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# A REVIEW OF THE EFFECT OF HARVEST TIME ON SUGARCANE PRODUCTIVITY

By

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## Abstract

The sugar industry is debating the effects of changing season start and finish times in an attempt to improve industry profitability in a number of regions. A difficulty for decision makers is lack of knowledge of the effects of harvesting cane outside the existing season. Past research from Australia has shown that the time of year when cane is harvested and ratooned significantly affects sugarcane productivity. However, the findings are often contradictory and obviously confounded by the effects of other factors such as crop age and management. Consequently, it is difficult to extrapolate knowledge from previous research to make decisions for the current industry. In this paper, a framework for understanding the effect of crop harvest date on sugarcane productivity is presented. The framework is based on the assumption that biomass accumulation under non-limiting conditions is dependent on crop class and age, cumulative radiation interception and the temperature regime during growth. However, for this to be ascertained for the Australian industry for different crop start and finish times, targeted field experimentation free from confounding factors is necessary. This experimentation combined with crop simulation modeling and operations analysis can help the Australian industry to develop harvest scheduling options.

**Introduction**

Expanding production in a number of regions in the Australian sugar industry has increased pressure on mill capacity. This pressure is forcing the industry to examine the returns on investment from additional milling capacity. However, current economics are such that milling companies are finding it difficult to justify further investment in milling capacity (Frawley, 1997).

Increasing the length of the harvest season is one option available to industry to cope with increasing production. There are, however, concerns that harvesting crops outside the existing season may reduce the productivity of individual crops and crop cycles. Existing harvesting arrangements have been based on interpretations of the Commercial Cane Sugar (CCS) curve. Canegrowers receive more revenue for their cane as its CCS content increases. The 1996 report of the Sugar Industry Review Working Party observed that 'given the pattern of CCS yield, a season length of less than 20 weeks would be desirable from their (canegrowers) perspective' (SIRWP, 1996). Conversely, to maximise returns from mill capital, millers would prefer an optimal season length of more than 20 weeks (SIRWP, 1996). Given the obvious conflicting interests in this debate, the industry requires accurate information on the effects of harvesting outside the current season on crop productivity to make decisions about maximising industry profitability.

The effect of harvest time on sugarcane productivity is a complex one. The time of year when a crop is harvested affects yield by imposing both crop age and seasonal factors on the crop. The yield of the following ratoon crop is affected by the seasonal conditions into which

KEYWORDS: Time of Ratooning, Radiation Interception, Sucrose Partitioning, Yield Potential.

the new crop grows. The following terms are defined as they have been used in this paper (Figure 1). 'Crop finish' refers to the time of year the crop was harvested. 'Crop start' refers to the time of ratooning, when a crop commences growing from a recently harvested stool. 'Crop age' refers to the number of days, weeks or months, since the crop was started. 'Crop class' refers to whether a crop is a plant, first, or second ratoon.

Management also affects the productivity of crops harvested at different times. For instance, a crop harvested in wet conditions may be subjected to adverse impacts on early growth due to stool damage, soil compaction and waterlogging. Alternatively, a crop finishing early in the season may yield poorly and have low CCS because it was started late in the previous year and was too immature to yield adequately. To fully understand the physiological effects of crop age and time of ratooning on productivity, the effects of climate (temperature and radiation) on a well managed crop (where no other factors limit growth) must be separated from other factors which limit growth. This allows potential yield to be determined for a range of crop scheduling options. Once this is established confidently, harvest scheduling options need to be examined in the light of practical considerations, such as the practicability of being able to harvest crops at a particular time of year or the risk of waterlogging impacting significantly on growth of the subsequent ratoon crop. Recognising potential yields will also allow the industry to identify areas where management can improve yields.

Given the importance of the issue to the Australian industry, there is relatively little published information on research into the effect of harvesting crops at different times of the year. In this paper, past published research into the effect of time of harvest on sugarcane productivity is reviewed to determine what information is available on the effects of crop start and finish on productivity and whether this information is useful for industry decision makers. The conceptual framework used to analyse previous work is also outlined.

### A conceptual framework for analysis of the factors affecting crop productivity

The potential yield is defined as the maximum yield a crop can achieve where water and nutrients are non-limiting and there are no external factors, such as pests and diseases, impacting on yield. The potential yield of crops started at different times of the year is achieved through the impact of the prevailing radiation and temperature regime on the processes of canopy development, radiation interception, radiation use efficiency (RUE), biomass and sucrose accumulation and the dry matter content of stalks. Actual yields achieved in the field are governed by the impact of factors such as drought, storms, floods, pests and crop management on these processes (Muchow *et al.,* 1997). This framework is illustrated in Figure 2.

The factors that determine potential yield (radiation and temperature) are the factors which affect all crop yields to a greater or lesser extent. Other factors, which are described in this paper as external factors, are not common to all crops. For example, while pests may affect some crops, others will remain unaffected and accordingly the effect of the external factors and the yield

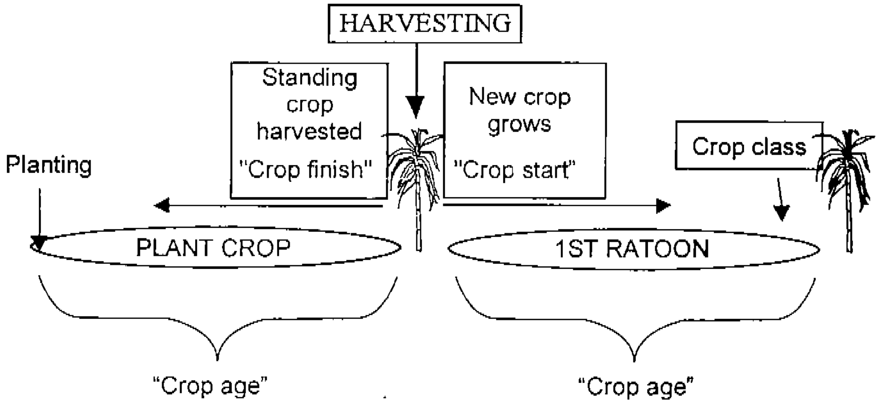


Fig. 1—Diagram explaining the definition of the terms used in this paper.

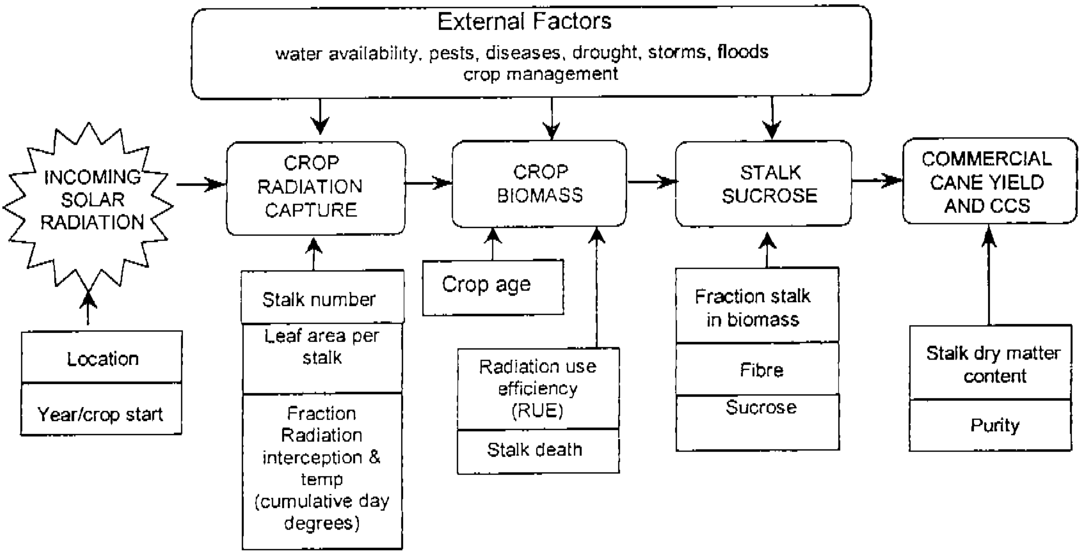


Fig. 2—Solar-radiation based framework of yield accumulation in sugarcane (from Muchow, 1998).

potential factors will vary for each crop. One of the difficulties in conducting field experimentation to determine the effect of time of harvest on crop productivity is that the risk of external factors having an impact on productivity changes throughout the year and between production areas. For example, there is a greater risk of a harvest being carried out in wet conditions between November and March than between May and October. To better determine the impact of different external factors, it is first necessary to determine the potential yield a crop can achieve under the prevailing climate (temperature and radiation).

To extrapolate potential yields to a wider industry context, simulation modeling provides an approach that can encompass some of the factors impacting on yield. At present, the APSIM-Sugarcane model framework (Keating *et al.*, 1999) is designed to account for the effects of varying temperature and radiation, soil moisture availability and nitrogen status on sugarcane yields.

If the framework described in Figure 2 is accepted, then crops started at any time of the year growing under potential conditions should be able to achieve similar yields given similar total radiation interception and RUE. The time of year of crop start will affect the rate at which it can grow, intercept radiation and produce biomass. Crops started late in the year will commence growing into conditions of high temperature and will accumulate leaf area quicker than crops started in conditions of low temperature. The rate at which crops started late in the year accumulate biomass then depends on incident radiation which, over the summer in north Queensland, may be reduced by excessive cloud cover during the wet season. However, there is evidence from experiments conducted in South Africa that crops which are started late in the year and develop their canopy over the summer are not disadvantaged in terms of radiation capture compared to crops which start their development in the winter. Crops that start in winter will commence growing into conditions of low temperature. In some areas, temperature may reduce RUE and hence biomass and sucrose accumulation. These crops may take longer to intercept the same amount of radiation as a crop started in warmer conditions, thus requiring more time to reach their mature yield potential.

## Previous experiments on the effect of time of harvest in Australia

Past published research in Australia on the effects of harvest time has, unfortunately, confounded the effects of crop age and start time with unquantified factors which limit yield. These confounding factors diminish the value of these studies to predict outcomes of different harvest schedules outside the conditions of the experiment. Leverington *et al.* (1978) used an experimental design which meant that the yields of crops started at different times of the year were compared at different crop ages.

Differences in yield were attributed to the effect of crop start time without considering the effect of crop age. Crop age determines total radiation interception and hence biomass and sucrose accumulation, in turn influencing commercial cane yield and CCS (Figure 2).

In the same experiments, Leverington *et al.* (1978) also reported that the crops started late in the season were subjected to prolonged periods of rain and were consequently waterlogged. The crops started late would have had their growth and subsequent yield affected by waterlogging, but waterlogging would not have affected the yield of crops that were started at other times of the year to the same extent. Subjecting sugarcane plants to excessive wetness reduces their growth (Gosnell, 1971; Webster and Eavis, 1971; Carter, 1976) and can kill ratooning plants (Webster and Eavis, 1971). Further, the effect of waterlogging is greater on younger crops than on older crops (Webster and Eavis, 1971). Thus external factors would have affected the yield of crops started at different times of the year in different ways.

Leverington *et al.* (1978) concluded that crops started late were not able to yield as well as crops started earlier in the season because they did not have a fully developed canopy to take advantage of the 'boom' growth period between November and February. There is no evidence provided for this hypothesis, and the impact of waterlogging is more likely the reason for their depressed yield. While waterlogging is a real risk associated with late ratooning, its impact on a yield potential must be quantified in order for the results to be extrapolated outside the boundaries of that experiment.

Chapman and Leverington (1976) also reported poor yields in crops started late in the season in Mackay. Again external factors which were not common to all crop start times were present. The experiments were conducted in fields in which 'imperfect drainage conditions prevailed'. The crops started late were not only harvested in wet conditions, possibly causing stool damage, but experienced prolonged periods of waterlogging while the crop was young. These external factors would have interfered with the potential of the crop to grow leaf area, intercept radiation and their RUE. These factors were not present in crops ratooned earlier in the season and thus confound any physiological comparisons between start times. The external factors were not quantified and the results of these experiments cannot be used for extrapolation outside the conditions specific to the experimental sites.

**Previous experiments on the effect of time of harvest in South Africa**

Previous experiments from South Africa support the framework outlined in Figure 2. Inman-Bamber (1991, 1994) reported that the efficiency of the canopy of crops started at a range of different times throughout the year in intercepting light varied significantly and that temperature was a major factor affecting canopy development. Crops starting in December (early summer) grew into high temperatures and had more rapid canopy development than crops starting in April (early winter) which grew into lower temperatures. In two months of growth, crops started in December had significantly greater efficiency of light interception (0.9 of photosynthetically active radiation-PAR), than crops started in April (0.6 of PAR) (Inman-Bamber, 1991). This evidence conflicts with the current perception that crops started late in the harvest season perform poorly because they have insufficient canopy development to take advantage of the high temperature/radiation regimes which occur during the Australian summer period.

Biomass accumulation is directly related to radiation interception. Inman-Bamber's (1991) observations of differences in the fraction of radiation intercepted by crops started at different times of the year are easily related to Rostron's (1972) findings on biomass accumulation. Rostron (1972) observed after 100 days of growth, the shoot height of crops started in December was around 140 cm compared to less than 10 cm for crops started in June. At 32 weeks of age, cane dry matter yield was 2500 $g/m^2$ for December crops compared to 1200 $g/m^2$ for June crops (Figure 3). The conditions of high radiation and temperature present when the December crop commenced clearly boosted its growth and allowed it to intercept a greater amount of radiation compared to the lower temperature and radiation conditions present when the April crop commenced. This evidence supports the framework in Figure 2.

Rostron (1972) found there were significant differences in the final cane yield of crops 72 weeks of age ratooned at different times of the year. This was related to lodging in some of the crops. Figure 3 shows that while the crop started in December showed significantly greater early growth, stalk yield did not increase significantly after 40 weeks, after the crop lodged. Large well-grown crops often lodge, after which, yield is seen to decline (Muchow *et al.*, 1995).

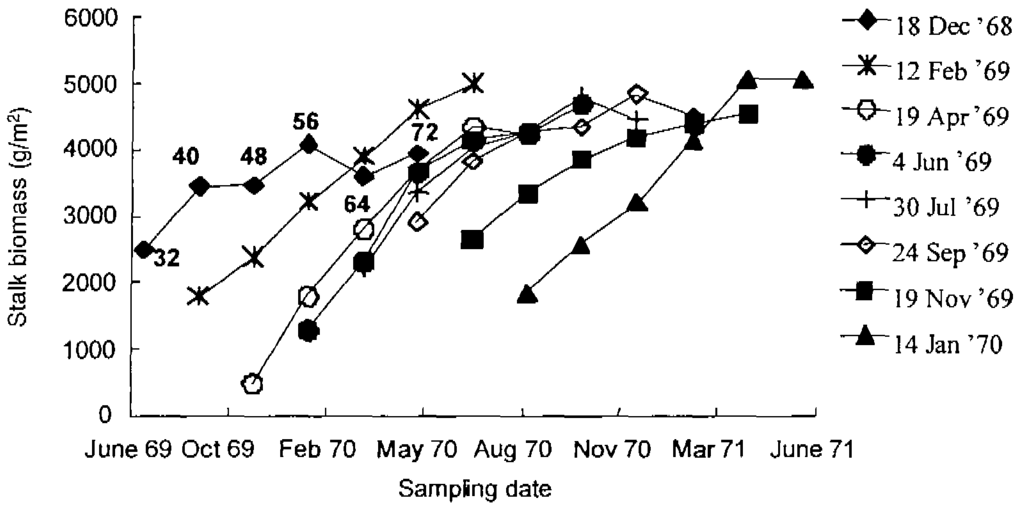


Fig. 3—The effect of time of ratooning and crop age on stalk biomass accumulation. For each crop (represented by a line) the first measurement was taken at 32 weeks and subsequently every 8 weeks until the crop reached 72 weeks of age (numbers at each point on the line represent the age of the crop in weeks when stalk biomass was measured). (Adapted from Rostron, 1972).

Rostron (1972) concluded that the yield of crops that lodged at the beginning of summer were not improved by carrying them over to the next season and that crops which had not lodged at the beginning of summer would show large yield increases over the summer. Clearly lodging and the time of the year when a crop lodges can prevent a crop from achieving its yield potential. The factors causing the yield plateau are not fully known but have been attributed to stalk death and reduced radiation interception (Muchow *et al.,* 1995). The issue of yield plateau associated with crop lodging is currently being investigated within the CRC for Sustainable Sugar Production (Anon., 1998).

One of the concerns with commencing the harvesting season earlier than normal is that sugar yields will be reduced. The framework described in Figure 2 shows that sucrose accumulation is directly related to biomass accumulation. This relationship has been shown to be linear (Muchow *et al.,* 1996a; Muchow *et al.,* 1997) and strongly indicates that sucrose accumulates in stalks as they grow rather than stalks 'ripening' due to factors such as temperature or water stress. However, factors such as water stress and chemical ripener application can cause deviations from that linear relationship (Gosnell, 1970; Donaldson and van Staden, 1995). Data collected by Rostron (1972) for crops ratooned at eight different times of the year also demonstrated a significant linear relationship between sucrose accumulation and stalk biomass accumulation (Figure 4).

Rostron's (1972) data support the framework in Figure 2 and the concept that for crops started under a wide range of conditions, stalk biomass accumulation is the main driver of sucrose yield. This relationship compares well to those reported by Muchow *et al.* (1997) for Australian and South African cane varieties, which were: Q117, $y=0.55x-404$ ($r^2=0.97$), and for NCo376 and N12; $y=0.54x-200$ ($r^2=0.95$). The standard error of the relationship means that dry weight sucrose concentration (DWSC) can vary by 5.5% for a particular stalk dry weight. For example, for a sucrose yield of 4000 g/m$^2$, the DWSC can vary by ± 0.025 g/g from an average of 0.463 g/g. Thus, crops grown under potential conditions and finished early, or prior to the start of the existing season, will have reasonable sugar yields provided they are finished at an age where they have been able to develop sufficient crop biomass.

Commercial yield of sugarcane is determined by biomass and sucrose accumulation and the moisture content of the cane at harvest. The moisture content of cane affects cane fresh weight yield and CCS (Muchow *et al.,* 1997). Cane dry matter content has also been shown to increase to a maximum value of 0.30 g/g with increasing crop age, but again, can vary due to factors such as nitrogen supply (Muchow *et al.,* 1996b) and water supply (Inman-Bamber and de

Jager, 1988; Robertson and Donaldson, 1998). Rostron's (1972) data (Figure 5) show a significant relationship between stalk biomass and stalk dry matter content. There is variation but it is clear that crop biomass accumulation is one of the driving forces behind increasing stalk dry matter content.

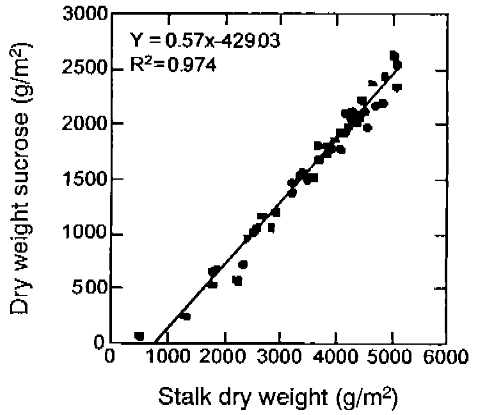


Fig. 4—Relationship between stalk sucrose accumulation and stalk biomass accumulation. Relationship is shown for data pooled for the eight first ratoon crops that were ratooned at different times of the year. Standard error of estimate: 101.074. (Adapted from Rostron, 1972).

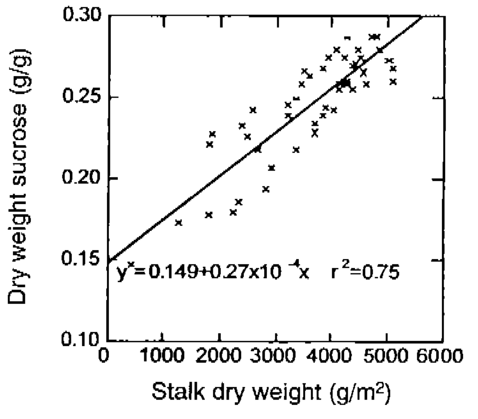


Fig. 5—Relationship between stalk dry matter content and stalk biomass. Adapted from Rostron (1972).

Following the framework in Figure 2 and evidenced by Rostron's (1972) data, it would be expected that as crops age and accumulate biomass, so their fresh weight sucrose concentration (FWSC) and CCS will increase and be less affected by seasonal factors. CCS is directly related to FWSC as pol is a measure of sucrose in juice and pol is used to calculate CCS. Rostron (1972) observed large differences in FWSC in cane ratooned at 8 different times and aged between 32 and 56 weeks (Figure 6), indicating that time of ratooning and seasonal conditions may have had some effect on (FWSC) of cane of this age. However, after 56 weeks of age the difference between crops harvested at different times of the year diminished, with a difference of around only 0.02 (g/g) between the highest and lowest values. Thus, as crops reach a certain age, seasonal factors have a diminished influence an FWSC and CCS.

## Discussion

The South African data presented in this paper support the framework outlined in Figure 2. This framework states that potential sugar yield will be dependent on crop biomass accumulation and that the factors influencing the commercial yield of sugarcane are also determined largely by age, particularly when crops have grown for approximately 12 months. Applying the framework to the Australian situation, it can be seen that crops harvested early in the season may produce good yields provided they are mature enough, or have accumulated enough biomass. It also suggests that there is scope for improving the yield of late ratooned crops. The Australian data on late ratooning are heavily biased by factors such as waterlogging and factors associated with wet weather harvesting.

Field experimentation under potential conditions is necessary to determine the effects of different crop start and finish times free from confounding influences. Block productivity data have been used to derive trends and, while useful in providing averages, is confounded by a number of factors such as management. Often crops ratooned late and early in the season are older ratoons and therefore likely to be less productive. Higgins (unpublished data, 1997) showed that at the beginning of the season (June) a large proportion of fourth, fifth and sixth ratoons (0.334) were harvested in Mossman, presumably for plough-out/replant, compared to a very small proportion of earlier ratoons harvested at that time (0.055). Crop class affects yield (Muchow *et al.*, 1996a) and subsequent ratoons have reduced yields. These management trends impact on the average yields that are derived from ratoon date/harvest time interactions from block productivity data.

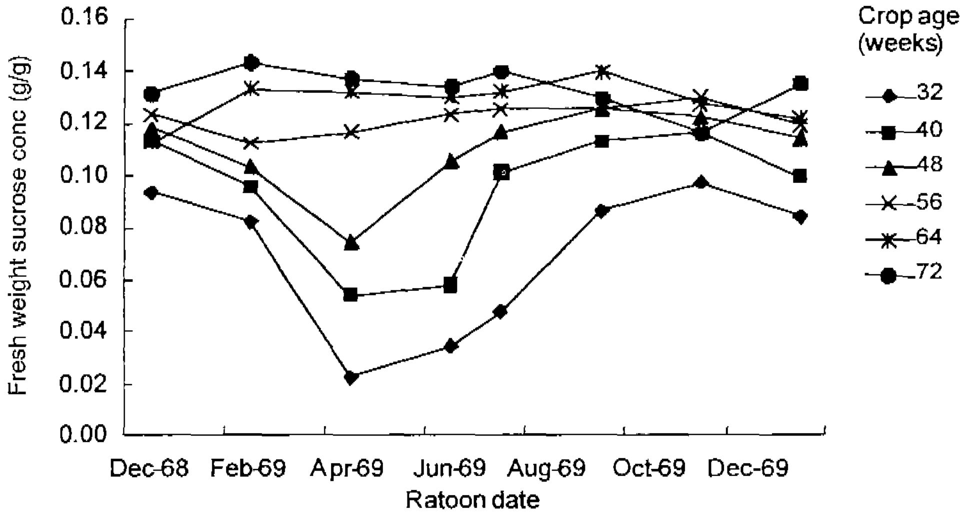


Fig. 6—The effect of time of ratooning and crop age on fresh weight sucrose concentration of stalks. (Adapted from Rostron, 1972).

The interaction between crop start time and crop age has not been explored in Australia to the extent of Rostron's (1972) experiment. His design, with eight times of ratooning and measurements of crop growth at 32, 40, 48, 56, 64 and 72 weeks of age allowed the collection of data from crops of a range of ages at all different times of the year. This is necessary for determining how these two factors impact individually on biomass and sucrose accumulation. Learning from past Australian research, it is clear that this type of experiment must be conducted in a way in which confounding factors are minimised so that the physiological potential of crops ratooned and harvested at different times of the year can be determined. When the industry can be confident of the potential yields from crops ratooned and harvested at different times, then more practical issues associated with harvesting and management risks can be examined.

In order to address the issues of season start and finish times, an experiment of a similar design has been initiated within the CRC for Sustainable Sugar Production. This experiment, conducted under potential conditions and managed to avoid confounding factors, will impose eight times of ratooning and conduct regular measurements of crop growth. These data will allow the effects of age and start time to be quantified in a similar manner to Rostron's (1972) experiment. A high priority is placed on the collection of data on the climate, soil and management conditions the experiments are conducted under. These data will be used to test the assumptions in APSIM-sugarcane. The model is one of the tools crucial to developing cane supply options using operations analysis (Higgins and Muchow, 1998a, 1998b).

## Conclusion

Decisions are currently being made in the sugar industry about harvest season start and finish dates. The data currently available cannot be used to guide decision making because they are confounded with unquantified external factors. There is a need to collect detailed physiological data on crop response to different start and finish dates along the lines of the South African experiments reviewed in this paper. Risk assessment regarding the impact of external factors on the potential yields of crops is a crucial step in the process of providing industry decision makers with the data required. This is work currently being conducted in Program 3 of the CRC.


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