Potentially mineralizable nitrogen: Estimation of the labile and stabilized pools under woodland and cultivated soils in Mexico

Avilés-Marín, Silvia M.[1*]; Galvis-Spínola, Arturo[2]; Salcedo-Pérez, Eduardo[3]; Escobosa-García, María I.[1]; Brigido-Morales, Juan G.[1]

[1] Universidad Autónoma de Baja California, Instituto de Ciencias Agrícolas. Carretera a Delta s/n. Ejido Nuevo León, Mexicali, Baja California, México C.P. 21705.

[2] Colegio de Postgraduados, Campus Montecillo. Texcoco, Estado de México. Carretera México-Texcoco, km 36.5, Montecillo. C.P. 56264.

[3] Universidad de Guadalajara, Centro Universitario de Ciencias Biológicas y Agropecuarias. Carretera a Nogales, km 15.5, Predio Las Agujas, Zapopan, Jalisco, México.

* Corresponding author: monica_aviles@uabc.edu.mx

ABSTRACT

Objective: The aim of this work was to evaluate nitrogen pool and its variation due to land uses in different soil orders.

Design/methodology/approach: Alfisols, Entisols and Inceptisols under different uses (woodland and cultivated soils) were incubated for 20 weeks under controlled temperature and humidity. The mineralizable N (NO_3^- and NH_4^+) was obtained and the potentially mineralizable nitrogen (N_0) was estimated by the method of iterative adjustment. Nitrogen from 0 to 5 weeks was considered as labile nitrogen, and from 5 to 20 weeks was the stabilized nitrogen. The labile nitrogen was described by a potential model, while the stabilized nitrogen was described by a logistic model. The labile nitrogen and stabilized nitrogen pools were estimated after obtaining the first derivate and solving the integral of the potentially mineralizable nitrogen equation.

Results: The greatest estimated amounts of labile and stabilized nitrogen were detected in an Alfisol under woodland use, and the minimum values were obtained in an Entisol under agricultural use. Similar results were obtained for the estimated amount of labile and stabilized nitrogen pool.

Limitations on study/implications: It is important to measure the labile and stabilized fraction of nitrogen, which requires long-term incubations to obtain models of soil N pools, so other methods realiable and faster need to be considered.

Findings/conclusions: The potentially mineralizable nitrogen was positively related to the different fractions of labile and stabilized nitrogen under the different land uses.

Keywords: Nitrogen supply, soil fertility, woodland, agricultural soils

INTRODUCTION

Extractive practices and low organic inputs reduce the content of the organic matter in the soil (MOS), which negatively impacts the sustainability of agricultural production systems. For increase the levels of MOS, organic inputs can be used to promote greater water storage capacity in the soil, enhance resistance to erosion, and nutritional contributions, among others. The C and N content in the soil results from a complex interaction between the C

Citation: Avilés-Marín, S. M., Galvis-Spínola, A., Salcedo-Pérez, E., Escobosa-García, M. I., & Brigido-Morales, J. G. (2024). Potentially mineralizable nitrogen: Estimation of the labile and stabilized reserve under woodland and cultivated soils in Mexico. *Agro Productividad*. https://doi.org/10.32854/agrop.v17i11.3158

Academic Editor: Jorge Cadena Iñiguez
Associate Editor: Dra. Lucero del Mar Ruiz Posadas
Guest Editor: Daniel Alejandro Cadena Zamudio

Received: May 14, 2024.
Accepted: September 30, 2024.
Published on-line: December 09, 2024.

Agro Productividad, 17(11) supplement. November. 2024. pp: 233-240.

and N additions from organic waste (plant and animal) and inorganic sources (fertilizers), with the C and N losses through decomposition and microbial mineralization and erosion (Gregorich *et al.*, 1994; Cheng *et al.*, 2016). The supply of nitrogen to crops consists of the nitrogen contained in the previous crop, which is incorporated into the soil, and eventually it is mineralized for unprotection of the aggregates of soil (Matus and Rodriguez, 1994). Galvis and Hernández (2004) mentioned that to increase the available nitrogen for crops, organic inputs of quick decomposition should be applied. Currently, research relating to the function of the edaphic component in the mineralization processes of organic materials are scarce; however, there has been an increased the interest in studying the influence of soil on mineralization processes and nitrogen protection that forms functional reserves, as well as the need to assess the rate of mineralization and accumulation of N. This goal can be achieved more efficiently with a better understanding of the factors that affect the mineralization processes and accumulation of nitrogen in the soil. This research evaluated nitrogen mineralization in relation to land use in different types of soil.

MATERIALS AND METHODS

Soil samples

Alfisols, Entisol, and Inceptisol were selected from the states of Nayarit and Campeche in Mexico. Soils were classified according to Soil Taxonomy (Soil Survey Staff, 2006). Soil samples were collected under different use, woodland and cultivated soils (Table 1). From each type of soil, 10 subsamples were taken from 0-20 cm, to form composite samples. These samples were air-dried in the shade, ground and sieved through a 2mm mesh. pH was measured using the potentiometric method, soil/water ratio 1:2, and electrical conductivity, with a conductimeter at a soil/water ratio of 1:5 (v/v).

Soil incubation

Residue of alfalfa (*Medicago sativa*, C/N13), previously dried at 65 °C, ground and sieved through a 40-mesh sieve was used. Amounts of residue applied to soil were equal to 10 t ha^{-1} of dry matter. Each treatment was repeated three times. Soil samples were incubated according to Stanford and Smith (1972) method, at 65% field capacity at a temperature of 30 °C for 20 weeks, each treatment was repeated three times. Mineralized N (NO_3^- and NH_4^+) from the soils was measured weekly until number 12 (1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12), after 15 and 20 weeks, an initial extraction was performed.

Table 1. Soil classification, site, vegetation and use.

Soil Classification	Land Use	Vegetation (Scientific name)	State
Entisol	Cultivated soil	(*Zea mays*)	Campeche
Inceptisol	Woodland	(*Haematoxylon campechianum*)	Campeche
Alfisol	Woodland	(*Cedrela odorata* L.)	Campeche
Entisol	Cultivated soil	(*Agave*)	Nayarit
Inceptisol	Cultivated soil	(*Saccharum officinarum*)	Nayarit
Alfisol	Cultivated soil	(*Solanum lycopersicum* L.)	Nayarit

Nitrogen Mineralization

Mineralized nitrogen (NO_3^- and NH_4^+) were measured using electrodes of selective ions (pH/mV, Coulter Beckman), and the potentially mineralizable nitrogen (N_0) was calculated (μg N g^{-1} suelo), N_0 was considered as an indicator of the soil's nitrogen supply for crop production.

Labile and Stabilized Nitrogen

The mineralized nitrogen (NO_3^- and NH_4^+) after incubation was divided in two phases, from 0 to 5 weeks was considered labile nitrogen (LN), while 5 to 20 weeks was considered stabilized nitrogen (SN) (Galvis and Hernández, 2004). The mineralized nitrogen was related to each type of soil use, and the tendency for labile nitrogen was described by a potential model $\left(y = ax^b\right)$, while the stabilized nitrogen was described by a logistic model $\left(y = C/1 + e^{(a-bx)}\right)$, where *a* is the amount of nitrogen mineralized (at first week of incubation or the change in tendency), *b* is the rate of nitrogen mineralization and *y* is potentially mineralizable nitrogen (N_0), for both labile and stabilized, respectively. Using the values of N_0 determined by the iterative adjustment method, Gauss-Newton non-linear procedure (NLIN) of the Statistical Analysis System program (SAS 8.01), a statistical means trial test (Tukey α=0.05) was carried out to determine if there were significant nitrogen mineralization effects related to soil use. The labile nitrogen and stabilized nitrogen pools were also estimated after obtaining the first derivative and solving the integral of the potentially mineralizable nitrogen equation by each type of use of soil.

RESULTS AND DISCUSSION

Soil pH values ranged from 5 to 8, and electrical conductivity was not higher than 1 dS m^{-1}, thus avoiding extreme values of acidity, alkalinity, or salinity, respectively that could affect nitrogen mineralization processes.

To analyze the soil nitrogen supply, mineralized nitrogen was obtained and potentially mineralizable nitrogen (N_0) was determined from 0 to 5 weeks (labile nitrogen), and from 5 to 20 weeks (stabilized nitrogen), the mean coefficient of determination was r^2=0.97 for the 18 trials.

The amount of N_0 and mineralization rate (coefficient b) of labile nitrogen (Table 2), showed a significant relation ($p<0.05$) between the labile nitrogen and land use.

Values of labile nitrogen were 93 μg g^{-1} in the Alfisol under woodland use (*Haematoxylon campechianum*). In contrast, those obtained in the Entisol under agricultural use (*Zea mays*) were 15 μg g^{-1}, at the same mineralization rate (0.7 μg g^{-1} week^{-1}). The Entisol under agricultural use (*Zea mays*) exhibited lower nitrogen mineralization over time, resulting in a smaller amount of labile nitrogen compared to the Alfisol under woodland use (*Cedrela odorata* L.). This was due to soil order and land use; agricultural use (*Zea mays*) causes the extraction of nitrogen from crops with less nitrogen is replenished. Tillage also promotes the unprotection of the soil organic matter, thus diminishing supply nitrogen than under woodland use (*Cedrela odorata* L.). Stanford and Smith (1972) report that soils with N_0

Table 2. Labil nitrogen (L_N) and mineralization rate (R_{LN}) by soil order and land use.

Soil Order t	**Land use**	**Vegetation**	**L_N ($N_L=a(x)^b$) $\mu g\ g^{-1}$**	**MSD**	**R_{LN} (value of b=rate) $\mu g\ g^{-1}$/week**	**MSD**
Alfisol	Woodland	*Cedrela odorata* L.	93 a		0.7 c	
Inceptisol	Woodland	*Haematoxylon campechianum*	86 ab		0.8 c	
Inceptisol	Cultivated soil	*Saccharum officinarum*	33 ab		2.8 a	
Alfisol	Cultivated soil	*Solanum lycopersicum* L.	31 ab		2.1 ab	
Entisol	Cultivated soil	*Agave*	31 ab		1.3 bc	
Entisol	Cultivated soil	*Zea mays*	15 b	76	0.7 c	0.97

Mean values with different letters in the same column are statistically different, Tukey (α=0.05). MSD=Minimum Significant Difference.

between 11.5 to 13.5 percent of total N were associated with intensive cultivation with little or no application of N. Collins *et al.* (1992) explained that during the first few weeks, organic materials, such as simple sugars, organic acids and proteins, are consumed, which are more likely to be mineralized by the microbial biomass. Soil organic compounds that are mineralized in the first 5 weeks of incubation give place to a fraction of labile nitrogen, which is related to short-time crop nutrition.

In the Alfisol conditions there was a significant relation ($p<0.05$) between nitrogen mineralization rate (slope b) and land use (natural vegetation). While less is value of the slope (b), less is the nitrogen mineralization rate, which in turn corresponds to a slower loss of soil nitrogen after time (t). The Inceptisol, Alfisol and Entisol under agricultural use (*Saccharum officinarum*, *Solanum lycopersicum* L. and *Agave*), respectively showed a middle level of labile nitrogen (31 to 33 $\mu g\ g^{-1}$), at a rapid nitrogen mineralization rate over time (1.3 to 2.8 $\mu g\ g^{-1}$ week^{-1}). This means that if the same soil and crop management practices continue over time, the nitrogen supply to crops will diminish more quickly, affecting the crop yield and soil fertility. Galvis (1998) mentioned that through soil tillage, the organic material becomes unprotected, which increases the activity of the microbial biomass and accelerates the mineralization process (Geisseler *et al.*, 2010); in other words, increases the mineralization rate.

Table 3 shows the amount (N_0) and mineralization rate (coefficient b) for stabilized nitrogen.

Similarly to labile nitrogen, there was a significant relation ($p<0.05$) between stabilized nitrogen and land use. Values of labile nitrogen were 128 $\mu g\ g^{-1}$ in the Alfisol under woodland use (*Cedrela odorata* L.), whereas those obtained in the Entisol under agricultural use (*Zea mays*) were 34 $\mu g\ g^{-1}$, at mineralization rates of 0.36 $\mu g\ g^{-1}$ week^{-1} and 0.56 $\mu g\ g^{-1}$ week^{-1}, respectively.

This was also attributed to soil order and land use; agricultural use (*Zea mays*) that causes less accumulation of nitrogen (stabilized nitrogen) overtime compared to the Alfisol under woodland use (*Cedrela odorata* L.) where the process of nitrogen accumulation continues, leading to greater organic inputs. Vigil and Kissel (1991) found that after 17 weeks of incubation, there was an evident tendency of stabilization of accumulated mineralized N. They attributed this to the fact that the incorporation of

Table 3. Stabilized nitrogen (S_N) and mineralization rate (R_{SN}) by soil order and land use.

Soil order	Land use	Vegetation	S_N ($N_E = C/1+e^{(a-bx)}$) $\mu g\ g^{-1}$	MSD	R_{SN} (value of b=rate) $mg\ g^{-1}\ week^{-1}$	MSD
Alfisol	Woodland	*Cedrela odorata* L.	128 a		0.36 c	
Inceptisol	Woodland	*Haematoxylon campechianum*	122 ab		0.49 abc	
Alfisol	Cultivated soil	*Solanum lycopersicum* L.	98 ab		0.45 bc	
Inceptisol	Cultivated soil	*Saccharum officinarum*	68 ab		0.66 a	
Entisol	Cultivated soil	*Agave*	48 ab		0.59 ab	
Entisol	Cultivated soil	*Zea mays*	34 b	52	0.56 abc	0.19

Mean values with different letters in the same column are statistically different, Tukey (α=0.05). MSD=Minimum Significant Difference.

organic material is less than the material being lost from the soil across crop production systems. Galvis and Hernández (2004) mentioned that the mineralization rate after the fifth week of incubation declined compared to that observed in the first five weeks. This decline was attributed to the mineralization of organic compounds that are resistant to degradation by the microbial biomass. This stabilized nitrogen is associated with the long-term nitrogen supply, promoting microbial activity and enhancing the physical fertility of soil.

To evaluate the nitrogen pool, the labile and stabilized nitrogen pools were estimated by obtaining the first derivative and solving the integral of the potentially mineralizable nitrogen equation from each land use of soil order. The level and loss rate of nitrogen pool were compared using ANOVA (Table 4 and 5).

There was no significant difference ($p<0.05$) between labile nitrogen pool and land uses (Table 4). The results showed that in woodland soils, Inceptisol and Alfisol, the labile nitrogen pool were from 199 to 190 $\mu g\ g^{-1}$ respectively, and in cultivated soils (*Zea mays*), corresponding to Entisol, it was 30 $\mu g\ g^{-1}$. No significant differences were found in the nitrogen mineralization rate of the labile pool; these ranged from 12.2 $\mu g\ g^{-1}\ week^{-1}$ in Inceptisol and Alfisol under woodland use to 2.2 $\mu g\ g^{-1}\ week^{-1}$ in Entisols under agricultural use (*Zea mays* and *Agave*).

Table 4. Labile nitrogen pool (P_{LN}), and mineralization rate (R_{LNP}) by soil order and land use.

Soil Order	Land Use	Vegetation	P_{LN} $\mu g\ g^{-1}$	MSD	R_{LNP} (value of b=rate) $\mu g\ g^{-1}$ week	MSD
Alfisol	Woodland	*Cedrela odorata* L.	190 a		12.2 a	
Inceptisol	Woodland	*Haematoxylon campechianum*	199 a		16.8 a	
Inceptisol	Cultivated soil	*Saccharum officinarum*	123 a		19.2 a	
Alfisol	Cultivated soil	*Solanum lycopersicum* L.	103 a		12.9 a	
Entisol	Cultivated soil	*Agave*	89 a		8.0 a	
Entisol	Cultivated soil	*Zea mays*	30 a	177	2.2 a	17.5

Mean values with different letters in the same column are statistically different, Tukey (α=0.05). MSD=Minimum Significant Difference.

In contrast, there was a significant difference ($p<0.05$) between stabilized nitrogen pool and land uses (Table 5). The results showed that in woodland soils, Inceptisol and Alfisol, the level of stabilized nitrogen pool was from 922 to 891 $\mu g\ g^{-1}$, while in cultivated soils (*Zea mays*), corresponding to Entisol, it was 307 $\mu g\ g^{-1}$.

In this period, the microbial population is compelled to consume more resistant organic materials, which can lead to an increase in microbial activity as the system approaches a new equilibrium state (Collins *et al.*, 1992; Ajwa and Tabatabai, 1994, Wu *et al.*, 2024). The decrease in the value of the slope indicates a reduction in microbial biomass activity, leading to an increased accumulation of organic matter on the soil surface. The soil acts as a physical barrier, limiting the microbial biomass's access to the organic reserves, which in turn reduces the nitrogen mineralization.

Benbi and Richter (2002) suggest that, in order to obtain stable parameters in models describing N mineralization, incubation should continue until the mineralization rate declines to a minimum and reaches a constant level. This was achieved in most soils in the current study, in contrast to that reported by Wang *et al.* (2004), who observed a reduced and constant mineralization rate for some soils, but not for others. Even after 29 to 41 weeks of incubation, they did not identify stable nitrogen reserve sizes. Wang *et al.* suggested that extending the incubation time to 41 weeks would be practically unacceptable and of little relevance to understanding the N mineralization process. Galvis (1998) mentioned that when the soil is tilled, the organic material becomes unprotected, leading to an increase microbial biomass activity, which consequently accelerates the mineralization process, or in other words, increases the rate of mineralization. Other considerations must be considered in the evaluation of soils for agricultural use, which allow synchronizing nitrogen availability with plant demand (Grzebisz *et al.*, 2022, Hussain *et al.*, 2022; de Jesus *et al.*, 2024), or addressing salt-affected soils, which can modify nitrogen mineralization (Peangdin Chaiyapo, 2024). Further studies are needed to model and predict N dynamics in agricultural production systems based on soil types and climatic conditions, with the application of organic fertilizers and manures in different crops.

Table 5. Stabilized nitrogen pool (P_{SN}), and mineralization rate (R_{SNP}) by soil order and land use.

Soil Order	Land Use	Vegetation	P_{SN} $\mu g\ g^{-1}$	MSD	R_{SNP} (value of b=rate) $\mu g\ g^{-1}$ week	MSD
Alfisol	Woodland	*Cedrela odorata* L.	922 a		2.3 a	
Inceptisol	Woodland	*Haematoxylon campechianum*	891 a		1.2 b	
Alfisol	Cultivated soil	*Solanum lycopersicum* L.	598 ab		0.8 bcd	
Inceptisol	Cultivated soil	*Saccharum officinarum*	422 bc		0.3 cd	
Entisol	Cultivated soil	*Agave*	307 bc		0.2 d	
Entisol	Cultivated soil	*Zea mays*	233 c	331	0.2 d	0.73

Mean values with different letters in the same column are statistically different, Tukey ($\alpha=0.05$). MSD=Minimum Significant Difference.

CONCLUSIONS

The mineralized N from the labile fraction (LN) was adjusted to a potential model, while the stabilized fraction (SN) was fitted to a logistic model. Labile nitrogen (LN) and stabilized nitrogen (SN) were significantly higher ($p<0.05$) at 93 μg g^{-1} and 128 μg g^{-1} respectively, in the Alfisols under woodland (*Cedrela odorata*). In contrast, Entisol under agricultural use (*Zea mays*) was had the lowest LN (15 μg g^{-1}) and SN (34 μg g^{-1}). In these same soils, the labile nitrogen pool (LNP) for the Alfisols was higher than in the Entisol, with 199 and 30 μg g^{-1} respectively, while the stabilized nitrogen pool (SNP) was 922 and 233 μg g^{-1}, respectively. In these soils, N_0 correlated positively with both the labile and stabilized nitrogen pool.

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