STRATEGIES FOR THE OPTIMAL USE OF NITROGEN FERTILISERS IN THE SUGARCANE CROP IN GUATEMALA

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Abstract

THE OBJECTIVE of this work is to present practical criteria that will help sugarcane growers to optimice their investment in nitrogen fertilisers in the sugarcane crop in Guatemala. The importance of this objective is in relation to the general increase of fertiliser price and particularly of nitrogen fertiliser. The criteria are based on knowledge of crop response to N application in the region after 14 years of experience in research on the topic. Crop N response is a function of cane yield, soil fertility, crop age or crop cycle and other variables associated with agronomical practices and soil condition. As a result, N rate used in sugar mills' fertilisation programs can be adjusted by comparing the current relation of kg of nitrogen per tonne of cane (N:TC), with reference ratios recommended for different soils according to organic matter content (OM) and other factors. Besides, N rates must be adjusted to fertiliser and sugar price for different production groups. As an alternative to reduce dependence on nitrogen fertilisers, there are practices that must be taken into account and be optimised in the short term. These practices consist of usage of species of green manure adapted to the intercropping system, the use of co-products and, in the mid and long term, there is potential for N biological fixation in the sugarcane crop.

Introduction

Nitrogen use in Guatemala is generalised in the sugarcane production as in most cane producing countries. In Guatemala, it is estimated that, in the 2006–07 harvest season, there were approximately 20 000 tonnes of nitrogen applied over 210 000 hectares (Pérez, 2007). The nitrogen fertiliser item is gaining importance in the crop production cost because of the increase in nitrogen fertiliser price that, only in the past year (2008), increased over 80% while the sugar price stood relatively constant. Under these circumstances, sugar mills have seen themselves forced to make adjustments in their budgets, requiring an effective and judicious use of fertilisers to ensure maximum advantage of investment.

The objective of this work is to present some practical strategies for sugarcane growers to support their decision-making process to maximise investment on nitrogen fertilisers, beginning with current fertilisation programs and presenting some options that will help in the future to reduce dependence on chemical fertilisers.

Generalities of Guatemala sugarcane region and yield potential

Based on the physiographic features that respond to a natural landscape of plain terrain and foothill, there is a gradient in terms of temperature, amount of rainfall, solar radiation, forms and slopes of terrain and presence of Allophane in soils, varying from the proximity to the mountain chain towards the Pacific Ocean, in a North–South direction. These gradients are captured with regional altitudinal stratification and are expressed in yield potentials of sugarcane as shown in Table 1. Table 1 shows that the higher yield potentials are in the lower zones of the region decreasing with altitude where there is lower temperature, more cloudiness associated with higher rainfalls, soils with undulating relief, and there are greater amounts of Allophane clays (Andisols).

Table 1—General and chemical features of Guatemala sugarcane region and cane yield according to four macro altitudinal strata.

Altitudinal stratum	General features				Chemical features			TCH[1] average
	Annual average T°(°C)	Rainfall (mm)	Predominant soil	Terrain relief	OM (%)	P (ppm)	K (ppm)	
High (> 300 masl)	23.6	3239	Andisol	Undulated and knolls	5.3	5.5	98	74.1
Middle (100–300 masl)	26.7	2779	Andisol Inceptisol	Undulated and slightly sloped	5.6	7.5	193	84.5
Low (40–100 masl)	27.3	2134	Andisol Inceptisol	Slightly plain and sloped	4.3	13.6	221	93.5
Coastal (< 40 masl)	27.5	1631	Mollisol Entisol	Plain	2.4	49.3	538	104.7

[1]TCH: tonnes of cane per hectare (sugarcane harvests: 2006–07 and 2007–08).

There is a particular relationship between OM and cane yield under the sugarcane growing area of Guatemala. The OM contents are greater in the middle and higher zones of the region in which Andisol soils predominate and decrease in the coastal zone in Mollisol and Entisol soils. Although amounts of OM in Andisol soils are higher, they are not associated with greater yields. This is because of the presence of other limiting factors like climate, terrain relief and soils that make yield potentials in these soils lower.

There are features in Guatemala's sugarcane zone regarding the relationship between altitude, climate, relief and soil and their relation with yield. The results are interesting when yield is stratified in ranges for the estimation of fertiliser doses as is currently made in mills, simultaneously with other factors associated with these yields.

Crop response to N application

With regard to soil fertility, it has been found that, in the sugarcane region of Guatemala, the OM is a factor that explains responses of nitrogen applications (Table 2).

Data in Table 2 show that, in 94% of cases, an increase in tonnage is achieved (higher than 20%) when OM contents in soil are lower (OM <3.0%) whereas, in soils with higher OM contents (>5.0%), in 100% of the cases the increase is lower than 11%.

In soils with medium OM content, responses were variable, but in most of the cases they were lower than 20%. As was indicated before, lower values of OM are found in the coastal zone where high yield Mollisol and Entisol soils are located which are the areas with high response to nitrogen.

Table 2—Response probabilities to N according to Guatemala sugarcane soil OM content (Adapted from Perez, 2007).

Predominant soil	OM category	Low response	Median response	High response
		< 11 % TCH	11–20% TCH	> 20 % TCH
Mollisol–Entisol	Low (< 3.0%)	0	6	94
Andisol–Inceptisol	Medium (3.0–5.0%)	31	47	21
Andisol	High (> 5.0%)	100	0	0

In Table 3, nitrogen dose recommendations for Guatemala sugarcane zone are presented, based on defined OM criteria and crop responses found in plant cane and ratoon cane in different experimental and validated tests carried out by sugar mills (Pérez, 2007; La Unión Mill, 2005).

Nitrogen recommendations for plant cane crop varies from 60 to 80 kg of N/ha whereas, in ratoon crops, recommendations are higher depending on OM in soil and yield potential of the sugarcane plantation.

In soils with lower OM content (<3.0%), it has been found that there is a need of 1.14 kg of N per tonne of produced cane (Nitrogen Cane Tonne Ratio: N:TC) whereas, in soils with medium and high OM contents, N:TC ratio is lower (1.0) (Perez, 2007). These two values from now on will be named Reference N:TC ratios.

N recommendations (kg/ha) for different OM categories in Table 3 indicate the fluctuation in nitrogen doses in less productive plots (doses lower range) to more productive plots (doses higher range).

Table 3—Nitrogen recommendations (N kg/ha) and reference N:TC ratio for volcanic ash derived soils in Guatemala. (Adapted from Perez, 2007).

Predominant soil	OM category	Plant cane	Ratoon	
		N dose (kg/ha)	N dose (kg/ha)	Reference N:TC ratio
Mollisol–Entisol	Low (< 3.0%)	80	100–170	1.14
Andisol–Inceptisol	Medium (3.0–5.0%)	60–80	90–140	1.0
Andisol	High (> 5.0%)	60	80–110	1.0

Nitrogen dose adjustment according to N:TC ratio

Nitrogen doses adjustment in current fertilisation programs involves a better way to optimise investment in chemical fertilisers used in sugar mills, avoiding overdose in lower response areas and adapting doses in areas that have higher probabilities to respond.

Given that nowadays all of the Guatemalan sugar mills use sugarcane plantation yield criteria and crop age to establish N doses to be used in defined fields, it was decided to review current N:TC ratios adding OM content as a decision criterion in recommendations.

This criterion is expected to result in N dose adjustments that will have greater economical impact on fertilisation programs mainly in ratoon crops given by the variability that exists in N:TC ratios for the same cane yield range (same yield group).

Current ratio variations will depend on range cane yield amplitude that is being used, and it would be wider variation in cases where only two categories exist (high and low yield).

Nitrogen dose adjustments will depend on crop cycle. In plant cane, adjustment has less impact, due to the fact that sugar mills currently fertilise according to the recommendations given in Table 3; however, a different situation applies in ratoon crops.

Table 4 shows a typical case of ratoon cane where the current fertilisation program is based exclusively on cane yield (TCH) with three different groups: low (< 90 TCH); intermediate (90–110 TCH) and high (>110 TCH) with applications of 100, 120 and 140 kg of N/ha respectively.

As a result, N:TC ratios vary from >1.12, 1.33 to 1.09 and < 1.26 for the three yield categories: low, intermediate and high, respectively.

Inside the three main groups of TCH, N:TC ratios increase as yield decreases, due to the fact that N dose remains constant. Variations in N:TC are greater as yield ranges are extended.

Table 4—Cane yield groups and intra-group variation of current relation N:TC ratios according to current N fertilisation.

Cane yield (TCH)			Current relation N:TC ratios[1]
Group	TCH intra-group	Current N doses (kg/ha)	
< 90	80	100	1.25
	85		1.17
	89		1.12
90–110	90	120	1.33
	95		1.26
	100		1.20
	105		1.14
	110		1.09
> 110	111	140	1.26
	115		1.21
	120		1.17

[1]Current relation N:TC ratios= Current N dose/TCH intra-group.

As mentioned, current fertilisation programs generally are based only on TCH categories. However, N dose adjustment is proposed according to N:TC ratio based on OM content applied in four categories. Table 5 shows an example of how to optimise N:TC ratio variability, introducing first a new approach consisting of an extra cane yield category into the current intermediate category and second by using as a reference OM contents of the soil. The reason why two new intermediate categories are proposed is because the average TCH of the Guatemala industry is in this range. Thus, as a result, the new intermediate category groups have more yield data, so any variation will have better impact on adjustments.

Table 5—Adjusted N doses by using Reference N:TC ratios and intra-group variation of N:TC ratios adding a new cane yield category.

Cane yield (TCH)		[1]Adjusted N dose (kg/ha)		[2]Adjusted N:TC ratio	
Group	TCH Intra-group	Soils with OM < 3.0%	Soils with OM > 3.0%	Soils with OM < 3.0%	Soils with OM > 3.0%
< 90	80	100	90	1.25	1.12
	85			1.17	1.05
	89			1.12	1.01
90–100	90	114	100	1.27	1.11
	95			1.20	1.05
	100			1.14	1.00
101–110	101	126	110	1.25	1.09
	105			1.20	1.05
	110			1.14	1.00
> 110	111	138	120	1.24	1.08
	115			1.20	1.04
	120			1.15	1.00

[1]Adjusted N dose=estimated from superior TCH in each Intra-group multiplied by respective reference N:CT ratio (1.14 and 1.00). [2]Adjusted N:TC ratio=Adjusted N dose/TCH intra-group.

In Table 5, it is observed that splitting the intermediate original category (90–110 TCH) in two: from 90 to 100 and from 101 to 110 TCH and adjusting N dose with Reference N:TC ratios 1.14 and 1.0 for soils with OM < 3.0% and soils with OM > 3.0%, respectively, a better balance of N doses is achieved. It is also observed that, in soils with high OM content (> 3.0%), N recommendations are reduced significantly compared to the original recommendations shown as current N doses (kg/ha) in Table 4. Additionally, for soils with less than 3.0% OM, N recommendations are better distributed when four TCH classifications are considered.

Obviously better adjustments could be achieved by introducing more categories to fertilisation programs. N recommendations would be advisable to the parcel level (specific site recommendations). The above improvements can be obtained by taking into consideration that all Fertilisation Programs must be operative and functional based on real possibilities and that the programs have economic feasibility.

It is advisable that each Guatemalan sugar mill reviews its current fertilisation program and then makes the necessary recommended N dose adjustments. Afterwards, the recommended programs must be adjusted slightly according to particularities inherent to site and agronomical management. Finally, it is important to emphasise the need for review and supervision of applications in order to make them correctly, including calibration of fertiliser machines, the seasons, and methods of fertiliser application.

N dose review as a function of fertiliser price variations

N optimal economic doses (NOED) must relate to N price variations and current sugar prices. However, this NOED variation with given prices changes depending on crop N response. When N response is high, NOED variation is smaller than in lower responses. In Table 6, NOED adequacy from one year to another according to fertiliser and product price update for different N response in terms of OM in soils is presented.

Table 6—NOED variation from 2007 to 2008 according to N price variation.

Soil OM (%)	Year	[1]Price relationship I/P	[2]NOED (kg/ha)	NOED reduction with new prices (%)
> 5.0	2007	1.21	109	13.0
	2008	1.93	95	
3.0–5.0	2007	1.21	126	11.0
	2008	1.93	112	
< 3.0	2007	1.21	162	8.6
	2008	1.93	148	

Fertiliser price (urea): 2007: US$19.00/qq; 2008: US$35.00/qq. Note: 1 qq=45.45 kg Cane price (without Cut, Raise and Transport): 2007: US$15.8/t; 2008: US$17.8/t

[1]Price relationship I/P = Price relationship of: US$ 1qq Urea/US$ 1 t of cane. [2]NOED: Nitrogen optimal economic dose: Estimated from regression functions for soils with low, medium and high OM content.

When the price of a quintal (45.45 kg) of fertiliser increases from US$19 to $35 and in the presence of a relatively constant sugar price (in price per tonne of cane terms), NOED are reduced invariably. Nevertheless, NOED percentage reduction is lower in high N response soils (OM < 3.0%), 8% reduction compared with a 13% reduction necessary for soils with lower response (OM >5.0%).

Alternatives to reduce dependence on chemical nitrogen fertilisers

Options and practices that can be mentioned and used to reduce the crop´s nitrogen fertiliser need are: green manure, vinasse, filter mud, and biological nitrogen fixation.

Green manure use

Green manuring constitutes one of the most viable options to reduce sugarcane crop N use, and it is a practice that helps improve cane yield and sustainability. Introduction of a leguminous crop in a conventional sugarcane system brings a series of direct and indirect benefits on breaking sugarcane monoculture (Garside and Bell, 1999; Wiseman 2005).

Crotalaria juncea and *Canavalia ensiformis*, planted as green manures in sugarcane nurseries as a crop rotation, allow 100% of nitrogen fertilisation savings, with an expected increase of cane seed production. In Guatemala, in a Mollisol soil, four and 11% cane seed yield increases were obtained when *C. juncea* and *C. ensiformis* were rotated in relation to the control without rotation (Cengicaña, 2009). In Australia, increases are reported of 20 and 30 percent of tonnage with soybean and peanut rotations in sugarcane plantation renewals. (Garside *et al*., 2001)

In Guatemala, under an superficial Andisol, it has been demonstrated that *C. juncea* monoculture could accumulate up to 235 kg of N/ha in its aerial bio-mass in only 65 days, while *C. ensiformis* N accumulation is slightly slower (175 kg of N/ha) (Pérez *et al.,* 2008). On the other hand, it has been shown that *C. ensiformis*, intercropped between sugarcane rows in plant cane and ratoons, could be an option in high OM content soils such as superficial Andisols in the region (Table 7).

Table 7 shows that cane yield was not affected by the intercropping of any of the legumes as compared with the control, even when they were not chemically fertilised. Rather, it appears that cane yields were on average slightly higher (though not significant at P: 0.05) than the control at the end of four years, particularly with *Canavalia*.

Table 7—TCH for four years under intercropping two legumes system in an Andisol Soil (MO:6.0%) Guatemala. (Adapted from Perez *et al.,* 2009).

Treatment	Plant cane (2006)	First ratoon (2007)	Second ratoon (2008)	Third ratoon (2009)	Average
Canavalia ensiformis + cane without N	82.8(a)	111.2(a)	95.0 (a)	108.7(a)	99.4 (a)
Crotalaria juncea + Cane without N	74.7(a)	109.3(a)	91.1 (a)	108.6(a)	95.9 (a)
Control (cane alone + N)	74.1(a)	103.7(a)	88.3 (a)	109.9(a)	94.0 (a)

In any column, means followed by a common letter are not significantly different (Tukey 0.05).

Green manures represent a great potential in sugarcane crop N savings. In the short term, it is recommended to initiate these practices in sugarcane nurseries, because their designated areas are without any use for three to four months. In the sugarcane crop of Guatemala, the potential of this technique is estimated to be the 5000 hectares which are designated for nurseries in a year. While leguminous management is becoming familiar and experience is achieved, the thought of its use will be possible in renewable areas where there is time pressure between harvest and planting a new plantation, and more research will be needed. Finally, the intercropping system will have to be focused in marginal areas where sugarcane growth is slower due to limiting climatic conditions, and in areas susceptible to erosion and pests and diseases.

Vinasse use

Vinasse is an industrial residue from the alcohol distillation process and basically it is made up of water, OM and mineral salts. It is being used in sugarcane crop fields because it increases yield, reduces fertiliser use and, generally, improves soil. (Pennati *et al*., 2005)

Possibilities of reducing N doses used in sugarcane crop fields with vinasse could be important. Table 8 presents an average of TCH observed in four years with different and successive vinasse applications under different N doses in a Guatemalan sugarcane Andisol.

Table 8—TCH with continued vinasse applications for four years under three N levels in a high OM content (7.6%) Andisol soil. (Adapted from Perez *et al.,* 2009)

Vinasse (m^3/ha)	N (kg/ha)			[1]Average effect of vinasse
	0	50	100	
0	103.8 (b)	110.3 (ab)	111.1 (ab)	108.4 (b)
30	114.2 (ab)	116.3 (a)	112.1 (ab)	114.2 (a)
60	115.4 (a)	117.3 (a)	120.6 (a)	117.8 (a)
90	119.9 (a)	115.1 (a)	119.1 (a)	118.0 (a)

Means followed by a common letter are not significantly different (Tukey 0.05)
[1]The means of this column are interpreted separately from 0, 50 and 100 N (kg/ha)

In Table 8, it is observed that, in absence of vinasse, tonnage increased with variable N doses from 103.8 to 111.1 TCH with 0 and 100 kg of N/ha respectively. However, in presence of any vinasse level applied, the effect of nitrogen is lower.

Although the nitrogen content of the vinasse is low, it is possible that the addition of this energy-rich material in soils with high carbon content such as Andisols of Guatemala has a 'priming' effect, thus increasing the availability of nitrogen to the crop.

On the other hand, trying to explain why there is a positive effect due to increased vinasse applications, there is an indication that the effluent is contributing to the nitrogen crop needs and it would be correcting at the same time other limiting nutrients in these soils.

Due to the fact of existing soil diversity in Guatemala, it is recommended to have wider evaluations and validate promising treatments at semi-commercial levels in order to reduce N doses where vinasse is applied. This approach will help growers to have information in the short term for their decision-making process over N optimisation and vinasse use.

Nitrogen biological fixation

N biological fixation (NBF) in sugarcane crops is a recent and interesting subject due to the great potential depicted by crop nutrition and nitrogen economy. NBF in sugarcane is supported by the discovery of endophytic diazotrophic bacteria, being *Gluconacetobacter diazotrophicus*, the most studied species related to the process.

The most recent progress refers to the end of the *Gluconacetobacter diazotrophicus* genome sequence (Guedes *et al.* 2008). In the near future, this advance will allow information about bacterial genes interaction with sugarcane genotypes. When the gene decoding process is finished, it will be possible to increase NBF efficiency using Biotechnology (Segundo Urquiaga, personal communication).

In Guatemala, *Gluconacetobacter sp* has been isolated in most sugarcane cultivars, and it has been found that some cultivars like PGM89-968, at an experimental level, is capable of obtaining 50% or more N via NBF (Pérez *et al.* 2005)

Conclusions

The use of reference N:TC ratios of 1.14 and 1.0 for soils with OM<3.0% and soils with OM>3.0% respectively as a decision criterion in nitrogen recommendations permit the optimisation of the investment in chemical nitrogen fertiliser in the sugarcane crop in Guatemala. On the other hand, N doses must be adjusted to fertiliser and sugar prices according to crop N response.

To reduce dependence on nitrogen fertilisers, there are practices that must be taken into account and be optimiced in the short term.

These practices consist of usage of species of green manure adapted to the intercropping system, the use of co-products and, in the mid and long term, there is potential for nitrogen biological fixation in the sugarcane crop.

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STRATEGIES POUR UNE UTILISATION OPTIMALE DES ENGRAIS AZOTES EN CULTURE DE CANNE A SUCRE AU GUATEMALA

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MOTS CLES: Azote, Optimisation, Jachère Verte, Fixation Biologique de N.

Résumé

L'OBJET de ce travail est de présenter des éléments pratiques qui aideront les producteurs de canne à sucre à optimiser leur investissement en matière d'engrais azotés pour la culture de la canne à sucre au Guatemala. Cettte étude est importante à cause de l'augmentation générale du prix des engrais et plus particulièrement celui de l'engrais azoté. Les critères ont basés sur la connaissance de la réponse de la culture à la fertilisation azotée dans la région après 14 années de recherche sur le sujet. La réponse à l'azote est fonction du rendement canne, de la fertilité du sol, de l'âge et du cycle de la culture, ainsi que d'autres variables en relation avec les pratiques agronomiques et le sol. Ainsi, le niveau de fertilisation azotée en usage dans les programmes de fertilisation des industries sucrières peut être ajusté en comparant la quantité d'azote en kg par tonne de canne (N:TC), avec des taux de référence recommandés pour divers types de sol selon leur teneur en matière organique (OM) et d'autres facteurs. Parallèlement, les quantités d'azote doivent être ajustées au prix des engrais et de la canne pour différents groups. En alternative de réduction de la dépendance aux engrais azotés, il y existe des pratiques qui doivent être prises en compte et optimisées à court terme. Ces pratiques portent sur l'usage d'engrais verts en culture intercalaire, l'usage de co-produits et, à moyen et long terme, il y a un potentiel de fixation d'azote par une culture de canne à sucre.

ESTRATEGIAS PARA EL USO ÓPTIMO DE FERTILIZANTES NITROGENADOS EN EL CULTIVO DE LA CAÑA DE AZÚCAR EN GUATEMALA

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PALABRAS CLAVE: Nitrógeno, Optimización, Abonos Verdes, Fijación Biológica de Nitrógeno.

Resumen

EL OBJETIVO del presente trabajo es presentar criterios prácticos que ayuden a los productores a optimizar su inversión en fertilizantes nitrogenados para el cultivo de caña de azúcar en Guatemala. La importancia de este objetivo está relacionada con el incremento general en el precio de los fertilizantes, especialmente de los nitrogenados. Los criterios se basan en el conocimiento de la respuesta del cultivo a la aplicación de N en la región después de 14 años de experiencia en investigación sobre el tema. La respuesta del cultivo al N es una función del rendimiento de caña, fertilidad del suelo, edad del cultivo, ciclo de cultivo y otras variables asociadas con prácticas agronómicas y condiciones del suelo. Como resultado, las dosis de N utilizadas en los programas de fertilización de los ingenios pueden ajustarse comparando la relación de kg de nitrógeno por tonelada de caña (N:TC) con rangos de recomendaciones de referencia para distintos suelos, de acuerdo al contenido de materia orgánica (OM) y otros factores. Además, las dosis de N se deben ajustar al precio de los fertilizantes y del azúcar para diferentes grupos de producción. Como alternativa para reducir la dependencia de fertilizantes nitrogenados, se deben tomar en cuenta algunas prácticas y optimizarlas al corto plazo. Estas practicas consisten en el uso de especies de abonos verdes adaptadas al sistema de cultivo intercalado, el uso de co-productos y, en el mediano y largo plazo, hay potencial para la fijación biológica de nitrógeno en el cultivo de caña de azúcar.