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NITROGEN MANAGEMENT IN SUGARCANE AND ITS INFLUENCE ON YIELD, PROFITABILITY AND LEACHING LOSSES

[MANEJO DEL NITRÓGENO EN CAÑA DE AZÚCAR Y SU INFLUENCIA EN RENDIMIENTO, RENTABILIDAD Y PÉRDIDAS POR LIXIVIACIÓN]

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SUMMARY

The excessive use of nitrogen (N) in sugarcane (*Saccharum officinarum* L.) is a source of contamination for aquifers. The objective was to evaluate sugarcane yield, as well as profitability and amount of N leached resulting from the application of different split N doses. Three N doses (250, 200 and 150 kg ha^{-1}) and three different application numbers (2, 3 and 4) were evaluated using a factorial design in randomized blocks. When the N dose was divided in three and four applications yields higher than 125 ton ha^{-1} were obtained. The greatest benefit-cost-ratio (1.8) resulted from using 150 kg ha^{-1} of N divided in three applications. The lowest N losses due to leaching were obtained using 150 kg ha^{-1} of N divided in three (16.8 kg ha^{-1}) and four (15.4 kg ha^{-1}) applications. Low N doses divided in three or four applications did not reduce sugarcane production; furthermore, it was more profitable and had a lower environmental impact by reducing N leaching.

Key words: nitrogen fertilization; leaching; agroecosystems.

RESUMEN

El uso excesivo de nitrógeno (N) en caña de azúcar (*Saccharum officinarum* L.) es fuente de contaminación de acuíferos. El objetivo fue evaluar el rendimiento de caña de azúcar y la rentabilidad y cantidad de N lixiviado como resultado de la aplicación dividida de diferentes dosis de N. Se evaluaron tres dosis de N (250, 200 y 150 kg ha^{-1}) y tres números de aplicaciones (2, 3 y 4); se usó un diseño factorial en bloques al azar. Cuando la dosis de N se dividió en tres y cuatro aplicaciones se obtuvieron rendimientos superiores a 125 ton ha^{-1}. La mayor relación beneficio/costo (1.8) se logró con 150 kg ha^{-1} de N dividida en tres aplicaciones. Las menores pérdidas de N por lixiviación se obtuvieron con 150 kg ha^{-1} de N dividida en tres (16.8 kg ha^{-1}) y cuatro (15.4 kg ha^{-1}) aplicaciones. Dosis menores de N divididas en tres o cuatro aplicaciones no redujo la producción de caña de azúcar, resultó más rentable y tuvo menor impacto en el ambiente al haber menor lixiviación de N.

Palabras clave: fertilización nitrogenada; lixiviación; agroecosistemas.

INTRODUCTION

Sugarcane requires of several inputs such as nitrogen (N) fertilizers. Nitrogen fertilization is one of the management practices that influence the most sugarcane production. Therefore, it is necessary to apply fertilizers in adequate doses (Segura *et al.*, 2000; Smith *et al.*, 2000, Weterings and Russell, 2004), so they meet plant requirements in each growth and development phase (Gowda *et al.,* 1988; Toledo *et al.,* 2002). Nitrogen is a very mobile element; it is exposed to losses due to leaching, volatilization and denitrification. Thus, it is important to incorporate N into the soil in fractions, to make it available for the plant in its different phenological stages (González *et al.,* 2007). In addition, the inefficient and excessive use of N increases production costs and can be a nitrate contamination source for groundwater (Yepis *et al.,* 1999). Negative impacts on human health derived from the consumption of water contaminated with nitrates are a matter of concern, since it has been related with the occurrence of cancer cases (FAO, 1997; Pretty and Conway, 1998).

The inefficient use of water at plot level, inappropriate timing, and the actual way in which fertilizer is applied contribute to worsen N leaching. Castro-Luna *et al.* (2006), indicate the need of developing and establishing inexpensive and more efficient sustainable fertilization practices, since evidence suggests that sugarcane only uses 57 % of N applied under current management practices (Landeros *et al.,* 2007).

The community of Salmoral is in the area of the Irrigation Module 1-I La Antigua, Veracruz, Mexico. Here, N fertilization has gradually increased until reaching an average of 254 kg ha^{-1}, regardless sugarcane variety, soil type and water availability. The most common N sources used are urea (46-0-0) and mixtures such as 20-10-10 (N-P-K). Usually, N applications are made at once or divided twice but untimely, due to delays when the fertilizer is obtained via credit (Moreno-Seceña *et al.,* 2007). Some countries such as Brazil and Cuba, used to apply up to 350 kg ha^{-1} of N. They have reduced fertilizer doses since two decades ago; currently they use 50 to 100 kg ha^{-1} of N (Demattê *et al.,* 2005). They are obtaining similar yields than in the past and also compared to those recorded in other countries, such as Mexico, where average N doses applied are higher than 180 kg ha^{-1}.

Not only N is absorbed in limited amounts by the plants; this situation is similar for other fertilizers. It is known that plants absorb only 20 % of phosphorus applied to the crops and the rest is fixed to the soil, as insoluble compounds. The excessive use of fertilizer is causing them to be leached by surface waters, resulting in eutrophication. Therefore, the objective of the present study was to evaluate the sugarcane yield, as well as the profitability and amount of N leached when used for sugarcane production in divided applications and different N doses.

MATERIALS AND METHODS

The study was carried out from January to December 2009 in the community of Salmoral, municipality of La Antigua, Veracruz, Mexico. Soil is alluvial, with clay loam texture and 75 to 95 m depth to groundwater. The sugarcane variety used was CP 72-2086, propagated by ratooning. Nine treatments from a factorial combination were evaluated (Table 1): dose (250, 200 and 150 kg ha^{-1} of N), number of applications (2, 3 and 4).

Table 1. Treatments evaluated to study the effect of the dose and number of applications of nitrogen (N) in sugarcane plantations, on the crop yield, benefit-cost ratio and nitrogen leaching in the community Salmoral, municipality of La Antigua, Veracruz, Mexico.

Code	Dose of N (kg ha^{-1})	Number of N applications
t1 250:2 [C]	250	Two (125, 125)
t2 250:3	250	Three (80, 90, 80)
t3 250:4	250	Four (60, 70, 60, 60)
t4 200:2	200	Two (100, 100)
t5 200:3	200	Three (70, 70, 60)
t6 200:4	200	Four (50, 50, 50, 50)
t7 150:2	150	Two (75, 75)
t8 150:3	150	Three (50, 50, 50)
t9 150:4	150	Four (40, 40, 40, 30)

[C]Control: Dose and number of applications recommended by sugar mills.

First fertilizer application was five days after the plant sprouted. Following applications were at 30, 60 and 90 days after the first one. To balance the nutritional plant system, in all treatments 20 kg ha^{-1} of P_2O_5 and 60 kg ha^{-1} of K_2O were added. During the crop cycle, l5 cm irrigation plates were added to experimental units and the nine lysimeters installed. A randomized block design in a factorial arrangement was used. Response variables were: yield at harvest (ton ha^{-1}); benefit-cost ratio (BCR) as an indicator of profitability (considering the yield obtained and production net cost) and N leaching, measured in nine weighing lysimeters, in which conditions of treatments were assayed and replicated.

RESULTS AND DISCUSSION

Field yield

Yields obtained on each treatment were greater than an average of 100.1 ton ha^{-1} obtained in the area of study (Figure 1).

According to ANOVA, the dose had no significant effect on yields obtained. Thus, if a lower dose of fertilizer is used, there will be no negative impact on yield. However, the number of N applications did have a significant effect on yield. When the N was divided in three and four applications, no significantly different yields, greater than 125 ton ha^{-1}, were obtained (Table 2).

The use of N fertilizing doses higher than 150 kg ha^{-1} does not guarantee higher yields. However, fractioning N application results in higher crop yields. According to Pacheco (1992) and Weier *et al.* (1996), fractioned application of N fertilizers increases crop absorption efficiency.

Table 2. Comparison of mean yields in sugarcane crop with respect to dose and number of applications of nitrogen (N) in the community Salmoral, municipality of La Antigua, Veracruz, Mexico.

	Number of applications			
Dose of N (kg ha^{-1})	**2**	**3**	**4**	**Mean**
250	126.17	128.20	128.20	127.52[a]
200	122.90	125.50	126.33	124.90[a]
150	119.40	121.63	121.63	120.88[a]
Mean	122.82[b]	125.10[a]	125.38[a]	

[a,b]Different superscripts among columns indicate statistical difference (Tukey, $P \leq 0.05$).

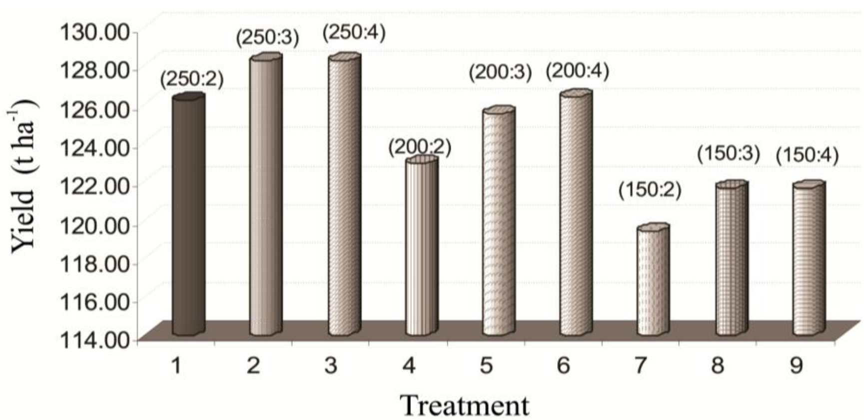

Figure 1. Sugarcane yields obtained at Salmoral, municipality of La Antigua, Veracruz, Mexico. The dose of nitrogen and the number of applications are shown in parenthesis.

Benefit-Cost ratio (BCR)

Treatment with the greatest BCR (1.80) used 150 kg ha^{-1} of N divided in three applications. Treatment with the lowest BCR (1.67) involved 250 kg ha^{-1} of N fractioned in two. ANOVA showed significant differences caused by the dose in the BCR, due to considerable saving in the N dose. Important economic saving increased the BCR of treatments with lower N doses (Table 3). Number of applications did not affect the BCR.

Therefore, the use of 150 kg ha^{-1} of N divided in three applications resulted in greater profitability in sugarcane production. Wilcox (1991) indicated that reduction in N dose, its divided application, and the use of sugarcane byproducts such as vinasse, and other organic residues, are viable options to reduce fertilization costs. Nonetheless, Hernández *et al.* (2008), after making an economic analysis of using reduced doses of N fertilizers in combination with vinasse and cachaza, concluded that chemical fertilization is the most profitable option. However, these authors failed to mention the residual beneficial effects that compost and vinasse have on the soil. Not only the reduction in dose and the divided application of N fertilizer should be considered in the BCR, but also the incorporation of crop residues or other organic residues with potential as compost.

Table 3. Mean comparison of the benefit-cost ratio obtained in sugarcane crop, with respect to the factors dose and number of applications of nitrogen (N), in the community Salmoral, municipality of La Antigua, Veracruz, Mexico.

	Number of applications			
Dose of N (kg ha^{-1})	**2**	**3**	**4**	**Mean**
250	1.67	1.70	1.71	1.69^{b}
200	1.73	1.76	1.77	1.75^{a}
150	1.77	1.80	1.79	1.79^{a}
Mean	1.72^{a}	1.75^{a}	1.76^{a}	

Nitrogen leaching

In this study, the application of a lower dose of N resulted in a lower loss due to leaching of this nutrient. When a dose of 250 kg ha^{-1} of N was given divided in two, three and four applications, the accumulated loss ranged from 30.62 to 40.86 kg ha^{-1} of N, which accounts for 16.3 %. When a dose of 200 kg ha^{-1} of N was given in two, three and four applications, the accumulated loss ranged from 21.82 to 30.16 kg ha^{-1}, representing up to 15 %. This is in agreement with Bergström and Johansson (1991), who indicated similar losses due to N leaching for the same N doses. When 150 kg ha^{-1} of N was divided in two, three and four applications, losses ranged from 15.40 to 18.18 kg ha^{-1}, accounting for up to 12.1 % (Figure 2). The lowest N loss was obtained with a dose of 150 kg ha^{-1} of N divided in four applications. Chávez (1999) also indicated that the divided application of N fertilizers is a practice that reduces N loss by leaching.

Figure 3 shows that water management plays an important role in the N leaching process, since most leaching was recorded during irrigation period, followed by rainy period, whereas the lowest losses were recorded during dry period. However, in all periods the highest doses resulted in the highest leaching.

Table 4 includes recommendations on fertilization and regional management based on our results. Sugarcane growers from Irrigation Module I-1 La Antigua are recommended to use 150 kg ha^{-1} of N divided in three applications. This would allow the highest economic and environmental benefits, with lower groundwater impact due to N contamination. Likewise, to improve natural soil fertility and sugarcane yields, and to incorporate crop byproducts, it is recommended to manage irrigation water efficiently.

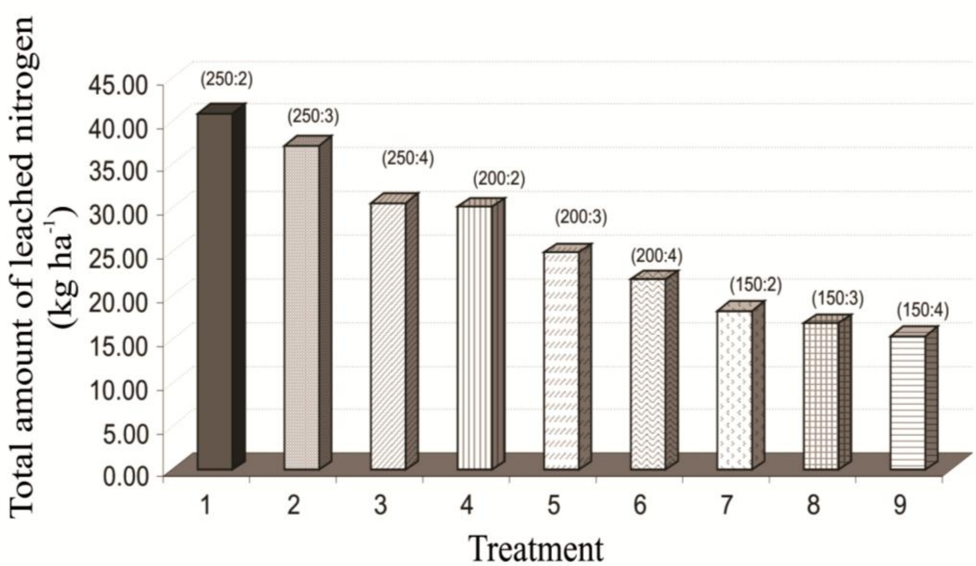

Figure 2. Total accumulated nitrogen leaching recorded in lysimeters in Salmoral, municipality of La Antigua, Veracruz, Mexico. Dose of nitrogen (250, 200, 150 kg ha^{-1}) and number of applications (2, 3, 4) are in parenthesis.

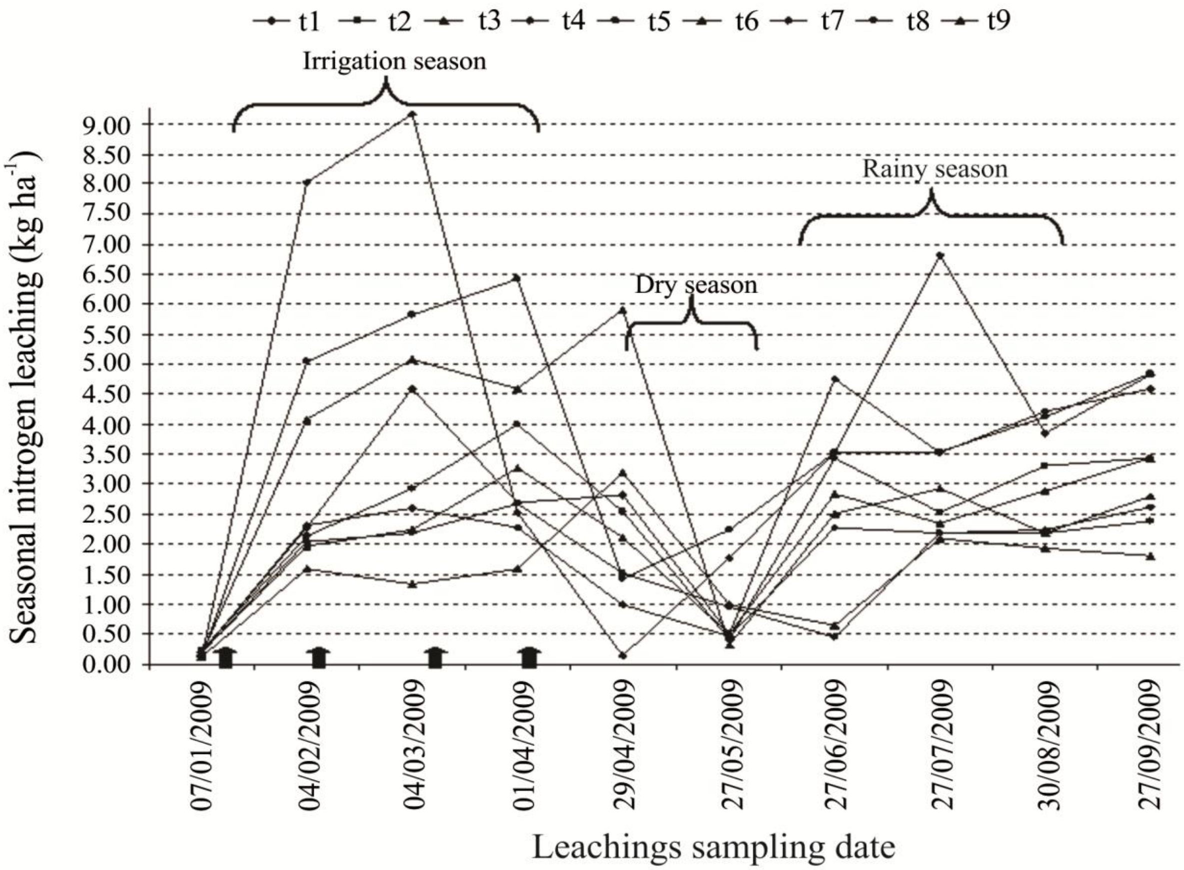

Figure 3. Nitrogen leaching in sugarcane during the irrigation, dry and rainy periods in Salmoral, municipality of La Antigua, Veracruz, Mexico. Arrows indicate the time of fertilizer application. Treatment includes dose of N ha^{-1} and number of applications: t1: 250:2; t2: 250:3; t3: 250:4; t4: 200:2; t5: 200:3; t6: 200:4; t7: 150:2; t8: 150:3; t9: 150:4.

Table 4. Productive, economic and environmental variables studied in sugarcane cultivation in the community Salmoral, municipality of La Antigua, Veracruz, Mexico.

Code	Dose of N (kg ha^{-1})	Number of applications	Productive Yield (ton ha^{-1})	Economic R B/C	Environmental N leaching (kg ha^{-1})
250:2	250	2	126.1	1.67	40.9
250:3	250	3	128.2	1.70	37.2
250:4	250	4	128.2	1.71	30.6
200:2	200	2	122.9	1.73	30.1
200:3	200	3	125.5	1.76	24.9
200:4	200	4	126.3	1.77	21.8
150:2	150	2	119.4	1.77	18.1
*150:3	150	3	121.6	1.80	16.8
150:4	150	4	121.6	1.79	15.4

* Treatment appropriate to the objective of the study.

CONCLUSION

Divided application of N fertilizer in sugarcane induced greater absorption of this nutrient by the plant, resulting in increased field yields. Reduction of N fertilizer doses in sugarcane at the Irrigation Module I-1 La Antigua resulted in economic savings and fewer losses due to groundwater leaching. The use of 150 kg ha^{-1} of N divided in three applications can improve yields and help mitigate N groundwater contamination.

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