Research Article

Physicochemical Factors Affecting Nitrogen Mineralization in Soil Cultivated Tropical Pastures

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Abstract | At present, there are no reliable criteria for how much nitrogen fertilizer to add in pasture soils, so it is important to improve the efficiency of nitrogen (N) fertilizer use in pasture soils. It is therefore necessary to identify a fast and reliable soil N test procedure for predicting mineralizable N (mN), for soils cultivated with tropical grasses. In this investigation the Nm of 35 farms (depth 0.20m) of the North zone of Manabí was analyzed, integrating them with certain physicochemical properties and as reference method of the Nm was worked from the data obtained by the Walkley-Black indicator (WB). The Illinois Soil Nitrogen Test (ISNT) and Direct Steam Distillation (DSD) indicators were strongly correlated with each other (R^2 = 0.92), while correlating the WB indicator with DSD was obtained (R^2 = 0.94). The results showed that higher Nm was estimated by ISNT and DSD than by WB, and that its content was different depending on the apparent soil density and carbon level C as soil parameters. The methodology that best correlated with the WB indicator was DSD, so this indicator is a great predictor tool of nitrogen fertilization to achieve agronomic and environmental sustainability of livestock farms in tropical Ecuador.

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Introduction

Recently, high nitrogen fertilizer prices, as well as increased attention to the possible negative environmental impacts of N_2 over-application, have intensified the need for tools that more accurately predict the N_2 response of crops (Kristensen *et al*., 2022), although it has been shown that the indiscriminate use of chemical fertilizers has caused losses in soil productivity, and has detrimental effects on the structure and its health, leading to erosion and low yields, causing property degradation. biological, physical and chemical properties of the soil (Reichert *et al*., 2023), it is evident that its excessive use alters the natural balance of the soil and can chemically burn the roots of plants (Bastidas *et al*., 2022). According to Iderawumi and Kamal (2022), the management and conservation of soil fertility in a tropical climate is a critical detail for its sustainability, making it necessary to select appropriate soil quality indicators, such as organic matter content, nitrogen mineralization, to effectively measure the responses to change, so there are physicochemical indicators that are considered relatively stable, since changes in a system take time to appreciably modify this type of properties and for this reason it does not justify measuring them in short intervals (Zhu *et al*., 2022).

Studies have shown that there are some factors that affect the rate of mineralization of organic matter and therefore the contribution of N_2, so if there are factors that affect mineralization, it is also recognized that it has been difficult to develop an N_2 test in soil that provides reliable predictions of N_2 needs, especially in humid regions. According to Rambaut *et al*. (2022), yield-based N_2 recommendation methods have predominated for several decades for estimating N_2 application rates in the field, despite the fact that their original intent was to provide generalized N fertilizer recommendations. long-term at a regional scale (Banerjee and van der Heijden, 2022).

This detail has caused many investigations to be carried out to determine the proportion of N_2 that is generated from the mineralization of organic matter; Li *et al*. (2022), reported that it is not easy to determine the real availability of N_2, given the difficulties presented by the different laboratory methods to measure its mineralization; additionally, it has been suggested that N_2 is, after water, the nutrient that constitutes the most limiting factor for plant productivity; thus, the illinois soil nitrogen test (Khan *et al*., 2001; Mulvaney and Khan, 2001; Klapwyk and Ketterings, 2005) and the Direct Steam Distillation (Roberts *et al*., 2009), have gained interest as predictors of the N response (Bushong *et al*., 2007). The objective of this research was to determine which factors related to the soil in the physical and chemical part affect the mineralization of the determined N in soils cultivated with tropical pastures.

Materials and Methods

Soil sampling and preparation

35 soil samples were taken from a variety of farms for the cultivation of pastures located in the north-central area of the province of Manabí between the years 2021-2022, the same ones that are represented in Table 1. The soils from the area, continue to form on volcanic and alluvial deposits, product of the erosion of the upper parts of the existing formations and alluvial deposits that extend throughout this area.

Table 1: *Location of the soils cultivated with tropical pastures used to evaluate the incidence of the physical-chemical parameters that affect the mineralization of N.*

ID	Code	Site	Alti-tude	UTM location	
				X	Y
1	MN1	El Carmen	81	640681.6	9999570.1
2	MN2	El Carmen	170	647359.5	9987101.4
3	MN3	El Carmen	200	655273.7	9975061.9
4	MN4	Maicito	227	621017.7	9972546.7
5	MN5	Maicito	227	620428.8	9958113.9
6	MN6	Flavio Alfaro	295	624169.1	9955165.4
7	MN7	Flavio Alfaro	345	624384.8	9950466.9
8	MN8	Sesme	347	621231.1	9947734.3
9	MN9	Sesme	354	621292.3	9943619.4
10	MN10	Sesme	411	615511.2	9942637.7
11	MN11	Pavón	396	610966.4	9939137,8
12	MN12	Pavón	398	608431.2	9936773.7
13	MN13	Pavón	268	607441.9	9936374.7
14	MC1	Ricaurte	101	605463.4	9935945.1
15	MC2	Ricaurte	102	600300.9	9934594.9
16	MC3	Ricaurte	76	606884.8	9932628.5
17	MC4	Ricaurte	20	607193.6	9930939.6
18	MC5	Garrapata	18	607069.9	9930448.3
19	MC6	Garrapata	87	607286.1	9929711.3
20	MC7	El Guabal	85	607471.3	9928206.6
21	MC8	El Guabal	17	606976.5	9927162.6
22	MC9	Chone	15	606327.2	9926303.0
23	MC10	Chone	52	605368.7	9924890.6
24	MC11	Chone	33	604441.2	9924430.2
25	MC12	Chone	29	604224.7	9923846.8
26	MC13	Chone	33	603328.2	9923417.1
27	MC14	Sitio Ánima	33	602988.1	9923110.1
28	MC15	Sitio Ánima	43	600855.4	9923693.9
29	MC16	Sitio Ánima	14	597856.9	9923141.8
30	MC17	Badeal	12	597238.7	9923602.5
31	MC18	Badeal	11	596744.2	9923725.4
32	MC19	Los Bravos Chicos	11	596404.2	9923879.0
33	MC20	Los Bravos Chicos	11	595909.6	9923940.5
34	MC21	Los Bravos Grande	11	596219.7	9925936.3
35	MC22	Los Bravos Grande	8	595415.3	9925598.7

Physical analysis

Samples of 35 farms were analyzed, the same ones that were located in their position coordinates x, y, z; then the physical variables were analyzed at depth (0.20 m); which were: apparent density (cylinder method), real density (pycnometer), field capacity and permanent wilting point (0.33 pressure cooker method and 15 atm pressure for 24 hours), humidity (gravimetric method), position (relationship between apparent density and actual density), texture was determined by particle size analysis using the pipette method (Villaruel *et al*., 2022) and the USDA classification of sand, silt and clay (Brady and Weil, 2008), aeration capacity, aeration porosity, available water, critical level of soil density (integration of previous results).

Chemical analysis

The chemical analyzes carried out in this investigation were: Soil pH analysis (1:2) was measured in water (USDA, 1996) using a pH meter for Mettler Toledo electrodes (Mettler-Toledo, Zurich, Switzerland).

Determination of MO by WB

According to the WB method (Walkley and Black, 1934), the concentrated H_2SO_4 is initially added to a mixture of soil and aqueous $K_2Cr_2O_7$. The heat of dilution raises the temperature sufficiently to induce substantial, but not complete, oxidation by the acidified dichromate. The residual dichromate is titrated again using ferrous sulfate ($FeSO_4$). The difference in $FeSO_4$ addition is compared to a blank titration and determines the amount of easily oxidizable Organic Carbon (OC). The percentage of OC was multiplied by the Van Bemmelein factor 1.724 according to (Bahadori and Tofighi, 2017), to obtain the percentage of OM (Pramod *et al*., 2014).

Determination of Nm by ISNT

To determine Nm, the content of N-amino-sugars (ISNT) was used and it was quantified as proposed by Khan *et al*. (2001). The technique used uses 350 mL glass flasks with an 84 mm diameter metal cap in which 1.00 g of dry soil was weighed, covered with parafilm paper to prevent the escape of vapors and hydrolyzed with sodium hydroxide (2M NaOH), heated in a water bath at 50 °C for 5 h. The ammonia released by hydrolysis was collected in boric acid (4% H_3BO_3 plus 0.25 mL of mixed indicator) in a 250 mL Erlenmeyer flask. Ammonia was quantified by titration of $(NH_4)_3BO_3$ with sulfuric acid (H_2SO_4, 0.00714N). The ISNT in mg kg^{-1} was calculated as V x T, where V is the volume of H_2SO_4 used in the titration and T is its title.

Determination of Nm by DSD

This method is based on obtaining N in the form of ammonia by steam distillation for its subsequent volumetric measurement, this modified steam distillation technique is based on the work of Bushong *et al*. (2007). 1 g of soil was weighed and 50 mL of distilled water and 20 mL of 40% NaOH were added, at the same time 10 mL of 4% H_3BO_3 plus 0.25mL of indicator was placed in an Erlenmeyer flask mixed; then both vessels went to a Kjeldahl still. Steam distillation was carried out at a rate of 7mL min^{-1} until 35mL of distillate was collected in 5mL of 4% H_3BO_3 indicator solution. The amount of NH_4-N captured in the distillate was quantified using acid metric titration techniques (0.00714N H_2SO_4) to a predetermined end point (purple color for at least 30 seconds). The concentration of N is expressed in mg kg^{-1}.

Statistical analysis

A descriptive study of the physical-chemical properties and the indicators of the mineralization of N was carried out, of the 35 soils belonging to farms cultivated with tropical pastures, the entire group of physical properties of the soil was analyzed in reference to the coefficient of variation (Shahidin *et al*., 2002). For data treatment, a multivariate analysis of principal components (PCA) was performed from which those with eigenvalues greater than or equal to one were selected, thus explaining the highest percentage of the total variation of the data, in order to identify relationships between the variables studied in the evaluated farms, which allowed to identify the groups based on the behavior of the variables evaluated.

Regarding hierarchical grouping (clusters), Ward's distances were used, which allowed the groups to be identified based on the behavior of the variables evaluated. Likewise, simple correlations and regressions were developed between variables to establish the possible relationships between the physical properties studied and the predictors of Nm. As well as to obtain the recovery percentage and correction factor of WB, ISNT and DSD.

To design the maps of the mineralizable N estimators, the information from the results of the laboratory analyzes was collected, the data were grouped by area and the average, median, standard deviation, minimum and maximum values, as well as percentiles, were determined. The normality of the data distribution was tested using the Proc Univariate routine of the R Core Team (2021) program. To generate the maps, the Qgis 3.83 program was used, for which a point, latitude and longitude corresponding to the center of each site was forged, which was related to the value of the statistic used (Issiako *et al*., 2021). The interpolation method used to make the Nm estimators maps was the Ordinary Kriging (KO) according to Vázquez and Macias (2017).

Results and Discussion

Variation of the physicochemical properties of the soil and estimated parameters of mineralizable N

The predominant soil texture in this research was loamy (clay between 7%-27% and silt between 28%-50%), these soils stand out, according to SQI (1996), for offering good retention of water, favoring the diffusion of gases, therefore the metabolism of mesophilic aerobic bacteria, responsible for the mineralization of N (Delin and Lindén, 2002). The soils of the 35 sampled farms present six textural classes; silty clay loam (n= 5), loam (n= 16), silty loam (n= 3), clay loam (n= 9), sandy loam (n= 1) and clay (n= 1) (Figure 1).

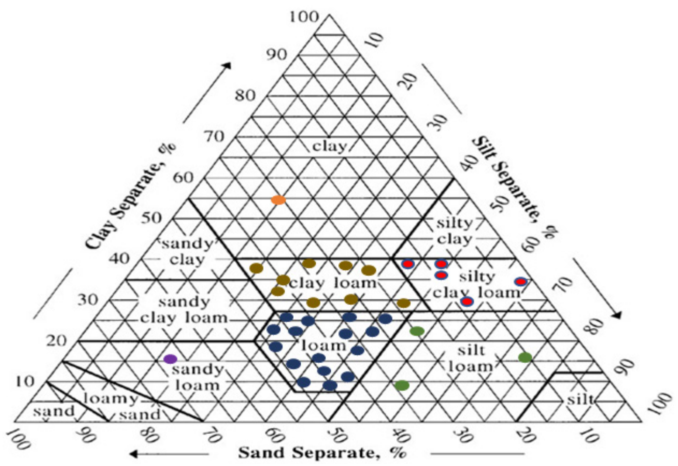

Figure 1: *Textural diagram of soils cultivated with tropical pastures.*

It is important to mention that as indicators of soil quality, physical, chemical and biological properties are usually used (Soil Quality Institute, 1996). The soils analyzed in this research report an altitude gradient ranging from 8 to 411 meters above sea level. It should be noted that the physical-chemical parameters can present different values from one area to another and also depending on the type, management and soil formation factors (Arshad and Coen, 1992).

With regard to pH, this parameter presented an average value of 7.25 (slightly alkaline). This is in contrast to what was expressed by Toledo *et al*. (2011), who determine that the acidity of the soils allows the solubility of nutrients and their availability for the pasture. However, Delgado *et al*. (2016), found values between 6.61 and 7.31; for the pH value in conventional and organic sugarcane systems.

The apparent density, this parameter describes the compaction of the soil, representing the relationship between solids and porous space (Alzate, 2017), in the present study it had a minimum of 0.96 and a maximum of 1.70g cm^{-3}; These values are higher than those registered by Rendón *et al*. (2011), who determined apparent density values for soils cultivated with blackberry, avocado and grass in Rionegro Colombia (0.20m). According to Hribljan *et al*. (2015), the apparent density of the soil, allows to explain the behavior of multiple physical-chemical properties that strongly influence fertility, quality and the use of land management.

The critical level of soil density has a mean value of 1.81g cm^{-3}, this value is higher than that reported by Albán (2009) in a study of compaction and hydrological properties in soils confined to the cultivation of sugarcane. High levels of density determine the degradation of the soils causing them to compact and there is no diffusion of air through the pores of the soil.

Flores and Alcalá (2010), determine that soil moisture affects most of the physical properties, such as compaction, penetrability, bulk density, pore space, shear resistance, consistency, total water suction, and soil color. This parameter had an average of 292g kg^{-1}, which determines that these areas have good humidity and, therefore, an average field capacity of 245g kg^{-1}; These values coincide with Regehr *et al*. (2015), who determine that there is a significant effect of moisture content on N mineralization, increasing as moisture increases from 250 to a maximum of 650 and 800g kg^{-1}.

The total porosity and aeration porosity have average values of 457 and 164 g kg^{-1} respectively, these values are related to those found by Leyva *et al*. (2018) in soils with cultivated pastures, where they obtained values for total porosity of 432 g kg^{-1} and aeration porosity of 41.5 g kg^{-1}.

Analyzing the values obtained, we can notice that there is a great variability between them, presenting a greater range and dispersion of the variables: sand

(33.1%), available water (35.99%), permanent wilting point (31.04%), space (34.47%), organic carbon (37.01%), WB (37.74%), ISNT (34.30%) and DSD (39.27%) (Table 2).

Table 2: *Statistical analysis of the textural content and the physical-chemical parameters of the soils cultivated with tropical pastures, (n = 35).*

Variable	Units	Average	S.D.	Min	Max	C.V
Sand	g kg^{-1}	299.00	99.00	72.00	544.00	33.11
Silt	g kg^{-1}	439.09	63.84	312.00	544.00	14.54
Clay	g kg^{-1}	262.86	77.76	128.00	480.00	29.58
Ad	g cm^{-3}	1.27	0.16	0.96	1.70	12.24
Clsd	g cm^{-3}	1.81	0.01	1.80	1.82	0.33
Moisture	g kg^{-1}	292.23	47.42	207.00	381.00	16.23
AW	g kg^{-1}	116.97	42.10	52.00	227.00	35.99
FC	g kg^{-1}	244.89	47.08	128.00	331.00	19.22
PPW	g kg^{-1}	127.97	39.72	60.00	225.00	31.04
η	g kg^{-1}	456.57	35.51	400.00	540.00	7.78
Ps	g kg^{-1}	164.29	56.63	44.00	257.00	34.47
CA	g kg^{-1}	210.66	49.92	111.00	311.00	23.70
pH	----	7.25	0.23	6.90	7.80	3.11
OC	mg kg^{-1}	13.97	5.17	3.00	23.00	37.01
OM	mg kg^{-1}	23.96	9.04	5.30	39.90	37.74
ISNT	mg kg^{-1}	106.71	36.60	61.30	192.80	34.30
DSD	mg kg^{-1}	99.78	39.19	37.20	188.80	39.27

Ad = Apparent density, Clsd = Critical leve lof soil density, Aw = Available water, FC = Field Capacity, PMW = Point of Permanent Wilt, = Porosity, Ps = Pore space, Ac = Aireation capacity, pH = potential Hydrogen, OC = Organic Carbon, OM= Organic Matter, ISNT = Illinois Soil Nitrogen Test, DSD = Direct Steam Distillation.

Table 3: *Barlett's sphericity analysis of the physicochemical parameters and N mineralization indices of soils cultivated with tropical pastures, (n = 35).*

Kaiser Meyer Olkin's measure of sampling adequacy (KMO)		0.45
Barlett test of sphericity	ji- approximate square	1786.6
	Degrees of freedom	17
	Significance	*P*-value < 2.2e-16

Next, the Bartlett sphericity test was used to test if the variables are correlated and if the correlation matrix corresponds to an identity matrix, as presented in Table 3.

In the extraction of the principal components (PC), we find that the total variance explained by the first principal component is 27.1%, the second component 43.3%, the third component 56.2%, the fourth component 66.7% and the fifth component 75% (Table 4).

Table 4: *Analysis of the accumulated variance of the physical-chemical parameters of the soils cultivated with tropical pastures, (n = 35).*

Principal components	Initial eigenvalues		
	Standard desviation	Proportion of variance	Cumulative proportion
CP1	2.20	0.27	0.271
CP2	1.71	0.16	0.433
CP3	1.52	0.13	0.562
CP4	1.38	0.11	0.667
CP5	1.22	0.08	0.750

Table 5: *Analysis of the positive and negative correlations of the physical-chemical parameters, the estimators of the mineralization of the N versus the main components of the soils cultivated with tropical pastures.*

Variable	Principal components				
	CP1	CP2	CP3	CP4	CP5
Sand	0.81807	0.05715	-0.36321	-0.11132	-0.09186
Silt	-0.22664	-0.16029	0.78554	-0.37841	0.48526
Clay	-0.87212	0.02238	-0.03562	0.37417	-0.13658
Ad	-0.01668	-0.45455	0.47780	0.11903	-0.15327
Clsd	-0.37421	-0.46719	-0.05065	-0.32952	-0.25196
Moisture	0.75372	-0.05770	0.07723	-0.37703	0.20339
AW	0.15915	0.47608	0.32533	0.63641	0.25940
FC	-0.23443	0.67277	0.13104	-0.36198	0.25132
PPW	-0.81499	0.21129	0.07206	-0.26148	0.24699
η	-0.66346	-0.45139	-0.05289	0.08747	-0.00507
Ps	-0.32959	-0.28134	-0.43906	0.28757	0.69171
CA	-0.34898	-0.60742	-0.57772	-0.41020	0.20457
pH	0.55249	-0.42610	-0.34951	0.44424	0.27456
OC	0.23075	-0.66339	0.55239	0.14093	0.10342
OM	0.21749	-0.27468	0.11757	-0.13987	-0.21712
ISNT	0.36127	-0.05507	-0.00135	-0.00767	0.25930
DSD	0.10100	-0.40778	0.38929	0.21231	-0.07875

Ad = Apparent density, Clsd = Critical leve lof soil density, Aw = Available water, FC = Field Capacity, PMW = Point of Permanent Wilt, η = Porosity, Ps = Pore space, Ac = Aireation capacity, pH = potential Hydrogen, OC = Organic Carbon, OM= Organic Matter, ISNT = Illinois Soil Nitrogen Test, DSD = Direct Steam Distillation.

When observing Table 5, we can verify that the variables most positively correlated in the first main component are sand, the critical level of surface density of the soil, aeration capacity, and the ISNT; inversely, clays and field capacity are related. The variables most directly correlated with the second component are humidity and available water, while inversely the pH, apparent density and pore spaces. While with the third, fourth and fifth components there are only positive relationships with the variables silt, the C and the DSD; moisture and pores, respectively.

When performing the hierarchical analysis of clusters, we can realize that of the 35 farms, in terms of their physicochemical properties and indicators of N mineralization, they formed 2 groups (G1 and G2) (Figure 2). It is important to highlight that this grouping presents a consistent behavior with the variables analyzed in each farm.

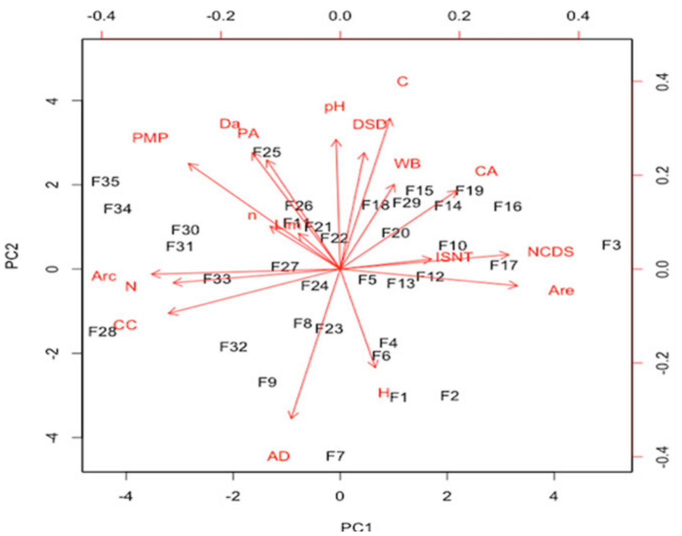

Figure 2: *Principal component analysis (PCA) for the 35 farms cultivated with tropical pastures in relation to the physical-chemical variables evaluated and the estimated mineralization of N.*

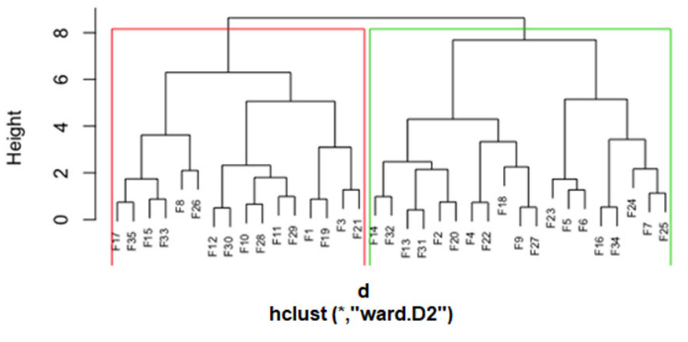

Figure 3: *Hierarchical cluster analysis (AJC) for the 35 soils cultivated with tropical pastures in relation to the physical-chemical variables evaluated.*

The hierarchical cluster analysis carried out to analyze the similarities/ differences of the 35 farms, in terms of their physicochemical properties, allowed us to find 2 groups of farms (G1 and G2) (Figure 3). It is important to highlight that this grouping presents a consistent behavior with the physical-chemical variables analyzed in each farm.

Estimators of N mineralization

Table 2 shows that the OM valued by WB throughout the 35 farms, has an average value of 23.96g kg^{-1}, we can determine that there is a high edaphic variability in the evaluated sites.

The OM values are below the average found by Leyva *et al.* (2018), who determine an OM value of 42.4 g kg^{-1} in the different land use systems. In contrast to an investigation carried out by Balin *et al.* (2017) in the Peruvian Amazon where it determines average OM values of 13.8g kg^{-1}.

Figure 4 illustrates the prediction maps generated for OM using the WB method and Nm mineralization using ISNT and DSD methods. These maps visually represent the spatial variability of OM and Nm across the studied farms, highlighting the potential for these estimators to support site-specific nitrogen management strategies.

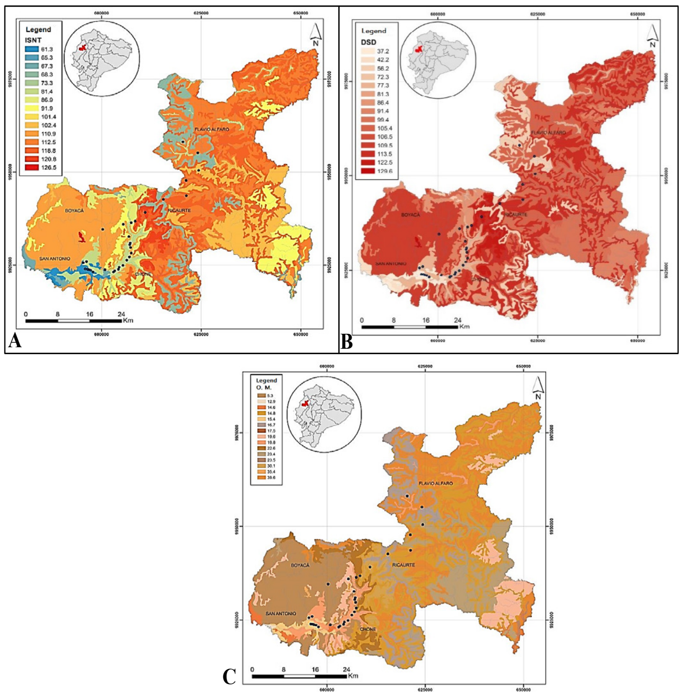

Figure 4: *Predictor maps of the present study, A: OM prediction map by the WB method (g kg^{-1}), B: Prediction map of N mineralization by the ISNT method (mg kg^{-1}), C: Prediction map of N mineralization by the DSD method (mg kg^{-1}).*

Table 6 summarizes the results of the N mineralization estimators (WB, ISNT, and DSD) for the two farm groups (G1 and G2) identified through the hierarchical cluster analysis. Significant differences were observed between groups, reflecting the influence of soil properties on the performance of each estimator.

Table 6: *Results of the estimators of the mineralization of the N by groups of farms from the hierarchical analysis of clusters.*

N mineralization estimator		n	Average	SD	min	max	CV
Farm groups			mg kg^{-1}				%
WB^{ns}	G1	19	25.14	9.55	5.3	39.9	37.99
	G2	16	22.57	8.48	12.9	37.4	37.61
ISNT*	G1	19	111.53	39.01	65.3	192.8	34.98
	G2	16	100.98	33.95	61.3	179.8	33.52
DSD**	G1	19	106.99	37.35	56.2	188.8	34.91
	G2	16	91.21	40.77	37.2	172.7	44.70

*n = number of farms per group. SD = Standard deviation, CV = Coefficient of variation; *,**,*** = Differences significant at 0,05; 0,01 and 0,001; ns = Non-significant differences.*

The ISNT method of estimating N mineralization, developed by Khan *et al.* (2001) will find a range from 61.3 to 192.8mg of N kg^{-1}, with an average value of 106.71mg of N kg^{-1}. These values are below those analyzed by Spargo *et al.* (2012) in 29 soils dedicated to corn cultivation. Regarding the DSD method, this record ranges from 37.2 to 188.8mg of N kg^{-1}, these values are related to (Delgado *et al.*, 2016), who have used this technique to predict the amount of nitrogen fertilizer in sugarcane fertilization works.

Correlations between estimators of N mineralization

In general, the analysis of the estimators of the Nm in the 35 soils dedicated to pastures showed a good correlation between the DSD and ISNT methodologies (R^2 = 0.92). In Figure 5, it is observed how the DSD methodology correlated very well with the ISNT method. Likewise, the existing correlation between the method of estimating N from WB, presented correlations between DSD and ISNT (R^2 = 0.94 and 0.48, respectively), so we can see that the WB methodology is significantly correlated with DSD and slightly ISNT.

The analysis of the weighted recovery averages and correction factors highlights that the WB method is the best estimator of nitrogen mineralization, with a recovery percentage (%R) of 74.76 % and a correction factor (CF) of 1.32. In comparison, the ISNT and DSD methods presented weighted recovery averages of 60.58% and 51.57%, respectively, with higher correction factors. (ISNT = 1.99; DSD = 2.12). These differences reflect the limitations of ISNT and DSD in tropical soils, which require more significant adjustments to accurately estimate nitrogen mineralization. However, the strong correlation between DSD and ISNT (R^2 = 0.92), as well as between DSD and WB (R^2 = 0.94), suggests that these methods are useful as complementary tools to validate the estimates made by WB.

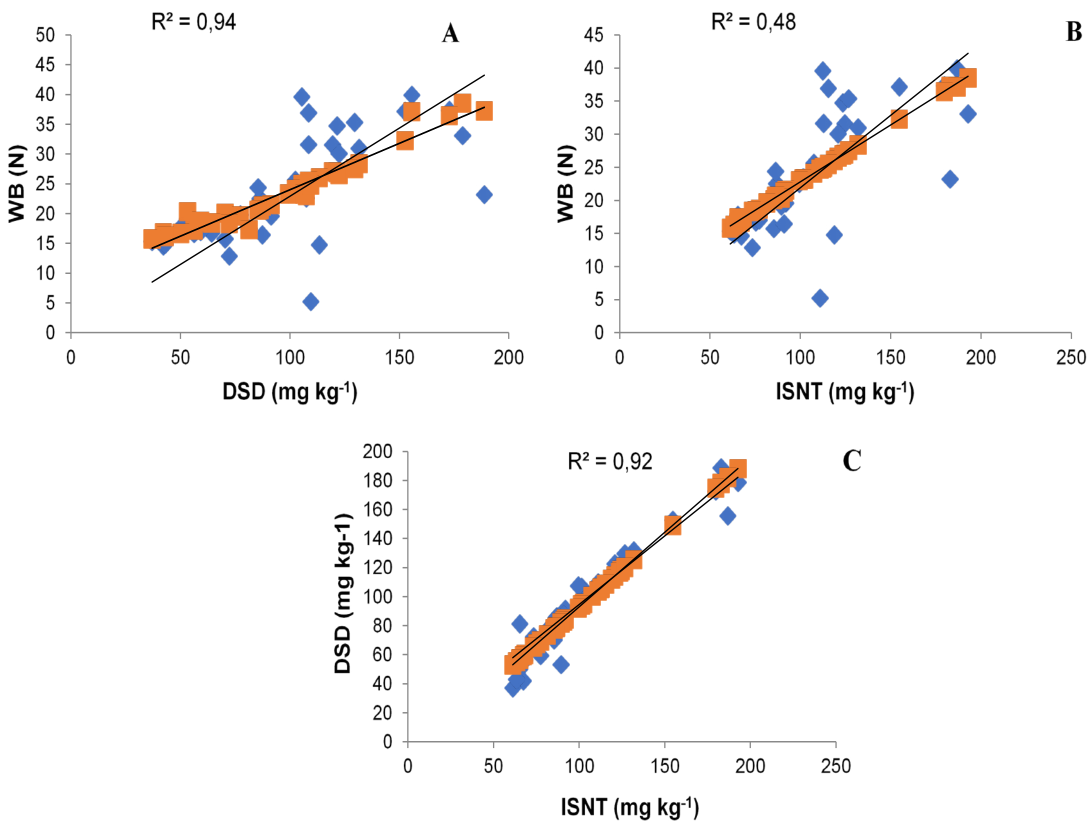

Figure 5: *Comparison between multiple regression lines between A: WB versus DSD method; B: WB method versus ISNT and C: DSD versus ISNT.*

Table 7 presents the recovery percentages and correction factors for the WB, ISNT, and DSD methods across the two farm groups. These results demonstrate that WB achieved the highest recovery percentage and lowest correction factor, supporting its reliability as an N mineralization predictor compared to ISNT and DSD.

Table 7: *Porcentajes de recuperación y factores de corrección de los estimadores de la mineralización del N por grupos de fincas a partir del Análisis Jerárquico de Clusters.*

N mineralization estimator		n	Recovered (%)			Correction factor		
Farm groups			Prom	D.E.	C.V.	Prom	D.E.	C.V.
WB	G1	19	79.31	14.59	18.39	1.31	0.31	23.44
	G2	16	70.14	17.63	25.14	1.34	0.33	24.68
ISNT	G1	19	54.59	13.38	24.50	1.96	0.55	28.04
	G2	16	67.69	11.57	17.10	2.02	0.56	27.92
DSD	G1	19	52.61	13.90	26.43	2.07	0.68	33.04
	G2	16	50.33	13.99	27.79	2.17	0.70	32.48

WB = Walkley Black; ISNT = Illinois Soil Nitrogen Test; DSD = Direct Steam Distillation. n = number of farms per group. SD = Standard deviation, CV = Coefficient of variation.

Conclusions and Recommendations

The results obtained in the 35 farms dedicated to pasture allow us to visualize that the best estimator of N mineralization was the ISNT test, but the estimator that best correlated with the WB value was the DSD. This study showed that the index that best fits the WB predictor is the DSD, which is why it is an alternative to make correct recommendations regarding the amount of nitrogen fertilizer that is going to be available in a tropical pasture crop, since after the respective regression analysis showed the highest correlation with the amount of OM estimated by WB. Likewise, it is important to note that the Nm content was different depending on the physicochemical properties, especially the critical level of soil density and the level of C. This allows us to conclude that it is necessary to continue carrying out additional evaluations on a larger data set of tropical soils with similar physicochemical properties and incorporating the biological component in order to establish nitrogen fertilization criteria in an optimal way, allowing the generation of a food safety culture. and be careful with the responsible environment.

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Novelty Statement

This study identifies for the first time the correlation between the chemical indicators of rapid nitrogen mineralization and the physicochemical properties of the soil in tropical Ecuadorian farms, offering bases for sustainable fertilization.

Author's Contribution

Gerardo J. Cuenca-Nevárez: Experimental design, statistical analysis, writing of the manuscript.
Juan Carlos Menjívar-Flores: Data collection, bibliographic review, validation of results.

Conflict of interest
The authors have declared no conflict of interest.

References

Albán, A., 2009. Índice preliminar de compactación y propiedades hidrológicas en suelos calcácicos bajo caña de azúcar (*Saccharum officinarum* L). Palmira: Universidad Nacional de Colombia. Facultad de Ciencias Agropecuarias. Coordinación General de Postgrados.

Alzate, G.A., 2017. Cambios en la permeabilidad y porosidad de medios porosos no consolidados debido a cambios en el esfuerzo de confinamiento y la temperatura. Bolet. Cien. Tierra Nº, 42: 64-72. https://doi.org/10.15446/rbct.n42.65497

Arshad, M. and G. Coen. 1992. Characterization of soil quality: Physical and chemical criteria. Am. J. Altern. Agric., pp. 25-31. https://doi.org/10.1017/S0889189300004410

Bahadori, M. and H. Tofighi. 2017. Investigation of soil organic carbon recovery by the Walkley-Black method under diverse vegetation systems. Soil Sci., 182(3): 101-106. https://doi.org/10.1097/SS.0000000000000201

Balin, N., Z. Dahlem, J. Machado, G. Cauduro, L. Stumpf and P. Conceição. 2017. Frações da materia orgânica, indice de manejo do carbono e atributos físicos de um latossolo vermelho sob diferentes sistemas de uso. Rev. Sci. Agraria, 18(3): 85-94. https://doi.org/10.5380/rsa.

v18i3.53114
Banerjee, S. and M.G. van der Heijden. 2022. Soil microbiomes and one health. Nat. Rev. Microbiol., pp. 1-15. https://doi.org/10.1038/s41579-022-00779-w
Bastidas, B.D., J. Ossa, C. Martínez, M.A. Vela, T. Betancur and A. Osorio. 2022. Region-scale estimation of potential groundwater recharge in soft and hard rock formations through a distributed water balance in the area of influence of the tropical dry forest in the Cauca River canyon, Antioquia, Colombia. Bolet. Geol., 49(1): 77-101. https://doi.org/10.32685/0120-1425/bol.geol.49.1.2022.625
Brady, C. and R. Weil. 2008. The nature and properties of soils. Fourteenth edition. Saddle River, NJ: Prentice Hall, Upper.
Bushong, J., R. Norman, W. Ross, N. Slaton, C. Wilson and E. Gburr. 2007. Evaluation of several indices of potentially mineralizable soil nitrogen. Commun. Soil Sci. Plant Anal., 38: 2799-2813. https://doi.org/10.1080/00103620701663040
Delgado, O., Menjívar, J. and Muñoz, F., 2016. Influence of management systems on thenitrogen mineralization and fertilization of sugarcane. Rev. Fac. Natl. Agric., 69(1): 1-10. https://doi.org/10.15446/rfna.v69n1.54742
Delin, S. and B. Lindén. 2002. Relations between net nitrogen mineralization and soil characteristics within an arable field. Acta Agric. Scand. Sect. B Soil Plant Sci., 52: 78-85. https://doi.org/10.1080/090647102321089819
Flores, L. and Alcalá, J., 2010. Manual de procedimientos analíticos. Laboratorio de Física de Suelos. México: Universidad Nacional Autónoma De México.
Hribljan, J., D. Cooper, J. Sueltenfuss, E. Wolf, K. Heckman, E. Lilleskov and R. Chimner. 2015. Carbon storage and long-term rate ofaccumulation in high-altitude Andean peatlands of Bolivia. Mires Peat, 15: 1-14.
Iderawumi, A.M. and T.O. Kamal. 2022. Green manure for agricultural sustainability and improvement of soil fertility. Farm. Manage., 7(1): 1-8. https://doi.org/10.31830/2456-8724.2022.FM-101
Issiako, D., O. Arouna, K. Soufiyanou, I.T. Imorou and B. Tente. 2021. Prospective mapping of land cover and land use in the classified forest of the upper alibori based on satellite imagery. Geoplann. J. Geomat. Plan., 8(2): 115–126. https://doi.org/10.14710/geoplanning.8.2.115-126
Khan, S., R. Mulvaney and R. Hoeft. 2001. A simple soil test for detecting sites that nonresponsive to nitrogen fertilization. Soil Sci. Soc. Am. J., 65: 1751-1760. https://doi.org/10.2136/sssaj2001.1751
Klapwyk, J. and Q. Ketterings. 2005. Reducing the analysis variability of the Illinois Soil Nitrogen Test with enclosed griddles. Soil Sci. Soc. Am. J., 69: 1129-1134. https://doi.org/10.2136/sssaj2004.0231
Kristensen, R.K., Fontaine, D., Rasmussen, J. and Eriksen, J., 2022. Contrasting effects of slurry and mineral fertilizer on N2-fixation in grass-clover mixtures. Eur. J. Agron., 133: 126431. https://doi.org/10.1016/j.eja.2021.126431
Leyva, S., A. Baldoquin and M. Reyes. 2018. Propiedades de los suelos en diferentes usos agropecuarios, Las Tunas, Cuba. Rev. Cienc. Agric., 35(1): 36-47. https://doi.org/10.22267/rcia.183501.81
Li, H., J. Van den Bulcke, O. Mendoza, H. Deroo, G. Haesaert, K. Dewitte and S. Sleutel. 2022. Soil texture controls added organic matter mineralization by regulating soil moisture evidence from a field experiment in a maritime climate. Geoderma, 410: 115690. https://doi.org/10.1016/j.geoderma.2021.115690
Mulvaney, R. and S. Khan. 2001. Diffusion methods to determine different forms of nitrogen in soil hydrolysates. Soil Sci. Soc. Am. J., 65: 1284-1292. https://doi.org/10.2136/sssaj2001.6541284x
Pramod, J.A., K. Biswas, R.B.L. Lakaria, S. Muneshwar and A.S. Rao. 2014. Predicting total organic carbon content of soils from walkley and black analysis. Commun. Soil Sci. Plant Anal., 45(6): 713-725. https://doi.org/10.1080/00103624.2013.874023
R Core Team, 2021. R: language and enviroment for statistical computing (Vienna, Austria: R Foundation for Statistical Computing).
Rambaut, L.A.E., J. Vayssières, A. Versini, P. Salgado, P. Lecomte and E. Tillard. 2022. 15-year fertilization increased soil organic carbon stock even in systems reputed to be saturated like permanent grassland on andosols. Geoderma, 425: 116025. https://doi.org/10.1016/j.geoderma.2022.116025

Regehr, A., M. Oelbermann, C. Videla and L. Echarte. 2015. Gross nitrogen mineralization and immobilization in temperate maize-soybean intercrops. Plant Soil. https://doi.org/10.1007/s11104-015-2438-0

Reichert, J.M., B. Morales, E.M. Lima, F. de Bastos, C.A.S. Morales and E.F. de Araújo. 2023. Soil morphological, physical and chemical properties affecting *Eucalyptus* spp. productivity on Entisols and Ultisols. Soil Tillage Res., 226: 105563. https://doi.org/10.1016/j.still.2022.105563

Rendón, S., F. Artunduaga, R. Ramírez, A. Quiroz and E. Leiva. 2011. Los macroinvertebrados como indicadores de la calidad del suelo en cultivos de mora, pasto y aguacate. Rev. Facult. Nacional Agronomía Medellín, [S.l.], 64(1): 5793-5802.

Roberts, T., R. Norman, N. Slaton, C. Wilson Jr, W. Ross and J. Bushong. 2009. Direct steam distillation as an alternative to the illinois soil nitrogen test. Soil Sci. Soc. Am. J., 73: 1268-1275. https://doi.org/10.2136/sssaj2008.0165

Shahidin, N.M., I. Roslan, S.S. Zaharah, S.H. Kang, A.A. Elisa, M.N. Malisa and S.S. Abe. 2022. Soil spatial variation in a sloping mango orchard of Northern Peninsular Malaysia. Malaysian J. Soil Sci., 26: 104-119.

Soil Quality Institute, S., 1996. Indicators for soil quality evaluation. USDA Natural Resources Conservation Service . NRCS, USDA.

Spargo, J., M. Alley, M. Cavigelli and J. Eastman. 2012. Changes in soil organic carbon and nitrogen fractions with duration of no-tillage management. Soil Sci. Soc. Am. J., 76(5): 1624-1631. https://doi.org/10.2136/sssaj2011.0337

Toledo, T.M., M. González and N. Rámirez. 2011. Tropical montane cloud forests: current threats and opportunities for their conservation and sustainable management in Mexico. J. Environ. Manage., 92: 974-981. https://doi.org/10.1016/j.jenvman.2010.11.007

USDA, 1996. Soil survey laboratory methods manual. Washington DC, USA: Soil Survey Investigations Report Nº 42. Version 3.0.

Vázquez, J. and F. Macías. 2017. Fraccionamiento químico del carbono en suelos con diferentes usos en el Departamento de Magdalena, Colombia. Terra Latinoamericana, vol. 35, núm. 1. Sociedad Mexicana de la Ciencia del Suelo, A. C, pp. 7-17. https://doi.org/10.28940/terra.v35i1.237

Villarruel, G., G.A. Sacchi and V.P. Zampar. 2022. Repelencia al agua en suelos afectados por incendio: Comparación con experiencias de calentamiento en laboratorio. Rev. Facult. Cien. Exact. Físicasy Nat., 9(2): 69-76.

Walkley, A. and A. Black. 1934. An examination of the Degtjareff method for determining soil organic matter, and proposed modification of the chromic acid titration method. Soil Sci., 37: 29-38. https://doi.org/10.1097/00010694-193401000-00003

Zhu, F., Y. Yan, E. Doyle, C. Zhu, X. Jin, Z. Chen and C. Gu. 2022. Microplastics altered soil microbiome and nitrogen cycling: The role of phthalate plasticizer. J. Hazard. Mater., 427: 127944. https://doi.org/10.1016/j.jhazmat.2021.127944