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FERTILIZER PLACEMENT AND FORMS OF APPLICATION AND SUGARCANE RESPONSE

Momentos y formas de aplicación de fertilizantes y la respuesta de la caña de azúcar

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ABSTRACT. The Best Agricultural Practices in sugarcane production contemplate fertilizer use, but many producers apply it at the beginning of the rains on soil surface. In order to evaluate the effect of fertilizer placement and fertilization moment, a research was carried with the first ratoon at Rancho Rincón de los Toros, Veracruz, Mexico. Seven treatments in random blocks design and four replications were studied: a) four treatments with application of 600 kg ha^{-1} of the 20-05-25 (N, P_2O_5, K_2O) complete formula after the harvest of plant cane, at the beginning of the rains and, at both times, incorporated and soil surface; b) two treatments with urea at rate of 200 kg ha^{-1} additional to the incorporated and soil surface application after the harvest; c) a control without fertilizer. The incorporated fertilizer produced at 8 months a population of 14,5 stems m^{-1}, 1,4 stems m^{-1} more than the soil surface fertilization and the yield was 68,89 Mg ha^{-1}; while with the applied on the soil surface was 59,44 Mg ha^{-1}, reaching an increase of 9,46 Mg ha^{-1}. Soil surface fertilization had no effect neither on the stems population nor on the cane yield. The stems population at eight months old was directly related to the cane yield obtained at harvest. Additional urea did not increase yields beyond those achieved with a single application of fertilizer, but increased the amount of N to produce 1 Mg of cane, ranging from 3,2 kg to 3,4 kg.

Key words: first ratoon, rain, stalks, yield

RESUMEN. Las Buenas Prácticas Agrícolas en la producción cañera contemplan el uso de fertilizantes, pero muchos productores lo aplican en la superficie del suelo al inicio de las lluvias. Con el objetivo de evaluar el efecto de la colocación del fertilizante y del momento de fertilizar, se desarrolló una investigación sobre el primer retoño de caña de azúcar en el Rancho Rincón de los Toros, Veracruz, México. Se ensayaron siete tratamientos en diseño de bloques al azar con cuatro réplicas: a) cuatro tratamientos con 600 kg ha^{-1} de la fórmula 20-05-25 (N, P_2O_5, K_2O) después del corte, al inicio de las lluvias y, en ambos momentos, incorporada y superficial; b) dos tratamientos con 200 kg ha^{-1} de urea adicional a la aplicación enterrada y superficial después del corte; c) un control sin fertilizante. A los ocho meses, el fertilizante incorporado produjo una población de 14,5 tallos m^{-1}, con 1,4 tallos m^{-1} más con respecto al fertilizante en superficie y el rendimiento fue 68,89 Mg ha^{-1}; mientras que con el aplicado en la superficie fue 59,44 Mg ha^{-1}, alcanzándose un incremento de 9,46 Mg ha^{-1}. La fertilización superficial no tuvo efecto ni sobre la población de tallos ni sobre el rendimiento. La población de tallos a los ocho meses de edad se relacionó directamente con el rendimiento obtenido en la cosecha. La urea adicional no incrementó los rendimientos más allá de los alcanzados con una sola aplicación de fertilizante, pero sí incrementó la cantidad de N para producir 1 Mg de caña, oscilando entre 3,2 kg y 3,4 kg.

Palabras clave: primer retoño, lluvia, tallos, rendimiento

INTRODUCTION

The cane area currently linked to "Central Progreso" mill, S. A. de C. V. is 11,000 ha and the average cane yield in the last six years was 58.83 Mg ha^{-1} (1,2).

Field yields are low compared to other sugar mills in the Central Veracruz region, which means increasing

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sugarcane yields through better agricultural practices, among which is the use and management of fertilizers, mainly nitrogenous, which they are advantageous because of their availability in the market and their immediate effect on the crop; but the producers wait for the beginning of the rains to apply the fertilizers, generally superficially on the ground, without knowing if this management is optimal, or at least adequate, for the conditions of the mill. In this sense, it was found, through a survey of 250 sugar cane producers in Veracruz, that 99.2 % of them apply formulas 20-10-10 or 20-10-20, among others and urea (46-0-0) as a complement to the nitrogen source; but the producers wait for the beginning of the rains to apply them, generally superficially on the ground (3).

By virtue of the above, the present work proposes to evaluate the effect of chemical fertilization, with complete formula in buried and superficial form, applied after the harvest and at the time of beginning the rains, with additional supply of urea in some treatments.

MATERIALS AND METHODS

The Central Progreso S.A mill of C.V, is located in the sugarcane area of Alto Papaloapan, in the Gulf of Sierra Madre Oriental, within the municipalities Paso del Macho, Camarón de Tejeda, Zentla, Tepatlaxco and Carrillo Puerto, in the State of Veracruz, Mexico (1).

The study was conducted in Paso del Macho municipality, in the Rincón de los Toros ranch, belonging to Mr. Pablo Hernández García, from January 4th, 2013 to February 8th, 2014, in first cycle shoots (soca) and under conditions of heavy weather conditions (rainfed), where the cycle cane plant (template) was maintained with good population of stems, without missing strains, free of weeds throughout the period of development of the crop and was harvested after applying the burning.

The soil on which the research was developed was classified as Luvisol ortic according to the WRB (4), the description of the soil profile is presented in Table 1.

In the soil samples of each genetic horizon, the pH was measured potentiometrically at a soil: water ratio of 1: 2.5; the organic matter was evaluated with the Walkley and Black method; interchangeable cations were extracted with a solution of ammonium acetate 1 mol L^{-1} of pH 7, Ca and Mg were determined by complexometry and K by flame photometry; the assimilable P was extracted according to the method of Bray and Kurtz No. 2 and it was determined by colorimetry, from the formation of the blue color of the molybothiophosphoric complex, all the techniques as described (5).

Table 1. Morphological description of the Luvisol soil profile of the Ranch Rincón de los Toros, Paso del Macho municipality, Veracruz

Horizont	Depth (cm)	Description
Ap	0 – 10	Color 10YR 3/3 (h) dark brown, loam to clay loam, nuciform to granular structure, compacted, dry, frequent fine and medium roots, some bright spots, white gravitas, frequent pores, no reaction to HCL, net transition.
Bt1	10 - 22	Color 10YR 3/2 (h) very dark grayish brown, clay loam, subangular block structure, compacted, fresh, frequent fine and medium roots, stones in an advanced state of decomposition, frequent pores, without reaction to HCL, net transition.
Bt2	22 – 34	Color 10YR 3/1 (h) very dark gray, clay, slightly damp, compacted, subangular block structure, few roots, few pores, presence of gravitas in an advanced state of decomposition, without reaction to HCL, bright faces, net transition..
Bt3 (g)	34 – 46	Color 10YR 3/1 (h) very dark gray, clayey, slightly moist, compacted, subangular block structure, without roots, few pores, increases the number of gravitas in a state of decomposition, presence of grayish spots, sudden transition.
CR	46 +	Conglomerate without carbonates

The activities carried out during the development of the experiment and the dates of execution are presented in Table 2.

The application of fertilizer was carried out mechanically, both on the surface of the soil and when it was incorporated on both sides of the strain to a depth that ranged between 10 cm and 15 cm.

The sugar cane variety of the study was CP72-2086, one of which is grown on a large scale in the region (6).

Table 2. Activities carried out in the experiment to evaluate the effect of fertilization on the development of sugar cane in the first shoot. Rincón de los Toros Ranch, Paso del Macho municipality

No	Activities	Execution Dates
1	Plant cycle harvest	January 4, 2013
2	Application of fertilizers after cutting to treatments 2, 3, 6 and 7	January 14, 2013
3	Phenological observations	April 5, 2013
4	Application of fertilizers at the beginning of the rains to treatments 4 and 5	June 6, 2013
5	Application of urea to treatments 6 and 7	June 30, 2013
6	Phenological observations	Sept 6, 2013
7	Sampling and harvest of the experiment	February 8, 2014

The fertilizer formula applied was 20–05–25 at a rate of 600 kg ha^{-1}

The second application was made with urea (46 % of N) at a rate of 200 kg ha^{-1}

A randomized block experimental design with seven treatments (Table 3) and four replicates was used.

Table 3. Treatments tested to evaluate their effects on the development of the first ratoon of sugarcane, variety CP72-2086. Rancho Rincón de los Toros, Paso del Macho municipality

Treatments	Description
1. T	Control without fertilizer
2. FDC-S	Recommended formula applied after cutting, superficial
3. FDC-I	Recommended formula applied after cutting, incorporated
4. FILL-S	Recommended formula applied at the beginning of the rains, superficial
5. FILL-I	Recommended formula applied at the beginning of the rains, incorporated
6. FDCU-S	Recommended formula applied after cutting + 2nd application with Urea, superficial
7. FDCU-I	Recommended formula applied after cutting + 2nd application with Urea, incorporated

Recommended formula: 05-20-25 at a rate of 600 kg ha^{-1}
Urea: at a rate of 200 kg ha^{-1}

Each plot had six furrows 12 m long and a distance between them of 1.20 m, considering the four central furrows for the evaluation.

In each plot, all the shoots and stems were counted at three and eight months respectively and the height measurement of 20 stems was measured from the soil surface to the last visible dewlap, after the harvest of the plant cane. The population of stems existing at eight months of age was expressed in stems m^{-1}.

The yield of cane was estimated from the mass of 20 stems taken at random in the four central rows of each plot and expressed in Mg ha^{-1}.

With the dose of N that was applied in each treatment and the yields, the Consumption Index of N was calculated, dividing the applied dose between the yields.

ANOVA was performed on the results of the evaluations performed in correspondence with the experimental design, after having checked the variance homogeneity with the Bartlett test and the normality of the data with the Kolmogorov-Smirnov test and when there were differences between the means, these were compared according to the Duncan Multiple Range test. Regression analysis was carried out between the number of stems counted at eight months and the cane yield, and the standard error statisticians of the estimation (Esŷ) and the Determination Index (R2) were determined. For the processing of the data, the statistical package STATGRAPHICS Plus version 5.1 for Windows (7) was used.

RESULTS AND DISCUSSION

Soil Characterization

Some characteristics of the soil on which the research was developed are presented in Table 4.

As shown in Table 4, P and K accumulate in the superficial horizon at concentrations suitable for sugar cane, which decrease abruptly from the first to the second horizon; while the interchangeable bases Ca^{2+} and Mg^{2+} increase with the depth of the profile, until duplicating the concentrations found in the upper horizon and in correspondence with the behavior of Ca^{2+} and Mg^{2+}, the pH of the soil also increases in depth.

Table 4. Some characteristics of the Luvisol ortic soil of the Ranch Rincón de los Toros, Paso del Macho municipality, Veracruz

Variable	Horizon (depth, cm)			
	Ap (0-10)	Bt_1 (10-22)	Bt_2 (22-34)	Bt_3 (g) (34-46)
Drainage	Moderately well drained			
Erosion	Little eroded			
Pending	Flat			
Effective depth	Little deep			
pH	5,58	6,13	6,67	6,86
Organic matter, mg g^{-1}	35,9	27,5	18,7	17,0
Ca, $cmol_{(c)}kg^{-1}$	14,77	23,40	28,23	29,50
Mg, $cmol_{(c)}kg^{-1}$	9,48	15,07	20,65	18,20
K, $cmol_{(c)}kg^{-1}$	0,56	0,24	0,14	0,13
P assimilable, mg kg^{-1}	26,40	12,01	15,10	46,80

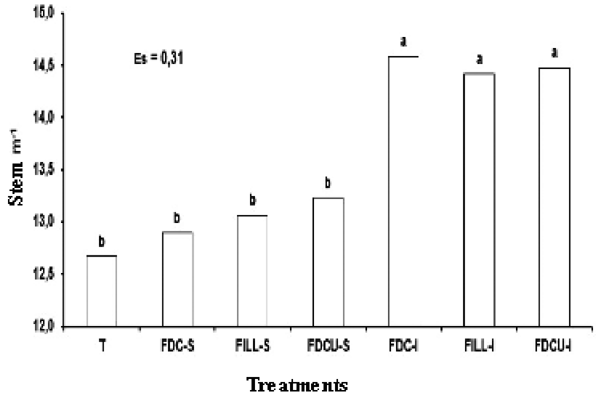
Poblation of stems and height of the plants

The evaluation made three months after the harvest of the plant cane indicated that the treatments did not influence either the number of shoots or the height reached by these.

After 80 days after fertilization (treatments FDC-S, FDC-I, FDCU-S and FDCU-I, the last two without the additional application of urea), the plant satisfied its nutritional needs from the reserves contained in the strain, the supply of nutrients from the soil and for the specific case of N, one could think of the biological fixation of N_2.

Already at eight months, significant differences were found between the treatments only on the population of stems per plot (Table 5).

The population averaged 13.6 stems m^{-1}, considering the Witness treatment; in those treatments in which the fertilizer was applied on the soil surface (FDC-S, FILL-S, FDCU-S), the average was 13.1 stems m^{-1}; whereas when the fertilizer was incorporated in the soil (FDC-I, FILL-I, FDCU-I), the average resulted in 14.5 stems m^{-1}, which meant an increase with respect to the superficial fertilization, of 1, 4 stems m^{-1}, equivalent to 11 % (Figure 1).



T: control without fertilizer; FDC-S: recommended formula applied after surface cutting; FILL-S: recommended formula applied at the beginning of the surface rainfall; FDCU-S: recommended formula applied after cutting + 2nd application with urea, superficial; FDC-I: recommended formula applied after the cut-in; FILL-I: recommended formula applied at the beginning of the incorporated rains; FDCU-I: recommended formula applied after cutting + 2nd application with urea, incorporated; Formula and recommended doses: 20-05-25 to 600 kg ha^{-1}, urea at a rate of 200 kg ha^{-1}

Figure 1. Stem population per linear meter at eight months of age of the first sugar cane ratoon due to the effect of fertilization. Rincón de los Toros Ranch, Paso del Macho municipality. Year 2013

Table 5. Results of the analysis of variance performed on the number of stems per plot and on the height at eight months of age of the first sugar cane shoot. Rincón de los Toros Ranch, Paso del Macho municipality

Sources of variation	gl	Amount of stems					Height, cm				
		CM	Fc	Ft		Sig.	CM	Fc	Ft		Sig.
				5 %	1 %				5 %	1 %	
Treatments	6	3253,25	3,6	2,66	4,01	*	130,48	1,27	2,66	4,01	NS
Replicas	3	805,86	0,9	3,16	5,09	NS	274,57	2,67	3,16	5,09	NS
Error	18	906,62	---	---	---	---	102,81	---	---	---	---
CV, %		5,04					5,78				

*Significant differences at 5% probability of error
NS: no significant differences
gl: degrees of freedom
CM: middle square
Fc: F Fisher's calculated
Ft: F Fisher's table
CV: coefficient of variation

In addition, the superficial application of the fertilizer (FDC-S, FILL-S, FDCU-S) showed no effect on the population of stems when compared with the control treatment (T), which indicated that an ineffective management was carried out that caused only economic and environmental damages, due to the cost of the activity, to the acidification of the soil and to the emission of N to the atmosphere respectively, ineffectiveness that reached a greater relevance when applying additional urea on the surface of the soil (FDCU-S).

Together with the above, it was found that the additional incorporation in the soil of urea (FDCU-I), did not benefit in any way the population of stems when compared with the other treatments where the incorporated fertilization was performed, reiterating that was incurred in an unnecessary expense and environmental damage.

Sugar cane yield

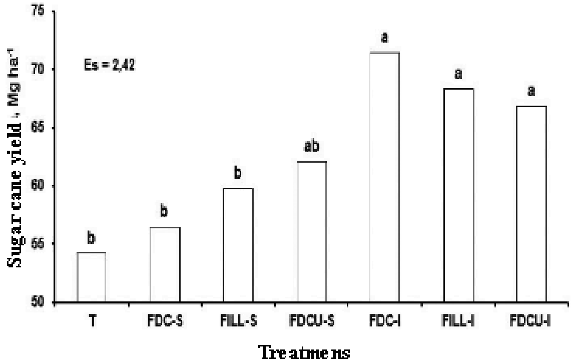
When the sugar cane yield was analyzed, it was found that the treatments caused differentiated effects on this indicator (Table 6).

Table 6. Results of the analysis of variance performed on the sugar cane yield of the first sugar cane shoot. Rincón de los Toros Ranch, Paso del Macho municipality

Source of variation	gl	Sugarcane Yield (Mg ha^{-1})				
		CM	Fc	Ft 0,05	Ft 0,01	Sig.
Treatments	6	335,7578	2,90	2,66	4,01	*
Replicas	3	231,1856	2,00	3,16	5,09	NS
Error	18	115,4273	---	---	---	---
C.V. %		10,2				

*: Significant differences at 5% error probability. NS: no significant differences; gl: degrees of freedom; CM: mean square; Fc: Fisher's F calculated; Ft: Fisher's F of the table; CV: coefficient of variation

When observing Figure 2, it was found that the treatments with the incorporated fertilizer (FDC-I, FILL-I, FDCU-I) provided higher cane yields than those achieved with the treatments in which the fertilizer was applied on the surface of the soil (FDC-S, FILL-S), except for the treatment that received the additional application of urea on the surface (FDCU-S).



T: control without fertilizer; FDC-S: recommended formula applied after surface cutting; FILL-S: recommended formula applied at the beginning of the surface rainfall; FDCU-S: recommended formula applied after cutting + 2nd application with urea, superficial; FDC-I: recommended formula applied after the cut-in; FILL-I: recommended formula applied at the beginning of the incorporated rains; FDCU-I: recommended formula applied after cutting + 2nd application with urea, incorporated; Formula and recommended doses: 20-05-25 to 600 kg ha^{-1}, urea at a rate of 200 kg ha^{-1}

Figure 2. Sugar cane yield of the first ratoon due to the effect of fertilization. Rincón de los Toros Ranch, Paso del Macho municipality. Year 2014

The average yield achieved with the fertilizer incorporated in the soil was 68.89 Mg ha^{-1}; while with the applied on the surface was 59.44 Mg ha^{-1}, an increase in yield in favor of the first application form of 9.46 Mg ha^{-1}, equivalent to 13.73 %.

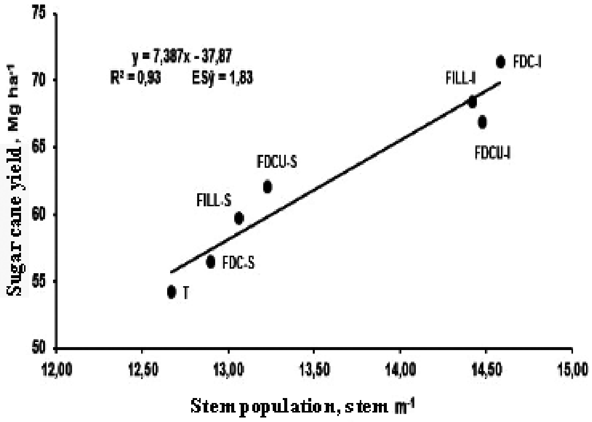
As it was manifested in the population of stems, the superficial application of the fertilizer (treatments FDC-S, FILL-S, FDCU-S) had no effect on the yield when compared with the control or control treatment (T).

Regarding the moment of application of the fertilizer, that is, immediately after the harvest or at the beginning of the rains, this last recurrent management among the producers, highlighted the fact that with the fertilization incorporated to the soil, at the beginning of the rains, they reached yields similar to those achieved when the incorporation of the fertilizer was carried out immediately after the harvest.

The additional application of urea did not increase the yields beyond those achieved with the treatments with a single application of fertilizer.

Relationship between the population of stems at eight months and yield

The population of stems at eight months was related to the yield of cane (Figure 3), illustrating the correlation of superficial fertilizations with the lowest yields and those incorporated in the soil, with the highest yields.



T: control without fertilizer; FDC-S: recommended formula applied after surface cutting; FILL-S: recommended formula applied at the beginning of the surface rainfall; FDCU-S: recommended formula applied after cutting + 2nd application with urea, superficial; FDC-I: recommended formula applied after the cut-in; FILL-I: recommended formula applied at the beginning of the incorporated rains; FDCU-I: recommended formula applied after cutting + 2nd application with urea, incorporated; Formula and recommended doses: 20-05-25 to 600 kg ha^{-1}, urea at a rate of 200 kg ha^{-1}

Figure 3. Relationship between the number of stems at eight months of age and the yield in cane of the first shoot due to the effect of fertilization. Rincón de los Toros Ranch, Paso del Macho municipality

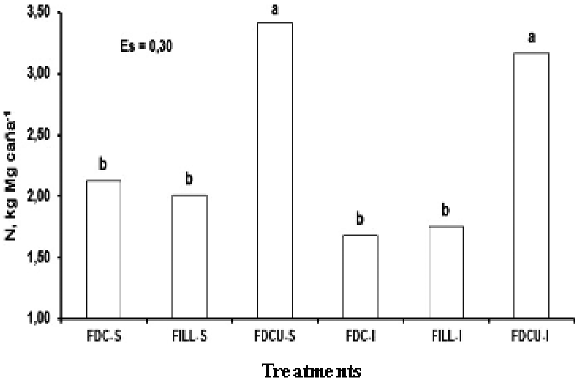
The Control Treatment, with the lowest stem population, was associated with the lowest absolute yield value.

The relation found, given the good adjustment according to the high R_2 and the low Standard error of the estimation (Esŷ), allows forecasting the expected yield in cane from the population of stems found in a linear meter at eight months, under conditions similar to those of the investigation.

N consumption index

Although the fertilization carried out included the three primary macronutrients, only the requirement of N to produce 1 Mg of sugar cane was analyzed, given that it is the nutrient considered to be the one that causes the most ecological damage due to contamination of groundwater when it is washed, its effect on eutrophication when it is dragged towards the mirrors of water and the emission of gases into the atmosphere from the volatilization of NH_3 and denitrification processes.

Figure 4 shows how the aforementioned N index varied according to the fertilization carried out.



T: control without fertilizer; FDC-S: recommended formula applied after surface cutting; FILL-S: recommended formula applied at the beginning of the surface rainfall; FDCU-S: recommended formula applied after cutting + 2nd application with urea, superficial; FDC-I: recommended formula applied after the cut-in; FILL-I: recommended formula applied at the beginning of the incorporated rains; FDCU-I: recommended formula applied after cutting + 2nd application with urea, incorporated; Formula and recommended doses: 20-05-25 to 600 kg ha^{-1}, urea at a rate of 200 kg ha^{-1}

Figure 4. Index of N consumption according to the treatment evaluated. Rincón de los Toros Ranch, Paso del Macho municipality

It was reiterated once again, the inconsistency and unnecessary to perform an additional application of urea (FDCU-I, FDCU-S), since with this management the amounts of N to produce 1 Mg of cane were high and ranged between 3.2 kg and 3.4 kg, quantities that reflected inefficiencies in the use and management of N, in addition to the low efficiency of the applied fertilizer.

With the remaining treatments the amount of N required to produce 1 Mg of cane was similar; however, considering the individual effect of each treatment on the population of stems and yield, those where fertilization was incorporated into the soil (FDC-I, FILL-I) allowed to consider them as the best and showed greater efficiency in the use of fertilizer, with quantities in the environment of 1.7 kg of N per Mg of cane.

The described behaviors are associated with the management of the fertilization of sugarcane under the conditions evaluated. The superficial application of fertilizers brings with it several disadvantages. Both P and K, nutrients that are not very mobile in the soil, especially P, accumulate in the humic horizon, as has happened in this study (Table 4) and can be lost from the agroecosystem through erosion, in addition to the one extracted from the field with the raw material that is brought to the industry.

For its part, nitrogenous fertilizer when applied superficially, is subject to losses due to volatilization, washing and erosion. In this regard, it has been found that the emission of N_2O was lower with the application of nitrogenous fertilizer in depth when compared with the placement near the surface of the soil (8).

The losses due to N volatilization are produced in an ammoniacal form from the urea granules, as suggested by authors who found losses between 28 and 45 % of the N applied to the surface of the soil cultivated with grasses, after 144 hours of the fertilizer application (9); also when a soil was incubated for 38 days after applying four organic fertilizers and urea, it was found that most of the N lost from urea was in an ammoniacal form and emissions between 62.4 and 69.6 % of the total N applied were evaluated. (10); other researchers measured up to 24 % of N losses in an ammoniacal form in a sugarcane agroecosystem (11).

Another adverse effect that occurs after nitrogenous fertilization is soil acidification; In this regard, it has been reported that following fertilization with nitrogenous sources, the microbial oxidation of NH_4^+ to NO_3^- in the soil releases H + ions, which results in long-term acidification of the soil (12), a behavior that explains the acidity of the soil under study in the superficial horizon and the increase of pH with depth (Table 4). In addition to this, nitrates can be washed from the root zone since neither the colloids nor the organic matter of the soil retain them and this washing is often accompanied by basic cations such as Ca^{2+} and $Mg^{2+,}$ which results in an accumulation of H^+ ions in the soil solution, increasing the acidification (13). The latter is an element to be considered to explain the increase in the concentrations of the dibasic cations in the depth of the profile, as shown in Table 4.

Fertilization management also had its effect, both in the stem population (Figure 1), and in the sugarcane yields (Figure 2). In this sense, it was concluded in Brazil that when the fertilizer was buried, the sugar yield was increased compared to the superficial application (14); other authors found that the incorporation of fertilizer at 0.08 m depth, provided more stems m^{-1} and produced 13 % more tons of cane than the surface application (15), results that are corroborated with those found in the present work (Figures 1 and 2). In Guatemala they recommend burying the nitrogen fertilizer on both sides of the furrow (16); in India they concluded that the proper placement of the fertilizer contributes to reduce the losses by volatilization of the N, to diminish the fixation of the P and consequently, to increase the efficient use of the fertilizer, all of which leads to increase the yields, reason why the authors recommend to bury the fertilizer 0.08-0.10 m deep on the furrow or on the sides of it and then cover it with soil (17).

Referring to the moment of application of the fertilizer, it was demonstrated that with the fertilization incorporated to the soil at the beginning of the rains, yields similar to those achieved when the incorporation of the fertilizer was made immediately after the harvest were achieved (Figure 2), so that it is justified to delay the fertilization because it would oblige to do it manually, due to the impossibility of introducing machinery in the field due to the growth of sugarcane.

The additional application of urea in the rainy season, whether it has been superficial or incorporated into the soil, did not constitute an effective management, although it was a practice that increased fertilization, with its consequent adverse environmental implications, as well as unnecessarily increasing the amount of N to obtain 1 t of cane (Figure 4).

CONCLUSIONS

- ♦ The soil under study presents acidification in the superficial horizon, the concentrations of the interchangeable cations and the pH increase with the depth while those of P, K and the organic matter decrease.
- ♦ The application of the fertilizer in the shoots should be done immediately after harvesting and incorporated into both sides of the furrow.
- ♦ The additional application of urea in the rainy period does not increase neither the population of stems nor the yields, but the Index of Consumption of N.
- ♦ The population of stems in 1 m linear at eight months of age of the plantation correlates with the yield in cane that is reached in the harvest.

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