

THEORETICAL ASSESSMENT OF POTENTIAL FOR INCREASING PRODUCTIVITY OF SUGARCANE THROUGH INCREASED NITROGEN FERTILISATION

By ¹J. C. S. ALLISON and ²R. J. HASLAM

¹South African Sugar Association Experiment Station, Mount Edgecombe

²Simunye Sugar Estate, Simunye, Swaziland

Abstract

The growth of sugarcane crops in an environment representing that of the Natal coastal belt was simulated on a computer to estimate the likely increases in productivity that could be obtained by increasing the supply of nitrogen (N) to the crop. Increased fertilisation should cause faster growth in leaf area and thus more rapid accumulation of dry matter in the early part of the life cycle. Later, an increased supply of N should cause increased leaf N content, and therefore more rapid photosynthesis. A comparison of growth of simulated crops suggests that increases in stalk, hence sugar, yield of about 15% can reasonably be expected by increasing the supply of N to the crop. However, it will be necessary to breed varieties in which cane quality does not suffer when increased applications of N are given. The possibility of even greater increases in yield was considered.

Introduction

About 20 years ago it had become apparent that sugarcane productivity was tending to reach a ceiling (Bull and Tovey, 1974). Moreover, the high productivity often attributed to sugarcane is at least partially the result of a long growth period rather than of inherently high photosynthetic efficiency (Bull and Glasziou, 1975). Two factors which would be expected to limit the productivity of sugarcane are characteristically slow growth in the early part of the life cycle (Allison and Haslam, 1982), and depression of photosynthesis by low leaf nitrogen content of the green leaves during approximately the second half of the life cycle (Haslam and Allison, 1985). Recent work (Stevenson *et al.*, 1992) showed yields to increase when greater than recommended amounts of nitrogenous fertiliser were applied, either with irrigation or in moderately water stressed conditions. However, the physiological changes which caused the increased yields were unidentified.

Measurements have been made of the effect of leaf N content on response of photosynthesis to increase in radiation intensity; on area, arrangement and N content of the parts of the green leaf canopy; and of the effect of an increased nitrogen concentration in the nutrient solution supplied to plants grown in sand culture on rates of tillering and of growth in leaf area and dry mass. These have made it possible to assess theoretically the increase in yield which could be expected in the Natal coastal belt by increasing the supply of N to the crop, and using varieties adapted to such improved nutrition.

Procedure

Simulated crops, consisting of a photosynthetic system and a system to distribute photosynthate, were 'grown' in a 'standard' coastal belt environment for a period of a year. There were three different crops, a 'normal' crop and two 'boosted' crops.

Environment. The standard environment comprised 50 'standard' weeks (~1 year), a week being defined as the period during which 58 heat units (HU) accumulate (mean annual temperature at Mount Edgecombe, 20,3°C, giving 8,3 HU/day, using a base temperature of 12, or 58 HU/wk). Mean annual photosynthetically active radiation (PAR) income at Mount Edgecombe is 7,9 MJ/m²/day, giving 55,3 MJ/m² per standard week. The Mount Edgecombe climate was used because the Experiment Station is situated more or less at the centre of the coastal sugarcane belt.

Photosynthesis. A photosynthetic system was constructed based on that of Monteith (1965). It consisted of horizontally stacked layers of leaves each of unit leaf area index (leaf area: land area ratio, L). A simulated crop began growing in leaf area at week 4, the assumed stage at which shoots began emerging, to reach a maximum L of 5, i.e. a total of five layers. The week at which the maximum was reached depended on the rate of growth in leaf area. After reaching the maximum L remained at five for the remainder of the growth period. Leaf angle, from the horizontal, decreased progressively from 67° in layer 1 (top) to 56° in layer 5.

Hourly gross photosynthesis per leaf layer was calculated as intercepted PAR flux density (determined by sun and leaf angle) × response of photosynthesis jointly to radiation and leaf N content (Figure 1). Summation over an assumed 14 hour day gave total daily photosynthesis.

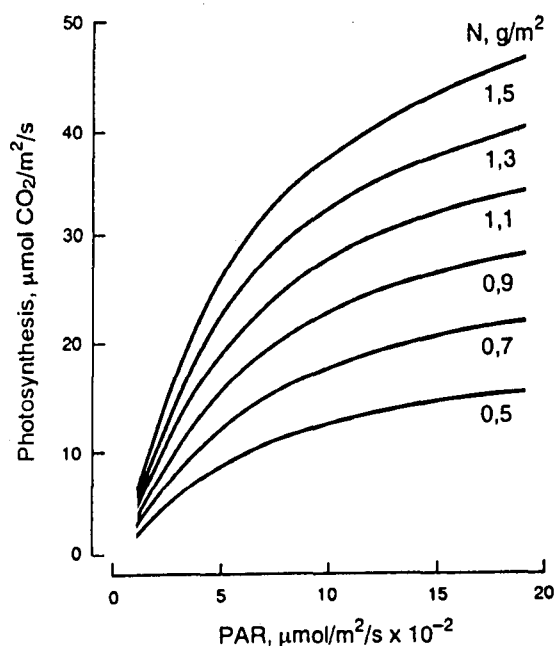


FIGURE 1 Response of rate of photosynthesis to increasing photosynthetically active radiation (PAR) for a range of leaf N contents.

Distribution of photosynthate

Respiration. Maintenance respiration was calculated as $1,44 \times 10^{-3} \times (0,2495 T - 3,046) \times \text{stem dry weight}$, and as $4,32 \times 10^{-3} \times (0,2495 T - 3,046) \times \text{leaf plus root dry mass}$ (Glover, 1972), where T = daily mean temperature. T was set at 24° rather than $20,5^\circ$, the mean of the standard season, because maintenance respiration increases exponentially rather than linearly with ambient temperature (Amthor, 1989). Growth respiration which is independent of temperature was calculated as (total photosynthesis - maintenance respiration) $\times 0,25$ (0,25 is the approximate minimum estimate of the growth respiration factor obtained in a number of studies (Amthor, 1989). Total photosynthesis less maintenance and growth respiration gave the dry matter (DM) available for allocation to the parts of the plant.

Allocation of DM. While leaf area was increasing during the initial part of the growth period, leaf growth in dry mass was proportional to the increase in L , with an estimated specific leaf mass of $\sim 67 \text{ g/m}^2$. During this period roots grew at a constant rate from 75 g/m^2 at week 4 to 275 g/m^2 , i.e. by 13 g/wk in the 'normal' crop and by 18 g/wk in both 'boosted' crops. Stems grew by the amount of DM remaining after leaves and roots had been supplied.

Maintenance respiration was calculated as before for the phase starting at the time that maximum L was reached; root weight remained constant; and leaves grew by 56 g/wk , but (green) leaf mass remained constant because leaves withered as fast as they grew (thus maintaining L at 5); $56 \times 0,8 \text{ g/wk}$ was added to mass of withered leaves, the factor of 0,8 being to take account of an assumed small loss of DM with senescence of leaves; stem growth was photosynthesis - (maintenance respiration + leaf growth).

Nitrogen uptake

Our measurements as well as those of Thompson (1991) and Stevenson *et al.* (1992) provide estimates of the N contents per cent of dry mass of the parts of the shoot at successive stages of growth of 'normal' and 'boosted' crops. These values multiplied by dry mass of the parts of the shoot give uptake of N.

The following crops were simulated:

1. 'Normal', receiving the locally recommended supply of N fertiliser, in which L increased at a rate so as to reach the maximum at week 21 (after the accumulation of $\sim 180 \text{ HU}$) (Figure 2). The N content of the top leaf layer decreased linearly from $1,5 \text{ g/m}^2$ at week 4 to $1,35 \text{ g/m}^2$ at week 21, at which stage leaf N content decreased progressively from this value in layer 1 to 1,12 in layer 5; the N content of each leaf layer then decreased steadily with time until week 50, when it was $1,05 \text{ g/m}^2$ in layer 1 and $0,87 \text{ g/m}^2$ in layer 5 (Figure 3).
2. 'Boosted-1', received an increased supply of N as a result of which leaves grew faster in area to reach the maximum at week 16 (at $\sim 130 \text{ HU}$); N content of the top leaf layer decreased from $1,5 \text{ g/m}^2$ at week 4 to $1,4 \text{ g/m}^2$ at week 21, with a decrease with depth in the canopy to $1,15 \text{ g/m}^2$ in leaf layer 5; the subsequent fall with time was slower than that in the 'normal' crop, and at 50 weeks leaf N content was $1,22 \text{ g/m}^2$ in layer 1 and $1,04 \text{ g/m}^2$ in layer 5 (Figure 3).
3. 'Boosted-2', in which leaf area increased at the same rate as in the 'boosted-1' crop, thus also reaching the maximum at 16 weeks. At four weeks leaf N content was $1,6 \text{ g/m}^2$ in layer 1, and this decreased to $1,55 \text{ g/m}^2$ by week 21, when the fall with depth in the canopy was to $1,26$ in layer 5 (Figure 3); leaf N content then decreased pro-

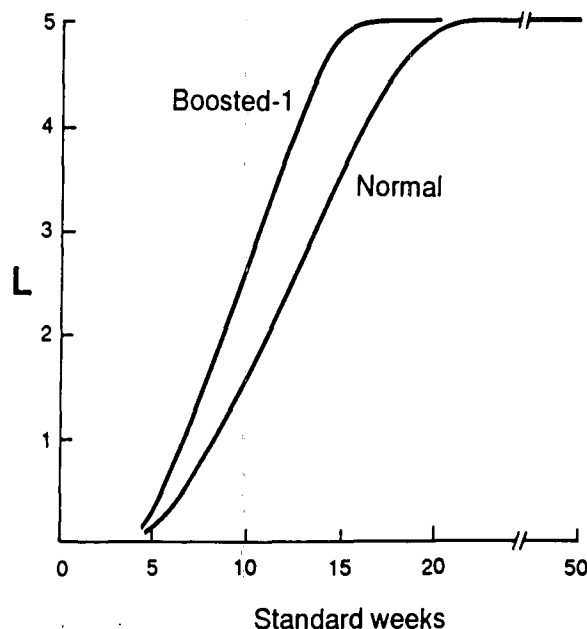


FIGURE 2 Leaf area index (L) of two simulated crops, plotted against time.

gressively to $1,45 \text{ g/m}^2$ in layer 1 and $1,39 \text{ g/m}^2$ in layer 5 at week 50.

The quantities describing the attributes of the 'normal' and 'boosted-1' crops are based on the measurements made, but the values of leaf N content of the 'boosted-2' crop are greater than any observed in sugarcane at Mount Edgecombe. They are, however, still slightly short of values observed during most of the life cycle in well fertilised maize (Hanway, 1962; Allison, 1984).

Results and Discussion

In the simulated crops L reached the maximum of 5,0 about four weeks sooner in the 'boosted' than in the 'normal' crops, by week 16 rather than week 21 (Figure 2). This is as large a shift as could conservatively be envisaged, although it still leaves sugarcane as an initially slow grower. Thus, in similar circumstances, a maize crop would be expected to reach a similar L within about 11 weeks (e.g. Allison and Eddowes, 1968). Because of faster growth in leaf area and somewhat greater leaf N content, total dry mass increased more rapidly up to week 21 in the 'boosted-1' than in the 'normal' crop (Figure 4). After this stage L was the same in all the crops, but dry weight continued to increase faster in the 'boosted-1' crop, because of its greater leaf N content, than in the 'normal' crop. At the end of the growth period the 'boosted-1' crop had accumulated about 12% more dry matter than had the 'normal' crop. Similarly, stems grew more rapidly in the 'boosted-1' crop and at 50 weeks stems were 15% heavier than in the 'normal' crop.

Interestingly, final stem dry mass of the 'boosted-1' crop ($4\ 245 \text{ g/m}^2$) was similar to those obtained in maximum production trials conducted at Mount Edgecombe some years ago; there cane yields at 12 months were $c 145 \text{ t/ha}$ (Glover, 1972), which, assuming a 30% DM content, amounts to $4\ 350 \text{ g/m}^2$ dry mass.

Thus, it seems that in the coastal belt increases in yield of about 15% should be obtainable with the use of increased quantities of N. It will, however, be necessary to breed varieties better adapted to such management. Present local varieties suffer in quality, particularly in respect of juice pu-

urity (sucrose/soluble solids, %) when given greater than recommended amounts of N; but there appears to be suitable genetic variation to make possible the breeding of varieties able to give good quality cane with large applications of N (Stevenson *et al*, 1992).

Calculated total amounts of N taken up over the 50 weeks of growth were 12,6 g/m² in the 'normal' crop and 16,8 g/m² in the 'boosted-1' crop. Even the larger of these amounts was less than that taken up by a good maize crop (>20 g/m²), or by optimally fertilised sugarbeet in England (about 22 g/m²), in growth periods of 5-6 months.

What scope is there for even greater increases in productivity through increasing leaf N content? The 'boosted-2' crop accumulated 30% more total dry matter and 38% more dry matter in the stem than the 'normal' crop (Figure 4); differences from the 'boosted-1' crop were, respectively 16% and 19% (N uptake by the 'boosted-2' crop amounted to c 21 g/m² by week 50). However, the leaf N content of the 'boosted-2' crop (Figure 3) was considerably greater than any observed locally, except during the first few weeks of growth, even in crops given exceptionally large and repeated applications of N, whether applied to the soil or as foliar sprays (Stevenson *et al*, 1992).

On the other hand, well fertilised hybrid maize is able to maintain leaf N content at near 1,6 g/m² (the maximum in the 'boosted-2' crop), hence a high rate of photosynthesis, until late in the life cycle (Allison, 1984). So, it should be possible, by appropriately designed crossing and selection, to slowly shift potential productivity at least a considerable part of the way towards that of the 'boosted-2' simulated crop.

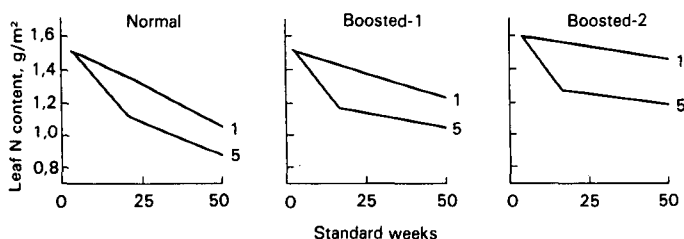


FIGURE 3 Changes with time in N content of green leaves of three simulated crops. 1 = top layer of leaves; 5 = bottom of five layers. N contents of layers 2-4 were intermediate.

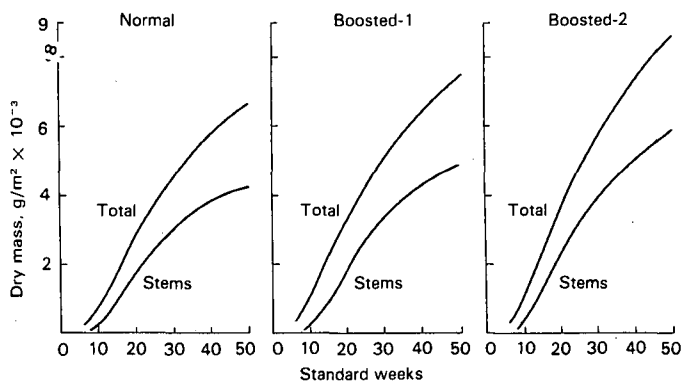


FIGURE 4 Growth in total and stem dry mass of three simulated crops.

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