

# EFFECT OF WATER STRESS ON SUGARCANE STALK GROWTH AND QUALITY

By N. G. INMAN-BAMBER

South African Sugar Association Experiment Station, Private Bag X02, Mount Edgecombe 4300

and J. M. DE JAGER

University of Orange Free State, PO Box 339, Bloemfontein 9300

## Abstract

Plots of varieties NCo376, N12 and N14 were established on a sandy soil of the Clansthal series near Umhlanga Rocks. Rain could be excluded from part of the site by a movable rain-shelter. Stalk volume was measured non-destructively at 14-day intervals and components of stalk quality were measured destructively at 21-day intervals. The plots in the sheltered area were deprived of water for about 5 months during the plant crop and for two 6-week periods during the first ratoon crop. Stalk growth responded rapidly to both the imposition and relief of water stress. Dry matter and sucrose contents of the stalk increased substantially during periods of stress and it appeared that moderate amounts of stress can lead to a substantial increase in sucrose yield. Amounts of dry matter and sucrose that were accumulated during a period of stress were not markedly affected when stress was relieved. The effect of stress on dry matter accumulation was associated with the differential responses of plant extension and stomata to water stress.

## Introduction

Dry spells occur frequently in the rainfield areas of the South African sugar industry. In irrigated areas water is often withheld before harvesting to improve stalk quality, but it is not clear if and how this practice enhances sucrose production. A lack of knowledge of the mechanisms of drought resistance in sugarcane varieties was the motivation for a field experiment to investigate the response of sugarcane to water stress. The effects of water stress on plant extension, stomatal resistance, canopy temperature and leaf water potential recorded in the experiment were reported by Inman-Bamber and de Jager.<sup>10</sup> Attributes of cane growth and water use were reported by Inman-Bamber and De Jager,<sup>11</sup> and this paper deals with the components of stalk quality and sucrose yield.

It is commonly accepted that low temperatures, nutrient deficiency and water stress, which restrict internode elongation, tend to favour sucrose storage (Bull and Glaziou;<sup>2</sup> Glaziou *et al.*<sup>4</sup>). Hatch and Glaziou<sup>6</sup> described a series of experiments in which the rate of internode elongation was negatively correlated with sucrose storage.

Clements<sup>3</sup> analysed the oldest 9 internodes of stalks removed from a ripening cane crop at monthly intervals over a period of 8 months. There was no measurable change in the fresh mass of this portion of the stalk, but dry matter and sucrose concentration and mass increased steadily. The effect of water stress on the translocation of the products of photosynthesis by sugarcane leaves was investigated by Hartt<sup>7</sup> using <sup>14</sup>CO<sub>2</sub>. Water stress depressed translocation more than it did photosynthesis, and the commonly observed increase in sucrose content during dry periods could not be reconciled with the results. Wardlaw and Passioura<sup>14</sup> suggested that the reduction in translocation rate observed by

Hartt<sup>7</sup> may have resulted from the weakening demand for assimilate by the extensible region of the stalk.

Carbon labelling experiments are required to provide definite proof of the movement of carbohydrates in cane stalks. The results presented here provide indirect evidence of the changes in dry matter and sucrose contents occurring in the stalk as the crop develops and during and after periods of water stress.

## Methods

The experimental techniques and methods of growth measurement used have been described by Inman-Bamber and de Jager.<sup>11</sup> Three varieties (NCo376, N12 and N14) were planted on 31 August 1983 in 8 randomised blocks on a loamy sand (Hutton form, Clansthal series) near Durban, Natal. Rain could be excluded from 4 of the blocks by a movable rain-shelter. The gross and net plot areas were 15,4 and 4,2 m<sup>2</sup> respectively.

Fertilizer applied in the furrow before planting provided 15 kg nitrogen (N) ha<sup>-1</sup> and 49 kg phosphorus (P) ha<sup>-1</sup>. A topdressing applied 41 days after planting provided a further 84 kg N ha<sup>-1</sup> plus 150 kg potassium (K) ha<sup>-1</sup>. The ratoon crop was topdressed with 147 kg N ha<sup>-1</sup> and 125 kg K ha<sup>-1</sup> on 4 September 1984, which was 61 days after harvesting the plant crop. Aldicarb was applied at a rate of 3 kg ha<sup>-1</sup> to both the plant and the ratoon crops, to control nematodes.

Trickle irrigation tubes with emitters at 0,3 m intervals were placed 0,3 m apart in all plots. Soil water was replenished when 30 to 40 mm of the previously determined 230 mm available water had been used by the crop. Water use was estimated by a budgeting method (Thompson<sup>12</sup>). Irrigation was suspended on 31 January 1984 in the area sheltered from rain when the plant crop was 125 days old until the crop was harvested after 307 days, by which time midday leaf water potential was approximately -1,2 MPa in the sheltered area (Inman-Bamber and de Jager<sup>9</sup>). During the ratoon crop irrigation of the sheltered area was suspended on 30 November 1984 when plants were 148 days old and it was resumed on 22 January when plants had lost all except 3 green leaves. Midday leaf water potential had by then declined to approximately -1,7 MPa. (Inman-Bamber and de Jager<sup>10</sup>). Irrigation was again suspended on 28 February and subsequently resumed on 23 April 1985, when plants were stressed to the same extent as before.

Cane yield was estimated from periodic measurements of the height and diameter of 15 to 36 stalks per plot from 2 of the 4 blocks, both inside and outside the sheltered area. The top of the stalk was defined as the topmost node that could be felt through the leaf sheaths and this node was usually within 40 mm of the apical meristem. Markers were secured to the fully extended portion of these stalks as soon as they were large enough. Once the height of the marker above the ground on each stalk was recorded, the heights of

other points on the stalk were measured from the marker. The proportion of marked stalks in the total in each plot varied between 0,2 and 0,3. The density of each internode of the marked stalks was measured at the time of harvesting.

Stalks from 1,0 m<sup>2</sup> sections of the plots in the other 2 replicates, both in the open or under the shelter, were cut at ground-level on 5 occasions during the plant crop and on 6 occasions during the ratoon crop. The plots were large enough to prevent interference between sampled sections. The stalks were weighed and macerated, one internode at a time. The dry matter (dm) % and sucrose % of wet mass and the juice purity by internode were determined in the laboratory. Quadratic functions were fitted to dm % and sucrose % of dry matter data in order to compute dm and sucrose yields on the occasions when cane yields were determined.

### Results

#### Quality components

The limited replication of treatments did not allow valid comparisons to be made of the quality components of the 3 varieties. In the plant crop, dm % cane, brix % dm, and sucrose % dm were increased substantially by withholding

water after January (Figure 1a). The brix % dm of unstressed plants remained nearly constant until the onset of winter (Figure 1a). The dm % of stressed plants in the ratoon crop was remarkably high in January when stress was severe (Figure 1b). Stalks of the stressed plants were small at this stage and were probably subject to large changes in dm % either because of desiccation or because of deposition of carbohydrates. About 70% of the dm was fibre at this stage. The dm % of stressed plants of the ratoon crop increased rapidly when stress was induced for the second time, but then dm % of stressed and unstressed plants became similar although plants differed substantially in size. The sucrose % dm of the ratoon crop increased rapidly in response to the second stress treatment, and after stress was relieved on 22 April it continued to rise but at a lower rate than that of unstressed plants.

#### Mass of fully extended internodes

At least 9 internodes had developed on all the stalks of the ratoon crop when stress was imposed for the second time. Fresh mass of the oldest 2 internodes was inconsistent because of variations in their length. Fresh mass of internodes 3 to 9 on unstressed stalks varied little, either between

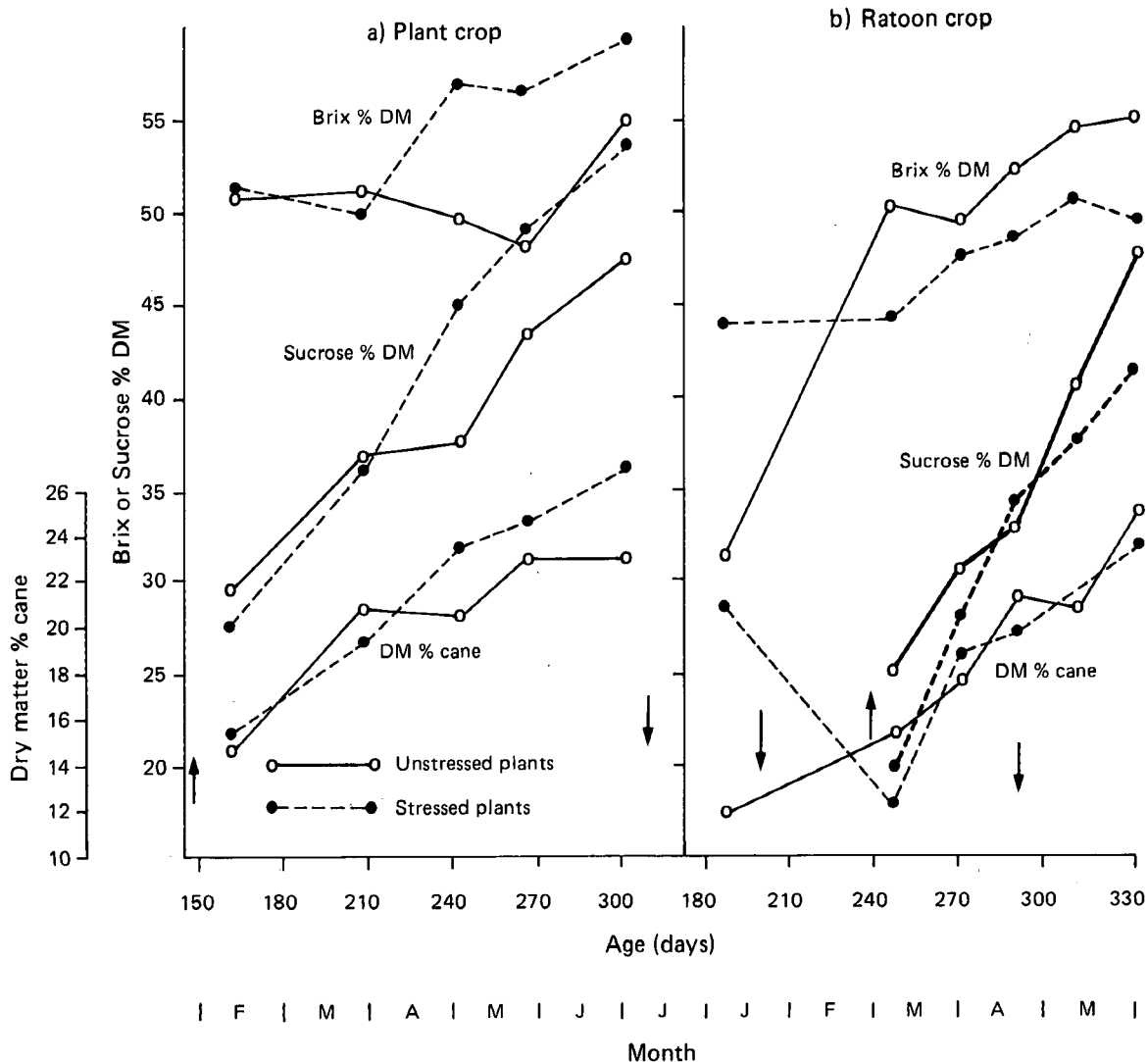


FIGURE 1 Dry matter % of cane stalks and % soluble solids (brix) and % sucrose in dried cane stalks of stressed and unstressed crops during the plant crop (a) and the ratoon crop (b). Arrows indicate when irrigation of the stressed crop was suspended (↑) and resumed (↓).

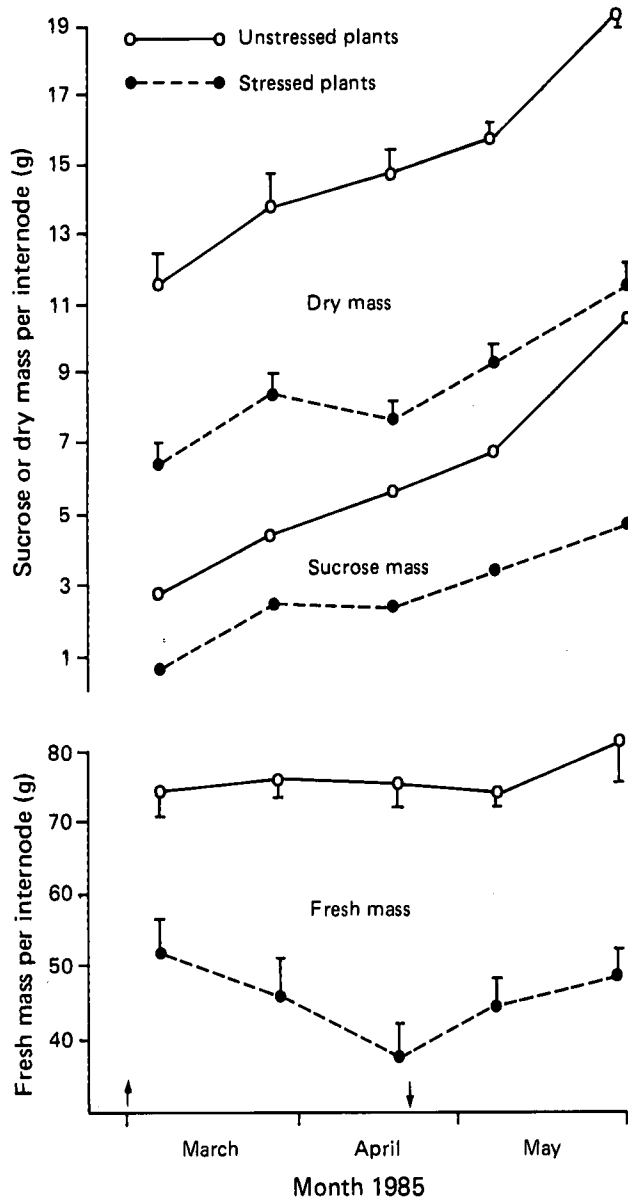


FIGURE 2 Mean mass of sucrose, dry matter and fresh matter of internodes 3 to 9 (from base) of unstressed plants and stressed plants during the ratoon crop. Arrows show when irrigation was suspended (↑) and resumed (↓). Bars denote standard errors.

varieties or between samplings. There was a slight increase in the mean mass of these internodes during May (Figure 2). The mass of dm and sucrose in unstressed internodes (obtained from the product of fresh mass and dm% and sucrose %) increased steadily during March and April while fresh mass remained constant.

The mean fresh mass of internodes of stressed stalks decreased during the second stress period and it increased again to pre-stress values after irrigation recommenced. The mass of dm and sucrose of stressed internodes increased during the first half of the second stress period but remained unchanged during the second half, and then increased once more when irrigation was resumed.

**Yield components**

The development of stress symptoms was very slow in the plant crop after irrigation was suspended in the sheltered area in February 1984, because of an exceptionally high rainfall (369 mm) in January. During February, before the period of imposed stress the cane yield of the crop in the sheltered

area was approximately 20 t ha<sup>-1</sup> more than that of the surrounding cane. The reason for this was not clear but the variation in yield between plots in each treatment was high. It was necessary to reduce the yields observed in the sheltered area by this amount to obtain a valid comparison with the cane outside the rain-shelter.

The cane yield of the unstressed crop and the adjusted yield of the stressed crop are shown in Figure 3. The growth of stressed cane stopped at the end of March when midday leaf water potential had fallen to approximately -0,7 MPa (Inman-Bamber and de Jager<sup>9</sup>) but dry cane mass increased steadily, although at a reduced rate. The effect of water stress on sucrose yield was small and if the data from the sheltered area had not been corrected for the discrepancy in cane yield during February then the stressed plots would have appeared to yield more sucrose than the unstressed plots.

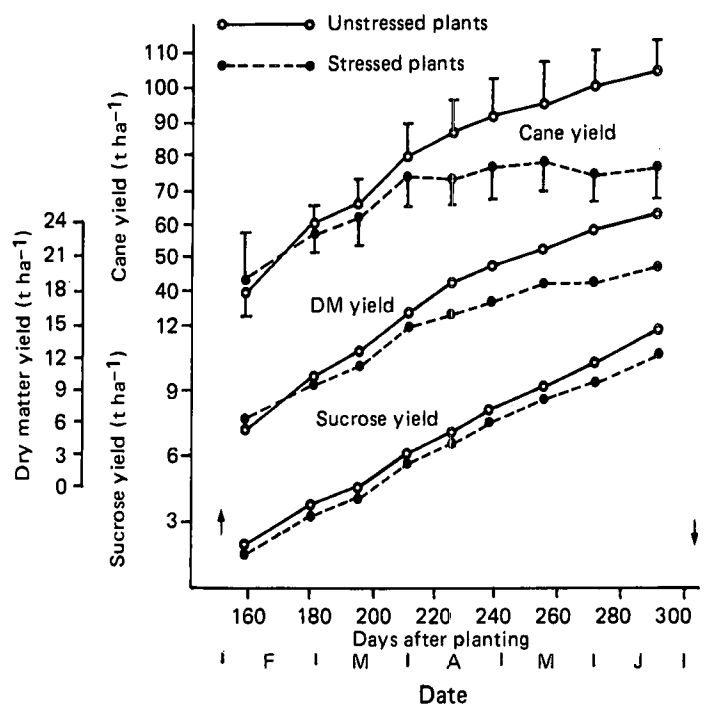
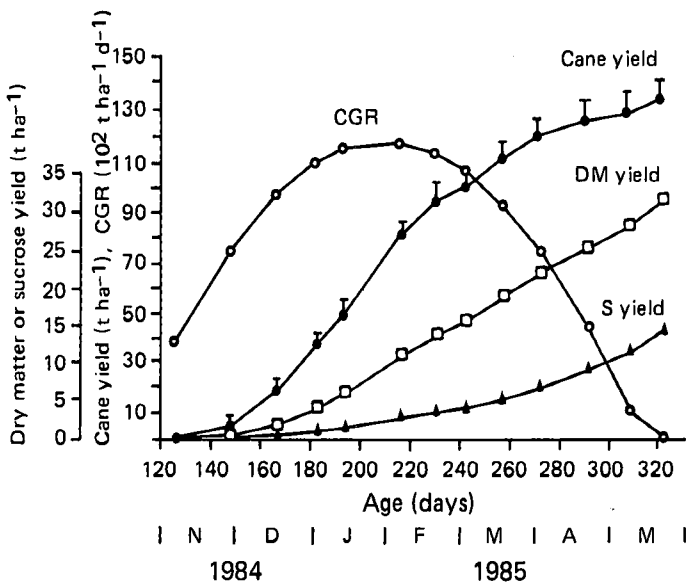


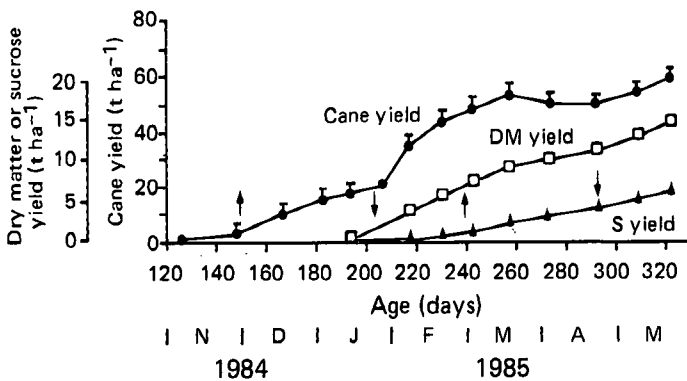
FIGURE 3 Yields of wet and dry cane stalks and sucrose yield of a plant crop of sugarcane either stressed by withholding water or irrigated to prevent stress. Arrows indicate when irrigation of the stressed crop was suspended (↑) and resumed (↓). Bars denote standard errors of means of 6 plots.

Cane growth of the ratoon crop was monitored from the start of the stalk elongation phase. Cane growth followed the expected sigmoid growth pattern and the first derivative of the polynomial curve fitted by least squares to the cane yield data showed a maximum rate of growth approximately 1,2 t ha<sup>-1</sup> d<sup>-1</sup> by the unstressed crop in January and February (Figure 4). In contrast the accumulation of dry stalk mass by this crop was linear. Sucrose yield of the unstressed crop increased more rapidly towards the end of the measured period than at the beginning because of the rapid increases in sucrose % dm and dm% cane as the crop aged. In the irrigated growth experiment of Gosnell,<sup>6</sup> cane growth rate decreased markedly during January of the second year of the experiment when the crop was 15 months old. The rate of increase in dry stalk mass was reduced only slightly at this point and it remained high until the crop was 18 months old.



**FIGURE 4** Yields of wet and dry cane stalks and sucrose yield of a ratoon crop which was irrigated regularly to prevent water stress. Cane growth rate (CGR) was obtained by differentiating a polynomial function fitted to the cane yield data. Bars denote standard errors of means of 6 plots.

The cane growth rate of the stressed crop responded almost immediately to changes in water regime but the changes in dry stalk mass were not as marked (Figure 5). Sucrose yields increased steadily despite the large changes in soil water content. The rate of growth for all these yield components was much lower in the stressed than in the unstressed crop but the greatest difference was observed in cane growth and the least in sucrose yield.



**FIGURE 5** Yields of wet and dry cane stalks and sucrose yield of a ratoon crop of sugarcane which was stressed by withholding water. Arrows indicate when irrigation suspended (↑) and resumed (↓). Bars denote standard errors of means of 6 plots.

**Discussion**

Cane growth is highly sensitive to stress. Stalk and leaf extension were reduced when leaf water potential fell to -0,2 MPa and tended to zero as leaf water potential approached -0,7 MPa (Inman-Bamber and de Jager<sup>10</sup>). Stomatal resistance increased rapidly only once leaf water potential fell below -1,2 MPa and it is likely that photosynthesis can proceed for a considerable time after stalk growth has been reduced. The dm% and sucrose % of the stalk are affected by changes in stalk growth and photosynthesis (Gla-

ziou and Gayler<sup>5</sup>) and the increase in these components at the onset of water stress (Figure 1) was probably partly due to a decrease in the demand for photosynthate in the apical region. The loss of water from the stalk during periods of water stress also accounted for some of the observed changes in dm% cane. It was evident (Figure 2) that water stress reduced wet mass due to desiccation and the increase in wet mass following irrigation appeared to be largely due to dehydration. The physics of water removal from mature portions of the stalk needs to be explained since the xylem water potential in these regions tends to be lower than that of leaves even in the most severely stressed plants (Meinzer, F C, personal communication).

When leaf water potential falls below -1,2 MPa, photosynthesis is likely to be reduced substantially and this would explain the absence of increases in the dm and sucrose masses of fully extended internodes during April 1985 (Figure 2). Leaf water potential fell from approximately -1,2 to approximately -1,8 MPa over this period (Inman-Bamber and de Jager.<sup>10</sup>). Rapid changes in growth rate may require the mobilisation of stored reserves.

Glaziou *et al.*<sup>4</sup> transferred sugarcane plants growing at a constant temperature of 17°C to an environment where the temperature was 30°C, which favoured rapid stalk elongation. The sucrose content of basal internodes fell from 16,0 to 6,5% of fresh mass over a period of 35 days. Changes in growing conditions as large as this seldom if ever occur in the field. In tall fescue only about 50% of the sugars stored in stem bases was removed to support leaf growth following total defoliation (Volenc<sup>13</sup>). The concentration of sugars was restored after 24 days of regrowth. Carbohydrate translocation to and from storage in lucerne roots depended to a large extent on the growth rate of the crop and the degree of defoliation (Brown *et al.*<sup>1</sup>). The resumption of growth of the sugarcane after the second period of stress in the ratoon crop, though substantial, did not correspond with a reduction in brix % dm as was expected even though leaf area index had been reduced to about 0,2. It is possible that reserves of carbohydrates would have been removed to support the vigorous growth that may have occurred had the stress been broken during the summer months. However, it appears that stored reserves in sugarcane are not readily removed to support new growth.

**Conclusions**

Water stress affected the development of cane and sucrose yields differentially. These different responses to water stress were related to the sensitivity of the extensible portion of the apical region and also to the relative insensitivity of stomata to water stress. If water stress remains moderate over a long period and growth is reduced more than photosynthesis, then dm and sucrose contents may rise sufficiently to offset the effect on sucrose yield of the marked reduction in cane yield. Severe stress resulting in stomatal closure will halt the increase in dry mass of stalks. Sucrose stored during crop development or during stress periods is not readily mobilised to support renewed growth when water stress is relieved provided that at least 3 leaves on each stalk remain alive. The large differences in the rates of accumulation of wet and dry cane yield and of sucrose yield need to be taken into account when consideration is given to the effects of age and season on sugar yield.

**Acknowledgements**

The authors are grateful to Dr G Thompson and to Mr M Murdoch for many suggestions regarding sampling

methods and the analysis and interpretation of the data, and to Mr Gopal Dorasamy, who recorded much of the data. The Director of the Natal Region of the Department of Agriculture and Water Supply is thanked for the loan of the rain-shelter.

#### REFERENCES

1. Brown, RH, Pearce, RB, Wolf, DD and Blazer, RE (1972). Energy accumulation and utilisation. In *Alfalfa science and technology*. Ed Hanson, CH. American Society of Agronomy, Madison, Wisconsin, USA: 143-166.
2. Bull, TA and Glaziou, KT (1975). Sugar cane. In *Crop Physiology*. Ed Evans, LT. Camb Univ Press: 51-72.
3. Clements, HF (1980). *Sugarcane crop logging and crop control principles and practices*. Pitman Pub Ltd, London: p 520.
4. Glaziou, KT, Bull, TA, Hatch, MD and Whiteman, PC (1965). Physiology of sugarcane. VII. Effects of temperature, photoperiod duration, and diurnal and seasonal temperature changes on growth and ripening. *Aust J Biol Sci* 18: 563-566.
5. Glaziou, KT and Gayler, KR (1972). Storage of sugars in stalks of sugarcane. *Bot Rev* 38: 471-490.
6. Gosnell, JM (1967). The growth of sugarcane. Unpublished PhD thesis, University of Natal.
7. Hartt, CE (1967). Effects of moisture supply upon translocation and storage of  $^{14}\text{C}$  in sugarcane. *Plant Physiol* 42: 338-346.
8. Hatch, MD and Glaziou, KT (1964). Sugar accumulation cycle in sugarcane. II Relationship of invertase activity to sugar content and growth rate in storage tissue of plants grown in controlled environments. *Plant Physiol* 38: 344-348.
9. Inman-Bamber, NG and de Jager, JM (1984). Effect of water stress on the growth and sucrose accumulation of sugarcane. Unpublished paper, *Sth Afr Soc Crop Prod Congr* 1984, Cedara, Natal.
10. Inman-Bamber, NG and de Jager, JM (1986). Effect of water stress on growth, leaf resistance and canopy temperature in field-grown sugarcane. *Proc S Afr Sug Technol Ass* 60: 156-161.
11. Inman-Bamber, NG and de Jager, JM (1988). Effect of water stress on cane growth and water use efficiency. *S Afr J Plant and Soil* (in press).
12. Thompson, GD (1976). Water use by sugarcane. *S Afr Sug J* 60: 627-635.
13. Volenec, JJ (1980). Non-structural carbohydrates in stem base components of tall fescue during regrowth. *Crop Sci* 26: 122-126.
14. Wardlaw, IF and Passioura, JB (1976). *Transport and transfer processes in plants*. Academic Press, London: 483.