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Carbon-nitrogen ratio in soils with fertilizer applications and nutrient absorption in banana (*Musa spp.*) cv. Williams

Relación carbono-nitrógeno en suelos con aplicación de fertilizantes y absorción de nutrientes en banano (*Musa spp.*) cv. Williams

Wilson Antonio Pérez^{1*} and Jaime Torres-Bazurto²

ABSTRACT

This research took place in Uraba, Antioquia, in the CENI-BANANO-AUGURA experimental field, where a research program on nutrition and fertilization in bananas is carried out. This crop requires high amounts of nitrogen for production, so it is indispensable to evaluate the impact of these applications on the carbon-nitrogen ratio (C/N ratio) in soil. Published literature is scarce for this problem. This research evaluated the C/N ratio in areas with fertilizer applications and nutrient uptake, along with the interaction with production in a banana crop of the AAA group giant Cavendish subgroup, Williams clone, sixth generation in two production cycles. A randomized complete block design was used with five treatments that consisted of differential doses of nitrogen (161, 321.8, and 483 kg ha⁻¹), and an omission and absolute control distributed in four replicates. The treatments with nitrogen doses generated statistical differences for the interactions between the two study zones for the percentages of carbon and total soil nitrogen and C/N ratios; the highest values were found in the fertilization zone during the first production cycle (2.47% C, 0.33% N, and 7.7 C/N ratio). The treatment with 483 kg ha⁻¹ of N obtained the greatest increases in the values for these variables that are attributed to the highest dose of nitrogen and the residual acidity of urea that was able to release non-free carbon from the soil. For this reason, the correlation analysis for the C/N ratio and production was significant for the study areas (absorption and fertilization), inferring that higher C/N ratio values tend to increase production.

Key words: crop nutrition, plant development, organic matter, edaphogenesis, soil moisture.

RESUMEN

La presente investigación se desarrolló en el Urabá antioqueño, en el campo experimental CENIBANANO-AUGURA, donde se lleva a cabo el programa de investigación en nutrición y fertilización en banano. Este cultivo requiere altas cantidades de nitrógeno en su proceso productivo, haciendo indispensable el evaluar el impacto de dichas aplicaciones en la relación carbono-nitrógeno (relación C/N) en el suelo. La literatura publicada es escasa para esta problemática. Esta investigación evaluó la relación C/N en las zonas de aplicación de fertilizantes y absorción de nutrientes, junto con la interacción con la producción en un cultivo de banano del grupo AAA, subgrupo Cavendish gigante, clon Williams de sexta generación en dos ciclos de producción. Se usó un diseño experimental en bloques completos al azar con cinco tratamientos que consistieron en dosis diferenciales de nitrógeno (161, 321,8 y 483 kg ha⁻¹), un testigo de omisión y uno absoluto distribuidos en cuatro repeticiones. Los tratamientos con dosis de nitrógeno generaron diferencias estadísticas para la interacción entre las dos zonas de estudio para los porcentajes de carbono y nitrógeno total del suelo y la relación C/N; los mayores valores se encontraron para la zona de fertilización durante el primer ciclo de producción (2.47% C, 0.33% N y relación C/N 7.7). El tratamiento con 483 kg ha⁻¹ N obtuvo los mayores incrementos en los valores para estas variables, los cuales se atribuyen a la mayor dosis de nitrógeno y a la residualidad ácida de la urea que pudo liberar carbono no libre del suelo. Por esta razón, el análisis de correlación para la relación C/N y la producción fue significativo para las zonas de estudio (absorción y fertilización), infiriendo que a mayores valores de la relación C/N la producción tiende a incrementarse.

Palabras clave: nutrición de cultivos, desarrollo vegetal, materia orgánica, edafogénesis, humedad del suelo.

Introduction

Bananas are one of the most cultivated fruit crops in the world; production exceeds 70 million t, making them one of the most important crops (Robinson and Galán, 2012).

For 2017, the main producing countries were the Philippines (251.792 t), Guatemala (236.571 t), Ecuador (158.991 t), Dominican Republic (143.744 t) and Colombia (117.797 t) (Carvajal *et al.*, 2019). About 20% of global banana production goes to international markets with 95% of the *Musa*

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acuminata cultivars from the Cavendish group (Robinson and Galán, 2012).

One of the most important agronomic practices for this crop is fertilization management, traditionally carried out with frequent applications in a small area. Fertilizers, especially nitrogen-based ones, are concentrated, causing the soil to have increased acidification and salinity. This leads to product loss through volatilization, runoff, and leaching, and generates changes in organic matter that can affect soil quality (Flores, 1991; López and Espinosa, 1998).

Nitrogen is one of the most important elements in crop nutrition because of the functions it performs and its high mobility in soil and plants (Havlin *et al.*, 2014). It is associated with soil carbon, as seen in the carbon-nitrogen ratio (C/N ratio), indicating the availability of nitrogen for plants and whose ideal value is between 10 and 20 reaching a value of 30 in extreme cases. Soils with a high content of organic matter have high nitrogen content (Fassbender, 1993), depending on the mineralization rates that are higher in cultivated and fertilized soils (Piccolo, 2001; Mosquera *et al.*, 2007).

The C/N ratio is a parameter that is related to the decomposition of organic matter, indicating the availability of nitrogen in a soil (Torres *et al.*, 2017). When organic matter has high nitrogen content, microorganisms have greater mineralization since the microflora (bacteria, fungi and actinomycetes) satisfy the nitrogen requirements so that it is not a limiting factor. On the other hand, if the nitrogen content is low, the rate of decomposition of organic matter decreases, and the rate of carbon mineralization will depend on the addition of nitrogenous sources (Ferrera and Alarcón, 2011).

The literature reports that 11 is the average value for the C/N ratio, which can vary from 4 to 30, depending on the soil, content, and type of organic matter, environmental conditions, and the use and management of the soil (Torres *et al.*, 2017). Therefore, organic matter with a C/N ratio of 30 (30:1) favors immobilization; lower ratios (20:1) have faster mineralization, so both processes increase soil fertility (Navarro, 2003).

The economic conditions seen in the global agricultural sector and the need to preserve soil resources require the efficient use of nutrients. Soil dedicated to the cultivation of bananas currently sees decreases in organic matter because of improper agronomic management, including fertilization. Therefore, soil recovery through management

practices reduces the negative impact of this activity on soil. Organic matter has a large influence on the chemical and physical properties of soils (Robert, 1996); although this fact is well known in banana-producing zones, its application is deficient.

Advances in nutrition and fertilization management in bananas are of crucial importance because of the high costs of this activity, representing between 30% and 40% of total costs. Additionally, improvements in the technologies and practices of this crop for increasing productivity have resulted in the need for more efficient fertilization management. For this reason, the objective of this study was to evaluate and compare the C/N ratio in areas with fertilizer applications and nutrient absorption for sixth-generation banana crops during two harvest cycles.

Materials and methods

Study area

This research was conducted in lots 3 and 4 of the experimental field at the AUGURA Tulenapa Research Center (Carepa-Antioquia), located at 7°46'46" N and 76°40'20" W, with an average altitude of 20 m a.s.l., an average temperature of 27°C, a solar brightness of 1,800 h/year, 87% relative humidity, and rainfall of 844.9 mm distributed in the first production cycle and 2.088 mm in the second cycle.

The soils included fine Fluventic Eutrudepts, fine loam over clay Fluvaquentic Eutrudepts and fine loam Vertic Endoaqupts. These soils were developed from deep, poorly drained, and poorly filtrated alluvial sediments with a moderately slow hydraulic conductivity, high cation exchange capacity (CEC) and low carbon content (Gutiérrez, 2007). Table 1 shows the data of the chemical analysis of the soils used in this study.

Plant material

The crop belonged to the AAA group, giant Cavendish subgroup, Williams clone, sixth generation, with a planting density of 1600 plants ha⁻¹.

Experimental management

For the development of the experiment, 20 experimental units were selected, corresponding to sections called "botalon" with 1563 m² (250 plants). Fertilization cycles began with the selection of the ratoon plant (September), which coincided with the periods of maximum flowering of mother plants. The experimental lots had the same agronomic management as the other productive units, except for fertilization through the application of the treatments.

TABLE 1. Chemical analysis of the soil.

Soils	Fine Fluventic Eutrudepts	Fine loam over clay Fluvaquentic Eutrudepts	Fine loam Vertic Endoaquepts
Organic Matter %	3.08	2.84	3.16
Total Nitrogen %	0.17	0.22	0.26
Total Carbon %	1.27	1.30	1.65
P (mg kg ⁻¹)	9.18	8.21	6.06
K (cmol kg ⁻¹)	0.39	0.40	0.43
Ca (cmol kg ⁻¹)	15.58	15.38	16.64
Mg (cmol kg ⁻¹)	5.83	6.24	5.76
Al (cmol kg ⁻¹)	0.16	0.33	0.14
N-NH ₄ (mg kg ⁻¹)	3.44	6.60	6.85
N-NO ₃ (mg kg ⁻¹)	34.93	25.14	33.64
pH	5.77	5.57	5.68
CEC (cmol kg ⁻¹)	23.64	25.28	25.18

CEC - cation exchange capacity.

Samplings were carried out in the fertilizer application area at 30 cm on the pseudostem, at depths between 5 and 15 cm and in the nutrient absorption zone at a space between 5 cm and 15 cm from the region of the soil bordering the corm that had the highest proportion of roots (López and Espinosa, 1998). Samples were collected at different phenological stages (vegetative phase, floral differentiation, flowering, fruit filling, and harvesting). Fertilization was carried out every three weeks, and sampling was performed one week before the fertilization cycles, 17 applications per year, spaced out at approximately three weeks between applications. The commercial fertilizer source used was urea (46%).

Evaluated variables

Total nitrogen and carbon were determined with the methodology of Dumas (Batjes, 1996), with dry combustion and 0.2 g of soil. Measurements were taken with a Tru Spec elemental analyzer (Laboratory Equipment Company LECO, Otario, Canada) calibrated with standardized samples in the Soil analysis laboratory at the Universidad Nacional de Colombia. Productivity was measured by subtracting the weight of the rachis before taking the samples from the fresh weight of the cluster. This value was presented in kg per plant and transformed to ha⁻¹.

Experimental design and statistical analysis

A randomized complete block design was used with five treatments and four replicates. The treatments were adjusted from soil analyses performed before the start of the research and from the balanced dose proposed by CENIBANANO (321.8 kg ha⁻¹ of N, 87.1 kg ha⁻¹ of P₂O₅, 678.8

kg ha⁻¹ of K₂O, 50.5 kg ha⁻¹ of CaO, 117.5 kg ha⁻¹ of MgO, 64.2 kg ha⁻¹ of S, 1.4 of kg ha⁻¹ of B, and 9.3 kg ha⁻¹ of Zn). Treatments included an absolute control, a control without nitrogen, and doses of 161, 321 and 483 kg ha⁻¹ of N.

Multivariate analyses of variance that met the criteria of homogeneity and normality of matrices were used, and the interactions between the study areas (application and fertilization) and treatments were evaluated by applying the Tukey test. The analyses were complemented with a correlation analysis to determine the best functional relationship between the production and C/N ratio (IBM SPSS Program).

Results and discussion

Total soil carbon and nitrogen content

The total nitrogen content of the soil showed significant statistical differences in the interaction zone of the study between the treatments. The treatment with 483 kg ha⁻¹ of N had the highest contents in the fertilization zone with an average of 0.33%. However, there were no significant differences with the other treatments (Tab. 2). In the absorption zone, the treatments did not show significant differences; the total nitrogen contents oscillating in the soil were between 0.25% and 0.27% (Tab. 2).

Nitrogen fertilizers can be lost through volatilization (44.1%), leaching (14.8%) and denitrification (4.4%). Fertilizers, along with the decomposition of roots, leaves or other contributions of organic matter that favor nitrogen fixation by microorganisms cause significant increases in

TABLE 2. Contents of total nitrogen (%) in soil of the study area and treatment interaction in two production cycles.

Treatments	Production cycles			
	1		2	
	Absorption zone	Fertilization zone	Absorption zone	Fertilization zone
Control	0.28 ns	0.28 ns	0.28 ns	0.28 ab
0 kg ha ⁻¹ N	0.29 ns	0.27 ns	0.27 ns	0.24 b
161 kg ha ⁻¹ N	0.29 ns	0.29 ns	0.29 ns	0.28 ab
321.8 kg ha ⁻¹ N	0.28 ns	0.28 ns	0.28 ns	0.29 ab
483 kg ha ⁻¹ N	0.27 ns	0.32 ns	0.29 ns	0.33 a

Values with the same letter within the column do not statistically differ according to the Tukey test ($P < 0.05$). ns: not significant.

the total nitrogen content of soil (Ju *et al.*, 2009) that was not observed in the present study.

A significant result for the fertilization zone was observed with the treatment of 483 kg ha⁻¹ of N, which had an increase of 27% in the N content, as compared to the control without nitrogen, in which the total nitrogen was 0.24%. This increase was due to the application of urea, whose dissolution allows nitrogen to take different routes. This could have possibly favored the incorporation of ammonium into the soil, along with other action pathways, such as being absorbed by the plants or by microorganisms, oxidized to a nitrate form, leached or denitrified (Gasser *et al.*, 1967) (Tab. 2).

The NH₄⁺ from urea can easily adhere to the cation exchange sites in inorganic and organic colloids in the soil, and its proportion depends on the soil's edaphogenetic characteristics (Fuentes and González, 2007). Specifically, the treatment with 483 kg ha⁻¹ of N showed a tendency to increase the total nitrogen in the fertilization zone and establish significant statistical differences in the second production cycle. These effects were attributed to the precipitation conditions (near the normal ranges for the period) and to the type of clay present in the studied soils

(vermiculite), which corroborates the proposal by Fuentes and González (2007).

The response to the nitrogen doses may have been related to the ammonium released by the urea in the soil that can be directly associated with the interaction between the clay present in the studied soil (vermiculite, illite, and montmorillonite). This interaction causes ammonium fixation through expandable clays and loss through runoff, an effect attributed to increases in the total nitrogen for the high doses (483 kg ha⁻¹ of N), as observed in the second production cycle with increases in precipitation, compared to the first cycle.

Total soil carbon showed significant differences between the treatments for the fertilization zone, where the treatment of 483 kg ha⁻¹ of N had the higher values (2.47 and 2.45%). No significant differences were found in the absorption zone although the observed values tended to be lower than those of the fertilization zone; however, the treatment with 483 kg ha⁻¹ showed the best response (Tab. 3).

Increase in total carbon was associated with the residual acid effect generated by urea that could have acted on the calcium carbonate applied to the crop and the possible

TABLE 3. Contents of total carbon (%) in soil of the study area and treatment interaction in two production cycles.

Treatments	Production cycles			
	1		2	
	Absorption zone	Fertilization zone	Absorption zone	Fertilization zone
Control	1.57 a	1.92 a	1.56 ns	2.05 ab
0 kg ha ⁻¹ N	1.92 b	2.25 ab	1.69 ns	2.02 a
161 kg ha ⁻¹ N	1.70 ab	1.97 a	1.83 ns	1.86 a
321.8 kg ha ⁻¹ N	1.74 ab	1.98 a	1.72 ns	2.11 ab
483 kg ha ⁻¹ N	1.79 ab	2.47 b	1.81 ns	2.45 b

Values with the same letter within the column do not statistically differ according to the Tukey test ($P < 0.05$). ns: not significant.

release of mineral carbon present in the parental materials (carbonates) of the soil (Guerrero, 2004; Zapata, 2004).

Urea reacts with moisture, $\text{CO}(\text{NH}_2)_2$ (urea) + H^+ + $2\text{H}_2\text{O}$; this reaction releases 2NH_4^+ (ammonium) and HCO_3^- (bicarbonate) (Guerrero, 2004). The latter was able to react with elements of the soil since the morphogenesis of the soils where the research was developed indicated that there was a high load of suspended sediments, sand, and some silt with calcium and magnesium contents. The calcium had a saturation over 70%, allowing carbonate and calcium to form calcium bicarbonate that affected the increases in the total carbon of the soil causing an increase in the total carbon in the fertilization zone. Liu *et al.* (2008) evaluated four treatments with fertilization and found that an increase in the inorganic carbon of the soil resulted from fertilization because of carbonate stability. Therefore, further studies in which organic carbon is dissociated from inorganic components are needed.

Carbon-nitrogen ratio (C/N ratio)

The C/N ratio displayed an interaction between the treatments and study areas. The treatments resulted in an increase in the C/N ratio values for the fertilization zone. The control and 0 kg ha⁻¹ of N showed values in the fertilization area similar to the dose with high N. These results are associated with the nitrogen and carbon present in the soil that was released from organic matter. This can also be influenced by the recycling process between a mother plant and its successors due to nitrogen-free fertilization (Robinson and Galán 2012). In the absorption zone, the behavior was similar, but with small variations between the treatments and values lower than in the fertilization zone (Tab. 4).

The highest carbon contents were observed for the fertilization zone with the treatment with 483 kg ha⁻¹ of N. These values are the product of the acidifying effect of urea accompanied by conditions of high humidity in the second

production cycle. This condition helped the movement of these elements to the absorption zone and impacted the C/N ratio (Jones and Jacobsen, 2005). For this reason, the values seen in the present study, all less than or equal to 8, were below the levels considered normal or ideal for agricultural land (Moreno and Moral, 2008; Osorio, 2014) (Tab. 4).

Torres *et al.* (2017) stated that, for the doses 161 and 321.8 kg ha⁻¹ of N, there was low agronomic efficiency, corroborating the low response in the nitrogen application as reflected in the C/N ratio with values oscillating between 6 and 6.4 for the absorption zone (Tab. 3). Moreno and Moral (2008) confirmed that low C/N ratios can be associated with an excess of nitrogen that is lost, a situation that can be associated with the low agronomic efficiency observed by Torres *et al.* (2017).

The C/N ratio values during the stages of development varied between 6.0 and 8.2, indicating a high nitrogen content compared to the carbon in the soil, but the values can also be interpreted as a rapid release of the mineral and organic carbon (Osorio, 2014) that occurred in the present study.

The variation of total carbon contents during the development of the banana crop tended to decrease; this can be attributed to the soil and climatic conditions and the agronomic management that implied a gradual loss of soil quality (Rosales *et al.*, 2006). It is necessary to establish a management plan for organic matter that maintains and improves carbon content and, therefore, nitrogen in order to proportionally reduce nitrogen doses for the benefit of producers and the environment (Torres *et al.*, 2017).

Carbon-nitrogen ratio and production

Production during the two cultivation cycles showed positive responses to the treatments of 321.8 and 483 kg ha⁻¹ of N, with values of 41.3 and 42.0 t ha⁻¹ for the first cycle and 40.9 and 46.4 t ha⁻¹ for the second cycle (Fig. 1), values within the production range reported by Robinson and Galán (2012) for cv. Williams (24 to 64 t ha⁻¹). The effect of

TABLE 4. Carbon-nitrogen ratio in soil for the treatment and study area interaction.

Treatments	Production cycles			
	1		2	
	Absorption zone	Fertilization zone	Absorption zone	Fertilization zone
Control	6.0 ns	7.0 ab	6.2 ns	7.2 ab
0 kg ha ⁻¹ N	6.8 ns	8.2 b	6.4 ns	8.2 b
161 kg ha ⁻¹ N	6.0 ns	7.1 a	6.5 ns	7.1 a
321.8 kg ha ⁻¹ N	6.4 ns	7.3 ab	6.3 ns	7.3 ab
483 kg ha ⁻¹ N	6.6 ns	7.7 ab	6.4 ns	7.6 b

Values with the same letter within the column do not statistically differ according to the Tukey test ($P < 0.05$). ns: not significant.

low production of absolute control in cycle two was associated with the loss of the nutritional recycling effect of the mother-ratoon relationship (Robinson and Galán, 2012).

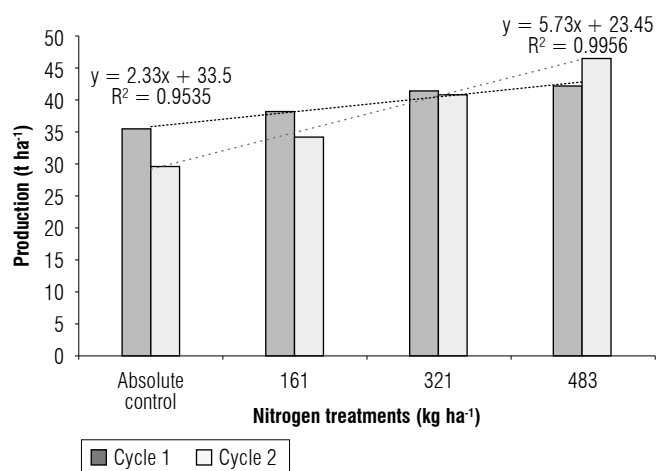


FIGURE 1. Production in t ha⁻¹ in the treatments and productive cycle.

Responses in production to high doses of nitrogen were associated with low levels of total carbon (<2%) in the study areas (Gutiérrez, 2007). It should be remembered that no applications of organic matter were performed on any treatment in the production cycles that accentuated the effect of the nitrogen doses, an effect similar to that found by Srikul and Turner (1995), Orozco and Pérez (2006) and Nyomby *et al.* (2010).

To evaluate the association between the production variable and the C/N ratio, a correlation analysis was performed that obtained coefficients of 0.44 and 0.42 in the absorption

and fertilization zones, respectively. These coefficients were positive, implying that, as the C/N ratio increased, production increased.

The regression analysis for the study areas between the production variable and the C/N ratio was significant ($R^2 = 0.2$). This led to the inference that, although the C/N ratio values were low, the best response in production was associated with the high C/N ratio. The low correlation coefficient that can be attributed to production did not depend on the C/N ratio alone.

The correlation analysis for the study areas during the two production cycles did not show significant results between the production and C/N ratio values. However, for the first production cycle, the best fit was seen for the treatment with 321 kg ha⁻¹ of N ($r = 0.95$). In the second cycle, the treatment with 483 kg ha⁻¹ of N ($r = 0.86$) had the best fit, leading to the inference that, even though the C/N ratio values were low, the treatments with the best response in production were associated with the higher C/N ratios. Robinson and Galán (2012) confirmed that the behavior of a cultivar is associated with its genetic characteristics, agronomic management, and climatic and soil characteristics (Tab. 5).

When analyzing the response by treatment, the control in the correlation between production and C/N ratio showed correlation coefficients of -0.49 and -0.37 for the absorption and fertilization zones, respectively (Tab. 5). This negative value means that, as production increased, the C/N ratio decreased; this could be attributed to the fact that the nitrogen extracted by the plants for production

TABLE 5. Correlation analysis of the carbon-nitrogen (C/N) ratio in soil and production by treatment.

Correlation analysis			
Production cycle	Treatments	Absorption zone	Fertilization zone
		C/N ratio	C/N ratio
1	Control	0.37	0.78
	0 kg ha ⁻¹ N	0.22	0.66
	161 kg ha ⁻¹ N	0.87	0.78
	321.8 kg ha ⁻¹ N	0.78	0.95**
	483 kg ha ⁻¹ N	0.82*	0.8*
2	Control	-0.49*	-0.37**
	0 kg ha ⁻¹ N	0.91	0.18
	161 kg ha ⁻¹ N	0.97	0.85
	321.8 kg ha ⁻¹ N	0.95*	0.63
	483 kg ha ⁻¹ N	0.75*	0.86**

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

was available in the soil and carbon decreased before the application of organic matter. Torres *et al.* (2017) confirm that the low productivity of the absolute control during the second production cycle is associated with the loss of the effect of nutrient recycling from the mother and ratoon relationship and the impoverishment of the soil without fertilizer, as corroborated by Robinson and Galán (2012).

The correlation values in the nutrient absorption zone for the two cycles reached coefficients higher than 0.7, reflecting the influence of nitrogen fertilization. Nave *et al.* (2009) stated that nitrogen inputs help meet the requirements of crops, improving productivity, and increasing carbon storage in the soil, as observed in the treatment with 483 kg ha⁻¹ of N with the best response in production and its interaction with the C/N ratio (Tab. 5).

For cycle two, the treatment with 483 kg ha⁻¹ of N obtained a correlation of 0.86 between production and the C/N ratio and 0.75 for the absorption zone. By taking into account the low correlation coefficient from one area to another, it could be inferred that the plants absorbed the nitrogen and the fertilizer was not immobilized; it passed from the fertilization zone to the absorption zone (Tab. 5) and was not lost through leaching or runoff processes. It is worth mentioning that for the second cycle the treatment with 321.8 kg ha⁻¹ of N showed a significant adjustment in the absorption zone for the production correlation and C/N ratio ($r = 0.95$). This demonstrates that the contributions of nitrogen through fertilizer had an impact on the production and, in turn, on the C/N ratio.

The high doses of nitrogen in the form of urea had an important impact on the carbon and nitrogen contents despite the possible losses of the latter through leaching and volatilization (Mengel and Kirkby, 2000).

Torres *et al.* (2017) concluded that production can be increased by improving the efficiency of fertilization that includes organic matter. This requires the development and promotion of technological models that take into account the observations of Robinson and Galán (2012) for interactions among soil, plants, climate, and agronomic management.

Conclusions

The residual acidity generated by the urea and the mineral composition of the parent material constituted possible causes for the atypical responses of the variables soil total carbon and C/N ratio for the studied areas and

demonstrated the effect of increasing doses of nitrogen in the form of urea, especially for the fertilization zone.

Higher production was associated with the higher C/N ratios and nitrogen doses, demonstrating the need to adjust nitrogen fertilization plans and taking into account the C/N ratio. So balancing doses of organic products with doses of synthetic nitrogen sources is important to improve the soils of banana crops and to make the process of nitrogen fertilization more efficient and friendly.

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