Research article

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Revista Facultad Nacional de Agronomía

Influence of management systems on the nitrogen mineralization and fertilization of sugarcane

Influencia del sistema manejo en la mineralizacion del nitrógeno y fertilización de caña de azúcar

doi: 10.15446/rfna.v69n1.54742

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ABSTRACT

Key words:
Mineralization
Organic sugar cane
Organic matter
Soils
Walkley Black (WB)

In Colombia, nitrogen fertilizer recommendations for sugarcane are based on data obtained with the WalkLey & Black method, but they do not always result in the best yield. In this sense, the present study aimed to compare the results of the determination of fast mineralizable nitrogen (amino sugars), performed with the Illinois Soil Nitrogen test (ISNT) and Direct Steam Distillation method (DSD) for nitrogen recommendations for crops. A complete randomized block design was used with six treatments, adding nitrogen through urea and compost to *Pachic haplustoll* soils in Valle del Cauca with organic and conventional production systems that were evaluated from 2011 to 2014. The results showed that higher nitrogen mineralization was estimated using ISNT and DSD methodologies than with the Walkley-Black method, and that its content was different depending on the management system. The best methodology that quantified mineralizable N was Direct Steam Distillation (DSD); however for conventional systems sugarcane was Illinois Soil Nitrogen Test (ISNT), showing differences for the variables associated with the production and yield between the tested systems.

RESUMEN

Palabras claves:
Mineralización
Caña de azúcar orgánica
Materia orgánica
Suelos
Walkley Black (WB)

En Colombia las recomendaciones de fertilización nitrogenada en caña de azúcar se hacen a partir de los datos obtenidos con Walkey & Black, sin embargo no siempre se obtienen los mejores rendimientos. En ese sentido la presente investigación tuvo como objetivo comparar los resultados de la determinación de nitrógeno rápidamente mineralizable (amino-azucares), con las metodologías Illinois Soil Nitrogen Test (ISNT) y Direct Steam Distillation (DSD) para realizar las recomendaciones de nitrógeno para el cultivo. Se utilizó un diseño en bloques completos al azar con seis tratamientos adicionando nitrógeno vía urea y abono orgánico, en un suelo *Pachic haplustoll* del Valle del Cauca bajo los sistemas productivos: orgánico y convencional evaluado desde el 2011 hasta el 2014. Los resultados mostraron que mayor nitrógeno mineralizable se estimó a través de ISNT y DSD que por Walkley-Black, y que su contenido fue diferente dependiendo del sistema de manejo. La metodología que mejor cuantificó el N mineralizable fue Direct Steam Distillation (DSD); sin embargo, para los sistemas convencionales de caña de azúcar fue por Illinois Soil Nitrógen Test (ISNT), mostrando diferencias para las variables asociadas con la producción y el rendimiento entre los sistemas evaluados.

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Received: September 4, 2014; Accepted: April 13, 2015

Nitrogen is one of the macronutrients that are commonly taken up by plants and its contribution to soil can be inorganic or organic. Thus, the organic matter and biological fixation of microorganisms are an important source of this nutrient. Cabrera and Zuaznábar (2010) stated that it is vital for the growth and development of sugarcane (*S. officinarum*).

Approximately 90-120 kg of nitrogen per hectare is used in sugarcane (*S. officinarum*); a good crop response is achieved with this dose (Rodríguez *et al*., 2006). In Valle del Cauca, Colombia, there are 225,580 ha planted with sugarcane (Asocaña, 2014), which represents a considerable amount of nitrogen that is used to meet the needs of the crops in each harvest.

There have been many studies to determine the proportion of nitrogen that is contributed by the mineralization of organic matter; Celaya and Castellanos (2011) reported that it is not easy to determine the actual availability of nitrogen, given the difficulties presented by different laboratory methods for measuring the mineralization; additionally, it has been suggested that nitrogen is, after water, the nutrient that constitutes the most limiting factor for plant productivity; similarly, Lopez and Campos (2012) claimed that the availability of N in the soil can be evaluated with mineralization tests that estimate the release and the potential risk of loss of this nutrient. It is clear that the current difficulty in carrying this out is due to the inability to objectively assess the contribution of organic material from mineralizable nitrogen.

Interpretation tables for N doses in Nitrogen fertilization are based on the content of organic matter and these values provide the performance data of nitrogen availability (Sosbai, 2014). In Valle del Cauca, Colombia, the determination of available nitrogen for sugarcane is made indirectly through the organic carbon determined with the Walkley-Black method, and the result is multiplied by a factor that depends on the calibration performed by a laboratory (Carreira, 2011). Therefore, sugar mills have these data, along with recommendations made by The Sugarcane Research Center (Cenicaña) with a fertilization expert system that carries out nitrogen applications. However, results sometimes do not show a response to nitrogen applications.

ISNT is a method that requires low technology; it was developed to quantify the available nitrogen in a soil sample subjected to alkaline hydrolysis, and the DSD technique has shown a strong correlation with the ISNT method because it reduces the analysis time and uncertainty in the results (Robert *et al*., 2009). In that sense, considering the above statement, the possibility to test alternative methodologies such as the Illinois Soil Nitrogen Test (ISNT) and Direct Steam Distillation method (DSD) was raised in order to directly determine the amount of nitrogen from amino sugars (mineralizable) and compare the results with the Walkley-Black method; afterwards, the response of the sugarcane after fertilization based on the content of mineralizable nitrogen with Walkley-Black methodology for sugarcane under organic and conventional production systems was observed to find the answer, optimize nitrogen fertilization, increase crop profitability and reduce environmental risk due to excessive nitrogen applications.

MATERIALS AND METHODS

This research was conducted in Palmira soils, classified as *Pachic Haplustoll,* on the farms: San Jerónimo (14 years with a organic production system) 76°20'8.055"W, 3°38'9.707"N and La Paz (40 years with a conventional production) 76°17'11.844"W, 3°39'26.768"N, located in Valle del Cauca, Colombia, from 2011 to 2014.

The soil samples were distributed every 200 m^2, taken from each plot in each production system and chemically characterized. The following were analyzed: pH 1:1 ratio, phosphorus with the Bray and Kurtz II methodology; Boron with hot water, and CIC, Ca, Mg, K, and Na with Ammonium Acetate at pH 7.0, 1N; the same soluble elements were determined in a saturation paste, subsequently quantified with a Perkin-Elmer atomic absorption spectrophotometer, Model 2380. Fe, Mn, Zn and Cu were extracted with DTPA-TEA and quantified through atomic absorption (Table 1).

The available amino sugar nitrogen was determined by the ISNT and DSD, according to methodologies proposed by Robert *et al*. (2009). This was carried out using the accelerated diffusion chamber developed by Khan *et al*. (2001). The organic matter was determined with the Walkley-Black method (WB) for organic carbon. It was multiplied by a factor of 1.724 according

Table 1. Chemical characteristics of the soil.

Management	Ca	Mg	K	Na	CIC	P	pH
Conventional	14.68 a	5.22 b	0.39 b	0.11 b	20.40 b	43.25 b	6.61 a
Orgánic	15.40 a	7.18 a	1.20 a	0.16 a	23.94 a	133.18 a	7.31 a

Tukey *P* <0.10. Same letters in the same column indicate that there was not a significant difference; Ca, Mg, K, Na, CIC (cmol kg^{-1} soil).

to Carreira (2011), with the assumption that, of all the organic material, the total nitrogen constituted 5% Graentz (1997) and that, of the total nitrogen, only 1.5% represented the mineralizable nitrogen (Julca *et al*., 2006).

A completely randomized design was used in a laboratory to compare the data of mineralizable nitrogen with the three methods. In the field, the experimental unit was approximately 200 m^2 (12 rows, 1.65 m apart and 10 m in length). A completely randomized block design was used with four treatments and six replications, formed based on the soil organic matter content; the treatments were based on the nitrogen recommendation; as a source of nitrogen, urea and organic fertilizer were used; the doses were based on Cenicaña's expert fertilization systems, which use the soil organic matter content determined with the WB method; the other treatments were above this level. In the organic system treatment, the nitrogen was higher mainly due to the lower organic matter content, as compared to the conventional system (Table 2). The obtained results were subjected to an analysis of variance, Tukey mean comparison test (*P*<0.10), correlation and regression (SAS.V 9.3).

Table 2. Description of the treatments according to management.

Treatments	Description	Conventional System Soil Organic Matter Content (%)	Conventional System Nitrogen Dose (kg ha^{-1})	Organic Soil Organic Matter Content (%)	Organic System Nitrogen Dose (kg ha^{-1})
T1	Absolute control plot/ sample	2.63	0.00	2.01	0.00
T2	Cenicaña-WB results	2.78	72.20	2.06	79.45
T3	T2 plus 10% nitrogen	2.62	81.24	2.06	87.37
T4	T2 plus 20% nitrogen	2.68	87.87	2.10	94.86
T5	T2 plus 30% nitrogen	2.64	95.71	1.76	107.15
T6	T2 plus 40% nitrogen	2.65	102.90	2.06	111.20

RESULTS AND DISCUSSION

Organic matter and mineralizable nitrogen content using ISNT and DSD

The results show that the nitrogen with the Walkley-Black, ISNT and DSD methodologies presented a significant difference in the production system (Table 3).

The mineralizable nitrogen content quantified by the two methods was statistically higher in the conventional system, as compared to the organic system. The ISNT and DSD methodologies developed by Khan *et al*. (2001) quantified more nitrogen; possibly, the amino sugars produced by dead or decomposing microorganisms were present in the soil; Celaya and Castellanos (2011) suggested that the organic matter in a soil cannot be used by the plants directly; it must decompose and mineralize; processes that are mainly carried out by soil microorganisms; plants do not synthesize significant amounts of amino sugars (for example, glucosamine, galactosamine), which mostly originate from soil microbial populations.

The content of rapidly mineralizable nitrogen from amino sugars is low (DSD, ISNT), according to Mulvaney *et al*. (2005). Research carried out by Otto *et al*. (2013) found that in oxisol soils in Brazil, there was no response in the production of sugarcane when the nitrogen content of amino sugars was above 160 and 175 mg kg^{-1}, with the DSD and ISNT methodologies, respectively. However, the conventional system had higher values in the three methods (Table 3). These values suggested that the quality of the organic matter has an influence on the available nitrogen, whose characteristic changes depending on the residue used (Pinochet *et al*., 2000), which is also a very complex fraction that is influenced by numerous components that present diverse states of alteration and decomposition complexity (Labrador, 2012). Organic amendments exert a positive influence on the soil because they promote water retention and improve the structure, buffer capacity, cation exchange capacity, and chelation capacity (Lopez and Campos, 2012), which are influenced by the physical properties of the soil.

Table 3. Comparison of soil organic matter and mineralizable nitrogen in the production systems.

Management	WB (N)	ISNT (mg kg^{-1})	DSD (mg kg^{-1})
Conventional	19.98 a	128.91 a	101.84 a
Organic	15.04 b	74.55 b	76.53 b

Same letters in the same column indicate that there was not a significant difference, Tukey P<0.10

It is possible that differences in the nitrogen contribution from a soil, determined according to different methods, are related to the microenvironment present in each system because the sampled soil differed in terms of the water storage capacity and they influenced the temperature and microbial activity; along these lines, Celaya and Castellanos (2011) stated that, in the nitrogen mineralization process, through the decomposition of the organic matter, the soil microorganisms transform the organic compounds into inorganic compounds that are available to the plant; however, the temperature and moisture affect their activity.

Robles (2013) found that soils under organic management located in Valle del Cauca showed high activity and microbial diversity, resulting in increased carbon consumption as a source of energy, causing an increased mineralization of organic matter in the soil in comparison with the conventional soil. Similarly, Shuping *et al*. (2010) concluded that the organic system shows a greater microbiological and enzymatic activity, which increased the availability of nutrients, such as nitrogen and phosphorous, contrary to the results obtained in this study.

From a practical standpoint, the results estimated 30 kg ha^{-1} of nitrogen in the organic system and 39 kg ha^{-1} in the conventional system, using WB, and 149 kg ha^{-1} in the organic system and 257 kg ha^{-1} in the conventional system, using ISNT; the DSD methodology estimated 153 kg ha^{-1} of nitrogen for the organic system and 203 kg ha^{-1} for the conventional system; these results should be confirmed with more research on different soils.

Correlations between the nitrogen content of the different tests

The conventional system presented a good correlation between the DSD and ISNT methodologies (Table 4). In the same table, the organic system with the DSD methodology had the highest correlation with the WB method, followed by the ISNT with the WB method; lastly, the DSD methodology correlated very well with the WB method in the organic system.

The DSD and ISNT methodologies presented a higher correlation because they determine the labile nitrogen from amino sugars (glucosamine, galactosamine, etc). Studies conducted by Roberts *et al*. (2009) found that the two methodologies recover 99% of the pure amino sugars compounds, such as glucosamine and N-Acetyl Glucosamine. However, when tests were conducted recovering these pure amino sugars directly from a soil, arguing that the differences between the methods could

Table 4. Correlation of the DSD, ISNT and Walkley Black methodologies.

	Conventional System			Organic System		
	DSD	ISNT	WB	DSD	ISNT	WB
DSD	1.00	0.70**	0.48	1.00	0.92**	0.94**
ISNT	0.70**	1.00	0.66	0.92**	1.00	0.93**
WB	0.48	0.66	1.00	0.94**	0.93**	1.00

(**) Tukey P<0.01 highly significant difference; (*) Tukey P<0.05, significant difference;

mainly be due to hydrolysable ammonium, which is difficult to identify and found in the exchangeable fraction of amino acids in soil organic matter. The same author stated that the ISNT and DSD methodologies differ by up to 20%.

In the present study, the difference between the systems reached an average of 12.3%. Otto *et al*. (2013) found correlations of 0.78 in oxisol soils and Robert *et al*. (2009) saw a correlation of 0.99 with the ISNT and DSD methodologies; it is important to note that this research was conducted on a Mollisol soil, a high saturation bases, ustic moisture regime, regular distribution of organic carbon to a depth of 125 cm and a hyperthermic temperature regime, characteristics that facilitate the mineralization.

In the conventional system, correlations were low between the WB and other methodologies according to Schumacher (2002). A high content of iron and manganese causes interference in the determination of soil organic carbon contents, asdetermined with WB; this may have been the case in this study, in which the conventional system soil had 53.91 ppm Fe, as compared to 27.78 ppm in the organic system, 94% more iron in comparison with the organic system soil.

The importance of knowing these correlations results from the dependence on the productive system (organic and conventional) seen in the rapidly mineralizable nitrogen methodologies ISNT and DSD, which more accurately determined the nitrogen content than the WB method. Also, the ISNT and DSD methodologies are more accurate at determining the rapid mineralization of nitrogen (Daverede, 2005). The procedure costsless, has no adverse effect on the environment due to toxic waste and allows for the optimization of the use of nitrogen fertilizers and may be an alternative for the estimation of N.

Additionally, a good correlation between the ISNT and DSD methodologies was obtained in the organic system (Table 5), with other soil variables such as clay content and nutrients such as calcium, which, according to Carrillo (2003), is also important for bacterial metabolism and the biological fixation of nitrogen. Additionally, the high correlation with iron might be, due to the fact that this element is important in soil for the nitrogenase enzyme complex, which facilitates biological nitrogen fixation. This behavior was not observed in the conventional system.

Table 5. Correlation of the DSD, ISNT and Walkley Black methodologies, with other variables.

	Correlation Matrix					
	DSD	ISNT	WB	Ca	Fe	Clay
DSD	1.0000	0.9272**	0.9453**	0.7275**	0.7576**	0.8208**
ISNT	0.9272**	1.0000	0.9312**	0.7184**	0.7439**	0.8065**
WB	0.9453**	0.9312**	1.0000	0.8053**	0.8001**	0.8806**
Ca	0.7275**	0.7184**	0.8053**	1.0000	0.5505**	0.7659**
Fe	0.7576**	0.7439**	0.8001**	0.5505	1.0000	0.7725**
Clay	0.8208**	0.8065**	0.8806**	0.7659**	0.7725**	1.0000

(**) Tukey P<0.01 highly significant difference; (*) Tukey P<0.05, significant difference.

Levels of mineralizable nitrogen and its relationship with production and yield

The results of the variance analysis showed no difference in tons of cane per hectare (TCH), tons of sugar per hectare (TSH) and sugar yield per the effect of the applied treatments and treatment system interaction. Highly significant differences were present in the variables TCH, TSH and yield due to performance of the production system (Table 6).

These results are consistent with studies in Cuba by Cabrera and Zuaznábar (2010), who, after 24 cumulative sugarcane harvests, observed that there was no response to nitrogen fertilization until after the fourth cut. Zérega and Hernández (1998) concluded that there is no response in sugarcane to nitrogen when the soil contains more than 3.3% organic matter in soils with good physical, chemical and biological characteristics.

Additionally, Otto *et al.* (2013) found that, in two of five oxisol soils studied in Brazil, there was no response of sugarcane to a nitrogen application when the content, according to the ISNT and DSD methodologies, exceeded 175 and 160 mg kg^{-1}, respectively; however, these soils had very different properties from those of the Mollisol soils used in this study.

Table. 6. Summary of ANOVA of variables associated with the production and yield of sugarcane variety CC 93-4418.

			TCH		% Yield		TSH	
Effect	**Num DF**	**Den DF**	**F-Value**	**Pr > F**	**F- Value**	**Pr > F**	**F-Value**	**Pr > F**
System	1	6	47.58	0.0005 **	5.34	0.0602*	33.12	0.0012 **
Treatment	5	30	1.90	0.1244^{NS}	1.41	0.2477^{NS}	1.98	0.1107^{NS}
Syst.*treatmt.	5	30	1.67	0.1725^{NS}	1.23	0.3191^{NS}	1.93	0.1187^{NS}

(**) Tukey P<0.01 highly significant difference; (*) Tukey P<0.05, significant difference; NS: no significant difference.

The best productivity trends were observed in the conventional system, in the TCH present in T4, TSH in T3 and yield in T2; the trend in the organic production system in the TCH presented the best trends in T5, TSH in T2 and yield in T4 (Table 7); the same table shows that the lowest productions in the TCH, TSH and yield in the conventional system were seen in T1, T2 and T1, respectively; while, in the organic system, the lowest values were recorded for the TCH in T3, TSH in T4 and yield in T6.

Table 7. Tons of cane per hectare (TCH), tons of sugar per hectare (TSH) and sugar yield in the production systems by treatment.

TREATMENT	TCH		TSH		Yield (sucrose content %)	
	S. Org.	**S. Conv.**	**S. Org.**	**S. Conv.**	**S. Org.**	**S. Conv.**
T1 (Absolute control)	228.75	181.5	29.95	24.23	13.6	14.17
T2 (Cenicaña-WB)	215.5	150.5	36.08	24.13	13.77	14.45
T3 (T2 +10% nitrogen)	214.5	177.25	30.98	28.83	13.92	14.28
T4 (T2 + 20% nitrogen)	220.75	203.25	29.88	25.15	14.06	14.18
T5 (T2 +30% nitrogen)	257.75	175.25	29.78	21.73	13.95	13.84
T6 (T2+40% nitrogen)	228.25	172.25	31.20	25.63	13.13	14.06
Avg. System	227.58 a	176.67 b	31.31 a	24.95 b	13.74 b	14.16 a

Different letters indicate highly significant differences, Tukey P <0.01.Treatments within the system presented no significant difference.

Tons of sugar per hectare for this variety, according to Cenicaña (2013), should be 16.82 t ha^{-1} at 13.3 months of age. In the organic system, the average was 31.31 t ha^{-1}; in the conventional system, the average was 24.95 t ha^{-1}; these crops were harvested at 14.85 months of age. It is important to highlight the fact that the two systems exceeded the results reported by Cenicaña, which means that, even if no nitrogen is applied in the systems, a production response is observed. The cane in the organic system had a positive response in production, as compared to the conventional system.

In the percentage of sugar yield (Yield %), the conventional system presented water stress; thus, there was a greater accumulation of sugar in the stem. This characteristic is highly variable to environmental conditions and crop management. Authors such as Romero *et al*. (2009) stated that there are high water and low sucrose and fiber contents. It is important to highlight the fact that the two systems exceeded the production and yield values reported by Cenicaña (2013).

The differences in the results can be related to the fact that the organic system presented highly significant differences, as compared to the conventional system; possibly, the organic system had biological (nitrogen biological fixation), chemical (solubility of nutrients) and physical (porosity and aeration) activities that have been established because of organic practices and tasks carried out for over 14 years. It is important to clarify that this study was conducted on zero-cut cane and this behavior may be different in successive cuts.

CONCLUSIONS

For the *Pachic Haplustoll* soil organic sugarcane system, the methodology that best quantified the mineralization was the Direct Steam Distillation technique (DSD) and, for the conventional sugarcane system, it was the Illinois Soil Nitrogen Test (ISNT).

The mineralizable nitrogen content was different depending on the agronomic management and production system. The quantified amount in each system provided enough nitrogen for agronomic crop development.

Generally, in the organic system, the rate of grow than development, tons of cane per hectare and tons of sugar per hectare were higher, as compared to the conventional system.

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