GROWTH OF SUGARCANE AND ITS USE OF NUTRIENTS IN ZIMBABWE

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Abstract

A sugarcane (*Saccharum* sp.) crop, planted shortly before mid-summer, produced about 7 000 g of above-ground dry matter m^{-2} by the time it was harvested, 56 weeks later; of this total 32% consisted of sucrose, 41% of other stem material, 10% of green leaf laminae and sheaths, and 17% of dead leaves. Number of tillers increased to 23 m^{-2} at week 18, then fell to a final number of 14 m^{-2} by week 32. Leaf area index (L) increased to a maximum of 5,2 at about week 24, then decreased slowly, falling to 4 by week 48. Total number of leaves per tiller increased steadily to 29 at final harvest; number of green leaves increased to 9 by about week 22, then decreased slowly, to 7 by week 48. Mean area per leaf increased until week 32, then decreased slightly. Specific leaf area increased initially, then decreased slowly until final harvest.

Crop growth rate (C) increased with L, reaching 26 g m^{-2} d^{-1} at week 24, then fell to 21 g m^{-2} d^{-1} during the winter, and increased again with the onset of the second summer, to reach 28 to 34 g m^{-2} d^{-1}, shortly before the final harvest.

Plants contained 14 g nitrogen (N) m^{-2}, 2,5 g phosphorus (P) m^{-2} and 46 g potassium (K) m^{-2} at final harvest; the stem contained more than half the N and about two-thirds of the P and K, green leaves contained a third of the N and about a quarter of the P and K, and dead leaves contained 5 to 10% of the total N, P and K. Approximately 80% of the N, 65% of the P and 75% of the K were taken up during the first half of the growth cycle. The nutrient content percent of dry weight of the green leaves and non-sucrose part of the stem decreased substantially with the age of the crop; the nutrient content of dead leaves was much less than that of living parts of the shoot. The N content per unit area of green leaves fell with time, from 19 mg dm^{-2} at week 8 to less than 12 mg dm^{-2} by week 40.

Introduction

Sugarcane (*Saccharum* sp.) is capable of producing large amounts of dry matter per unit area of land. Thus, results quoted by Thompson[14] show that at 12 months of age the mean dry matter yield of three experimental crops of variety NCo 376 at Pongola (where conditions are probably broadly similar to those in the Zimbabwe sugarcane region) were about 6 500 g m^{-2}; this represented the fixation of nearly 1,8% of solar radiation in dry matter. Other results quoted indicated similar fixation by irrigated crops. However, the large yields of sugarcane may be more the result of a long growing season than of an inherently large photosynthetic efficiency (Bull and Glasziou[6]).

The crop is harvested at intervals of 12 months or more, but most of the N and K in the above-ground parts of the plant at harvest is taken up during the first few months of growth; uptake of P usually does not slow down as markedly with time (van Dillewijn[16]; Bishop[5]). Dry matter is normally accumulated at an appreciable rate throughout the period up to harvest, so the average nutrient concentration of the plant falls during most of the growth cycle. However, a substantial part of the increase in dry weight of the sugarcane plant during the latter part of the growth cycle is in the form of sucrose, which of course contains no N, P or K. Moreover, the dead leaf or 'trash', initially including tillers, most of which remains attached to the plant, thus contributing to total dry weight, might before senescing have been a source of nutrients to growing parts of the plant. The N percent of dry weight of the third youngest leaf, (ie a successively higher leaf) does, however, normally decrease with the age of the plant (Meyer[9]).

In this paper, data on the growth and uptake and distribution of N, P and K by a conventionally fertilized and normally spaced NCo 376 plant crop in Zimbabwe are presented. Factors which are likely to have limited the productivity of the crop, are considered.

Methods

The variety NCo 376 was planted on 25 November 1975, in rows spaced 1,5 m apart, in four replicates on sandy clay loam soil, on the Zimbabwe Sugar Association Experiment Station, Chiredzi, Zimbabwe. More than the normal amount of seedcane was used to ensure a good stand of plants. Fertilizer applications were 40 kg N ha^{-1} and 26 kg P ha^{-1} at the time of planting and 100 kg N ha^{-1} two months later. These applications represent good commercial fertilizer management in Zimbabwe. The level of exchangeable K in the soil was high (1,1 me%) and no K fertilizer was applied. The crop was irrigated and probably did not suffer any serious water stress. Samples of shoots, initially of 15 and later of 10 shoots, were harvested from each replicate at intervals of 4 weeks, between 4 and 56 weeks after planting, to estimate number of shoots per unit area of land, dry weight of the parts of the shoot, total number of leaves and number of green leaves per shoot and area of green leaf laminae and sheaths. The N, P and K contents of the dried parts of the shoot were determined on alternate harvest occasions, starting 8 weeks after planting. N was determined by the micro-Kjeldahl method, P by the vanado molybdophosphoric colorimetric method and K with an atomic absorption spectrophotometer.

Results

Differences between successive values of mean total dry weight (W) fluctuated substantially (Figure 1b); quadratic regression lines gave a good fit to values of W between 4 and 28 weeks after planting (variance accounted for 98,7%), and to values of W between 40 and 56 weeks after planting (variance accounted for 98,9%). A linear regression gave a fairly good fit to values of W between 24 and 44 weeks after planting (variance accounted for 90,0%). Moreover, the last four values of W, between 44 and 56 weeks, were reasonably well fitted by a linear regression line (variance accounted for 94,1%). All but the last of these regression lines are shown in Figure 1b.

Green leaf area changed comparatively smoothly with time. Leaf area index (leaf area: land area ratio, L), including leaf lamina and sheath area, increased until 24 weeks after planting, reaching a maximum value of 5,2. It then decreased gradually to 4,0 by the time of final harvest (Figure 1b).

Number of tillers increased at first, to 23 m^{-2} 8 weeks after planting, then fell during the following approximately 10 weeks to reach a final number of 14 m^{-2}. The total number of leaves per tiller increased throughout the growth period (Figure 2a); rate of leaf appearance apparently increased between 4 and

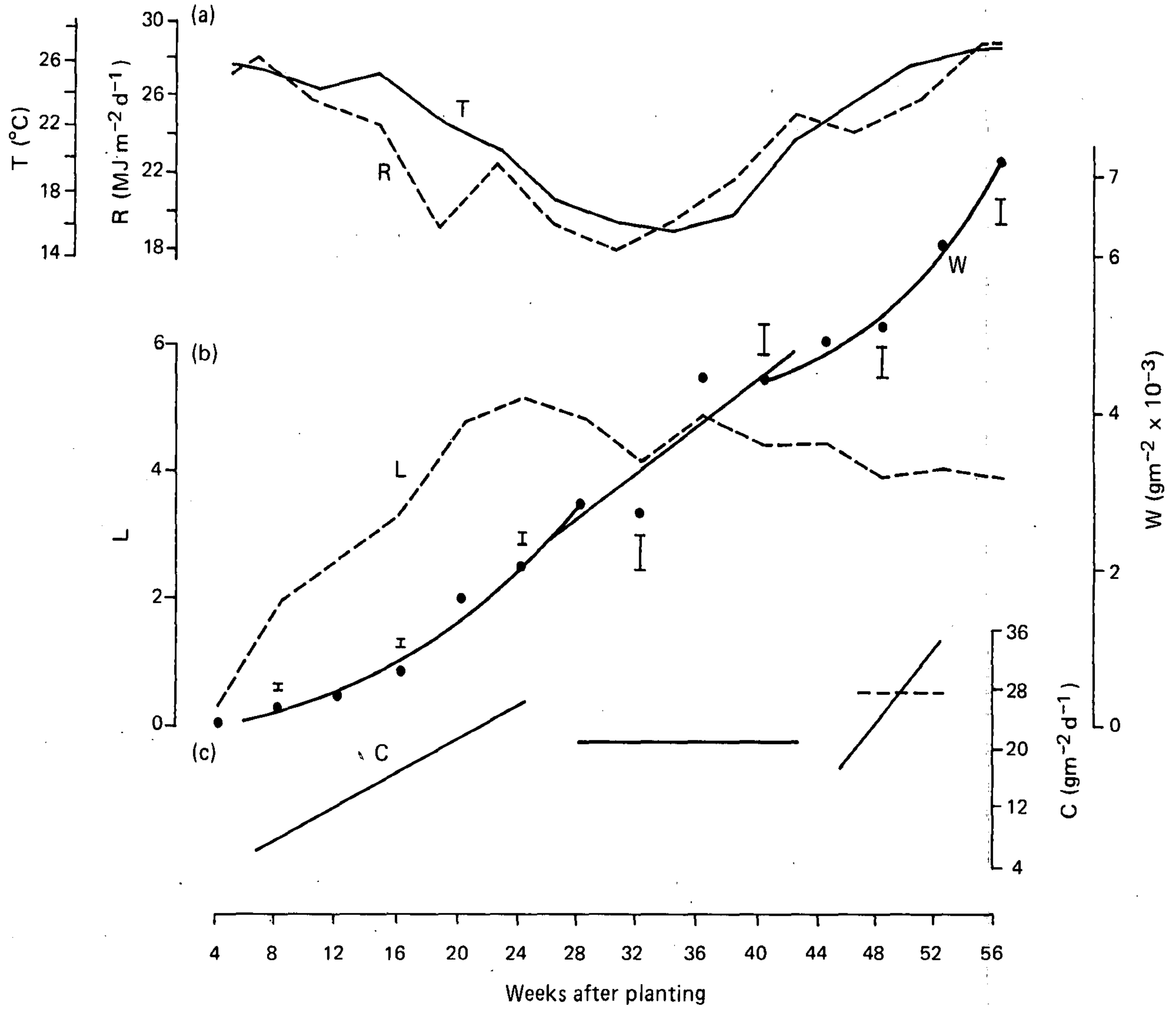

FIGURE 1 Weather, dry weight, leaf area and growth rate plotted against time between planting and final harvest. (a) Mean ambient temperature (T); solar radiation (R). (b) Leaf area index (L) ----, total dry weight (W), •, with regression lines, ——, fitted to values of W between 4 and 28 weeks, 24 and 44 weeks, and 40 and 56 weeks after planting, respectively. Short vertical lines represent standard errors of W at alternate harvests. (c) Crop growth rate (C); ——, derived as the slope of the fitted lines shown in (b); ----, derived from a straight line fitted to values of W between week 44 and 56.

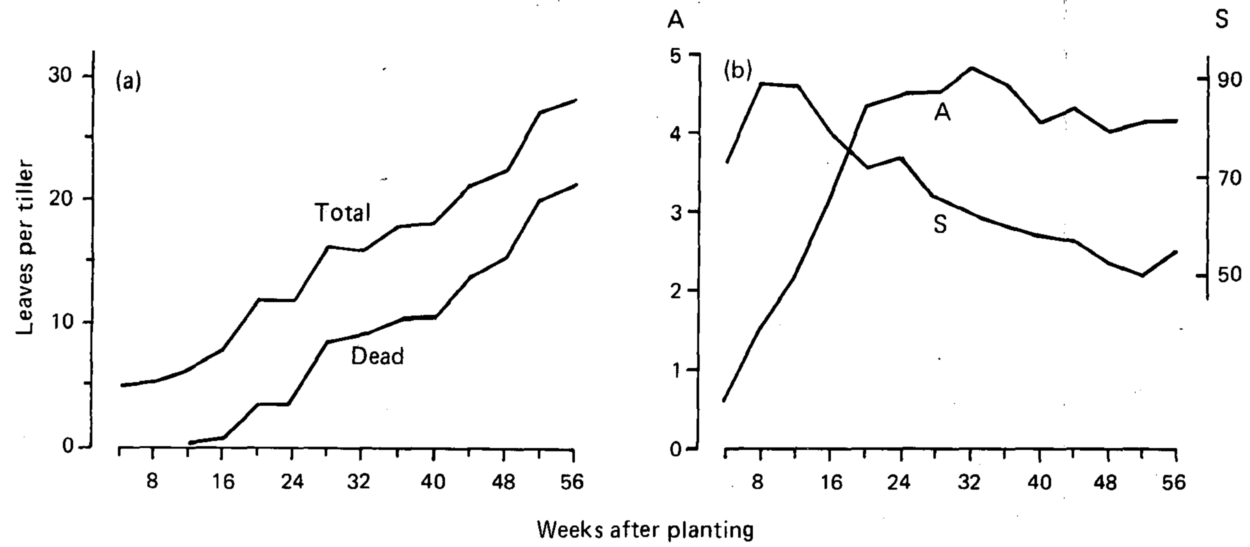

FIGURE 2 Changes with time in (a) total number of leaves and number of dead leaves per tiller, and (b) mean area per green leaf (A), dm^2, and specific leaf area (S), $cm^2\ g^{-1}$.

about 20 weeks after planting and may have decreased slightly during the cool period between about 28 and 40 weeks. Death of leaves commenced about 12 weeks after planting and continued until final harvest. Number of green leaves per tiller increased from 5 at week 4 to nearly 9 between 20 to 24 weeks and then decreased to approximately 7 at week 48. Mean area per leaf (A) increased rapidly until week 20 and more slowly until about week 32, and then decreased slightly (Figure 2b). Specific leaf area (leaf area: leaf dry weight ratio, S), after an initial increase, fell slowly until near the final harvest.

Crop growth (rate of increase of total dry weight per unit land area, C) was calculated as the slope of the respective regressions lines fitted to total dry weight. C initially increased with time (Figure 1c) reaching approximately 26 g m^{-2} d^{-1} 24 weeks after planting, when L reached its maximum, then fell to about 21 g m^{-2} d^{-1} for the winter period, and finally rose again as radiation (R) and temperature (T) increased (see Figure 1a). The extent of the increase in C towards the end of the growth period is not clear, but C was probably between 28 and 34 g m^{-2} d^{-1} at this time; C derived from the fitted quadratic curve was approximately 34 g m^{-2} d^{-1} at week 52, while that derived from the straight line fitted to total dry weight between 44 and 56 weeks, was approximately 28 g m^{-2} d^{-1}.

Total leaf dry weight increased throughout the growth period. However, dry weight of green leaves (G) increased only until about week 24 and thereafter changed only slightly (Figure 3a). Stems began elongating a few weeks after planting and sucrose began accumulating after about week 16. Subsequently dry weight of both sucrose (S) and non-sucrose (R) parts of the stem increased steadily until final harvest.

Nutrients were taken up more rapidly during the early part of the growth cycle than later (Figure 3b, c, d); N and P continued to be taken up, albeit comparatively slowly until final harvest, while uptake of K apparently ceased at about week 40. Nutrient contents of withered leaf (trash, D) increased slowly until near the time of final harvest, while that of the green leaves increased only until about week 24 and then decreased somewhat. The N and P contents of the stem increased until final harvest; that of K increased only until about week 40. At final harvest the stem contained more than half the total N in the plant and about two-thirds of the total P and K, green leaves contained a third of the N and about a quarter of the P and K, and the trash contained only 5 to 10% of the total N, P and K in the plant.

Nutrient contents percent of dry weight (Figure 4) of the leaves were always greater than those of the stem (except for K 8 weeks after planting). Nutrient concentrations decreased with time. In living parts of the shoot, they generally fell rapidly until 16 to 24 weeks after planting and then decreased slowly until near final harvest; the initial rapid decrease did not occur with K in the leaves. Dead leaves contained only a small amount of N and P, and also a fairly small amount of K per cent of dry weight.

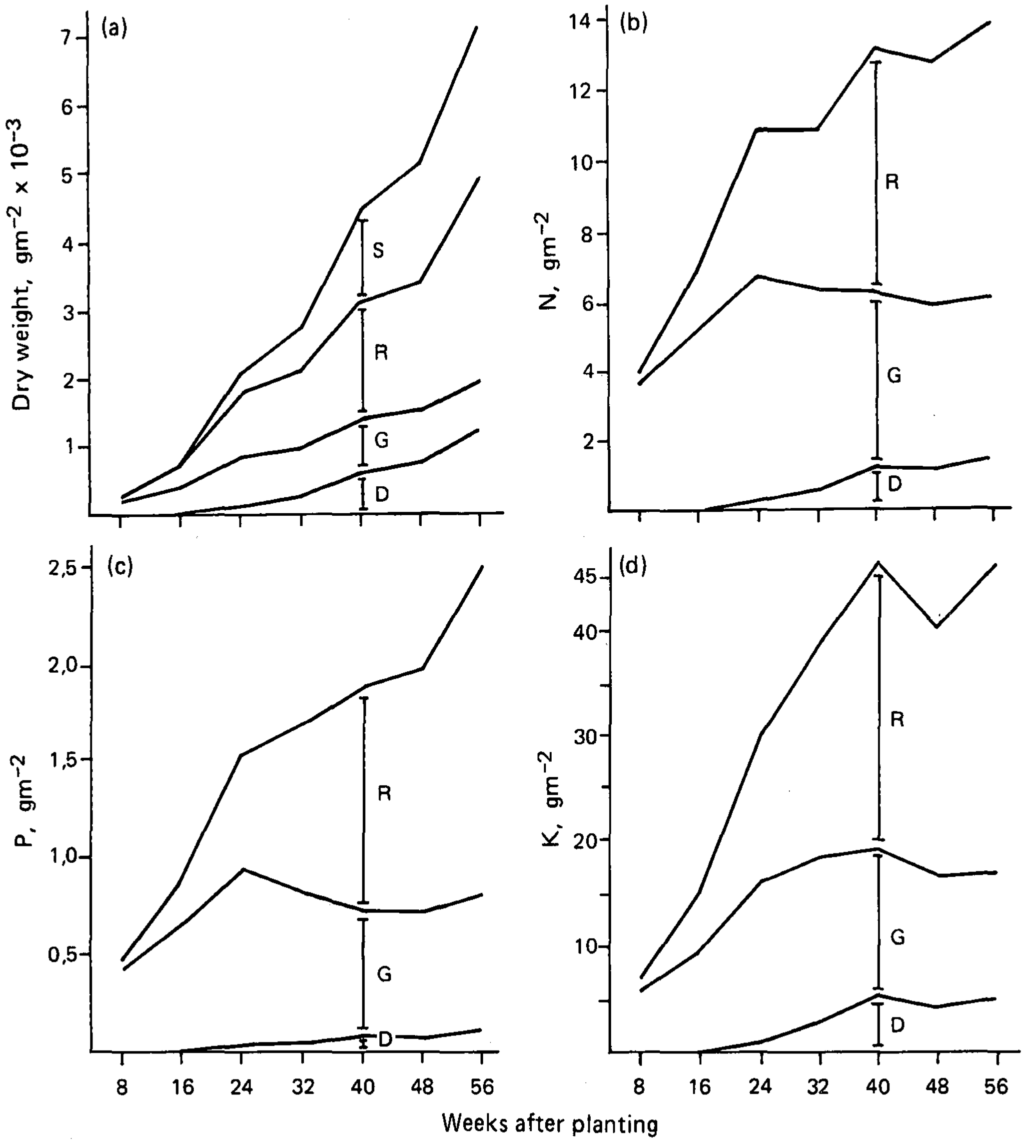

FIGURE 3 Changes with time in dry weight and in nitrogen (N), phosphorus (P) and potassium (K) contents of the parts of the shoot, per unit area of land. S, sucrose; R, rest of stem; G, green leaves; D, dead leaves.

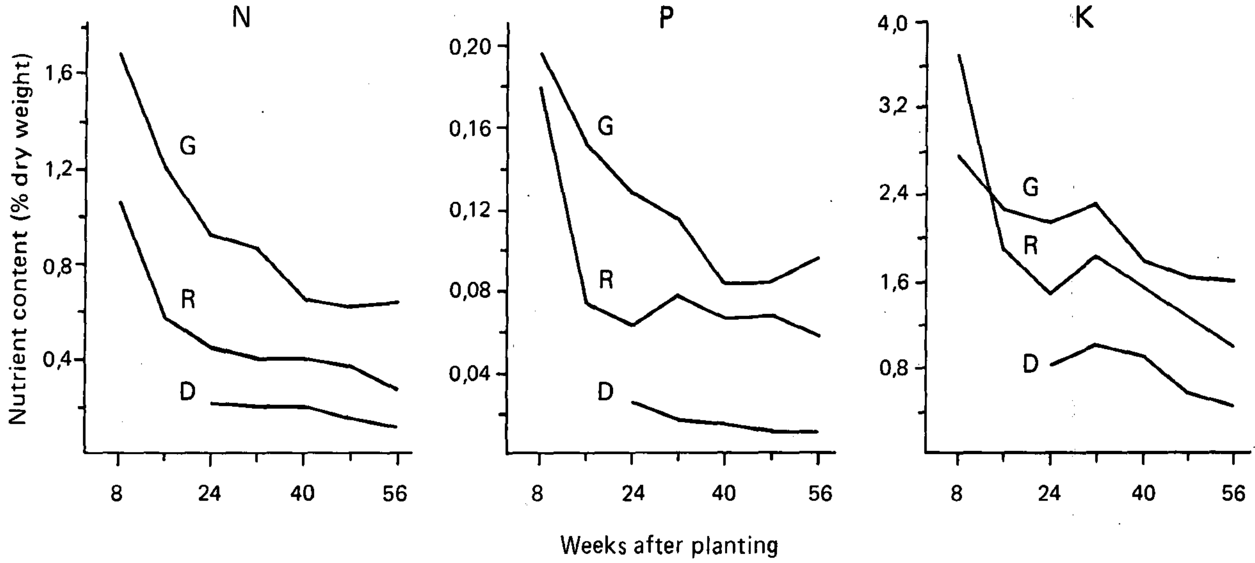

FIGURE 4 Changes with time in nitrogen (N), phosphorus (P), and potassium (K) content, per cent of dry weight, of parts of the shoot. G, green leaves; R, non-sucrose part of stem; D, dead leaves.

Discussion

The total above-ground dry matter produced in this experiment, approximately 6 100 g m^{-2} at 52 weeks (Figure 1b), was equivalent to the fixation of about 1,3% of incoming solar radiation in dry matter (assuming 17,6 KJ g^{-1}, Thompson[14]). Photosynthetic efficiency, derived in this way, can be expected to be comparatively small in conditions such as those in Zimbabwe, where fairly large daily totals of radiation (mean for 52 weeks in this experiment, 23 MJ m^{-2} d^{-1}) are received in relatively short days (*cf* Allison[2]).

Leaf area index (L) was small for a long time after planting, while radiation and temperature were close to their maximum summer values (Figure 1), so that much radiation must have fallen on bare ground at a time when the potential rate of photosynthesis per unit land area was large. L did not reach its maximum of about 5 until more than 20 weeks after planting, by which time radiation and temperature had decreased with the onset of the cool season. Moreover, even then the photosynthetic system may not have been fully able to exploit the incoming light. The extinction coefficient for light in the leaf canopy of variety NCo 376, which has rather erect leaves, is probably not more than 0,5, implying that L should be at least 6 if all the useful light is to be intercepted (Monteith[10]). In this connection Nagatomi, Maeda and Lo[11] found yield of cane to increase linearly with L values up to about 8. Initial rate of increase of leaf area appears to be characteristically slower in sugarcane than in other grasses of warm climates (Allison and Haslam[3]; Bull and Glasziou[6], Figure 3–2).

Rapid respiratory loss may have resulted in comparatively slow accumulation of dry matter towards the end of the lifecycle when there was a large mass of living tissue (Figure 1), and the temperature had risen rapidly after the end of the cool season, as is usual in Zimbabwe (*cf* Amthor[4]). Regressions of rates of respiration of leaves and stem on temperature, derived by Glover[8], working with NCo 376, give an estimate of the rate of loss of dry matter through respiration of approximately 24 g m^{-2} d^{-1} for the 12 weeks between 40 and 52 weeks, which is roughly equal to mean C for the same period.

It seems possible that rate of photosynthesis was depressed by a shortage of N and perhaps of P in the plant during the latter part of the growing period (Figure 4). A deficiency of P may depress photosynthesis though in a study on barley, rate of photosynthesis was independent of leaf P concentrations greater than 0,3% (Natr[12]). In the present experiment, however, the P content of the dry matter of the green leaves was always less than 0,3% and towards the end of the growth period was little more than a quarter of this value.

The effect of the N content of the leaves on the rate of photosynthesis is probably best considered in terms of the quantity of N per unit leaf area (Natr[12]; Cook and Evans[7]). This attribute is influenced by specific leaf area, which was comparatively small (Figure 2), ranging between 90 and 50 cm^2 g^{-1}. In contrast, in maize it was more than 150 cm^2 g^{-1} at the time of silking (Allison[1]). Thus, the N content of green leaves per unit area (Table 1) was not exceptionally small, despite their small N content percent of dry weight. Nevertheless, N content of the leaves per unit area was small enough after the first few months of growth to depress photosynthesis, if the relationship between rate of photosynthesis and N content is similar in sugarcane and rice (Takano and Tsunoda[13]). It seems significant in this connection that recently emerged leaves on old sugarcane plants had substantially smaller rates of photosynthesis than did leaves of young plants (Bull and Glasziou[6]). The decrease in photosynthetic efficiency was partly attributable to increased resistance to CO_2 movement, and in some cases this appears to be why rate of photosynthesis is depressed by a shortage of N (Natr[12]).

TABLE 1

Nitrogen (N) content per unit area of green leaves determined on successive occasions during the growth period

Weeks after planting	8	16	24	32	40	48	56
N, mg dm^{-2}	19,0	15,3	12,4	13,7	11,2	11,9	11,7

Nutrients commonly influence crop growth through their effect on the number, size and longevity of leaves (Watson, 1963). So, the decreases with time in number and area of green leaves per tiller (Figure 2), which resulted in L probably being too small to intercept all the incoming light (as referred to earlier) can be explained by an insufficiency of the supply of nutrients in the plant. Fertilizer was applied at or shortly after planting, so it is not clear whether these nutrients were taken up slowly after the first few months of growth (Figure 3) because they were in short supply in the soil, or because the 'requirement' of the plant decreased with time. No K was applied and since the availability of K does not change much with time in the soil used here, the apparent slowing down and later cessation of uptake of K presumably must have reflected a fall of demand by the plant. It could be interesting to test the effect of applying N and P and perhaps K to the leaves on a few occasions, starting, say, 25 weeks after planting (Thorne and Watson[15]).

Conclusion

Large annual yields of dry matter can be expected from a crop with a growth-cycle of indefinite length, in an environment which permits growth throughout the year. Moreover, sugarcane has an inherently efficient photosynthetic mechanism (Bull and Glasziou[6]). Nevertheless, sugarcane may, to the extent that it is represented by variety NCo 376, have certain drawbacks in respect of total dry matter productivity, namely slow increase in leaf area at the beginning of the growth period, diminished photosynthetic efficiency of leaves formed later, because of insufficient nutrients in the plant, and a large rate of respiration late in the growth-cycle, because the accumulated economic yield consists of physiologically active tissue (the sucrose-bearing parenchyma of the stem). A plant which stored photosynthate predominantly in the form of structural carbohydrate might be relatively more productive in terms of dry matter accumulation.

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REFERENCES

1. Allison, JCS (1969). Effect of plant population on the production and distribution of dry matter in maize. *Ann appl Biol* 63: 135-144.
2. Allison, JCS. (1981). Estimation of photosynthetically active radiation in Zimbabwe. *Zimbabwe J agric Res* 19: 225-228.
3. Allison, JCS and Haslam, RJ (1982). Comparison of growth of sugarcane and maize. *Zimbabwe J agric Res* 20: 119-127.
4. Amthor, JS (1984). The role of maintenance respiration in plant growth. *Plant, Cell and Environ* 7: 561-569.
5. Bishop, RT (1965). Mineral nutrient studies in sugarcane. *Proc S Afr Sug Technol Assoc* 39: 128-131.
6. Bull, TA and Glasziou, KT (1975). Sugarcane. In *Crop Physiology*, p. 51-72. *Ed.* L.T. Evans. Cambridge: Cambridge University Press.
7. Cook, MG and Evans, LT (1983). Nutrient responses of seedlings of wild and cultivated *Oryza* species. *Field Crops Res* 6: 205-218.
8. Glover, J (1973). The dark respiration of sugarcane and the loss of photosynthate during the growth of a crop. *Ann Bot* 37: 845-852.
9. Meyer, JH (1981). An evaluation of DRIS based on leaf analysis for sugarcane in South Africa. *Proc S Afr Sug Technol Ass* 55: 169-176.
10. Monteith, JL (1975). Light interception and radiative exchange in crop stands. In *Physiological Aspects of Crop Yield*, pp. 89-111. *Ed.* J.D. Eastin *et al.* Madison: American Society of Agronomy.
11. Nagatomi, S, Maeda, H and Lo, CC (1982). Studies on the selection methods for sugarcane breeding XVI. Analyses of yield components of sugarcane. *Jap J trop Agric* 26: 229-238.
12. Natr, L (1975). Influence of mineral nutrition on photosynthesis and the use of assimilates. In: *Photosynthesis and Productivity in Different Environments*, p. 537-555. *Ed.* J. P. Cooper. Cambridge: Cambridge University Press.
13. Takano, Y and Tsunoda, S (1971). Curvilinear regression of the leaf photosynthetic rate on leaf nitrogen content among strains of *Oryza* species. *Jap J Breed* 21: 69-76.
14. Thompson, GD (1978). The production of biomass by sugarcane. *Proc S Afr Sug Technol Ass*: 52: 180-187.
15. Thorne, GN and Watson, DJ (1955). The effect on yield and leaf area of wheat of applying nitrogen as a top-dressing in April or in sprays at ear emergence. *J agric Sci, Cambridge* 46: 449-456.
16. Van Dillewijn, C (1952). *Botany of Sugarcane.* Waltham, Mass: Chronica Botanica Co.
17. Watson, DJ (1963). Some features of crop nutrition. In: *The Growth of the Potato*, p. 233-247. *Eds* J.D. Ivins & F.L. Milthorpe. London: Butterworths.