ABSTRACT

The influence of chemical N forms (calcium ammonium nitrate and ammonium sulphate) and time of N fertilizer application on yield and fertilizer N uptake by sugarcane ratoon crops was studied using 15N-labelled fertilizer in four field trials. The results obtained showed that the difference in chemical N form had little impact on both yield and fertilizer N recovery by sugarcane. Withholding N fertilization invariably delayed leaf canopy development and to a lesser extent tiller formation by the sugarcane. However applying the whole N dressing (100 kg N/ha) to coincide with the beginning of the rapid growth stage in December or alternatively splitting the N application so that half the N was top-dressed in September and half in February to prolong the period of rapid growth enhanced fertilizer N recovery though the improvement was not always statistically significant (P=0.10). The observed improvement in fertilizer N use was not accompanied by a corresponding increase in cane or sugar yield. This finding suggests that to obtain increased sugarcane yields from N fertilizer in Mauritius other parameters having a direct impact on sugarcane growth need also to be optimized.

Key words: Ammonium sulphate, calcium ammonium nitrate, timing, sugarcane, growth pattern, yield, N uptake.

INTRODUCTION

The awareness of the economic importance of N losses from cultivated land together with the recognition that a high NO3 concentration in drinking water is potentially harmful to human health have stimulated numerous studies aimed at improving the efficiency of N fertilizer use by crops (Chichester and Smith7, Yadav et al.6, Malhi et al.4). An increase in the proportion of fertilizer N recovered by sugarcane should reduce the fertilizer N fraction susceptible to loss to the environment by surface run-off, leaching, denitrification and NH3 volatilization.

Many factors influencing fertilizer N uptake by plants, such as amount of sunlight, temperature and rainfall distribution however are still manageable or are as yet unpredictable (Harmsen6). Progress in the efficient use of N fertilizer by crops as
Diluted by De Datta, fertilizer management that can be manipulated and which have a bearing on transformation processes causing losses of N from the soil-water system. In this context, as reviewed by Stevens and Laughlin, time of application and chemical N forms can have large effects on N use efficiency by crops.

Field experiments have been conducted using fertilizer N tagged with 15N to assess the effects of timing and of different N carriers on N recovery by sugar cane. The present study making use of 15N-labelled fertilizers was therefore initiated to evaluate the merits of (i) sub-stituting ammonium sulphate, the currently used N carrier for sugar cane in Mauritius, by calcium ammonium nitrate and (ii) matching the timing of N fertilizer application more closely with the boom period of sugarcane growth.

### MATERIALS AND METHODS

**At harvest:**

Field experiments with the following N treatments replicated 4 times in a randomized block design were established at 4 sites with different climates.

- **Control:** 0 kg N (no N)
- **GN:** Calcium ammonium nitrate (100 kg N/ha) applied in September
- **AN:** Ammonium sulphate (100 kg N/ha) applied in September
- **BN:** Ammonium sulphate (100 kg N/ha) applied in December
- **BN:** Ammonium sulphate (100 kg N/ha) split in 2 equal doses in September and February

Relevant characteristics of the 4 sites (Belle Rive, Pamplemousses, Reduit and Union Park) are given in Table 1. About 70% percent of the rainfall in Mauritius occurs as high intensity downpours between December and April. To minimize fertilizer N loss by leaching, sugarcane ratoon crops receive N as early as possible after harvest. This implies that sugarcane harvested at the beginning or middle of the harvest season in July/September is fertilized during the dry and low temperature period when growth is slow. The rapid growth stage of sugarcane ratoons in Mauritius starts in December when the temperature is high and rainfall becomes abundant. This period of boom growth lasts until April.

As reviewed by Keeney and Myers, applying N at the time of rapid plant growth is an obvious way of maximising the efficiency of fertilizer N. For this reason surface-banding 100 kg N/ha along the rows in December to coincide with the beginning of rapid growth and a split treatment with half (50 kg/ha) the N withheld until February to sustain the rapid growth were compared with the current practice of fertilizing in September when growth is generally slow. Because numerous studies (Broadbent and Nakashima, Powelson et al) have shown that crops utilize
TABLE 1. Relevant characteristics of soils at the experimental sites.

<table>
<thead>
<tr>
<th>Sites</th>
<th>Annual Rainfall (mm)</th>
<th>Soil (FAO/UNESCO Classification)</th>
<th>Texture</th>
<th>Clay Mineralogy</th>
<th>pH</th>
<th>Organic Matter (g/kg)</th>
<th>Total N (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pamplemousses</td>
<td>1500</td>
<td>Humic Nitosol</td>
<td>Silty clay</td>
<td>Halloysite &gt; goethite</td>
<td>5.4</td>
<td>30</td>
<td>1890</td>
</tr>
<tr>
<td>Réduit</td>
<td>1500</td>
<td>Humic Nitosol</td>
<td>Silty clay</td>
<td>Halloysite &gt; goethite</td>
<td>6.0</td>
<td>33</td>
<td>2050</td>
</tr>
<tr>
<td>Belle Rive</td>
<td>3800</td>
<td>Humic Acrisol</td>
<td>Silty clay loam</td>
<td>Gibbsite &gt; goethite</td>
<td>4.9</td>
<td>53</td>
<td>2220</td>
</tr>
<tr>
<td>Union Park</td>
<td>3850</td>
<td>Dystric Cambisol</td>
<td>Silty clay loam</td>
<td>Gibbsite &gt; goethite</td>
<td>5.4</td>
<td>85</td>
<td>3810</td>
</tr>
</tbody>
</table>

* 5:2 water/soil suspension
Each treatment plot consisted of four sugarcane rows 10 m long and spaced 1.6 m apart. In each treatment plot, with the exception of the control, \(^{15}\)N-labelled fertilizer was surface-banded along one cane row in both the first and second ratoon crops, the remainder of the plot received the equivalent unlabelled N compound. From the third ratoon crop until the study was discontinued after the fifth ratoon harvest, no \(^{32}\)N-tagged fertilizer was used but unlabelled N fertilizer was applied to all 4 rows of the treatment plots. The \(^{14}\)N-labelled (NH\(_4\))\(_2\)SO\(_4\) contained 0.675% atom excess \(^{15}\)N while the \(^{15}\)NH\(_4\)NO\(_3\) used in two replicates of treatment 2, was tagged with 0.949% atom excess \(^{15}\)N. In the other two plots of the same treatment, \(^{15}\)NH\(_4\)NO\(_3\) with 0.850% atom excess \(^{15}\)N was used. All plots, including the control, also received 350 kg KCl/ha and 250 kg triple superphosphate/ha.

At harvest every year in August, the cane stalks from the central two rows of each treatment plot were weighed to obtain cane yields and then sampled for determination of sucrose content. In addition, at harvest of the first and second ratoon crops 10 stalks from the cane treated with \(^{15}\)N-labelled fertilizer as well as those in the control plots were sampled, dried at 90°C in a forced draught oven and ground to pass a 0.5 mm sieve before analysis for total N and \(^{15}\)N/\(^{14}\)N ratios on the NO1-5 emission spectrometer. During the growth of the first and second ratoon crops tiller counts and leaf area index measurement as outlined by Mongelard\(^{16}\) were performed at intervals of 20 to 30 days in the central 2 rows of all plots except those receiving calcium ammonium nitrate.

RESULTS AND DISCUSSION

Sugar and cane yields

The significant yield response (P = 0.10) to N fertilizer obtained at each site (Table 2) meant that a reliable comparison of the relative merits of the different treatments could be effectively made. There was no difference in yield from using either calcium ammonium nitrate or ammonium sulphate as an N source for sugarcane ratoon crops. This result concurs with that of Yadav et al\(^{17}\) who showed that N carriers had little effect on yields of sugarcane in India.

Although the beneficial value of split N application on crop yield has frequently been recognized in the literature (Muirhead et al\(^{15}\)) the data in Table 2 show that timing of N application to ratoon cane had no real effect on sugarcane yields. This finding lends credibility to the assertion that since leaching of fertilizer N is insignificant in soils of Mauritius (Ng Kee Kwong and Deville\(^{18}\)), there is no sound basis for recommending that N fertilizer be applied to ratoon cane crops immediately after harvest.
TABLE 2. Influence of time of N fertilizer application and N carriers on sugarcane ratoon crop yields (mean of five ratoon crops at four sites in Mauritius.

<table>
<thead>
<tr>
<th>Treatment*</th>
<th>CANE YIELD (t/ha)</th>
<th></th>
<th></th>
<th></th>
<th>SUGAR YIELD (t/ha)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Réduit (M 13/56)**</td>
<td>Pamplenourse (M 13/56)</td>
<td>Union Park (M 574/62)</td>
<td>Belle Rive (M 574/62)</td>
<td>Mean 4 sites</td>
<td>Réduit</td>
<td>Pamplenourse</td>
<td>Union Park</td>
</tr>
<tr>
<td>Control (no N)</td>
<td>52.8</td>
<td>55.2</td>
<td>46.7</td>
<td>50.7</td>
<td>51.4</td>
<td>6.10</td>
<td>6.17</td>
<td>5.13</td>
</tr>
<tr>
<td>Calcium ammonium nitrate in September</td>
<td>79.8</td>
<td>74.9</td>
<td>75.7</td>
<td>71.8</td>
<td>75.6</td>
<td>9.21</td>
<td>8.65</td>
<td>8.59</td>
</tr>
<tr>
<td>Ammonium sulphate in September</td>
<td>81.0</td>
<td>78.1</td>
<td>75.8</td>
<td>71.8</td>
<td>76.7</td>
<td>9.13</td>
<td>8.62</td>
<td>8.56</td>
</tr>
<tr>
<td>Ammonium sulphate in December</td>
<td>80.9</td>
<td>82.6</td>
<td>76.0</td>
<td>71.0</td>
<td>77.6</td>
<td>9.03</td>
<td>9.14</td>
<td>8.42</td>
</tr>
<tr>
<td>Ammonium sulphate in two equal applications (September/February)</td>
<td>80.9</td>
<td>83.3</td>
<td>76.0</td>
<td>71.0</td>
<td>77.8</td>
<td>9.05</td>
<td>-9.16</td>
<td>8.27</td>
</tr>
<tr>
<td>LSD (P = 0.10)</td>
<td>6.9</td>
<td>5.2</td>
<td>5.1</td>
<td>5.3</td>
<td>5.9</td>
<td>0.91</td>
<td>0.57</td>
<td>0.62</td>
</tr>
</tbody>
</table>

* All treatments except the control received 100 kg N/ha
** Variety
Sugarcane growth pattern

Although timing of N fertilizer application to sugarcane ratoon crops had no real effect on sugar and cane yields (Table 2), it nevertheless changed the growth pattern of the sugarcane plant. Fertilizer N when applied in September, in spite of the prevailing dry conditions, stimulated tillering and leaf canopy development (Figure 1 and 2), a feature which is highly desirable if interception of radiant energy for photosynthesis is to be maximized (Anderson and Peterson). Yadav et al. have also noted that an initially high N concentration in the sugarcane plant was necessary for profuse tillering. The present study also showed that leaf development was greatly influenced by the N supply, leaf expansion being more extensive with 100 kg N/ha than with only 50 kg N/ha applied in September (Figure 2).

When N fertilizer application was delayed until December to coincide with the beginning of the rapid growth stage, tiller development and in particular canopy formation were both slow prior to the application of N (Figures 1 and 2). Once the N was applied in December a rapid compensatory expansion of the leaf surface took place accompanied by a more gradual rise in tiller number. The point that needs to be emphasized however is that despite the fast expansion of leaf canopy and the tiller formation which occurred after applying the N in December, the level attained by these growth parameters was not higher than that achieved by applying the N in September. This observation may help to explain why, in spite of a better synchrony of N supply with the rapid growth stage, an increase in sugar or cane yield was not obtained (Table 2). For probably the same reason, split dressings of N as practiced in the present study did not increase ratoon cane yields above those obtained when all the fertilizer N was applied in September. The data in Figures 1 and 2 further demonstrate that the sugarcane plant is capable of withstanding growth stress, in this instance an N stress, without its yield being significantly impaired.

N recovery by sugarcane

As reviewed by Jenkinson et al., plant recovery of applied N may be estimated either by 15N dilution or by the difference method. When evaluated by the difference method, however, fertilizer N uptake by sugarcane was found in the present study to be invariably higher than when determined by 15N dilution (Table 3). Similar observations have been reported elsewhere (Jansson, Steel et al., Roberts and Janzen). Causes of the dissimilar values of fertilizer N use efficiency obtained by the two techniques have been extensively discussed (e.g. Hauck and Bremmer, Harmsen and Moraghan). While the difference method measures the net effect of N fertilization on the crop, 15N dilution determines how much 15N was taken up by the crop as modified by the pool substitution of labelled N with unlabelled N (Jenkinson et al.). As a result of pool substitution, the 15N dilution technique most often underestimates fertilizer N recovery by plants (Jansson, Hart et al.). Accordingly the values of fertilizer N use efficiency as low as 10% found in the present
FIGURE 2. Influence of timing of N fertilizer application on the pattern of leaf canopy development of sugarcane ratoon crops at four sites in Mauritius, namely at Pamplemousses, Réduit, Union Park and Belle Rive.
study by the $^{15}$N trace method (Table 3) may not be an accurate reflection of fertilizer N utilization by the sugarcane ratoon crops. Although the two methods differed in their estimates of fertilizer N uptake by sugarcane, the same inferences may be drawn in respect of the relative performance of the various N treatments. No worthwhile improvement in fertilizer N use was found from applying either calcium ammonium nitrate or ammonium sulphate as the N source to sugarcane (Table 3) although the NO$_3$ component of the calcium ammonium nitrate had apparently been utilized more efficiently by sugarcane than had the NH$_4$ counterpart. This is in agreement with studies comparing the uptake of NO$_3$ with that of NH$_4$ (Broadbent and Nakshima, Dev and Rennie, Recous et al).

Many reasons have been proffered to explain why NO$_3$ tends to be more efficiently recovered by plants than NH$_4$. For instance when NH$_4$ and NO$_3$ are simultaneously available in the soil as happened with calcium ammonium nitrate, the preference of the heterotrophic microflora for NH$_4$ would deplete first and exclusively the NH$_4$ pool, NO$_3$ being immobilized only after NH$_4$ has been exhausted (Rice and Tiedge, Recous et al). The NO$_3$ component would in consequence be relatively more available in soil for plant uptake than the NH$_4$ fraction. In showing that there would in the end be no difference in fertilizer N recovery by sugarcane whether calcium ammonium nitrate or ammonium sulphate was the N carrier (Table 3) the present study supports Recous et al who indicated that mechanisms predominant during the later part of the growth cycle would negate any advantage derived at the beginning of the cycle. The NH$_4$ fraction for instance may have had the advantage that with more N being incorporated into the soil biomass, Longer term effects may be expected from it than from NO$_3$ (Steel et al).

The data in Table 3 shows that synchrony of N supply with rapid plant growth provided better scope for enhancing fertilizer N uptake by sugarcane than did the choice of different N carriers. From this viewpoint, fertilizer N use by sugarcane ratoons in Mauritius was enhanced by delaying N fertilizer application until rapid growth began in December, although the improvement was not always significant at P=0.10 (Table 3). Split application such that part of the N would be readily available during the period of rapid vegetative growth would generally also enhance fertilizer N use efficiency by ratoon cane in Mauritius.

The improvement in fertilizer N uptake by sugarcane ratoons as a result of a more accurate synchrony of N supply with rapid crop growth (Table 3) was, as shown in Table 2, not accompanied by a rise in sugar or cane yields. This observation emphasizes the fact that N fertilizer application is not the sole determinant of yield. In reality, as pointed out by Newbold, achievement of yield potentials must also depend on improvement of such parameters as soil physical and general chemical conditions, moisture control and good management practices.
<table>
<thead>
<tr>
<th>Treatment**</th>
<th>Réduit* (M13/56)</th>
<th>Pamplemousses (M13/56)</th>
<th>Union Park (M574/62)</th>
<th>Belle Rive (M574/62)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total N</td>
<td>Fertilizer N recovery</td>
<td>Total N</td>
<td>Fertilizer N recovery</td>
</tr>
<tr>
<td></td>
<td></td>
<td>¹⁵N Difference</td>
<td></td>
<td>¹⁵N Difference</td>
</tr>
<tr>
<td>Control (no N)</td>
<td>70.8</td>
<td>-</td>
<td>67.1</td>
<td>-</td>
</tr>
<tr>
<td>Calcium ammonium nitrate in September</td>
<td>93.0</td>
<td>-16.7</td>
<td>22.2</td>
<td>100.3</td>
</tr>
<tr>
<td>Ammonium sulphate in September</td>
<td>101.8</td>
<td>-18.0</td>
<td>31.0</td>
<td>102.5</td>
</tr>
<tr>
<td>Ammonium sulphate in December</td>
<td>115.1</td>
<td>20.0</td>
<td>44.3</td>
<td>123.0</td>
</tr>
<tr>
<td>Ammonium sulphate in two equal applications (September/February)</td>
<td>91.1</td>
<td>-15.1</td>
<td>20.3</td>
<td>107.7</td>
</tr>
<tr>
<td>LSD (P = 0.10)</td>
<td>13.6</td>
<td>1.7</td>
<td>13.1</td>
<td>9.4</td>
</tr>
</tbody>
</table>

* Site and variety
** All treatments except the control received 100 kg N/ha. Fertilizer N recovery was determined by ¹⁵N dilution and by difference method
*** Data in parentheses indicate kg N/ha coming from the NO₃ component of calcium ammonium nitrate
CONCLUSIONS

Fertilizer N management in sugarcane cultivation in Mauritius hinges on the storage in soil of N to be utilized by the plant during its growth. Such a practice of storing a large amount of N in the soil through N fertilizer application has contributed to the attainment of the level of sugar yield in Mauritius and elsewhere. In future fertilizer practices may have to be altered to maintain the same level of sugar production without imposing health hazards on consumers or groundwater or promoting algal growth in stored water. The present study shows that synchronizing the timing of N applied to soil with the stage of rapid plant growth provides some scope for minimizing the pollutant potential of fertilizer N, without impairing sugarcane yields. By showing that the concept of synchrony, by applying either all or part of the N during the boom phase of growth, did not substantially improve fertilizer N recovery, the present study demonstrates that our ability to manipulate N fertilizer use efficiency by rainfed sugarcane ratoon crops tends to be limited. Because of the diversity of soil and climate regimes no single fertilizer management practice should be expected to suit all crop situations.

REFERENCES


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POUR UNE MEILLEURE UTILISATION DE L’AZOTE PAR LES REPousseS DE LA CANNE À SUCRE À L’ILE MAURICE

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RESUME

L’effet de la forme et de la période d’application de l’engrais azoté (ammonitré de chaux ou sulfate d’ammoniaque) sur le rendement et l’utilisation de l’azote par les repousses fut étudié à l’aide d’engrais marqués au 15N dans 4 essais au champ. Les résultats ont révélé que le forme de l’engrais n’avait aucun effet sur le rendement ou sur l’utilisation de N par la canne à sucre. Par contre, un freinage dans l’apport de N- soit dans le temps ou dans la dose-causa un retard dans le développement foliaire et, dans une moindre mesure, dans la formation des tiges. L’apport de N en une dose (100 kg/ha) au début de la période de poussée, en décembre, ou en deux doses fractionnées, la 2ème étant fournie en février afin d’étendre la période végétative améliora l’utilisation de N. Cette amélioration n’est toutefois pas toujours significative (P=0.10) et n’est pas accompagnée d’une augmentation de rendement (canne ou sucre). Ces résultats suggèrent que d’autres conditions ayant une influence directe sur la poussée de la canne doivent être optimisées avant que la fertilisation azotée ne puisse donner lieu à des augmentations de rendement.
RESUMEN

Se hizo un estudio sobre la influencia de productos químicos nitrogenados (Nitrato de amonio y Sulfato de amonio) y época de fertilización, en los rendimientos y asimilación de N en retoños de caña de azúcar usando fertilizantes marcados con $^{15}$N en cuatro pruebas. Los resultados obtenidos indican que las diferencias en las distintas fuentes de N, tienen poca influencia en los rendimientos y asimilación de N. Deteniendo la fertilización nitrogenada se demora el cierre de la caña, y hasta cierto punto el macollamiento (hijería). Sin embargo, al aplicar el total de N (100 kg/ha) de manera que coincida con el comienzo del desarrollo activo en Diciembre, o dividiendo la aplicación de manera que la mitad fuese hecha en septiembre y la otra mitad en febrero, para así prolongar el periodo de desarrollo activo, se estima la asimilación de N aunque no siempre es estadísticamente significativo en $P = 0.10$. Las ventajas con el uso de la fertilización nitrogenada no iban a la par con el aumento del rendimiento; tanto en caña como en azúcar. Lo antes mencionado significa que para conseguir altos rendimientos mediante la aplicación de N en nuestras condiciones, deben de optimizarse otros parámetros que tengan un impacto directo en el desarrollo de la caña de azúcar.

Palabras claves: Sulfato de amonio, Nitrato Cálcico de Amonio, monitoreando la caña de azúcar, modelo de desarrollo, rendimiento, asimilación de N.