DETERMINING THE MAXIMUM DRYING OFF PERIODS FOR SUGARCANE GROWN IN DIFFERENT REGIONS OF THE SOUTH AFRICAN INDUSTRY

RA DONALDSON AND CN BEZUIDENHOUT

S.A. Sugar Association Experiment Station, Private Bag X02, Mount Edgecombe, 4300

Abstract

Mild moisture stress causes sucrose to be deposited preferentially in sugarcane stalks so that sucrose yields may be improved. The rule of thumb in the industry states that a crop should be dried off for the time it would take pan evaporation to equal twice the plant available water holding capacity of the soil in which the crop is rooted (or twice TAM). Despite this useful rule farmers often dry-off their crops excessively. A systems approach was employed to verify the aptness of the rule and develop recommendations in terms of drying off days that would prevent losses in sucrose yields. Data from past experiments were analysed to describe the relationship between sucrose yields and stalk biomass of well watered and dried off cane. This analysis showed that sucrose yields are increased or not affected when stress reduces stalk biomass by up to 4%. The CANEGRO model was validated using an independent data set. Thereafter, the stalk biomass for well watered and dried off treatments were simulated over periods of up to 120 days using 23 years of weather data from various regions of the industry. Simulations included soils with TAMs of 80,114,162 and 210 mm at five sites in the industry for crops harvested annually between April and November. From these simulations it would appear that the 2 x TAM rule, which excluded possible rainfall, is a good universal rule. However, our analyses provide the appropriate adjustment by including anticipated rainfall and seasonal effects. Recommended "drying-off days" have been tabulated for five areas within the SA sugar industry.

Introduction

Plants react to drying soil by initiating a sequence of physiological mechanisms that protect the plant against stress damage and conserve the integrity of structures such as membranes. Some of the mechanisms lead to reduced carbon assimilation so that the total plant biomass is reduced. During stress the stalk sucrose content rises due to a simultaneous lowering of the moisture content (dehydration) and, to a slightly greater extent, an increased amount of carbon deposition in the stalk. Since most of the assimilated carbon is deposited as sucrose when stress develops, growth of the stalk is retarded and cane yields then lag behind those of well watered crops (Robertson and Donaldson, 1998). However, at mild levels of stress the higher sucrose contents result in improved sucrose yields when cane yields are not severely affected. Although sucrose yields have been increased by 2.5 t/ha (Thompson and Boyce, 1968) in a plant crop, the average increase in a later series of experiments was 1.3 t/ha (or 8%) (Robertson and Donaldson, 1998). At greater levels of stress sucrose yields are reduced when the benefit from the higher sucrose content is negated by more severe reductions in cane yields. Therefore, it is important that the period of stress during drying-off is not excessive. There are no formally published recommendations in the South African industry for drying-off to improve sucrose yields at present. In a review of the early experiments Thompson (1977) suggested that irrigation should be suspended two months before harvesting in winter and one month in summer. Thereafter, a rule of thumb for drying-off that accounts for the month of harvesting, evaporative demands (season effects) and moisture holding capacity of soils was developed. This rule states that the dry-off period should be equal to the time it would take potential evapotranspiration to equal twice the plant available water holding capacity of the soil in which the crop is growing (i.e. twice the total available moisture (TAM) also known as plant available water capacity (PAWC)). Robertson et al (1999) have developed a framework for developing recommendations based on the relationships between relative sucrose yields and relative stalk biomass, using a systems approach. The essential element of their analysis, that we verify and apply in our analysis, is that when relative stalk biomass is reduced by less than 5%, sucrose yields may be improved. This has proved to be a useful target that can be used in simulation models to develop guidelines for drying off as has been done in Australia (Robertson et al, 1999). The objectives of this paper are (1) to quantify the relationship between sucrose yields and stalk biomass of a stressed crop relative to that of a well watered crop, using South African data and (2) to use this relationship in developing drying-off recommendations through CANEGRO (Inman-Bamber, 1991) simulations from which the aptness of the rule of thumb can be verified.

Methods

In an analysis of 37 drying off experiments Robertson and Donaldson (1998) used relative stalk biomass to express the severity of stress imposed by drying off. Only features of their analysis that are relevant to this paper are considered here. The analysis was performed on data from experiments in which either sucrose content or cane yields were significantly (P=0.05) affected by drying off. Because dry mass concentration (increased) and moisture content (decreased) are affected simultaneously during drying off, changes in cane yields and other components expressed in terms of fresh mass are difficult to interpret. The analysis was therefore done on dry mass yields to eliminate the changes due to dehydration. The effects of drying off were expressed relative to the well irrigated cane and in so doing the absolute changes were normalised across all experiments. Severity of stress could therefore be linked to the change in relative stalk dry mass (RSDM). Thus, it would be expected that as stress becomes more severe the stressed cane would reflect a decreasing amount of dry mass compared with that produced by the well-irrigated cane. The analysis of the combined South African, Zimbabwe and Australian data showed that sucrose yields are either increased or unchanged when RSDM is reduced to 96% (Robertson et al, 1999). For the purposes of this paper the data from Zimbabwe and South Africa were re-analysed. The data show that there are increases or no changes to sucrose yields as the RSDM falls below 1.0 (Figure1b). A regression line fitted through the data (y =1.0455x – 0.094) predicts that sucrose yields will exceed those of a well watered crop while RSDM is equal to or greater than 0.96. The value of 0.96 therefore becomes the target in which climatic and soil factors (including moisture) are dynamically integrated to simulate the benefits from drying off in terms of sucrose yield. In these simulations the time taken to reduce RSDM to 96% would be the basis from which drying off recommendations can be developed.

Figure 1a shows the relationship between RSDM and cane yields. From these data cane yields are shown to be more sensitive to drying off than sucrose yields. The regression on the data indicates that cane yields would be reduced by 5% when RSDM is 0.96. Such reductions in cane yields would translate into benefits to the farmer in terms of harvesting, loading and transport costs to the mill. These additional benefits from drying-off and others such as lessened risk of compaction from infield operations using heavy vehicles are not considered in this analysis.

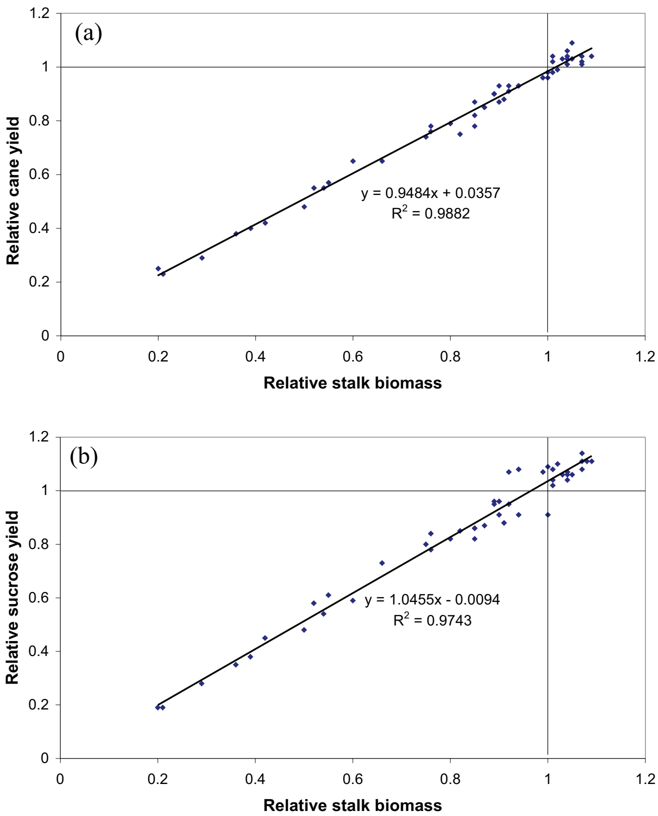

Figure 1. Relationship between relative stalk biomass and (a) relative cane yield and (b) relative sucrose yield with fitted linear equations

Validation

The CANEGRO model has previously been validated in KwaZulu-Natal by Inman-Bamber and Thompson (1989), Inman-Bamber (1991) and Inman-Bamber et al (1993). For the purposes of further establishing how well the CANEGRO model simulates the effects of stress, it was validated against 14 sets of drying off treatments from a series of four crops in one experiment and two sets of treatments in a plant crop from a second experiment. Both experiments were conducted at Pongola (27°25'S, 31°36'E, altitude 308m) and on the same site. The soil at the site is a Shorrocks sandy clay loam with a TAM of 464mm (Thompson, 1977). A soil profile with a rooting depth of 272cm and TAM of 409mm was used in the model simulations. Initial irrigation to all plots was by overhead sprinklers and then by perforated pipes raised by telescopic masts (for details see Thompson and Boyce (1968)) when drying off treatments started. Dates and amounts of irrigation were recorded for each treatment and used in the validation simulations. In the first series of experiments the validation sets consisted of no drying off, moderately dried off and severely dried off treatments and in the second experiment the treatments were no drying off and severely dried off. In the second experiment the varieties were N14 and N24, while NCo376 was used in the other experiments. Table 1 summarises the validation runs. The experiments were modelled with CANEGRO using the relevant weather data and irrigation amounts applied.

Model simulations to predict length of drying off period

A multiple combination of CANEGRO simulations was executed to represent different times of the year, soils, sites and drying off periods. Simulations were done for Mtubatuba, Pongola, Mhlati and Tenbosch in the northern areas and for Beaumont and Powerscourt in the midlands, these being sites for which sufficient long term weather data exist. Four categories of soils with TAMs of 80mm, 114mm, 162mm and 210mm were selected to provide a comparison with the analysis previously done by Robertson et al (1999). Weather data from 1966-89 (23years) were used in simulating yields of 12 month old NCo376. Irrigation was applied in the simulations to avoid any possible stress. Irrigation was suspended 0, 20, 40, 60, 80, 100 and 120 days before each of the annual crops were harvested in mid month from April to November. The simulated stalk dry mass yields for each drying off treatment at harvest were expressed as a fraction of the unstressed treatment (no suspension of irrigation). These RSDM values were calculated for each drying off treatment (drying off days before harvest), harvesting date (mid month), soil category (TAM) and site (weather station). From these values the median (50th percentile) time taken for RSMD

Table 1. Summary of data sets that were used for CANEGRO validation.

Validation set	Variety	Treatments
Set 1: 1987-1988	NCo376	No stress, 86 days, 147 days, 208 days.
Set 2: 1988-1989	NCo376	No stress, 10 days, 132 days, 266 days.
Set 3: 1989-1990	N14, N24	No stress, 85 days.
Set 4: 1991-1992	NCo376	No stress, 45 days, 177 days, 335 days.

to be reduced to 96% was derived for every soil category x harvesting time x site combination over 23 years. Similarly, the 25th and 75th percentile times at which RSDM was reduced to 96%, were derived. The accumulated reference evapotranspiration, derived from the Penman-Monteith equation (McGlinchey and Inman-Bamber, 1996), minus rainfall from the dates of suspending irrigation to the dates that RSDM was reduced to 96% were also calculated and expressed as multiples of the particular soil TAM.

Results and Discussion

Model validation

Model predictions for stalk biomass and RSDM were compared with the results from the experiments. Generally the model performed satisfactorily with root mean square errors (RMSE) of 4.85 t/ha (including NCo376, N14 and N24) and 2.59 t/ha (NCo376 only) on stalk biomass. Stalk biomass expressed in relative terms to the unstressed control could be simulated with a RMSE of 6.4% for data that fell in the range 80% to 100% of the unstressed control. Therefore, the level of skill needed to predict the effects of stress that reduces RSDM within the interval [80%-100%], was considered acceptable for the purposes of this paper.

Predictions of drying off days

From the simulations the median number of drying-off days taken to reduce RSDM to 96% were derived and tabulated (see table 2). The tables of the four soils at each of the five sites gives the median number of drying off days in parenthesis for

Table 2. Number of drying off days (median in parenthesis with 25th and 75th percentiles) for April to November and four soils with different water holding capacities at five sites in the South African sugar industry.

Mtubatuba

Harvest month	April	May	June	July	August	September	October	November
TAM 80mm	39(50)80	50(60)78	62(73)85	70(80)102	37(40)68	35(43)56	30(40)50	34(40)50
TAM 114mm	46(65)101	60(75)96	72(87)108	83(98)121	50(66)95	46(52)70	40(52)66	47(55)73
TAM 162mm	60(75)130	80(97)180	88(107)155	100(120)165	78(107)180	62(75)120	54(73)82	60(72)93
TAM 210mm	70(102)155	88(107)250	100(120)270	115(143)267	93(130)310	75(102)180	63(87)118	75(86)170

Pongola

Harvest month	April	May	June	July	August	September	October	November
TAM 80mm	40(48)57	45(50)62	50(53)61	53(60)65	45(49)56	33(35)45	29(35)44	30(40)48
TAM 114mm	53(69)80	60(65)75	60(70)80	65(72)80	55(61)70	40(46)56	35(43)60	42(50)58
TAM 162mm	70(100)105	75(80)100	80(95)105	80(90)105	72(80)93	55(60)80	44(57)70	48(65)75
TAM 210mm	83(107)125	82(100)125	87(105)115	100(105)120	87(92)110	65(75)88	58(68)85	55(75)95

Tenbosch

Harvest month	April	May	June	July	August	September	October	November
TAM 80mm	43(47)65	47(60)64	54(62)68	60(64)74	46(55)60	33(35)45	27(30)40	26(30)41
TAM 114mm	51(60)86	60(68)80	65(75)80	72(81)89	61(68)80	42(46)57	32(35)52	33(39)50
TAM 162mm	65(89)111	80(90)110	84(95)105	82(101)112	80(85)106	55(60)78	41(46)65	40(50)63
TAM 210mm	73(105)140	88(110)150	101(104)121	101(121)150	92(100)125	68(75)92	50(56)80	48(60)80

Mhlati

Harvest month	April	May	June	July	August	September	October	November
TAM 80mm	40(47)56	49(55)60	50(60)65	55(60)65	45(46)52	32(35)40	26(30)34	27(30)40
TAM 114mm	50(60)75	62(68)81	65(77)91	68(73)85	55(60)62	40(45)48	33(35)42	32(35)45
TAM 162mm	65(78)101	78(85)96	82(100)103	85(95)108	72(80)85	55(60)62	41(46)55	38(43)52
TAM 210mm	75(88)122	88(100)121	95(108)125	100(108)125	89(93)105	65(70)75	51(54)65	50(55)60

Powerscourt

Harvest month	April	May	June	July	August	September	October	November
TAM 80mm	54(100)167	44(70)185	45(52)80	43(48)60	35(39)48	34(47)55	40(51)70	60(72)100
TAM 114mm	74(118)>300	60(120)240	62(80)172	60(68)92	46(54)59	46(53)71	51(70)87	74(87)113
TAM 162mm	*	*	100(205)300	75(100)133	66(75)85	65(75)94	70(93)110	88(120)165
TAM 210mm	*	*	*	95(123)110	85(96)122	80(100)120	90(106)158	106(231)>300

Beaumont

Harvest month	April	May	June	July	August	September	October	November
TAM 80mm	63(74)90	40(52)80	42(43)50	44(49)52	33(37)40	30(34)40	33(38)48	47(59)69
TAM 114mm	78(92)120	52(70)102	54(60)69	54(60)63	41(49)50	40(46)50	42(51)60	54(69)86
TAM 162mm	109(121)>300	*	70(75)150	74(80)89	60(66)73	51(59)66	52(68)71	71(83)102
TAM 210mm	*	*	88(120)>300	84(94)107	72(80)89	62(70)83	67(80)90	84(92)111

crops harvested between April and November. The 25th and 75th percentile values appear before and after the parentheses, respectively. The 75th percentile is an indication of how much longer the crop would need to be dried off in wet years in order to reduce the RSDM to 96%, while the 25th percentile gives the equivalent drying off period during dry years. The differences between the 25th percentile and the median and also between the median and the 75th percentile are indications of the risk of drying off too much during dry years or too little during wet years, respectively. Large differences between the 25th percentile and the median indicate for example a higher risk of drying off too much and in a similar fashion small differences indicate lower risk situations. The results were limited by the longest simulated drying off interval of 120 days and recommendations longer than this were linear extrapolations from the last two points. Extrapolations beyond 300 days were not attempted. The general trends that are projected by the data are (1) an increasing number of drying off days between April and July and (2) decreasing drying off period between July and November. In many cases there were small increases in the number of drying off days between October and November. These trends were most pronounced for the drier areas and soils with the lower water holding capacities. The difference between the 25th percentile and the median is lowest when soil water holding capacities are low and the region is relatively dry (eg. Northern irrigated areas). This suggests that the risk of drying the crop off excessively is low. On the contrary, large differences between the 75th percentile and the median indicate that there is a greater risk that the crop might not be sufficiently dried off, especially during relatively wet years. Since regions with higher annual rainfalls and better soil water holding capacities normally require longer drying-off periods, a greater risk exists of drying the crop off too much. This risk increases systematically for wetter sites and better soil holding capacities.

Drying off and multiples of Et-Rain/TAM

The "2 x TAM" rule of thumb for the drying off period provides a measure of the crop water demand that is normalised across soils of varying moisture holding capacities. When estimating the drying off period by the rule of thumb, rainfall is ignored. However, the simulations of the crop water demand in this analysis take account of rainfall and it would therefore be expected that simulated values of TAM multiples would be lower than 2 x TAM. In months when rainfall is a common occurrence simulated values could be expected to be considerably less than 2 x TAM and in months of low or no rainfall they could be expected to be closer to 2 x TAM. The highest simulated multiples were in July and August in areas where rainfall is very low in winter. The multiples approached 2 x TAM only in soils with low water holding capacities (eg 1.8 multiple for Mtubatuba, Mhlati and Pongola, in July on a soil with a TAM of 80mm) and were generally closer to 1 x TAM for the soils that can hold 210mm. Similar values for soils with TAMs of 210mm, 162mm and 114mm have been reported for Australian conditions by Robertson et al (1999), using the APSIM –Sugarcane model.

This analysis used the net crop water demand to arrive at the drying off TAM multiple and would therefore be expected to be less than the rule of thumb multiple that uses potential evapotranspiration only. Because this analysis anticipates expected rainfall and adjusts crop water demand accordingly, it is possible to derive more appropriate drying off strategies across seasons and sites. Robertson et al (1999) have described two further possible reasons for arriving at lower TAM multiples. Briefly, they are (1) under estimations of effective rooting depth in earlier studies and therefore under estimations of plant available water and (2) an over estimation of crop water use by class A pan compared with model estimations of crop water use that are based on transpiration efficiency.

The accuracy of values produced from an analysis of this kind depends on (1) the quality of long term weather data (2) an accurate description of the soil moisture characteristics and (3) the accuracy of the model. The values developed in this analysis are applicable only to fields with uniform and well drained soils that are not affected by lateral movement of soil water.

Conclusions

This analysis has produced guidelines of drying off in terms of days for several areas of the South African sugar industry. A general trend is that longer periods are needed as the water holding capacity of soils increase. The drying off periods also increase between April and July and thereafter decrease into the early summer months. The drying off days are similar for four of the five locations used in this analysis. The multiples of TAM for drying off produced in this analysis are well below two in most cases. The multiples are close to one for the soils with the highest water holding capacity and only approached a multiple of two for soils with a TAM of 80mm; they increase slightly from April to July and decrease after August and are thus affected by season. This analysis is based on good long term weather data, takes account of probable rainfall during the drying off period and has incorporated a function of stress and sucrose yield derived from a large number of experiments. The recommendations developed are therefore an improvement on the 'rule of thumb' that is used in the industry. This analysis also suggests that there is a real risk of either drying off too much in drier than normal years or too little in wet years by following the "median dry-off days" alone. We propose that this can largely be overcome by linking into a decision support system based on the above values. The strategy would be to plan drying off schedules on the recommended drying off days provided in the tables and thereafter to adjust harvesting schedules according to the differences between the predicted and the actual rainfall that follow after irrigation is suspended.

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