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EFFECTS OF LOW TEMPERATURES ON IRRIGATED MAY AND DECEMBER RATOONS

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Abstract

Low temperatures during the early stages of a crop prolong the time it takes for a canopy to develop fully through its effects on leaf development and tillering. This reduces the fraction of incident sunlight intercepted by the crop and prevents the crop from reaching full maturity in annual harvested crops. December crops have been reported to yield poorly despite intercepting high fractions of incident solar radiation. An experiment was conducted to investigate the season effects on the growth and yields of some commercial cultivars. This study compared the growth of leaves, shoots and stalks of May and December ratoons of the cultivars NCo376 and N26. The December ratoons grew rapidly until winter temperatures slowed growth rates. These ratoons then recovered slowly from their moribund state when temperatures rose in the second summer and yielded poorly when compared with a May ratoon. Growth of the May ratoon was initially slow and it took seven months before canopies intercepted sunlight fully, and they therefore intercepted a relatively low fraction of incident sunlight. Based on this analysis and that of McCormick *et al.* (2006), together with a re-analysis of the data of Rostron (1974), it is proposed that the yield and quality of summer ratoons are directly related to the age at which they experience low winter temperatures.

Keywords: low temperatures, May ratoon, December ratoon, shoot densities, leaves, stalks, sucrose,

Introduction

In South Africa, sugarcane is grown for 12 to 24 months before being harvested, and therefore can be subjected to low winter temperatures on several occasions during a single crop cycle. Crops harvested annually in winter (May to July) are affected by low temperatures at the start and the end of 12 months. Crops harvested annually in December are subjected to low temperatures only once during a 12 month cycle. December ratoons intercepted 71-74% of incident radiation compared to only 61% by a June ratoon crop (Inman-Bamber, 1994) due to differences in canopy development.

Yields from 1968 to 1971 for Hippo Valley Estates (Zimbabwe) showed that sucrose yields per hectare per month ranged from 1.382 tons in September to 1.118 tons in December of the cultivar NCo376 (Gosnell and Koenig, 1972). The trends were similar for the cultivars NCo310 and Co462. Six-year means of annual cane yields from Triangle Limited in Zimbabwe (1974-1979) varied substantially through the season. December crops yielded about 28% less than the peak yields in April-June crops (Cackett and Rampf, 1981). The authors ascribed the poor mid-summer crop yields (October-December) to growth restrictions imposed by low winter temperatures. Poor yields from December ratoons have therefore been reported for several sugarcane estates in southern Africa. However, late summer crop yields on estates are known to be affected by lodging and flowering. These crops are also often affected by heavy rainfall in late summer when poor field drainage may lead to roots being subjected to anaerobic conditions. Data from sugarcane estates usually only report final yields without describing the mechanisms that determine yields. The effects of low temperatures on the yields of summer harvested crops on estates could therefore have been masked by several additional factors which affect growth of sugarcane.

In a season x growth experiment at Pongola, Rostron (1974) observed slow growth rates between August and October of January and February ratoons for which he could find no clear reason. Thus, Cackett and Rampf (1981) and Rostron (1974) alluded to two periods of slow growth in December ratoons that would affect yields, *viz*. (1) slow winter growth (due to low temperatures) and (2) slow spring growth (not responding to increasing temperatures). Recovery after slow winter and spring growth would therefore only be observed after October, as recorded by Donaldson (2009). An analysis of factors that lead to reduced growth rates in sugarcane by van Heerden *et al.* (2010) differentiated this slow growth during spring (RSGP) in young sugarcane crops from the reduced growth phenomenon (RGP) seen in older crops and described by Park *et al.* (2005). Donaldson *et al.* (2008) proposed that ‘end-product feed back’ suppression of photosynthesis, which has recently been demonstrated by Mc Cormick *et al.* (2008), could be implicated in the RSGP.

The effects of low winter temperatures have previously been reported for discrete phases of growth processes or for yields, e.g. canopy development and light interception (Inman-Bamber, 1994; Singels and Donaldson, 2000)), leaf development and population densities (Singels *et al.*, 2005), and light interception and final yields (Donaldson *et al.*, 2008). In this study the growth of a December ratoon was followed from the appearance of the first shoots and compared with that of a May ratoon; the final yields have previously been reported (Donaldson *et al.*, 2008); Donaldson, 2009). The main objective of the present study was to reveal the effects of low temperatures on the growth of crops that experienced this mid-way through the annual cycle (as in a December ratoon) by comparison with crops which experience low temperatures during crop emergence and early canopy development (as in a May ratoon). Also, the apparent incongruities in the observations of high fraction of solar radiation interception leading to low biomass yields in December ratoons and the relatively lower fraction of intercepted solar radiation leading to higher biomass yields of May ratoons (Donaldson *et al.,* 2008) need to be resolved.

Materials and Method

Site and crop husbandry

Growth and development of well-irrigated sugarcane crops were measured in an experiment at Pongola (27°25' S, 31°36' E, 308 m asl). Irrigation events were scheduled to avoid stress by estimating soil water status using the Canesim model (formerly the IRRICANE model) (Singels *et al*., 1998) and profit and loss balances. Irrigation water was delivered by dripper lines, placed in alternate interrows. Split fertiliser applications totaling 240 kg N/ha, 78 kg P/ha, 167 kg K/ha and 3.5 kg Zn/ha were made as side dressings to each crop. A final application of 51 kg N/ha was made when crops were 5 months old. Third leaf samples were taken one month after the last application of fertilizers to confirm plant nutrient status. The experiment was kept free of weeds at all times by the use of herbicides and manual control.

Weather

A weather station, within 100 m of the experiment site, provided daily data to develop relationships between growth, temperature and radiation. Maximum and minimum temperatures, rainfall and daily global incoming shortwave radiation were recorded during the experiment. Heat units that drive a given process were calculated by subtracting a base temperature from the mean daily temperature, *viz*. (maximum temperature + minimum temperature)/2 – base temperature = heat units or growing degree days. The minimum temperature below which a process ceases (e.g. leaf appearance ceases at 10 °C) (Inman-Bamber, 1994) is the 'base temperature'. The cumulative growing degree days (°C d) over a period is referred to as cumulative thermal time. Base temperature is cultivar and growth stage specific.

Treatment details

Ratoon crops of nine cultivars in two replications were started in March, April, May, August and December 1998 at Pongola. Each plot consisted of 12 rows spaced at 1.4 m and was 23 m long. Further details of treatments can be found in Donaldson *et al.* (2008). This study is a report on the ratoon crops of NCo376 and N26 started in May and December.

Leaf and shoot measurements

The number of shoots was counted in 4 m sections of 9 rows every two to three weeks. Where cane had lodged stalks were lifted carefully (to avoid breakage) so that shoots could be counted accurately. Ten shoots were tagged in each plot for easy identification and the total number of leaves on each shoot was recorded. A tag was placed between the most recently senesced leaf and the oldest green leaf on each occasion to assist with counting dead and green leaves. When tagged shoots died the tags were shifted to shoots of similar size. Leaf appearance and senescence rates were calculated from the reciprocal of the slope from regression of number of leaves on thermal time. On each sampling occasion (see below) the size of each green leaf on three shoots from each sample were measured with a Licor 3000 area meter and recorded in sequence of appearance.

Light interception measurements

The fraction of Photosynthetically Active Radiation (PAR) that was intercepted by the green canopy was measured on several occasions before canopy closure with a ceptometer (SF-80 model, Decagon Devices, Pullman, WA, USA). One above-canopy and eight to ten below-canopy readings were done on each plot between 11h00 and 13h00 on cloudless days. Daily fractions were estimated by interpolation and applied to daily incident short wave radiation measured at the weather stations, and the products summed over the season to derive seasonal intercepted short wave radiation (Singels *et al*., 2005).

Sample analysis

Samples of 15 stalks were taken from four points in each plot when crops were 4, 8, 10, 11 and 12 months old. One sample from each replicate was set aside for sectioning (see below). After removing all leaf material (for details see Donaldson *et al*., 2008) whole stalks were shredded with a modified wood planer to produce material from which dry matter content was determined as described below. The soft top sections of the stalk (called meristem) were analysed as a separate component and added to the stalk biomass. Each component was weighed immediately after collection. Sub-samples from each component were weighed and then dried to a constant mass and weighed again to determine dry matter content. Dry matter content of each component was calculated from fresh and dry mass. Sub-samples from shredded stalks were used to determine their total soluble solids (brix) content and sucrose content (Buchanan and Brokensha, 1974). Yields per stalk were calculated from sample data and then multiplied by stalk numbers and expressed as g/m². One sample from each replicate was combined into a single sample of 30 stalks for sectioning on each sampling occasion. Stalks were cut into 200 mm sections as follows: from the base to 200 mm up the stalk; from the apex to 200 mm down the stalk; 200 mm from base up to 400 mm from base; 200 mm from apex down to 400 mm from apex; etc. On each occasion the remainder of the stalk after sectioning (which was of variable length) was assigned as the mid-section. Sections were weighed and analysed in the same manner as whole stalks for dry matter, brix and sucrose content, described above.

Data were analysed using the residual maximum likelihood (REML) procedure (GENSTAT 10, 2007) to determine standard error of differences for cultivars and harvesting cycles. This study contains data that were produced and analysed in the study reported by Donaldson *et al.* (2008).

The association between sucrose yields of summer ratoons from a growth experiment conducted by Rostron (1974) and the age at which these crops experienced low temperatures during winter months was investigated. The aim of this simple approach was to provide further evidence of the detrimental effects of low temperatures on yields of annual summer ratoons.

Results

Weather, water and nutritional status

May and December ratoons received very similar amounts of solar radiation (6623 and 6614 MJ/m², respectively) and rainfall (620 and 581 mm, respectively) over the 12-month cycle. Both Et ref (1531 and 1546 mm, respectively) and mean temperatures (21.4 and 21.7 ºC, respectively) were also very similar for the two crops. Irrigation maintained high soil water levels and only on a few days when both crops were about 8.5 months old did soil water drop below 50% of estimated total available water of 200 mm. Analyses of third leaf samples taken one month after the last fertiliser application indicated that N, P, K Ca, Mg and Zn had been taken up in adequate amounts according to the threshold values of the Fertiliser Advisory Services of the South African Sugarcane Research Institute.

Shoot development

Shoot emergence

Logarithmic functions were fitted to the stalk densities that were determined for the first three occasions to estimate the day on which the first shoots emerged. The value at the intercept was taken as the day on which the first shoots emerged. Shoot emergence was defined as the day on which one shoot/m² had emerged (Lui *et al*., 1998). It took 12 and 15 days from cutting date to emergence of NCo376 and N26 in the May ratoon, respectively. Emergence was quicker in the December ratoons and took only 8 and 9 days in NCo376 and N26, respectively. Using base temperatures for germination to shoot emergence of 12.7 and 10.8 °C for NCo376 and N26, respectively, Donaldson (2009) calculated thermal times of 94 and 88°C d for NCo376 and N26, respectively.

Shoot population dynamics

Primary shoots were produced from the germination of buds left on the stubble after harvesting the previous crop. Secondary shoots that were produced by the tillering process could not be easily distinguished from primary shoots and therefore the descriptions of population densities include primary and all secondary shoots. Shoots continued to emerge for 72 days in December ratoons and for 169 days in the May ratoons (or approximately 655 and 461 °C d, respectively) at which time numbers of shoots peaked (SDmax). SDmax of 62.7 shoots/m² and 30.8 shoots/m² (significant at $p=0.05$) were produced by NCo376 and N26 in the December ratoons, respectively. SDmax was significantly ($p=0.05$) lower in the May ratoons at 38.2 and 16.1 shoots/m² for NCo376 and N26, respectively. Base temperatures for population dynamics were taken to be that reflected by the highest R^2 values of 4° polynomial functions fitted to shoot densities related to cumulative thermal times calculated from base temperatures ranging from 0 to 20 °C (Donaldson, 2009). The base temperatures of 16 and 9 °C best described the population dynamics of NCo376 and N26, respectively (Figure 1).

Shoots started dying rapidly after reaching SDmax, but the decline slowed after about 1000 °C d (base 16 °C) in NCo376 and between 2000 and 2800 °C d (base 9 °C) in N26. After 357 days shoot numbers in the December ratoons had declined to 14.4/m² and 9.9/m² in NCo376 and N26, respectively. In the May ratoons the final shoot densities (SDfin) at the age of 362 days were 16.7/m² and 10.7/m² (SED 2.1) for NCo376 and N26, respectively (Figure 1).

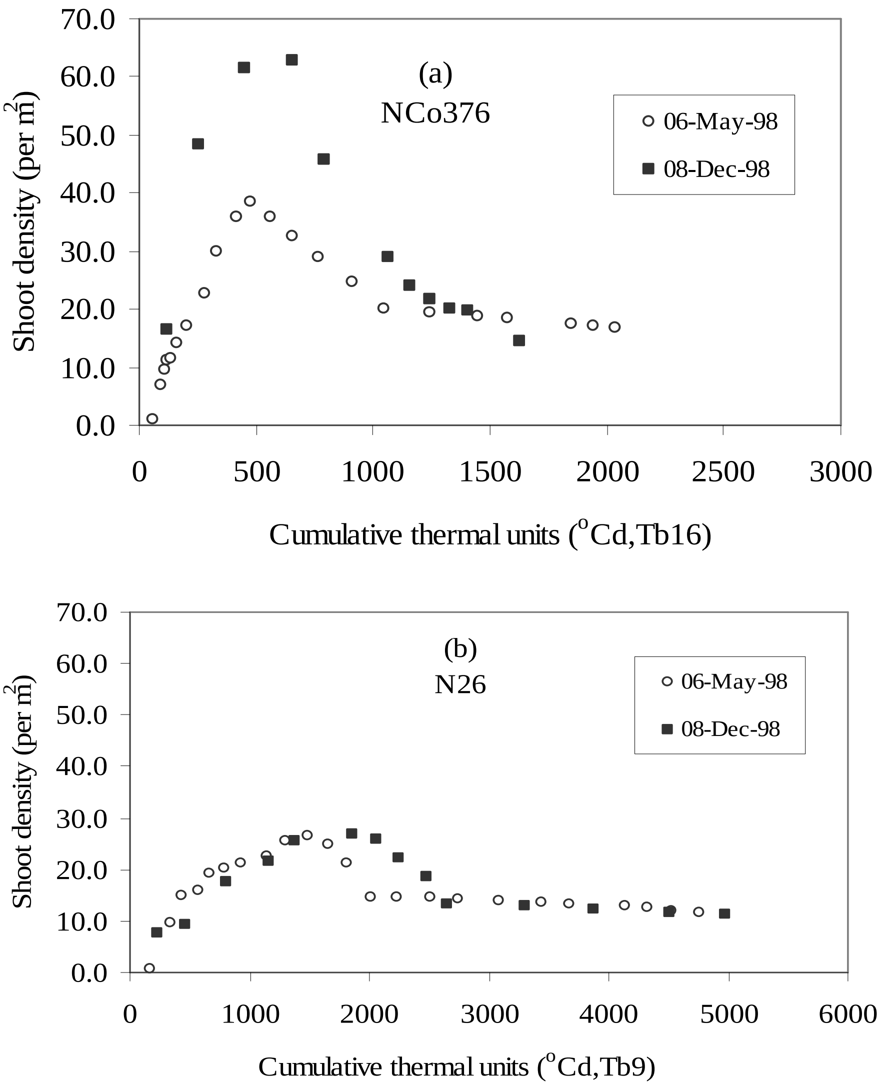


Figure 1. Shoot densities of May and December ratoons relative to cumulative thermal times of the cultivars (a) NCo376 (Tb 16) and (b) N26 (Tb 9).

Leaf development

Rate of leaf appearance

A power-law function fitted to number of leaves related to cumulative thermal time (Figure 2) described the continually changing time interval between the appearance of successive leaves on a culm (phyllochron) as leaf number increased (Bonnett, 1998). However, a biphasic linear description (Inman-Bamber, 1994) was considered the most appropriate model to apply in order to extract seasonal effects from the phyllochron data (Figure 2). The switch in the rate of leaf appearance (Tbase 10°C), separating phyllochrons 1 and 2, occurred between leaves 12 and 13

(Table 1) (Donaldson, 2009). The first leaves appeared at a slower rate in the December ratoons. The first leaves (phyllochron 1) of N26 appeared more rapidly in the December crop and slightly slower in the May crops than NCo376. Phyllochron 2 was much longer than phyllochron 1. These later leaves (phyllochron 2) appeared at a quicker rate in N26 of the May ratoon (Table 1).

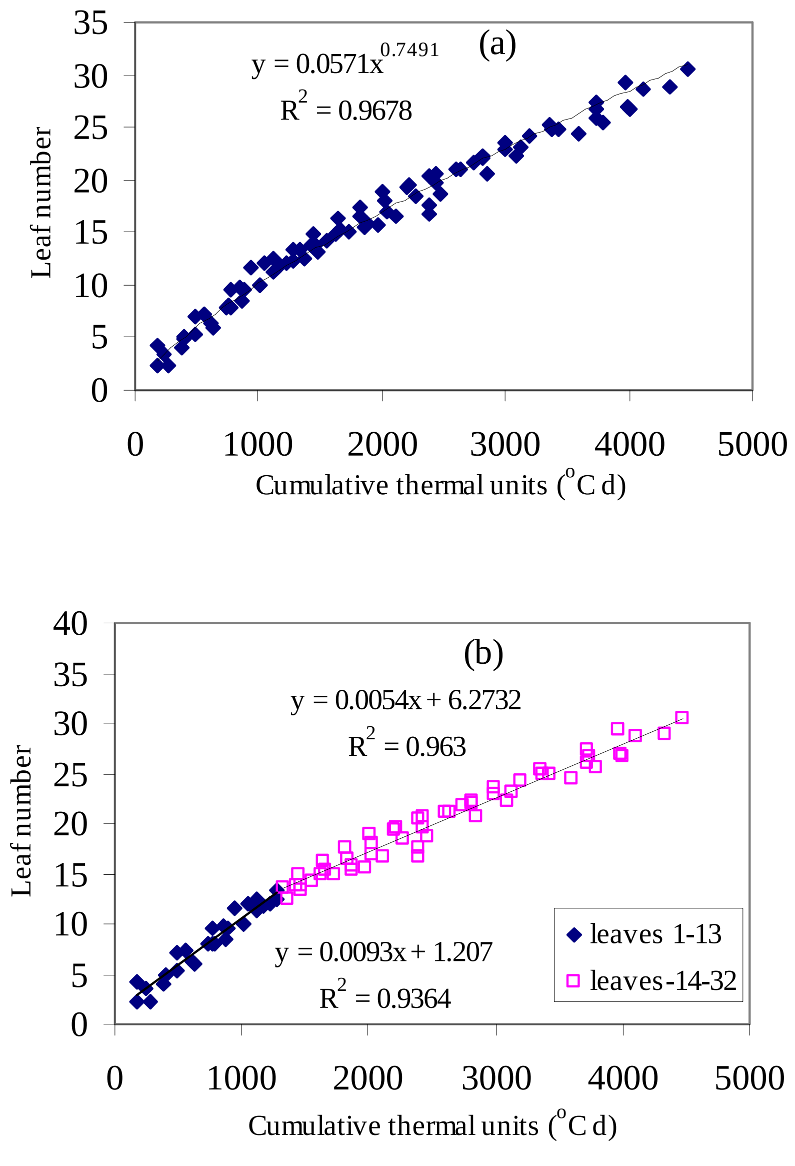


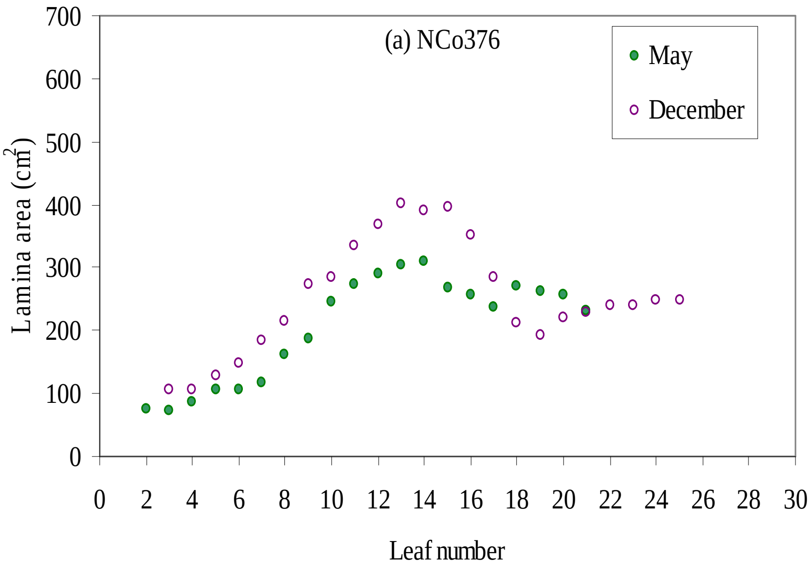
Figure 2. An example of leaf number production in relation to cumulative thermal time for crops started in March, April, May, August and December described by (a) a power-law function and (b) by two linear functions fitted to leaf numbers 1-13 and 14-32. Note that the phyllochron switch was deemed to occur between leaves 12 and 13 in Table 1.

Table 1. Phyllochrons 1 and 2 (°C d) for sugarcane cultivars NCo376 and N26 of crops started in May and December.

Phyllochron 1			
Start month	May	December	Mean
NCo376	97.1	113.6	105.4
N26	100.0	107.5	103.8
Phyllochron 2			
NCo376	188.7	185.2	186.9
N26	181.8	185.2	183.5

Leaf size

Leaves produced during the December ratoon were on average larger (499 cm²) than those produced in the May ratoon (393 cm²) and were larger in N26 than NCo376 in both ratoon dates. The average size of leaves from six shoots of N26 was 596 cm² in the December ratoon (Figure 3b). In comparison the average size of NCo376 was 401 cm² (Figure 3a). Leaf size increased in order of appearance up to leaf number 13 or 14 in NCo376. Thereafter, leaves were successively smaller. The decline in leaf size of NCo376 was particularly evident in the December ratoon so that the later emerging leaves of the December and May ratoons were similar in size. There was a similar decline in leaf size of the December ratoon of N26. Leaves of N26 in the May ratoon were smaller and maximum size was reached at leaf number 20. Thereafter, leaf size of N26 declined little.



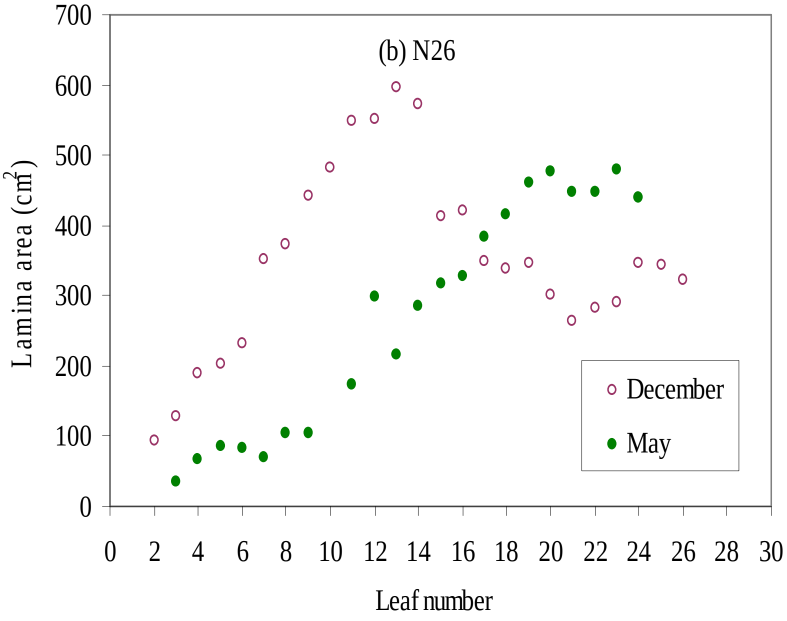


Figure 3. Leaf sizes of primary shoots from May and December ratoons of the cultivars (a) NCo376 and (b) N26.

Leaf senescence

Leaf senescence started after six leaves had been produced in the May ratoons and after eight leaves had emerged in the December ratoons. Robertson *et al*. (1998) found that leaf senescence started after seven leaves had appeared. The rate of leaf senescence, determined by the regression of the number of senesced leaves on the number of emerged leaves, starting from the leaf number when senescence first started (Donaldson, 2009) are shown in Table 2. Senescence was more rapid in the December ratoons than in the May ratoons. Leaf senescence was slower in N26 than in NCo376, particularly in the May ratoon.

Table 2. Rates of leaf senescence as a function of number of emerged leaves.

Ratoon	NCo376	N26
May	0.81	0.67
December	1.01	0.91

Stalk growth

Stalk elongation

Stalks elongated rapidly during the first four months of the December ratoons and after eight months (during August) stalks had attained heights of 2.10 m (Figure 4a). Stalks elongated very little between August and October (eight to 10 months old) after which 0.13 to 0.39 m were added to the heights of NCo376 and N26, respectively. In the May ratoons, stalks initially elongated slowly and reached about 2.0 m after 10 months (in February) and thereafter added about a further 0.8 m during the final two months.

Stalk mass

The cultivar N26 had heavier stalks than NCo376 throughout the sampling period (Figure 4b). N26 stalks of the December ratoon had accumulated 90% of their final stalk mass by the age of eight months and 100% of their final mass by the age of 10 months. Thus, between October (10 months old) and December (12 months old) N26 stalks of the December ratoon accumulated no mass. Similarly, NCo376 stalks of the December ratoon attained 79% of the final mass by August but accumulated very little mass between August and October. After October, stalk mass of NCo376 increased by 18%. In contrast, the stalks of the May ratoon had accumulated only 15-20% of their final stalk mass at the age of eight months (in December). Thereafter, stalk mass was gained more rapidly throughout the remaining period of four months. At the age of 12 months stalks of the May ratoons were heavier than the December ratoons.

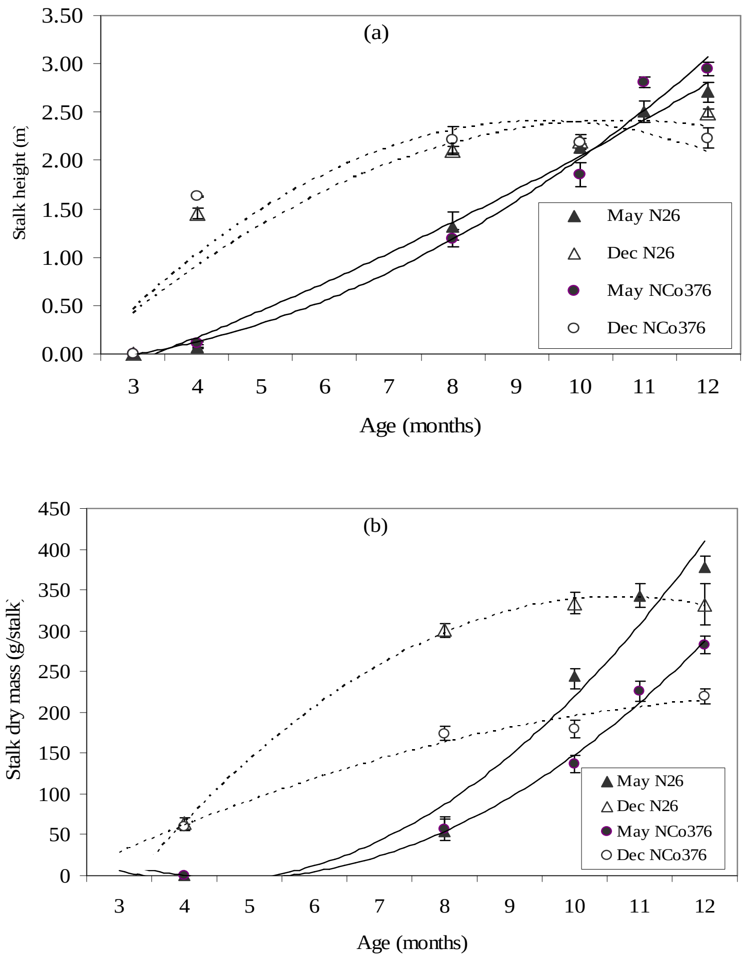


Figure 4. Stalk growth trends of May and December ratoons of the cultivars NCo376 and N26 indicated by (a) stalk elongation and (b) stalk dry mass over a 12-month period.

LAI and light interception

Peak LAIs (7-9) were attained at about four months of age in the December ratoons and were less than two between the ages of eight and 12 months (Figure 5b). In comparison, the May ratoons had much lower peak LAIs (c 4-5) which were developed when the crops were 11 months old (Figure 5a). After about 1.5 months from the time of emergence, the December ratoons were intercepting between 65% (N26) and 80% (NCo376) of PAR (Figure 6b). Such levels of sunlight (PAR) were only intercepted when the May ratoons were older than seven months when LAIs were, for the first time, >2 (Figure 6a). At the age of 12 months the December ratoons of NCo376 and N26 had intercepted 88 and 86%, respectively of incident solar radiation. In comparison, the May ratoons intercepted only 67 and 56% (NCo376 and N26, respectively) of incident annual solar radiation (data not shown).

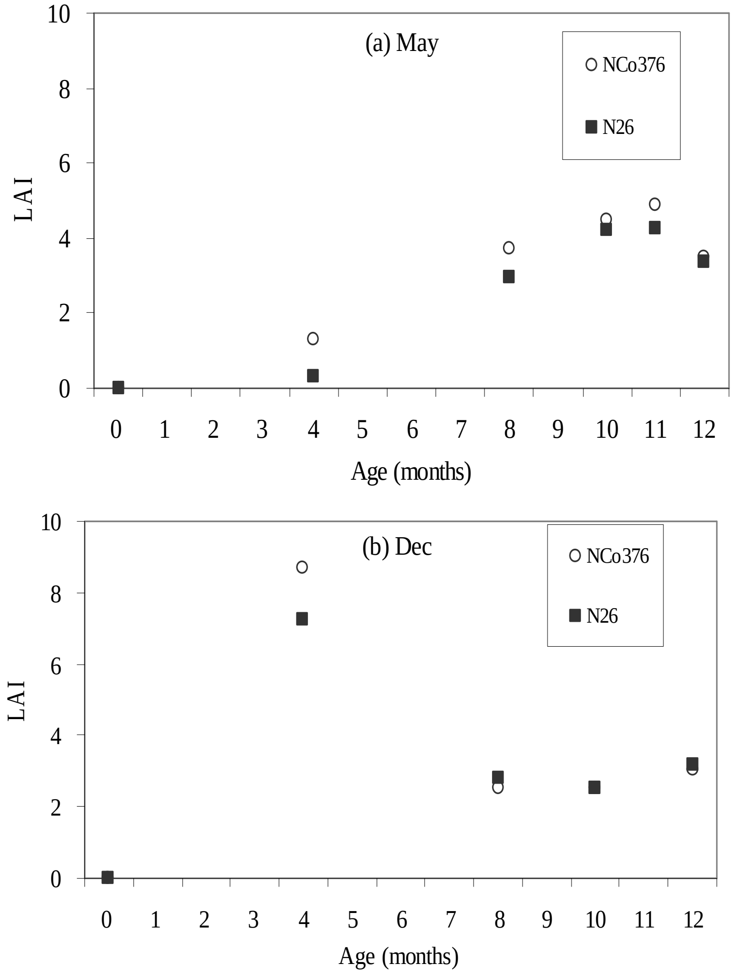
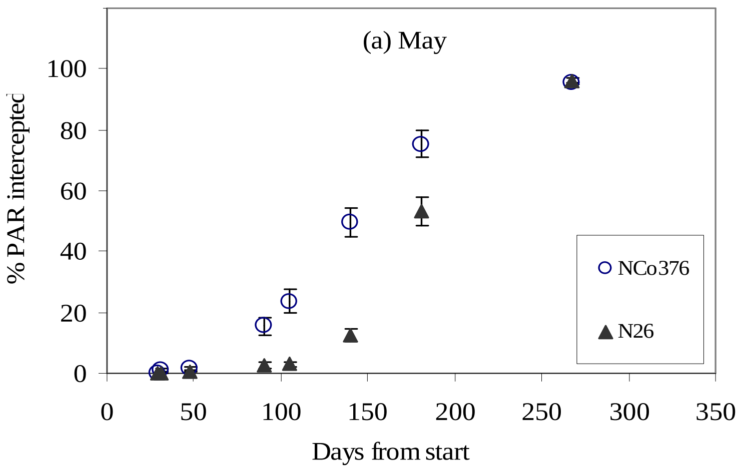


Figure 5. Leaf area index of the cultivars NCo376 and N26 for (a) May ratoons and (b) December ratoons.



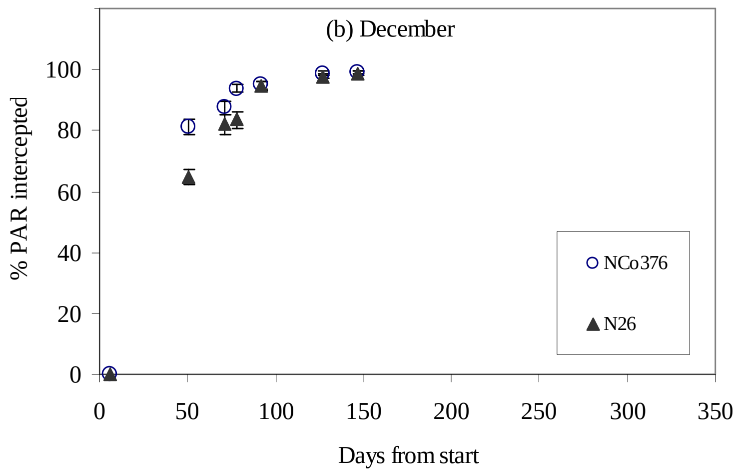


Figure 6. Light interception (% of incident PAR) of the cultivars NCo376 and N26 in (a) May ratoons and (b) December ratoons.

Sucrose

Sucrose mass

The stalks of the December ratoons accumulated sucrose rapidly during the first eight months and thereafter (August to December) little additional sucrose was gained. In contrast, the May ratoons accumulated little sucrose during the first eight months (Figure 7). Thereafter, sucrose was accumulated rapidly so that at the age of 12 months stalks of the May ratoons yielded significantly higher sucrose mass than stalks of the December ratoons. Stalks of N26 accumulated significantly higher amounts of sucrose than NCo376 (Figure 7).

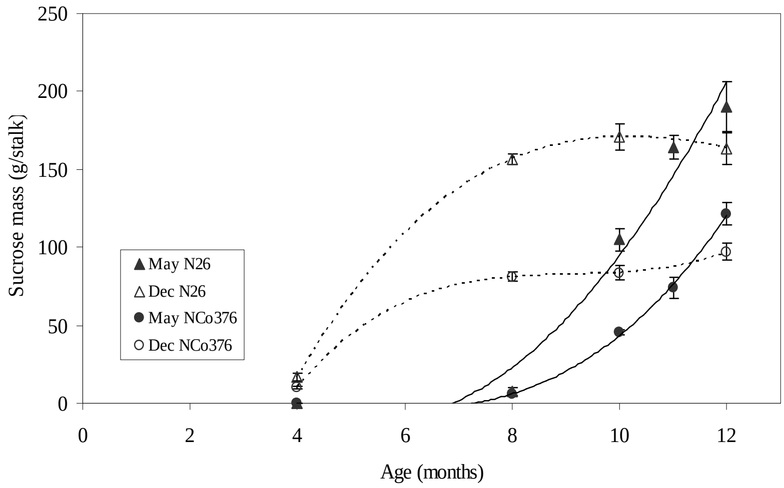


Figure 7. Sucrose mass (g/stalk) trends of December and May ratoons in maturing stalks of NCo376 and N26.

Stalk sucrose concentration

By the age of eight months (in August) the sucrose concentration (g sucrose/g dry mass) in stalks had risen to 0.52 in N26 and 0.46 in NCo376 of the December ratoons; during the final four months sucrose concentrations fell by 0.02 (NCo376) to 0.03 (N26) units (Figure 8). In comparison, sucrose concentrations of the May ratoon were between 0.11 and 0.14 after eight months (in January) but then rose, almost linearly, to be equal to that of the December ratoons at the age of 12 months (Figure 8).

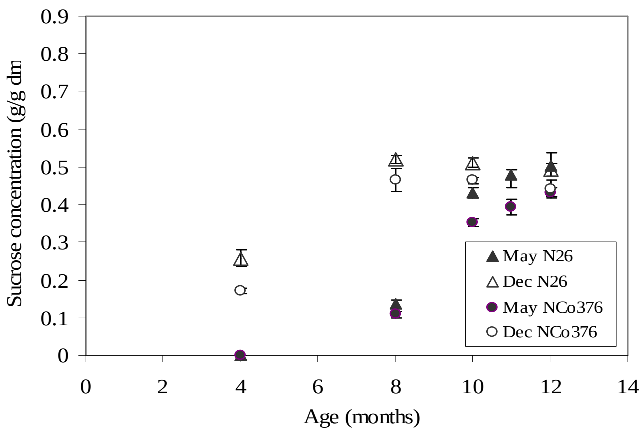


Figure 8. Sucrose concentrations in stalks of the cultivars NCo376 and N26 from May and December ratoons.

The sucrose concentrations in the top 20 cm of stalks from December ratoons rose to 0.35 and 0.41 (NCo376 and N26, respectively) at the age of eight months and then remained at relatively high levels (0.34) until the age of 12 months (data not shown). Sucrose concentrations of the May ratoons had risen to only 0.18 and 0.11 in the tops of NCo376 and N26, respectively, at the older age of 10 months and then rose steadily to 0.21-0.25 (data not shown).

Yields of summer ratoons (Rostron, 1974)
Sucrose yields of ratoons harvested at the age of 11 months between September and February declined linearly from 17.5 to 10.7 tons/ha (Figure 9). Thus, the younger the age at which a summer ratoon experienced low winter temperatures (May), the lower the sucrose yield.

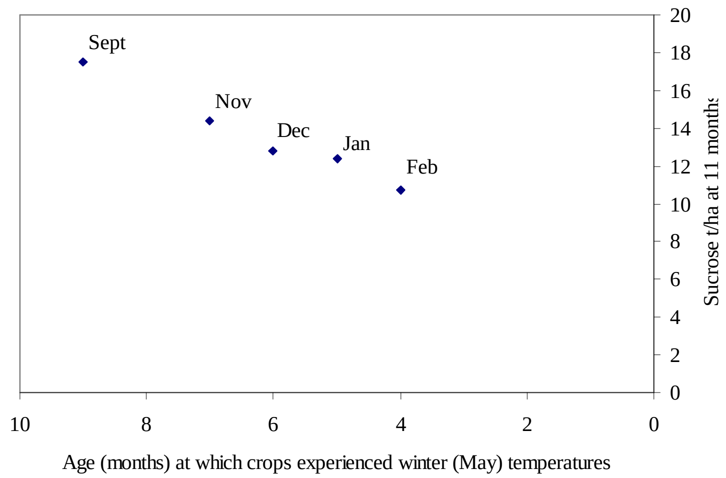


Figure 9. The association between sucrose yields of summer crops ratooned between September and February (y axis) and the age at which crops experienced May (winter) temperatures (x axis). Data from Rostron (1974) have been re-analysed.

Discussion

The December ratoons of NCo376 and N26, which are described in this study, yielded on average 21% less than the May ratoons (Donaldson, 2009). This is similar to the 19% drop in sucrose yields of 12 month old crops harvested between September and December at Pongola that was estimated by Thompson (1979). Shoots and early leaves of the December ratoons emerged when temperatures and solar radiation were high. Leaves were then larger and higher numbers of shoots were produced up to 500 ºC d in the December ratoon than in the May ratoons. In the December ratoons canopies grew rapidly, produced high LAI, and started to intercepted light fully at a very early age. Stalks elongated rapidly and relatively large amounts of sucrose were accumulated during the first eight months in the December ratoons. In comparison, low temperatures at the start of the May ratoons delayed full canopy development and stalk growth. Sunlight was only fully intercepted when the crops were about eight months old. Once stalks had emerged, rates of stalk growth and sucrose accumulation increased steadily throughout the May ratoons until harvested at 12 months of age.

Stalk elongation of the December ratoons was curtailed by the low winter temperatures experienced when they were six to eight months old. The effect of the low temperatures on growth was also evidenced by the smaller leaves produced after maximum leaf size was attained. During the winter period sucrose rose to high concentrations, even in the top part of the stalks, of the December ratoons. It is probable that proportionately less photosynthate was then consumed in growth of leaves and internodes during winter so that larger portions were left for storage as sucrose in the stalks.

The inability of the December ratoons to resume rapid growth when temperatures rose after the cold winter period were implicated in the poor yields attained at the age of 12 months. This feature of the December ratoon growth has been named the Reduced Spring Growth Phenomenon (Donaldson, 2009; van Heerden *et al*., 2010). The low stalk numbers at the age of 12 months is a second factor that was implicated in the low yields of the December ratoons. We have shown, using Rostron's (1974) data, that the yields of annual summer harvested crops were related to the age at which they experienced low winter temperatures; the younger the age the more severe the impact is on final yields at 11 months of age. The declining cane quality of these summer harvested crops after the peak in spring is probably also related to the effects of low temperature on crop growth, and this needs to be investigated. This analysis also gives credence to the contention that ripeners can be used successfully for only a short period in the late part of the milling period. The yields of autumn and winter ratoons are mainly determined by the effects of low temperatures on canopy development.

The possible sequence of events that lead to the poor response of the December ratoons during the second summer include the reduction of leaf and stalk development when temperatures were declining through autumn into winter. Lower autumn/winter temperatures can favor the partitioning of photosynthate towards sucrose storage (Waldron *et al*., 1967), and this was evident in the top sections of stalks. However, mean weekly minimum temperatures declined to below 10 °C for six weeks while mean maximum temperatures remained above 23 °C. Such low temperatures reduce photosynthetic rates and impair the movement of sugars (Waldron *et al.*, 1967). It is conceivable that sugars accumulated in the culm then lead to end-product inhibition of photosynthesis, as recently demonstrated by McCormick *et al.* (2006). Low temperatures also down regulate the production of invertase and Hatch *et al.* (1962) showed that at 18 ºC acid invertase levels in sugarcane were only 20% of the levels at 30 ºC. Growth and maintenance respiration rates decline as temperatures drop. When daylength shortens in autumn/winter, less photosynthate (sucrose) is produced and concomitantly there is less hydrolysis of sucrose due to lower demand for respiration and/or lower levels of invertase. This is a simplistic scenario of a probably very complex network of processes that lead to accumulation of sugars in the culm. McCormick *et al*. (2008) have proposed that the high sugar levels in the culm have a knock-on effect of accumulation of sugars in the leaf, leading to down regulation of photosynthesis. The reversal of this state, the greater demand of photosynthate for maintenance respiration of a relatively large crop, and the restoration of leaf area appear to have been the reasons for the delayed recovery of culm growth rates when temperatures rose during the second summer of the

December ratoons. The effects of the low temperatures on all parameters measured were evident in both NCo376 and N26. The ability of N26 to accumulate higher amounts of sucrose per stalk before growth was severely restricted by low temperatures in the December ratoons, was the reason why this cultivar yielded better than NCo376 (Donaldson *et al*., 2008).

Conclusions

During the low autumn/winter temperatures smaller leaves were produced and stalk growth was severely curtailed, probably due to reduced rates of photosynthesis. These conditions favour the accumulation of sucrose, particularly in the upper part of the stalk. The moribund condition of the crop created by low winter temperatures is associated with low photosynthetic capacity (reduced source because of smaller leaves) and reduction in storage (sink) capacity due to smaller internodes. This condition persists through spring when temperatures are rising. End-product suppression from the accumulation of sugars in the top parts of the plant together with the increasing respiratory demand from photosynthate to maintain a relatively large biomass, are possible factors contributing to the lagged growth response to increasing temperatures. The rapid decline in shoot numbers during the second summer is a second factor contributing to the poor yields of December ratoons. The age at which summer ratoons experience low winter temperatures, and their consequences on growth, largely determines its final yield.

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