gravity. The system is design to generate water recirculation, therefore, drainage waters are discharged again into the reservoir (Martínez-Mera et al., 2017a).

The municipality of Repelón displays seasonal temperature variability, fluctuating between 24 and 34 °C, with the highest temperatures in April. In the wet season (July to November) the average rainfall is 81.4 mm, with the greatest precipitation in October (110 mm). In the dry season (December to June) the average rainfall is 23.5 mm, with the lowest precipitation during January to March (2.25 mm) (Weather Spark, 2021).

Agricultural soils in the RID are located in a flat relief, with medium to coarse subangular blocky structures and a moderate stability. Soils are classified as inceptisols of the fluventic haplustepts and typic haplusteps groups, at a depth of 30 cm the soils exhibit a sandy loam and clay loam texture, respectively, characterized by a low to moderate fertility and being susceptible to erosion (IGAC, 2008). Common crops in the study area include cotton, tomato, maize, sorghum, cassava, plantain, rice, guava, papaya and mangoes. Agricultural activity in transient crops intensifies between August and January (Martínez-Mera et al., 2017a).

Soil sampling and laboratory analysis

The study area was divided into four zones (Z1, Z2, Z3, and Z4) starting at the northern area of the RID. Zone divisions were established based on natural streams running through agricultural soils (Figure 1). Sampling was performed during the dry

(June) and wet (October) seasons of 2016. Soil samples were randomly taken, considering the extent of each zone. The vegetative cover was removed and a individual soil sample was taken at a depth of 30 cm from the soil surface. Soil samples were stored in Ziploc® bags and transported in polyethylene boxes at environment temperature, where they were kept until processing.

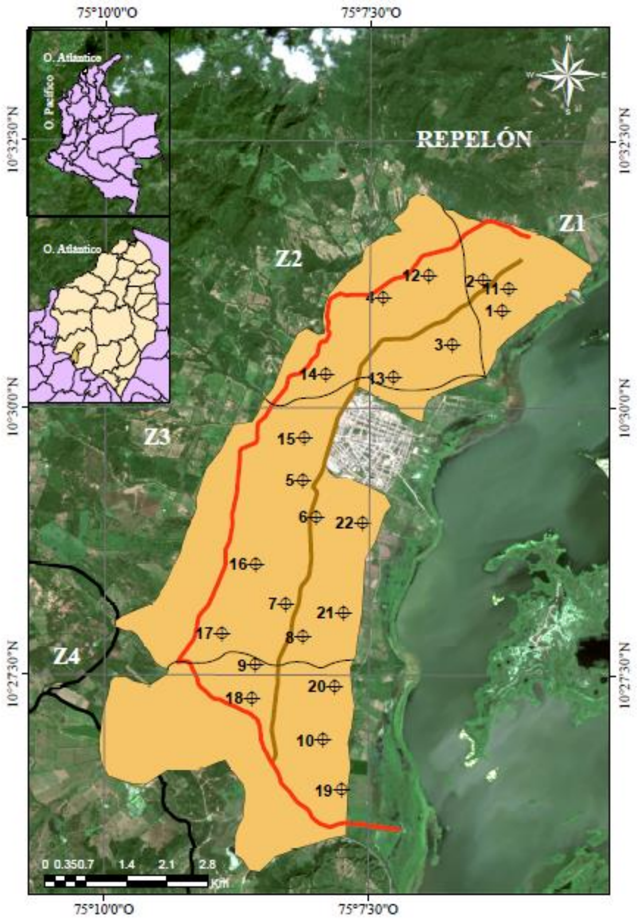

Figure 1. **Repelón municipality, Atlántico Department, Colombia. The red and brown lines correspond to an irrigation district (RID).** The red line is an upper channel. The brown line is a lower channel. The symbols with numbers correspond to sampling points.

Samples were analyzed at the Environmental Laboratory of the Universidad de la Costa (CUC). Each analyzed parameter was measured three times using standardized methods. The gravimetric method (IGAC, 2006) used for the measurement of soil water content. Soil pH was measured by potentiometric method (NTC 5264, 2008). Texture was determined by the method of Bouyoucos (Bouyoucos, 1962). For organic carbon (OC), the method of Walkley-Black (Walkley and Black, 1934) was used. Organic matter (OM) was calculated from OC values, using a conversion factor of 1.72 (IGAC, 2006). Finally, the C/N ratio was calculated with the OC content (%) divided by the total N (%) (Gamarra-Lezcano et al., 2017).

Estimation of Nitrogen mineralization

Nitrogen mineralization (Nm) was estimated following the method of Castellanos-Ramos et al. (2005). Assumptions of this calculation include a Nm rate of 1%; 55% of organic carbon in OM, and a C/N ratio of 10:1 [each 10 g of organic carbon (OC) contains 1g of N] in a hectare of soil. Nm was calculated by the following equation:

Nm (kg ha^{-1}) = ((OM*0.55)*(sw))/100*0.001

Where:
Nm: Mineralized Nitrogen
OM: Organic matter (%)
sw: soil weight (kg ha^{-1})
bd: bulk density (g cm^{-3})
0.55: Factor of OC content in OM
100: Conversion factor percentage
0.001: Conversion factor of kg OC ha^{-1} in kg of organic N

Bulk density was determined from mineral bulk density according to the method of Rawls (1983), contour base map on percentage sand and clay, organic matter bulk density and organic matter, by the following equation:

Soil bulk density (g cm^{-3}) = 100/((OM/OMbd)+((100-OM)/Mbd))

Where:
OM: Organic matter (%)
OMbd: Organic matter bulk density (0.224 g cm^{-3})
Mbd: Mineral bulk density (g cm^{-3})

Soils were classified in five categories according to calculated Nm values: very low (0.0-14.5 kg ha^{-1}), low (14.6-29.7 kg ha^{-1}), medium (29.8-50.9 kg ha^{-1}), high (51.0-82.4 kg ha^{-1}) and, very high (82.5-212.0 kg ha^{-1}) (Castellanos-Ramos et al., 2005).

Data analysis

Pearson correlation analysis was conducted to examine the relationship between Nm and soil physicochemical parameters (pH, water content, texture, bulk density, OM and C/N ratio). All analyses were performed with the software Infostat (Di Rienzo et al., 2019), with a *P*-value ≤0.05. Spatial and temporal distribution of Nm was mapped using the Surfer v.23 (developed by Golden Software).

RESULTS

During dry season, pH ranged from slightly acidic (6.41 ± 0.014) to neutral (7.26 ± 0.014). On the other side, during the wet season soil pH went from slightly acidic (6.00 ± 1.25) to slightly alkaline (7.54 ± 0.16). Soil water content was higher in the wet season (21.7 ± 0.04 %) than in the dry season (19.04 ± 0.70 %), however both values are in the range medium (15-25%) (Ramírez-Carvajal, 1997). OM content was higher during the dry period (1.13 ± 0.13%) compared to the wet season (0.82 ± 0.08%) (Table 1), nervertheless according to IGAC (2008) agricultural soils have a low OM content.

The C/N ratio was low and showed little variation between both monitoring periods, dry (4.80 ± 1.68 average) and wet (4.19 ± 0.79 average). However, in comparision with all soils evaluated soil 2 (11.0 ± 3.31) and 12 (8.51 ± 3.37) presented higher C/N ratio, both located in the northern area of the irrigation district. Regarding soil texture, there was variation in the percentage of sand, silt and clay, although the prevailing resulting texture in both study periods was clay loam (50% of soils). Aditionally, there were soil with loam texture (23%), sandy clay (18%) and sandy clay loam (9%) (Table 1).

Land use in the study area comprised different agricultural activities. Annual crops of *Zea mays* (maize), *Manihot esculenta* (cassava), *Oryza sativa* (rice), *Cucurbita maxima* (pumpkin), *Cucumis melo* (melon), and *Musa sp*. (plantain) were observed. In some sampling sites, fruit or forestry trees such as *Psidium guajava* (guava), or *Azadirachta indica* (neem), were found growing associated to fallow (Table 1).

Table 1. Characterization of the agricultural soils of the Repelón irrigation district.

			Soil properties					
Season	**Zone RID**	**Soil Sampling**	**pH**	**Moisture (%)**	**OM (%)**	**C/N ratio**	**Texture**	**Land Use**
Dry	1	1	7.26 ± 0.01	16.60 ± 1.63	0.71 ± 0.40	2.74 ±0.26	Loam	Forestry tree with grass
	1	2	6.80 ± 0.10	16.70 ± 0.78	1.28 ± 0.02	11.0 ± 3.31	Clay loam	Fallow
	2	3	6.97 ± 0.21	24.60 ± 0.14	0.92 ± 0.17	5.15 ± 2.45	Clay loam	Fallow
	2	4	7.23 ± 0.04	16.00 ± 0.21	1.49 ± 0.26	3.56 ± 1.27	Loam	Annual crops
	3	5	7.22 ± 0.06	21.30 ± 2.05	1.40 ± 0.09	7.81 ± 3.21	Clay loam	Annual crops
	3	6	7.20 ± 0.09	16.10 ± 0.35	1.42 ± 0.20	7.56 ± 4.50	Clay loam	Annual crops
	3	7	7.20 ± 0.01	25.00 ± 1.34	1.46 ± 0.13	2.74 ± 0.32	Sandy clay loam	Fallow
	3	8	6.50 ± 0.09	8.15 ± 0.07	0.94 ± 0.10	2.30 ± 0.07	Clay loam	Annual crops
	4	9	6.41 ± 0.01	23.30 ± 0.21	0.82 ± 0.12	2.82 ± 0.41	Loam	Fruit trees, Fallow
	4	10	6.44 ± 0.07	22.30 ± 0.28	0.91 ± 0.28	2.62 ± 0.81	Sandy Clay	Fallow
Wet	1	11	7.54 ± 0.16	25.00 ± 0.01	0.55 ± 0.10	2.83 ± 0.53	Loam	Rice crop
	2	12	6.49 ± 0.50	18.00 ± 0.02	0.56 ± 0.04	8.51 ± 3.37	Clay loam	Platain crop
	2	13	7.43 ± 0.007	17.50 ± 0.01	0.68 ± 0.94	4.06 ± 0.26	Loam	Fallow
	2	14	7.50 ± 0.11	17.50 ± 0.20	0.77 ± 0.03	3.98 ± 0.16	Loam	Fallow
	3	15	6.96 ± 0.05	26.20 ± 0.00	0.89 ± 0.10	3.69 ± 0.66	Clay loam	Rice crop
	3	16	7.48 ± 0.03	17.60 ± 0.03	0.71 ± 0.05	4.85 ± 0.02	Loam	Corn crop
	3	17	7.06 ± 0.50	21.80 ± 0.05	0.86 ± 0.07	4.03 ± 0.90	Clay loam	Fallow
	4	18	6.00 ± 1.25	27.60 ± 0.00	0.96 ± 0.05	3.57 ± 0.18	Clay loam	Paddock
	4	19	7.22 ± 0.01	26.50 ± 0.02	1.01 ± 0.17	3.73 ± 0.58	Clay loam	Annual crops
	4	20	6.95 ± 0.09	26.00 ± 0.06	0.99 ± 0.02	3.55 ± 0.62	Clay loam	Rice crop
	3	21	6.85 ± 0.07	21.10 ± 0.17	0.94 ± 0.19	3.80 ± 1.50	Clay loam	Annual crops
	3	22	6.57 ± 0.55	16.00 ± 0.07	1.15 ± 0.07	3.69 ± 0.65	Clay loam	Fallow

Note: OM: Organic Matter

Bulk density values showed little variation between seasons (Table 2). During the dry season average density was 1.38 ± 0.04 g cm^{-3} and, 1.39 ± 0.07 g cm^{-3} in the wet season. On the other hand, in the dry season, average Nm was 35.7 ± 2.46 kg ha^{-1}, whereas in the wet season it was 26.3 ± 2.00 kg ha^{-1}. Considering these values, the categorical classification of agricultural soils based on Nm, presents variability, corresponding to the medium category for the dry season and, the low category for the wet season.

Table 2. Classification of the mineralized nitrogen in agricultural soils of the Repelón irrigation district.

Season	**Zone RID**	**Soil Sampling**	**Bulk Density (g cm^{-3})**	**Nm (kg ha^{-1})**	**Classification**
Dry	1	1	1.39 ± 0.09	22.10 ± 2.84	Low
	1	2	1.33 ± 0.02	37.70 ± 2.34	Medium
	2	3	1.42 ± 0.01	30.80 ± 3.54	Medium
	2	4	1.27 ± 0.10	39.80 ± 0.52	Medium
	3	5	1.40 ± 0.03	46.10 ± 0.82	Medium
	3	6	1.40 ± 0.01	46.70 ± 7.57	Medium
	3	7	1.40 ± 0.03	31.40 ± 1.62	Medium
	3	8	1.42 ± 0.01	29.30 ± 3.09	Low
	4	9	1.34 ± 0.13	24.30 ± 1.39	Low
	4	10	1.47 ± 0.00	32.70 ± 0.89	Medium
Wet	1	11	1.36 ± 0.01	16.80 ± 2.90	Low
	2	12	1.45 ± 0.00	19.60 ± 1.53	Low
	2	13	1.35 ± 0.01	20.70 ± 2.64	Low
	2	14	1.34 ± 0.00	23.20 ± 0.86	Low
	3	15	1.42 ± 0.01	30.10 ± 4.80	Medium
	3	16	1.25 ± 0.00	18.50 ± 0.87	Low
	3	17	1.24 ± 0.00	21.20 ± 1.79	Low
	4	18	1.42 ± 0.01	28.40 ± 0.95	Low
	4	19	1.46 ± 0.02	35.00 ± 0.91	Medium
	4	20	1.46 ± 0.00	33.50 ± 1.39	Medium
	3	21	1.48 ± 0.02	29.40 ± 3.02	Low
	3	22	1.40 ± 0.01	37.80 ± 2.27	Medium

Note: Nm: mineralized nitrogen

In this investigation, was observed spatial variation of Nm (Figure 2). During the dry season, Nm distribution in agricultural soils was medium, excepting for the soil samples 1 (Z1-north), 8 (Z3-center) and 9 (Z4-south) which were classified as low. On the other side, the overall Nm distribution in the wet season ranged from low in the northern zone to medium in the southern zone. Soil samples 15 and 22 from the center zone (Z3), as well as samples 19 and 20 from the south zone (Z4) exhibited medium Nm values.

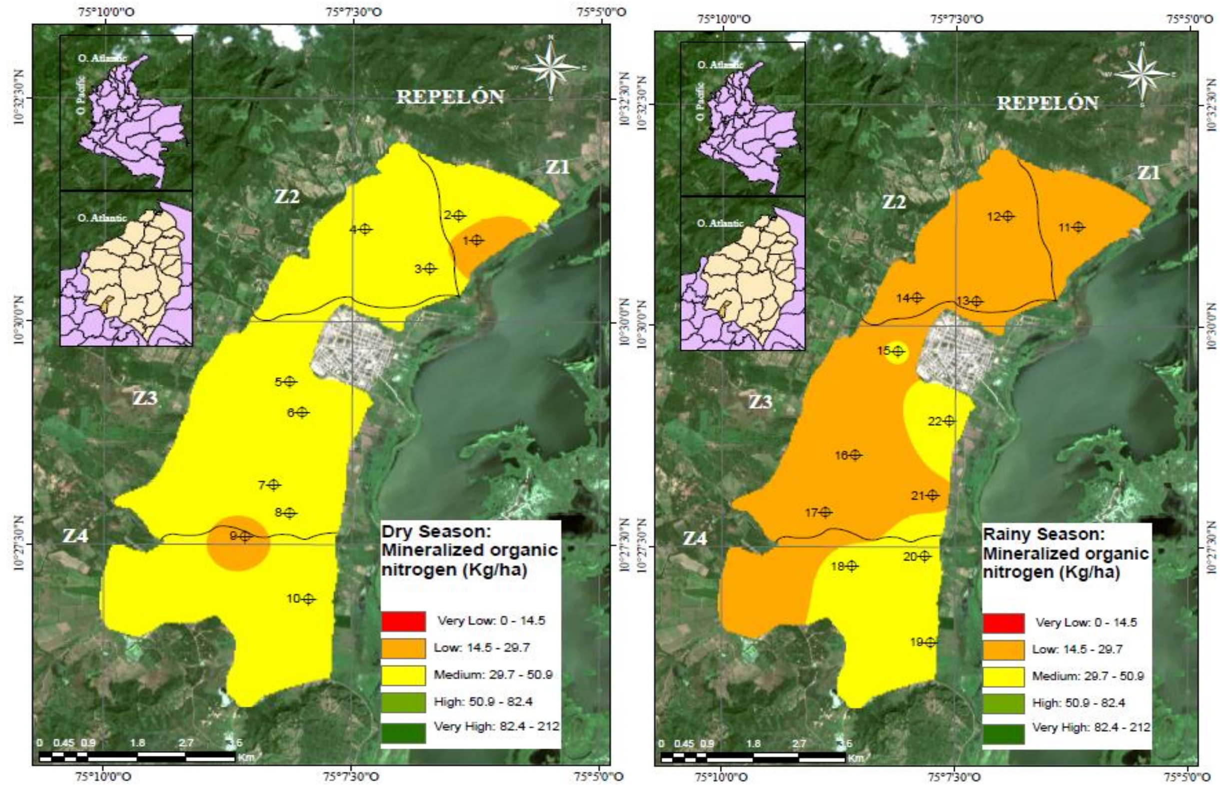

Figure 2. Variation of mineralized organic nitrogen in agricultural soils in dry season and wet season (rainy season) in soils of the Repelón irrigation district. The symbols with numbers correspond to sampling points.

Correlation analysis shows the relationship between physicochemical parameters and Nm, depending on the season. In the dry season (Table 3), pH, OM and C/N ratio are positively correlated to Nm ($P \leq 0.05$). In the same way, in the wet season (Table 4), OM, silt, sand, clay and bulk density are positively correlated with Nm ($P \leq 0.01$). On the other side, silt showed a strong negative correlation with Nm ($P \leq 0.01$).

Table 3. Correlation analysis between physicochemical parameters and mineralized nitrogen in the dry season in soils of the Repelón irrigation district.

		pH	Moisture	OM	Silt	Sand	Clay	Bulk Density	C/N ratio	Nm*
		***P*-value**								
pH		-	0.86	0.02	0.83	0.98	0.75	0.56	0.31	**0.03***
Moisture		0.04	-	0.89	0.78	0.94	0.62	0.67	0.87	0.67
OM		0.51	0.03	-	0.90	0.85	0.94	0.06	0.05	**0.00***
Silt		0.05	-0.07	0.03	-	0.00	0.00	0.00	0.83	0.25
Sand	Correlation Coefficient	0.00	-0.02	-0.04	-0.88	-	0.00	0.00	0.96	0.31
Clay		-0.08	0.12	-0.02	-0.94	0.67	-	0.00	0.71	0.29
Bulk Density		-0.14	0.10	-0.043	-0.83	0.76	0.75	-	0.65	0.76
C/N ratio		0.24	-0.04	0.44	-0.05	-0.01	0.09	-0.11	-	**0.04***
Nm		0.51	0.15	0.92	-0.27	0.25	0.25	0.50	0.47	-

Note: *Nm: mineralized nitrogen (*P* <0.05)

Table 4. Correlation analysis between physicochemical parameters and mineralized nitrogen in the wet season in soils of the Repelón irrigation district.

		pH	Moisture	OM	Silt	Sand	Clay	Bulk Density	C/N ratio	Nm*
		***P*-value**								
pH		-	0.41	0.42	0.06	0.08	0.10	0.04	0.34	0.17
Moisture		-0.18	-	0.35	0.00	0.01	0.00	0.07	0.08	0.19
OM		-0.17	0.20	-	0.02	0.03	0.08	0.35	0.19	**0.00***
Silt		0.39	-0.58	-0.46	-	0.00	0.00	0.00	0.57	**0.00***
Sand	Correlation Coefficient	-0.36	0.54	0.44	-0.99	-	0.00	0.00	0.58	**0.00***
Clay		-0.34	0.71	0.37	-0.94	0.89	-	0.00	0.34	**0.00***
Bulk Density		-0.43	0.38	0.20	-0.90	0.91	0.86	-	0.84	**0.00***
C/N ratio		-0.20	-0.36	-0.28	0.12	-0.12	-0.20		-	0.27
Nm		-0.29	0.33	0.90	-0.74	0.73	0.64	0.59	-0.23	-

Note: *Nm: mineralized nitrogen (*P* <0.01)

DISCUSSION

Inceptisols are young soils with a low to medium evolution level, strongly influenced by tropical climates (SSSA, 2018). Variations in soil physicochemical properties can be attributed to natural and/or anthropic factors e.g. parental material, topography, environmental conditions, organisms, and land use (Zhang et al., 2010). The degree of soil development of inceptisols is low, with low clay content and slightly acid pH (6.1). Prevailing vegetation types of Inceptisols include forests, prairies and agricultural zones (SSSA, 2018).

Soil acidification may be due to leaching, acidic precipitation, deposition of acidifying gases or particles from the atmosphere, and use of fertilizers (Goulding, 2016). Agricultural activities and management practices such as fertilizing, farming, and the establishment of irrigation/drainage systems, are the most influential in soil pH variations (Chimdi et al., 2012). The pH variability was observed in soils of the RID, which could be associated to their parental origin, climatic conditions of the region, and agricultural practices implemented in the area. For example, Martínez-Mera et al. (2017b), reported the use of pesticides and fertilizers such as LorsbanTM 4E (insecticide), glyphosate (herbicide) and NPK 15-15-15 (fertilizer-Triple 15), mainly during the wet season because during this period agricultural activity intensifies due to a greater availability of water from the El Guájaro reservoir. Additionally, the variation in the intensity of precipitation can cause leaching on days of heavy rains (Crouse and Denny, 2015). In spite of this, the pH of soils in the study area is suitable for crop development (5.11-7.66). In the same way, crops and microorganisms exhibit tolerance to changes in different ranges of optimal pH (6.5-7.0) (Goulding, 2016; Martínez-Mera et al., 2017b).

On the other hand, physicochemical properties may influence ecosystem function (Zhang et al., 2010). For example, pH directly affects chemical and biological properties of soils, as it is a determining factor for nutrient availability, as well as for the diversity of organisms implied in biogeochemical cycling by transforming crop essential elements (Martínez-Mera et al., 2017b). Soil pH determines the activity of the microorganisms and influences the availability of nutrients for plants, because when the soil pH is less than 5.5 the decomposition of OM towards ammonia production (ammonification) is accelerated due to action of ammonifying bacteria. Contrary to this, when the soil pH is between 6.5 and 7.6 nitrification is favored (the conversion of ammonium to nitrite). Likewise, considering that OM and its labile fractions are determining in the amount of Nm and availability in crops, its decomposition is heavily dependent on residue input and weather conditions (Martínez et al., 2018; Li et al., 2018).

Bulk density and moisture are parameters that vary with the soil structure, texture, precipitation, topography and depth (Chaudhari et al., 2013; Wang et al., 2018). Bulk density can be used as an indicator of soil health due density increase is related to soil compaction and root growth is restricted at values greater than 1.6 g cm^{-3}. The prevailing texture type (clay loam) is a soil mixture with greater content of clay, a type of particle that diminishes critical bulk density values of soil due to its size and colloidal properties (Chimdi et al., 2012). In addition, Wang et al. (2018), reported that plant cover is not a significant factor in soil moisture increase as this is related to microbial activity and OM input. Soils in the study areas with fallow only had grass as plant cover, a type of plant with poor root development, low contribution to soil OM and little water infiltration. Therefore, soil porosity is low, further affecting OM incorporation (Castro-Rincón et al., 2018). Further, Fageria and Moreira (2011), affirm that root systems influence the total organic carbon of the soil, N and the population of effective microorganisms for a better accumulation of OM by contributing to soil pools. Root-derived soil C is retained and forms more stable soil aggregates than shoot-derived soil C.

Seasonality and variability of precipitation in tropical dry areas influence other characteristics of soils, as 50-70% of water does not reach crops, causing surface runoff that leaching the finest particles of the soil (clay and OM) (Rockström and Falkenmark, 2015). Consequently, this process is also related to the seasonal difference in OM content, the low content registered during the wet season due to soil loss. In the same way, farming increases soil aeration and shreds organic debris, leaving them more accessible to microbial decay, and crop harvesting removes OM (Chimdi et al., 2012), during the dry season OM is accumulated by the contribution of plant debris, which, together with the lack of rain, increases the nitrogen reservoir of soils (Cregger et al., 2014), as it was the case in the RID. In contrast, Nm decreases as soil water content increases due in high humidity conditions, the oxygen content causing decrease in aerobic microorganisms that participates in the mineralization process therefore increases denitrification (Li et al., 2012).

In this work, Nm was calculated from %OM. Kader et al. (2010), claim that a realistic estimate of Nm can be obtained from %OM. The results of this work indicate that, in general, during the dry season and according to Nm, soils were mostly classified as middle (35.9 ± 9.46 kg ha^{-1} in average). In contrast, for the wet season Nm distribution ranged from low to medium from the north zone to the south zone (26.6 ± 7.38 kg ha^{-1}). In the same way, Nm is influenced by parameters such as temperature, pH, moisture, soil biology, C/N ratio and organic debris. In tropical regions with marked seasonality, the wet season favors microbial activity (factor that depends on soil texture, field capacity and the response of the microorganism to moisture content) and water adsorption by soil particles, whereas in the dry season, uv radiation fragments OM through weathering (Celaya-Michel and Castellanos-Villegas, 2011).

The C/N ratio is a parameter that indicates the functionality of soils mainly because infuence biochemical processes of decomposition of OM and mineralization that occurs in soils (Zenteno-Rojas et al., 2020). The variability of this parameter can also be attributed to nitrogen mineralization due the C/N ratio of the soil determines OM decay, therefore, it has an important impact in plant nitrogen availability. C/N ratio values are related to variations in the microbial biomass in charge of organic compound and debris decay (Paolini, 2018). Even though soils in de RID did not exhibit differences in C/N ratio with season, Celaya-Michel and Castellanos-Villegas (2011), claims that nitrogen might be mineralizing in different amounts due to the differing compositions of organic debris, and C/N ratio might not be reflecting these compositional differences. In the same way, Martínez-Mera et al. (2017b) reported a greater density of three nitrogen-fixing bacteria in the RID, in the order of 107 CFU g soil^{-1}. This feature is associated to a greater Nm activity as, regardless of the season, the south zone displayed Nm levels in the medium range compared to other assessed areas. Nm varies noticeably between soils and time of the year due to management history, crop types, farming, amendments, and fertility (Cerón and Aristizabal, 2012). Similar research in Mexico evidences Nm variability, from very low to very high ratios. However, low Nm prevails (Rivera-González, 2013).

In dry season, Nm showed a positive correlation with all the parameters evaluated with the exception of the silt fraction. Of these parameters, the variables pH, OM and C/N ratio were statistically significant. As mentioned above, physicochemical properties can influence ecosystem function. The C/N ratio is an indicator of the OM mineralization rate. In this research, low values (<15) are indicators of a more efficient microbial activity in the decomposition of OM (Gamarra-Lezcano et al., 2017). Soil biomass are sensitive to very acidic or very alkaline pH, however, soil microorganisms that grow with soil pH range 5.5–7.5 can have greater tolerance to pH changes than those grow in the acid or alkaline soil pH conditions, favoring mineralization rates of nutrients in soils (Dridi and Gueddari, 2019), Finally, OM is considered a dynamic property which is affected by the use and management of the soil (Bünemann et al., 2016). Evaluations in Calcisol soils, showed that the highest inorganic N contents were recorded due to the high OM amount and low C/N ratio (Dridi and Gueddari, 2019).

During the wet season, Nm showed a positive correlation with moisture, clay, sand, OM, bulk density. Of these parameters, the variables sand, clay, silt, OM and bulk density, were statistically significant. Najmadeen (2011), affirm that soil texture determines distribution of soil minerals, water content, aeration, microbial community, nutrient cycles, OM retention and nitrogen mineralization. Consequently, the amount of mineralized nitrogen is greater in sandy soils, compared to clay or silty soils. These differences are explained by a faster mineralization in sandy soils, due to their lower amounts of OM and higher aeration. Because of these factors, decay rate in sandy soils is two times higher than in clay soils (Habai-Masunga et al., 2016). On the other side, clay soils have a greater capacity to preserve biomass, higher proportion of microbial decay products, and use metabolic products in a more efficient way for biosynthetic reactions (Paolini, 2018). In this research, soil sample 7, with a sandy clay loam texture, represents the highest quantity of Nm, in comparison to other soil samples. With respect to bulk density, is a soil parameter that depends on other soil features such as soil texture and OM content. Bulk density of silty and clay soils is lower than in sandy soils, due to a greater total pore space and higher OM content (SSSA, 2018). In the same way, these parameters correlate with factors conditioning microbial development such as soil water content and air content. As mentioned above, mineralization is enhanced in aerobic conditions and it is an energy source for microbial metabolism (Chaudhari et al., 2013). A similar response was observed in Mollisols under no-tillage of the Argentine Pampas was evaluated Nm with aerobic incubation, concluded that sand content is the most influential predictor of potential N mineralization (Martínez et al., 2018).

In the two seasons evaluated, the negative correlation between Nm and silt fraction was common. It is possible due to an N mineralization decrease by an increase in clay and silt contents (Sistani et al., 2008). Only in the rainy season there was a negative correlation with the pH and C/N ratio. Dridi and Gueddari (2019) reported that in luvisol soils, the lower Nm contents are due to a large clay-silt fraction and a low pH level.

Taking into account the importance of N mineralization and the knowledge that the physical and chemical properties affect this process, several studies have tried to understand its interrelationships with other soil properties in cycle N that can improve our ability to predict N mineralization (Ros et al., 2011). Likewise, understanding the interactions between microbial biomass and soil properties can facilitate understanding of anthropogenic influences on soil processes (Risch et al., 2019). The mineral content N supplied by the mineralization are of great importance to develop fertilization strategies. Physicochemical and climate factors in the study area are favorable for Nm and local farmers could take advantage of conditions in the study area to develop environmentally friendly fertilization plans, as a tool for preservation of soils. Consequently, to complement the nutritional requirement of the crops, a friendly fertilization plan must consider the dose and the moment of N administration and the application, due this can vary according to the cultivation method used. Likewise, the interactive effect of N and availability of water on growth and yield, physiological response of crops. Also, it is important to know the characteristics of the soil and the climatic conditions (Santiago-Arenas et al., 2019).

CONCLUSION

Organic nitrogen in the soil remains unavailable to the plants until it mineralizes, a process that is affected by several factors. Nm and OM presents variation between seasons, during dry season the Nm was medium (35.7 kg ha^{-1}) and during wet season was low (26.3 kg ha-1) in most of soils. Similarly, OM in dry season was higher (1.14%) than wet season (0.83%).

Correlation was found between physicochemical properties and Nm. In the dry season, the variables pH, OM and C/N ratio were positively correlated. Similarly, during the wet season there was a positive correlation between OM, sand, clay and bulk density. And a negative correlation between silt and Nm in both seasons. The interaction between these factors can influence the mineralization process and the strong seasonality in the study area has a positive effect on soil conservation, due to the high accumulation of OM and Nm in the dry season.

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