Effect of Nitrogen on Growth and Yield of Sugarcane

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ABSTRACT

Sugarcane is a tropical plant and requires a warm, humid climate for good growth, but is grown in the subtropics of Pakistan with semiarid climate. Sugarcane responds well to higher N application rates and this study utilized crop yield and nitrogen use efficiency as two important criteria of crop performance to identify optimum nitrogen levels. A field experiment was conducted for two consecutive years at Ayub Agricultural Research Institute, Faisalabad, Pakistan. The treatments were comprised of three nitrogen rates (recommended, 168 kg ha⁻¹; 50% more than recommended, 252 kg ha⁻¹ and 100% more than recommended, 336 kg ha⁻¹) applied full at planting or at 90 days after planting (DAP) or in two equal splits, i.e., 50% at planting and 50% at 90 DAS. A control (no nitrogen) was also utilized. Results revealed significant effects of dose and time of nitrogen application on most studied parameters except commercial cane sugar (%). The maximum stripped cane yield and sugar yield were recorded when nitrogen at 252 kg ha⁻¹ was applied in two equal splits, although high N rate (336 kg ha⁻¹) was not inferior statistically. Crop growth rate and leaf area duration were maximized with high nitrogen dose applied in two equal splits. Nitrogen use efficiencies also varied greatly among different treatments. The results suggest a need for revision of already recommended N rates in sugarcane growing areas of Pakistan and possible other areas of the world.

INTRODUCTION

Sugarcane is a tropical plant (Humbert, 1968) and requires warm, humid climate for good growth. However, it is being grown throughout the sub tropical land surface of earth between latitude 30° N and 35° S; it can be grown in a wide variety of soil types ranging from sandy loam to heavy clay (Nazir, 1994). Pakistan lies in the sub tropics with semi arid climatic conditions where sugarcane is grown within an area of 1.029 million hectares with a total annual stripped cane production of 50.04 million tons giving an average stripped cane yield of 48.64 t ha⁻¹ (Govt. of Pakistan, 2010). This yield is far lower than most of sugarcane growing countries; Guatemala (107.33 t ha⁻¹), Egypt (90.24 t ha⁻¹), Australia (86.66 t ha⁻¹), Brazil (77.63 t ha⁻¹), Mexico (75.49 t ha⁻¹), Indonesia (72.55 t ha⁻¹) etc. (FAO, 2009).

A number of factors are responsible for low yield of sugarcane in Pakistan including scarcity of irrigation water, low plant population per unit area and imbalanced as well as inadequate use of fertilizers. Sugarcane is a long duration crop that requires a high quantity of
nutrients. Moreover, continuous planting of sugarcane in the same field depletes the soil nutrients. A crop having yield of 100 t ha\(^{-1}\) removes 207 kg N, 30 kg P\(_2\)O\(_5\) and 233 kg K\(_2\)O from the soil (Jagtap et al., 2006). Therefore these elements must be added in adequate quantities in the root zone of the crop to obtain higher yield. Among these elements N is the primary nutrient limiting sugarcane production (Wiedenfeld and Enciso, 2008) throughout the world. Differences in soils (Anderson, 1990), environmental factors (Knust, 1954) and sugarcane cultivars (Verna, 1965) limit the usefulness of research from other areas. World recommended rates of N fertilizer for sugarcane production vary between 45 and 300 kg ha\(^{-1}\) yr\(^{-1}\) (Srivastava and Suarez, 1992).

Dry matter accumulation increased significantly when a high N rate (225 kg ha\(^{-1}\)) was compared with 175 or 150 kg N ha\(^{-1}\) (Lal, 1991). The large amounts of N fertilizer applied to most cropping systems support high yields but may result in excessive N levels in groundwater or surface water (Robinson et al., 2007). Nitrogen use efficiency (NUE) has been well studied in many crop species, especially grain crops, where kernel N content is a key harvest index. In contrast NUE in sugarcane has not been properly understood, since N is an insignificant component of the harvested product. However, increasing concerns about pollution from N run off due to excessive fertilization demand an improved understanding of NUE in sugarcane, so that applied N is effectively utilized (Whan et al., 2007). Moreover, unlike in cereals, the longer span of sugarcane growth presents different challenges for efficient N use. For many locations, the depletion of plant-available soil N over time justifies the need for split application of the yearly total N rate. Wiedenfeld (1997) observed a progressive decline in soil NO\(_3\)-N concentration with delay in soil sampling after N fertilizer application. Proper land management programs should include the establishment of fertilization regimes that optimize growth with minimum nutrient leaching (Van Miegroet et al., 1994). These involve adjusting fertilizer application rates and frequencies to maximize N utilization while minimizing N leaching from the rooting zone (Lee and Jose, 2005).

Stanford and Ayers (1964) recommended that only a small proportion of the N fertilizer be applied in the establishment period of a 24-month cane crop. Knust (1954) reported that split N fertilizer application on a 12-month cane crop, however, may delay maturity and decrease sucrose (Samuels and Alers-Alers, 1963). Early N fertilizer application resulted in lower cane yield, while the late fertilizer application resulted in lower sugar yield due to lower juice quality rather than any loss in growth (Wiedenfeld, 1997). Application of the recommended dose of fertilizer (150 kg ha\(^{-1}\)) in two equal splits either at planting and within 30 days after planting (DAP) or at 30 and 60 DAP benefited the crop so that more millable canes were produced at harvest which ultimately resulted in increased cane and sugar yield (Lakshmi et al., 2003). Application of N in splits increased the fertilization program cost, but its use was justified by increased sugar yield (Obreza and Pitts, 1998). In Pakistan around 85 kg ha\(^{-1}\) of N, 21 kg ha\(^{-1}\) of P\(_2\)O\(_5\) and 0.73 kg ha\(^{-1}\) of K\(_2\)O are applied (Govt. of Pakistan, 2003) which seems to be inadequate and imbalanced to optimize the production potential of the crop. With the introduction of high-yielding varieties with high-nutrient requirements and intensive, exhaustive crop rotation, sugarcane is becoming more responsive to higher levels of fertilizer than recommended rates. The present study has been designed to explore the production potential of spring planted sugarcane at higher rates of N and to improve the nutrient use efficiency of sugarcane by optimizing the rate and timing of N application.
MATERIALS AND METHODS

A field experiment was conducted for two consecutive years during the springs of 2006 and 2007 at Sugarcane Research Institute, Ayub Agricultural Research Institute, Faisalabad, Pakistan (31°25’ N, 73°09’ E).

Physico-chemical analysis of experimental soil was conducted before planting and after harvest of the crop for each experimental unit during both years. Soil samples did not differ significantly, for the studied parameters, among different treatments and between years. Therefore, average values are presented in Table 1. The soil analysis indicated that the experimental soil was a loam with slight alkaline reaction which represents most of the sugarcane growing area of Pakistan. The soil seemed to be productive without any problem for crop husbandry. The soil was medium in K but deficient in N, P and organic matter.

Sugarcane plants were analyzed for determination of N uptake. The procedures used for physico-chemical analysis of all the aforementioned soil and plant samples are given in “Analysis manual of soil, plant and water” (Govt. of Pakistan, 1984).

The experiment was comprised of ten treatments including no N (T₁), 168 kg N ha⁻¹ at planting (T₂), 168 kg N ha⁻¹ at 90 DAS (T₃), 84 kg N ha⁻¹ at planting + 84 kg N ha⁻¹ at 90 DAS (T₄), 252 kg N ha⁻¹ at planting (T₅), 252 kg N ha⁻¹ at 90 DAS (T₆), 126 kg N ha⁻¹ at planting + 126 kg N ha⁻¹ at 90 DAS (T₇), 336 kg N ha⁻¹ at planting (T₈), 336 kg N ha⁻¹ at 90 DAS (T₉) and 168 kg N ha⁻¹ at planting + 168 kg N ha⁻¹ at 90 DAS (T₁₀). The recommended N rate for sugarcane crop in Punjab province of Pakistan is 168 kg ha⁻¹.

The experiment was laid out according to a Randomized Complete Block Design (RCBD) having three replications with a net plot size of 6 m x 8 m. Each year before seed bed preparation, pre-soaking irrigation of 10 cm depth was applied. When the soil reached the proper moisture level for planting, the seed bed was prepared by cultivating 2 times with a tractor mounted cultivator to a depth of 10-12 cm followed by leveling. Thereafter chiseling was done twice followed by leveling and finally trenches were made by use of a ridger and spaced 1.2 m apart. Sugarcane variety HSF-240 was sown on 5 March 2006 for the first year and 7 March 2007 for the second year. Seed rate of 75,000 double budded setts (DBS) per ha was used and it was planted end to end in two parallel rows within the trenches.

Phosphorus (P) and potash (K) were each applied at 112 kg ha⁻¹ in trenches at the time of planting in the form of SSP (Single Super Phosphate) and SOP (Sulfate of Potash) respectively, while N fertilizer was applied in the form of urea as per treatments.

Insect pests were kept under the threshold level through chemical control. Chloropyriphos was applied @ 5 L ha⁻¹ with the 1st irrigation after planting to control the termites. Carbofuran granules @ 35 kg ha⁻¹ were applied at 90 days after planting to control borers. Weeds in the crop were controlled through the application of premixed formulation of Ametryn + Atrazine (@ 2 kg a.i. ha⁻¹) five days after first irrigation with a knapsack sprayer and also with hoeing. In addition to rainfall, the crop received a total of fifteen irrigations (1500 mm) each year.
The crop was harvested manually at its physiological maturity (Brix = 20%) on 16 December 2006 and 18 December 2007. Data on various growth and yield parameters of the crop were recorded by using standard procedures during the course of study. Number of millable canes was counted from 28.8 m² and was converted to millable canes m⁻². At harvest the length of ten randomly selected canes was measured from base (ground level) to the top (highest node) and then averaged. At harvest the diameter of ten randomly selected canes from the base, middle and top internodes was measured and averaged. Then diameter was converted to cane girth by using the following formula (Mali et al., 1982).

\[
\text{Cane girth (cm)} = \text{diameter (cm)} \times \frac{22}{7}
\]

All stripped canes of each plot (28.8 m²) were weighed for stripped cane yield (t ha⁻¹).

Agronomic nutrient use efficiency (NUEₐ) was determined by the following formula (SSSP, 1994):

\[
\text{NUEₐ (kg kg}^{-1}\text{)} = \frac{\text{Stripped cane yield}_F (\text{kg}) - \text{Stripped cane yield}_C (\text{kg})}{\text{Fertilizer nutrients applied (kg nutrients)}}
\]

Total N uptake by shoots of crop in each treatment was converted into ha⁻¹ and the physiological nutrient efficiency (NUEₚ) was determined by the formula (SSSP, 1994) as follow:

\[
\text{NUEₚ (kg kg}^{-1}\text{)} = \frac{\text{Stripped cane yield}_F (\text{kg}) - \text{Stripped cane yield}_C (\text{kg})}{\text{Nutrient uptake}_F (\text{kg ha}^{-1}) - \text{nutrient uptake}_C (\text{kg ha}^{-1})}
\]

Where

F = Fertilized crop
C = Control crop

Total sugar (t ha⁻¹) was determined by the following formula:

\[
\text{Total sugar (t ha}^{-1}\text{)} = \frac{\text{Stripped cane yield (t ha}^{-1}\text{)} \times \text{CCS\%}}{100}
\]

Where

CCS = commercial cane sugar
Commercial cane sugar (CCS %) was calculated by using the method of Spancer and Meade (1963).

\[
\text{CCS (\%)} = \frac{3}{2}P \left(1 - \frac{F + 5}{100}\right) - \frac{1}{2}B \left(1 - \frac{F + 3}{100}\right)
\]

P = Pol % in juice
B = Brix % in juice
F = Fiber % in juice

Plants from an area of 0.6 m² in each treatment were harvested at ground level on 30 day intervals. Fresh and dry weights of component fractions of plants (leaves and stalks) were determined. A sub sample of each fraction was taken to dry in oven at 70°C to constant weight.
Total shoot dry weight was obtained by summing weight of all components and converted to m⁻². Also an appropriate sub sample (50 g) of green laminae was used to record leaf area using leaf area meter (Cl-202 Area meter CID, Inc). From the measurement of leaf area and dry weights following parameters of growth were calculated:

Leaf area duration (LAD) (days) = \((LAI_t1 + LAI_t2) \times (t_2 - t_1)^{1/2}\) (Hunt, 1978)

Where
- \(LAI_t1\) = Leaf area index at \(t_1\)
- \(LAI_t2\) = Leaf area index at \(t_2\)
- \(t_1\) = Time of 1st observation
- \(t_2\) = Time of 2nd observation

Crop growth rate (CGR) (g m⁻² day⁻¹) = \(\frac{W_2 - W_1}{t_2 - t_1}\) (Hunt, 1978)

Where
- \(W_1\) = Shoot dry weight m⁻² at \(t_1\)
- \(W_2\) = Shoot dry weight m⁻² at \(t_2\)
- \(t_1\) = Time of 1st harvest
- \(t_2\) = Time of 2nd harvest

Meteorological data
Meteorological data for growing periods of the crop were collected from the Observatory, Pakistan Agricultural Research Council (PARC) unit, Ayub Agriculture Research Institute, Faisalabad, Pakistan (Fig. 1).

Statistical analysis and graphics
Data collected from both experiments were statistically analyzed by the computer package MSTATC (Anonymous, 1986) and differences among the treatments’ means were compared for significance by using the Duncan’s New Multiple Range Test (DNMR) at the 5% probability level (Steel et al., 1997). STATISTICA-V-5.5 (developed by StatSoft) was used for contrast analysis. The computer package SPC (Software Publishing Corporation) Harvard Graphics was used to prepare the graphs.

RESULTS AND DISCUSSION

Effect of varied dose and time of N application on number of millable canes (MC) m⁻², cane length (CL), cane girth (CG) and stripped cane yield (SCY) was significant \((P<0.05)\) (Table 3a). These parameters gained maximum values when the crop was supplied with a total of 252 kg N ha⁻¹ in two equal splits i.e., half at planting and half at 90 days after planting (DAP) (T7). This was closely followed in magnitude by the crop that received an even higher dose of N (336 kg ha⁻¹) but again in two equal splits i.e., half at planting and half at 90 days after planting (T10). Both these treatments performed significantly better than the control (T1) as well as than the lower dose of N (168 kg ha⁻¹) (T’s 2, 3 and 4) for all the above mentioned parameters. Considering contrast analysis (Table 3b) it is clear that two contrasts relevant to rate of N application i.e., 168 vs 252 and 168 vs 336 kg ha⁻¹ were significant for all the four parameters under discussion, while one contrast, i.e 252 vs 336 kg N ha⁻¹ was non-significant for all these
parameters. The three meaningful contrasts related to time of N application (all N at planting vs all at 90 DAS, all N at planting vs splits and all N at 90 DAS vs splits) were non-significant only for MC but significant for CL, CG and SCY.

Number of millable canes per unit area is an important yield determining parameter in sugarcane. Maximum and statistically equivalent number of millable canes (m⁻²) was observed in T₇ and T₁₀ where higher dose of N i.e. 252 and 336 kg ha⁻¹ was applied. The more millable canes at higher levels of N might be due to availability of nutrients sufficient to meet the requirement of the cane per unit area. Higher number of millable canes per unit area with increasing dose of N was also observed by Ahmad et al. (1995), Kolage et al. (2001), Afzal et al. (2003) and Sinha et al. (2005). However, Singha (2002) and Mishra et al. (2004) found no significant difference in number of millable canes; in contrast with the present findings.

Significantly higher cane length in T₇ and T₁₀ was attributed to increased availability of nutrients, which enhanced the crop growth rate (Fig. 2) leading to greater length of internodes (data not shown) accounting for longer canes. Rate and time of N fertilizer application affected the height of sugarcane plants (Wiedenfeld and Enciso 2008). Gana (2008) found increase in stalk length with increasing N rate but this increase was nonsignificant above 120 kg ha⁻¹. Maximum cane girth in T₇ (126 kg N ha⁻¹ at planting + 126 kg N ha⁻¹ at 90 DAS) might be due to availability of balanced nutrition at the time of cane formation that resulted in better crop growth rate (Fig. 2). These findings are in accordance with those of Bangar and Sharma (1992), Mahboob et al. (2000) and Shafshak et al. (2001) who obtained maximum cane girth at higher doses of NPK. More cane girth in 2006 (Table 3a) might be due to lower temperature, more rainfall and higher relative humidity than in 2007 (Fig. 1).

Higher stripped cane yield at higher levels of nutrients, particularly in T₇ and T₁₀ was attributed to more cane length, cane girth and number of millable canes. Significant increase in stripped cane yield in response to higher levels of N (Bastidas et al., 1989; Bangar et al., 1994; Mishra et al., 2004 and Singh et al., 2004) has already been reported. Sugarcane growth and yield were lower with no-split applications (Table 3) indicating that N applied early in the crop (full at planting) might not have remained available late in the season due to leaching concerns while delayed applications (90 DAS) might have enhanced the detrimental effects that occur when late season excess N availability interferes with uptake of other nutrients and delays crop maturity (Thomas et al., 1985). Split applications of N produced a significant increase in cane yields in other studies (Obreza et al., 1998; Wiedenfeld and Enciso, 2008). Stripped cane yield was more in 2006 than 2007 probably because of more rainfall, high relative humidity and comparatively low temperature during the former year (Fig. 1). It has been suggested that sugarcane growth may decline or cease when temperatures are high (> 38 °C) even if water is not limiting (Inman-Bamper, 2004).

The real cane quality is reflected by its commercial cane sugar percentage. Data presented in Table 4a revealed non-significant effects of dose and time of N application on percentage of commercial cane sugar (CCS %) of spring planted sugarcane during both the years (2006 and 2007). Data exhibited a non-significant numerical increase in CCS % up to 168 kg N ha⁻¹, either applied at planting, at 90 DAS or half at planting + half at 90 DAS, which then trended lower at higher levels of N in 2006 and 2007. This non-significant effect on CCS %
might be due to non-significant effects on brix, sucrose and fiber (data not shown but used in CCS calculations) percentages. Jeyaraman and Alagudurai (2003), Patel et al. (2004) and Kadam et al. (2005) also reported non-significant difference in CCS % at varied levels of N. While Ali et al. (2002) noted a significant decrease in CCS % at higher rates of N. Gawander et al. (2004) found that cane yield and sucrose content are significantly interrelated with applied fertilizers.

Effect of dose and time of N application were significant on total sugar yield, which is cumulative effect of stripped cane yield (t ha\(^{-1}\)) and CCS (%). In 2006, the maximum sugar yield (12.8 t ha\(^{-1}\)) was recorded in T\(_7\) (126 kg N ha\(^{-1}\) at planting + 126 kg N ha\(^{-1}\) at 90 DAS) and it was statistically equal with T\(_{10}\) (168 kg N ha\(^{-1}\) at planting + 168 kg N ha\(^{-1}\) at 90 DAS) which produced 12.1 t ha\(^{-1}\) sugar yield. The minimum sugar yield (5.5 t ha\(^{-1}\)) was measured in T\(_1\) (no N). Almost similar results were noted in 2007. Contrast analysis exhibited that all the contrasts were significant except for C\(_3\) which was non-significant where comparison of 252 kg N ha\(^{-1}\) with 336 kg N ha\(^{-1}\) was made during both the years i.e. 2006 and 2007. These significant differences in sugar yield were ascribed to different stripped cane yield (table 3). Differences in sugar yield in response to different fertilizer levels were also reported by Afzal et al. (2003); Jeyaraman and Alagudurai (2003); Raskar and Bhoi (2003); Sinha et al. (2005) and Jagtap et al. (2006). Contrary to that, Devi et al. (1990) and Ramesh and Varghese (2000) did not record any appreciable difference in sugar yield due to different fertilizer treatments while a numeric increase in sugar yield with increasing N rate at each recorded harvest has been reported by Muchovej and Newman (2004).

Data given in Table 4a revealed significant effect of dose and time of N application on agronomic nutrient use efficiency (NUE\(_A\)) of sugarcane during both crop years (2006 and 2007). In 2006, significantly maximum NUE\(_A\) (241 kg kg\(^{-1}\) of N) was recorded in T\(_7\) (126 kg N ha\(^{-1}\) at planting + 126 kg N ha\(^{-1}\) at 90 DAS), followed by T\(_4\) (84 kg N ha\(^{-1}\) at planting + 84 kg N ha\(^{-1}\) at 90 DAS) giving NUE\(_A\) of 194 kg kg\(^{-1}\) of N while minimum NUE\(_A\) (83 kg kg\(^{-1}\) of N) was observed in T\(_3\) (168 kg N ha\(^{-1}\) at 90 DAS) which was statistically equal with T\(_9\) (336 kg N ha\(^{-1}\) at 90 DAS) and T\(_8\) (336 kg N ha\(^{-1}\) at planting) with a NUE\(_A\) of 102 kg kg\(^{-1}\) of N and 123 kg kg\(^{-1}\) of N, respectively. Almost similar results were found in 2007. All contrasts were significant during both years (2006 and 2007) except C\(_3\) (168 kg N ha\(^{-1}\) VS 336 kg N ha\(^{-1}\)) for NUE\(_A\).

Significant effects on physiological nutrient use efficiency (NUE\(_P\)) were observed during both crop years (2006 and 2007). In 2006 the maximum NUE\(_P\) (377 kg kg\(^{-1}\) of N) was recorded in T\(_7\) (126 kg N ha\(^{-1}\) at planting + 126 kg N ha\(^{-1}\) at 90 DAS) which was statistically equal with T\(_{10}\) (168 kg N ha\(^{-1}\) at planting + 168 kg N ha\(^{-1}\) at 90 DAS) and T\(_4\) (84 kg N ha\(^{-1}\) at planting +84 kg N ha\(^{-1}\) at 90 DAS). During 2007, again the maximum NUE\(_P\) of 384 kg kg\(^{-1}\) of N was noted in T\(_7\) and it was statistically equal with T\(_{10}\). The minimum NUE\(_P\) was for T\(_3\) (168 kg N ha\(^{-1}\) at 90 DAS), during both years. All contrasts exhibited significant differences during both years except C\(_3\) (252 kg N ha\(^{-1}\) VS 336 kg N ha\(^{-1}\)) in 2006 while C\(_1\) (168 kg N ha\(^{-1}\) VS 252 kg N ha\(^{-1}\)), C\(_2\) (168 kg N ha\(^{-1}\) VS 336 kg N ha\(^{-1}\)) and C\(_3\) (252 kg N ha\(^{-1}\) VS 336 kg N ha\(^{-1}\)) in 2007 were non-significant.

Maximum NUE\(_A\) in T\(_7\) was perhaps due to more stripped cane yield. More NUE\(_P\) might be attributed to better distribution of N throughout the crop with treatment T\(_7\). Sharma and Gupta (1991) reported that NUE\(_P\) in sugarcane was significantly higher at higher fertilizer levels, however, the maximum N rates were higher in our study. Higher N rate may have made the
vegetation growth period longer and shortened the period of sugar accumulation. A better balance was achieved with a medium fertilizer dose (Koochekzadeh et al., 2009). Lee and Jose (2005) revealed that increasing N application rates raises N leaching without making any difference in woody plant growth.

Periodic data regarding leaf area duration (LAD) as a function of dose and time of N application of spring planted sugarcane during 2006 and 2007 are depicted in Fig. 3. Visible differences in LAD at varied levels of N and time of its application were observed. However, the differences were less visible at the start and became more pronounced as the crop advanced towards physiological maturity. Higher and comparative total LAD values of 1260, 1259, 1250, 1222 and 1219 were recorded at T7 (126 kg N ha\(^{-1}\) at planting +126 kg N ha\(^{-1}\) at 90 DAS), T10 (168 kg N ha\(^{-1}\) at planting +168 kg N ha\(^{-1}\) at 90 DAS), T8 (336 kg N ha\(^{-1}\) at planting), T5 (252 kg N ha\(^{-1}\) at planting) and T9 (336 kg N ha\(^{-1}\) at 90 DAS), respectively, in 2006. An almost similar trend was noted in 2007. According to Gardner et al. (1988) LAD expresses the magnitude and persistence of the leaf area during the crop growth period. Increase in LAD with increasing N rate was attributed to more LAI. Increasing N rate resulted in increased LAI but the response was quadratic in a study by Wiedenfeld and Enciso (2008).

Data pertaining to periodic crop growth rate (CGR) are depicted in Fig. 2 and revealed that the maximum crop growth rate was recorded up to 180 DAS during 2006 and in 2007. In 2006, the higher and nearly equivalent ACGR (average crop growth rate) values of 12.33 g m\(^{-2}\) d\(^{-1}\) and 11.93 g m\(^{2}\) d\(^{-1}\) were obtained at T7 (126 kg N ha\(^{-1}\) at planting + 126 kg N ha\(^{-1}\) at 90 DAS) and T10 (168 kg N ha\(^{-1}\) at planting + 168 kg N ha\(^{-1}\) at 90 DAS), respectively. The minimum ACGR (5.54 g m\(^{-2}\) d\(^{-1}\)) was produced by T1 where no N was applied. Similar results were recorded during 2007. Variability in genetic potential and efficient utilization of applied inputs in a particular environment is indicated by crop growth rate (Gardner et al., 1988). Different ACGR in sugarcane grown at different N levels and times of its application was ascribed to variable biomass production (Robinson et al., 2007). Singh et al. (2001) recorded maximum ACGR at a higher dose of N. In 2006 the ACGR was more than 2007 because of more rainfall and relative humidity during the former year (Fig. 1).

This study indicated better responses of sugarcane crops to high N application rates, when applied in splits on a loam soil, than currently recommended. In conclusion, N requirements of sugarcane crops must be reconsidered with special reference to its application timing and type of soil.

**REFERENCES**


Anonymous. 1986. MSTATC. Microcomputer Statistical Program. Michigan State University, Michigan, Lansing, USA.


Table 1. Soil analysis

<table>
<thead>
<tr>
<th></th>
<th>pH</th>
<th>EC(dSm⁻¹)</th>
<th>N (%)</th>
<th>P (ppm)</th>
<th>K (ppm)</th>
<th>OM (%)</th>
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<tbody>
<tr>
<td>Before planting</td>
<td>7.8</td>
<td>1.4</td>
<td>0.04</td>
<td>8.1</td>
<td>126.4</td>
<td>0.91</td>
</tr>
<tr>
<td>After harvest</td>
<td>7.9</td>
<td>1.4</td>
<td>0.04</td>
<td>7.2</td>
<td>117.3</td>
<td>0.84</td>
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Table 2. *P* values for growth, yield and N use efficiency of sugarcane as affected by dose and time of N application.

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<tr>
<th>Contrasts</th>
<th>2006</th>
<th>2007</th>
</tr>
</thead>
<tbody>
<tr>
<td>Millable canes</td>
<td>0.0001</td>
<td>0.0025</td>
</tr>
<tr>
<td>Cane length</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
<tr>
<td>Cane girth</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
<tr>
<td>Stripped cane yield</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
<tr>
<td>Commercial cane sugar</td>
<td>0.4657</td>
<td>0.4031</td>
</tr>
<tr>
<td>Sugar yield</td>
<td>0.0000</td>
<td>0.0000</td>
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<tr>
<td>Agronomic nitrogen use efficiency</td>
<td>0.0000</td>
<td>0.0000</td>
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<tr>
<td>Physiological nitrogen use efficiency</td>
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<td>Leaf area duration</td>
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<tr>
<td>Crop growth rate</td>
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Table 3. Effect of rate and time of N application on growth and yield of sugarcane.

a) Comparison of treatments’ means

<table>
<thead>
<tr>
<th>Treatments</th>
<th>MC (m$^{-2}$)</th>
<th>CL (cm)</th>
<th>CG (cm)</th>
<th>SCY (t ha$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T$_1$</td>
<td>7.8 c</td>
<td>7.7 d</td>
<td>187 f</td>
<td>177 f</td>
</tr>
<tr>
<td>T$_2$</td>
<td>10.1b</td>
<td>9.8 bc</td>
<td>214 def</td>
<td>208 de</td>
</tr>
<tr>
<td>T$_3$</td>
<td>10.1b</td>
<td>9.7 c</td>
<td>200 ef</td>
<td>193 e f</td>
</tr>
<tr>
<td>T$_4$</td>
<td>10.0 b</td>
<td>10.0 bc</td>
<td>230 cde</td>
<td>225 cd</td>
</tr>
<tr>
<td>T$_5$</td>
<td>11.7 ab</td>
<td>11.4 abc</td>
<td>250 bc</td>
<td>245 bc</td>
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<tr>
<td>T$_6$</td>
<td>11.4 ab</td>
<td>10.9 abc</td>
<td>233 cd</td>
<td>228 cd</td>
</tr>
<tr>
<td>T$_7$</td>
<td>12.9 a</td>
<td>12.4 a</td>
<td>285 a</td>
<td>278 a</td>
</tr>
<tr>
<td>T$_8$</td>
<td>11.4 ab</td>
<td>11.4 abc</td>
<td>249 bc</td>
<td>242 c</td>
</tr>
<tr>
<td>T$_9$</td>
<td>11.4 ab</td>
<td>10.7 abc</td>
<td>230 cde</td>
<td>225 cd</td>
</tr>
<tr>
<td>T$_{10}$</td>
<td>12.3 a</td>
<td>11.9 ab</td>
<td>274 ab</td>
<td>266 b</td>
</tr>
<tr>
<td>SE</td>
<td>0.51</td>
<td>0.63</td>
<td>9.3</td>
<td>7.5</td>
</tr>
</tbody>
</table>

Means in a column not sharing the same letters differ significantly from each other at 5% probability level as per DNMR. T$_1$ = No N (control), T$_2$ = 168 kg N ha$^{-1}$ at planting, T$_3$ = 168 kg N ha$^{-1}$ at 90 DAS, T$_4$ = 84 kg N ha$^{-1}$ at planting + 84 kg N ha$^{-1}$ at 90 DAS, T$_5$ = 252 kg N ha$^{-1}$ at planting, T$_6$ = 252 kg N ha$^{-1}$ at 90 DAS, T$_7$ = 126 kg N ha$^{-1}$ at planting + 126 kg N ha$^{-1}$ at 90 DAS, T$_8$ = 336 kg N ha$^{-1}$ at planting, T$_9$ = 336 kg N ha$^{-1}$ at 90 DAS, T$_{10}$ = 168 kg N ha$^{-1}$ at planting + 168 kg N ha$^{-1}$ at 90 DAS

b) Meaningful orthogonal contrasts

<table>
<thead>
<tr>
<th>Contrasts</th>
<th>MC (m$^{-2}$)</th>
<th>CL (cm)</th>
<th>CG (cm)</th>
<th>SCY (t ha$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>200 6</td>
<td>200 7</td>
<td>200 6</td>
<td>200 7</td>
</tr>
<tr>
<td>C$_1$ = 168 VS 252 kg N ha$^{-1}$</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>C$_2$ = 168 VS 336 kg N ha$^{-1}$</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>C$_3$ = 252 VS 336 kg N ha$^{-1}$</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>C$_4$ = All N at planting VS all at 90DAS</td>
<td>NS</td>
<td>NS</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>C$_5$ = All N at planting VS splits</td>
<td>NS</td>
<td>NS</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>C$_6$ = All N at 90DAS VS splits</td>
<td>NS</td>
<td>NS</td>
<td>**</td>
<td>**</td>
</tr>
</tbody>
</table>

MC = millable canes, CL = cane length, CG = cane girth (cm), SCY = stripped cane yield. *, ** = significant at 1 and 5 % probability, respectively. NS = non significant.
Table 4. Effect of rate and time of N application on cane sugar and nitrogen use efficiency in sugarcane.

a) Comparison of treatments’ means

<table>
<thead>
<tr>
<th>Treatments</th>
<th>CCS (%)</th>
<th>SY (t ha(^{-1}))</th>
<th>NUEa (kg kg(^{-1}) of N)</th>
<th>NUEp (kg kg(^{-1}) of N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>11.81</td>
<td>11.60</td>
<td>5.5 e</td>
<td>4.9 e</td>
</tr>
<tr>
<td>T2</td>
<td>12.33</td>
<td>12.18</td>
<td>9.0 cd</td>
<td>8.1 cd</td>
</tr>
<tr>
<td>T3</td>
<td>12.22</td>
<td>12.09</td>
<td>7.4 d</td>
<td>6.5 de</td>
</tr>
<tr>
<td>T4</td>
<td>12.24</td>
<td>12.16</td>
<td>9.7 c</td>
<td>8.9 c</td>
</tr>
<tr>
<td>T5</td>
<td>11.88</td>
<td>11.75</td>
<td>10.7 bc</td>
<td>9.9 bc</td>
</tr>
<tr>
<td>T6</td>
<td>11.75</td>
<td>11.77</td>
<td>9.9 c</td>
<td>9.0 c</td>
</tr>
<tr>
<td>T7</td>
<td>11.85</td>
<td>11.95</td>
<td>12.8 a</td>
<td>12.1 a</td>
</tr>
<tr>
<td>T8</td>
<td>11.54</td>
<td>11.37</td>
<td>10.2 c</td>
<td>9.3 c</td>
</tr>
<tr>
<td>T9</td>
<td>11.72</td>
<td>11.74</td>
<td>9.5 c</td>
<td>8.6 c</td>
</tr>
<tr>
<td>T10</td>
<td>11.76</td>
<td>11.78</td>
<td>12.1 ab</td>
<td>11.3 ab</td>
</tr>
<tr>
<td>SE</td>
<td>0.379</td>
<td>0.355</td>
<td>0.58</td>
<td>0.56</td>
</tr>
</tbody>
</table>

Means in a column not sharing the same letters differ significantly from each other at 5% probability level as per DNMR. T1 = No N (control), T2 = 168 kg N ha\(^{-1}\) at planting, T3 = 168 kg N ha\(^{-1}\) at 90 DAS, T4 = 84 kg N ha\(^{-1}\) at planting + 84 kg N ha\(^{-1}\) at 90 DAS, T5 = 252 kg N ha\(^{-1}\) at planting, T6 = 252 kg N ha\(^{-1}\) at 90 DAS, T7 = 126 kg N ha\(^{-1}\) at planting + 126 kg N ha\(^{-1}\) at 90 DAS, T8 = 336 kg N ha\(^{-1}\) at planting, T9 = 336 kg N ha\(^{-1}\) at 90 DAS, T10 = 168 kg N ha\(^{-1}\) at planting + 168 kg N ha\(^{-1}\) at 90 DAS

b) Meaningful orthogonal contrasts

<table>
<thead>
<tr>
<th>Contrasts</th>
<th>SY</th>
<th>CCS</th>
<th>NUEa</th>
<th>NUEp</th>
</tr>
</thead>
<tbody>
<tr>
<td>C(_1) = 168 VS 252 kg N ha(^{-1})</td>
<td>**</td>
<td>**</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>C(_2) = 168 VS 336 kg N ha(^{-1})</td>
<td>**</td>
<td>**</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>C(_3) = 252 VS 336 kg N ha(^{-1})</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>C(_4) = All N at planting VS all at 90DAS</td>
<td>*</td>
<td>**</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>C(_5) = All N at planting VS splits</td>
<td>**</td>
<td>**</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>C(_6) = All N at 90DAS VS splits</td>
<td>**</td>
<td>**</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

SY = sugar yield, CCS = commercial cane sugar, NUEa = agronomic nitrogen use efficiency, NUEp = physiological nitrogen use efficiency

*, ** = significant at 1 and 5 % probability, respectively. NS = non significant
Fig. 1 Meteorological data at AARI, Faisalabad, Pakistan, (a) 2006 and (b) 2007
Fig. 2 Periodic changes in crop growth rate of sugarcane (a) 2006 and (b) 2007
Fig. 3 Periodic changes in leaf area duration of sugarcane (a) 2006 and (b) 2007.