THE EFFECT OF ROW SPACING ON AN IRRIGATED PLANT CROP OF SUGARCANE VARIETY NCO376

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Abstract

The effect of five row spacings (RS) on source/sink processes in a plant crop of NCo376 was investigated at Mount Edgecombe. Tiller population (TPOP), fractional light interception (FI), intercepted radiation (RADI), cane and sucrose yields were recorded over the duration of growth. The crop was fully drip irrigated in order to avoid water stress conditions. Differences in FI_{PAR} between the treatments were most pronounced early in the growing season. It took 140, 188 and 215 days after emergence (DAE) to reach 0.8 FI_{PAR} at 0.73m, 1.69m and 2.66m RS, respectively. The rate of canopy closure had a direct linear relationship with RS and increased by 26%m^{-1} reduction in RS. The total accumulated incident global radiation from day of planting until final harvest was 5772 MJm^{-2}, giving a seasonal fraction of radiation intercepted of 0.49, 0.37 and 0.26 for 0.73m, 1.69m and 2.66m RS respectively. The rate of increase in TPOP was directly related to the amount of seed cane planted, and the timing of peak TPOP (or onset of tiller senescence) did not relate to FI for the different RS treatments. These results confirm previous observations that the light environment within the stool zone, rather than in the inter-row zone, dictates tiller phenology prior to peak TPOP. Final TPOP demonstrated a linear increase of 4.29 tillers m^{-2} with decrease in RS (R^2=0.86). Radiation use efficiency (RUE) ranged from 1.25, 1.35 and 1.72gMJ^{-1} for 0.73, 1.69 and 2.66m RS respectively. In addition to achieving higher RUE, wider rows partitioned a higher fraction of aerial dry mass to stalks. At 12 months there was an average response of 13% increase in stalk dry mass per metre decrease in RS. This relates well to previous South African studies.

Keywords: sugarcane, row spacing, fractional interception, tiller population, radiation use efficiency, NCo376

Introduction

Tiller growth in sugarcane (*Saccharum* spp.) constitutes the major sink for photosynthate. The tiller population (TPOP) supports the leaf canopy that generates the potential source of photosynthate. Factors that affect TPOP also affect light interception and consequently cane production. Amongst these factors are crop nutrition, (Moberly, 1971; Moberly and Stevenson, 1971), trash management (Thompson, 1965), crop rotation (Garside *et al.*, 2001), water (Thomas *et al.*, 1978, Thompson and du Toit, 1965), genotype (SASEX, 2001), crop management (Braunack and Hurney, 2000) and row spacing (Mali and Singh, 1988; Irvine and Brenda, 1980). This paper investigates the relationship between row spacing and tiller development in a plant crop and its interaction with radiation capture and conversion to biomass and stalk yield.

Examples from the literature of the impact of row spacing on tiller population (TPOP), canopy development and cane yield of crops grown under optimal conditions show a good relationship between yield response and tiller population (Table 1). The slightly lower response in yield compared to tiller population is due to a negative response in stalk mass found in most studies.

Table 1. Percentage change in tiller population in response to per m reduction in row spacing.

Tiller population %	Stalk mass %	Yield change %	Reference
24	-12	13	Boyce (1968)
24	-9	12	Thompson and du Toit (1965)
64	-	53	Bull and Bull (1996)
62	-6	49	Bull and Bull (2000)

The work of Bull and Bull (1996) has lead to a drive by the Australian industry to explore the practical feasibility of increasing yields through various high density planting arrangements (Bull and McLeod, 2000; Bull *et al.*, 2001). Generally, the yield responses reported in Australia coincide with response in tiller population from a very low base at 1.5m wide rows. It seems that certain varieties have a low tiller production potential in the plant crop, and therefore perform poorly at wide rows. Another possible reason for these low tiller populations could be the method of planting (billets as opposed to whole stick) or the small amount of seed cane used for planting. Few studies report quantitatively on canopy development and radiation interception. The apparent discrepancies between the findings from Australia and other studies highlight the lack of understanding of the processes involved and reasons for plant cane response to row spacing.

The simulation of row spacing effects in crop models is a reflection of the current state of knowledge on this topic. In the Canegro model (Inman-Bamber, 1991), biomass is accumulated through the conversion of intercepted radiation. Radiation is intercepted by the canopy which is calculated from the product of green leaf area per tiller and tiller population. A variety specific empirical equation is used to simulate the typical pattern of tiller population over time. The daily increase in tiller population during the tiller production phase is calculated using thermal time. The rate of tiller production and the maximum tiller population are directly proportional to the amount of seed cane planted (ratio between the 'standard' row spacing of 1.4m and actual row spacing. The value of TPOP is not allowed to exceed 30.0m^{-2}. Tiller population is set to a variety specific constant level after thermal time reaches 2000 ^{o}Cd (Bezuidenhout, 2000). For NCo376 this value is 13.30 tillers m^{-2}. In the model, tiller populations influence radiation interception (source) but have no direct influence (through sink effects) on stalk yield.

The APSIM-Sugarcane model (Keating *et al*., 1999) also simulates biomass accumulation through the conversion of intercepted radiation, which is determined by the size of the canopy. Tiller population as such is not simulated in APSIM-Sugar. The effect of tiller population on radiation interception is simulated through an empirical 'tillering factor'. Effects of row spacing on canopy development could be accounted for adjusting 'model coefficients'. Once fractional radiation interception reaches 0.85, light competition is simulated to induce senescence.

In the Canesim model (Singels *et al.*, 1998) yield is calculated from cumulative transpiration (Singels *et al.*, 1999), which in turn is calculated from intercepted radiation. Radiation is intercepted by the canopy which is calculated from thermal time using a variety specific base temperature (Singels and Donaldson, 2000). The effect of row spacing on canopy development is simulated by adjusting the thermal time required to reach 50% cover. This value is variety-specific and is directly proportional to a unit change in row spacing (and not the amount of seed cane).

Van Dillewijn (1952) identified light intensity and day length as the most important factors influencing tillering, and Inman-Bamber (1994) reported that higher order tillers would senesce rapidly when total radiant energy interception exceeds 70%. The spatial dynamics of tillering, senescence, light interception and energy conversion is crucial to the understanding and modelling of the source-sink relationship.

This study was undertaken in an attempt to fill some of the more obvious gaps in knowledge regarding the effect of row spacing on plant cane growth and development. The objectives were to quantify the effect of row spacing on tiller development, radiation interception, biomass accumulation and stalk yield. The information could (1) assist in improving the understanding (and modelling) of the processes involved, and (2) identify opportunities to increase the agronomic efficiency of sugarcane production.

Methods

Experiment details

The variety NCo376 was planted on 28 May 2000 in a 35% clay, 0.5-0.7m depth melanic over lithocutanic soil of the Mayo (USDA Mollisol) form at SASEX, Mt Edgecombe (29°42'18,4"S, 31°02'48,5"E, ±105m). Unless stated otherwise, standard cultivation, fertiliser and weed control practices were followed. Double stick seed cane was planted 100mm deep. The crop was drip irrigated with emitters arranged in a 1m grid in order to avoid water stress conditions. Irrigation totalled 796mm, while 779mm of rain were recorded over the duration of the trial. Total reference evapotranspiration (calculated according to the method of McGlinchey and Inman-Bamber, 1996) and mean temperature for the period between emergence and final harvest was 1088mm and 21.7°C respectively.

The trial consisted of 17 rows arranged radially from a centre point to 3m apart at a radius of 31m. The inner 5m and outer 1m of each row were regarded as side effects. The remaining cane was sampled for the effect of row spacing (RS) which ranged from 0.48m to 2.9m.

Where possible, the RS relevant to a specific sample was recorded. Time series analysis and comparison between variables were done by interpolating data to common dates and standard RS. The standard RS' were 0.73m, 1.21m, 1.69m, 2.18m, and 2.66m respectively.

Sub-optimal irrigation practices and low temperatures after planting resulted in very slow germination and emergence. The date of emergence was taken as 3 August 2000, the day when the number of emerged shoots equalled 40% of the estimated number of buds planted.

Radiation interception

Fractional interception of photosynthetic active radiation (FI_{PAR}) was monitored starting from the ninth week after emergence with a model SF-80 Ceptometer (Decagon Devices, Pullman, WA, USA). Five readings below the canopy were taken weekly at midday on days with clear skies. The FI_{PAR} was determined by relating these readings to an above canopy reading. The average FI_{PAR} value was calculated and allocated to RS of 0.65m, 1.21m, 1.79m, 2.18m, and 2.66m respectively. Where the full inter-row distance could not be covered by the 0.80m line sensor, it was angled across either one half or two quarters of the inter-row space in order to obtain representative readings for the full inter-row. The instrument was positioned horizontally and the reading taken just below the lowest green leaf.

At given dates FI_{PAR} was estimated for standard RS by fitting equations 1 to 3 to the data.

$$FI_{PAR} = 100 / (1 + \exp (- a * (DAP - b) , R^2 > 0.99 \qquad (1)$$

where FI_{PAR} is the estimated FI_{PAR} on any given day, DAP is days after planting and a and b are RS specific parameters calculated by:

$$a = -0.0103 * RS + 0.0552, \quad R^2 > 0.99, \text{ and} \quad (2)$$
$$b = 35.658 * RS + 157.79, \quad R^2 > 0.99. \quad (3)$$

The amount of radiation in the PAR spectrum intercepted (PARI) from planting (P) up to a day D was calculated by eq. 4:

$$PARI_D = \sum_{D=P}^{D=DAP} (FI_{PARD} * PAR_D), \quad (4)$$

where PAR_D is the incident PAR ($MJm^{-2}d^{-1}$) on day D and PAR_D was assumed to be half of incident global radiation (Spitters et al., 1986) as measured by a Li-2000 pyranometer (Li-Cor, Lincoln, NE, USA).

The interception of global radiation was also calculated to facilitate comparison of interception efficiencies with values from the literature:

$$RADI_D = \sum_{D=P}^{D=DAP} (FI_{RADD} * RAD_D), \quad (5)$$

where FI_{RADD} is the fractional interception of global radiation on day D and RAD_D is the global radiation ($MJm^{-2}d^{-1}$) measured on day D. The FI_{RAD} was derived by applying the radiation interception theory used by Jovanovic and Annandale (1998). Briefly, the theory states that light of any waveband is intercepted according to Beer's law:

$$FI_b = 1 - \exp(- K_b * L), \quad (6)$$

where FI_b is fractional interception of light of waveband b, K_b is the extinction coefficient for light of waveband b, and L is leaf area index. The relationship between K_{RAD} and K_{PAR} is determined by the leaf absorptivity for the PAR and near infra red (NIR) wavebands respectively ($a_{PAR} = 0.8$ and $a_{NIR} = 0.2$ according to Jovanovic and Annandale, 1998) such that:

$$K_{PAR} = K_{RAD} [(a_{PAR}/(a_{PAR}.a_{NIR})^{0.5}]^{0.5}. \quad (7)$$

The FI_{RAD} was derived by using the relationship expressed in eq. 7 to solve eq. 6 for the PAR and RAD cases.

Tiller population

Tiller population (TPOP) was counted biweekly (eight replications of 5m length each) initially and then once every three weeks (five replications of 5m length) from 170 days after emergence (DAE) onwards. The TPOP for the mass sampling dates was estimated by interpolating between the two nearest measurements.

Biomass components

Biomass was sampled on 1.5m sections on four occasions, 35 days apart starting at 83 DAE. On 23 January and 4 April samples were taken at row spacings of 2.49, 2.00, 1.52, 1.04 and 0.55m. On 27 February and 8 May samples were taken at row spacings of 2.73, 2.25, 1.77, 1.28 and 0.80m. Each sample was replicated three times. The plant material was separated into stalks (up to natural breaking point), leaves, sheaths, meristem, trash, dead stalks and bull shoots. All components except dead stalks were oven-dried and weighed. A dry matter content of 30% was assumed for dead stalks. Aerial dry mass of a given sample was taken as the total of all the components while stalk dry mass was taken as the oven dry weight of stalks. Stalks were also analysed for sucrose, total solids and fibre content by standard methods.

Aerial dry mass (ADM) and stalk dry mass (SDM) for the standard row spacings were estimated by dividing the sample dry mass by the number of live stalks in the sample and multiplying it by the tiller population measured for the standard row spacings. While this adjustment primarily corrects for off-centre sampling of biomass, it also mitigates errors due to insufficient sample size.

Radiation use efficiency (RUE; gMJ^{-1}) was determined by dividing the total aboveground dry mass on a given date by the global radiation intercepted (RADI) since emergence.

Intercepted PAR (PARI), TPOP, ADM and SDM were also converted to relative values terms in order to facilitate systematic analysis and interpretation of trends and to enable a better understanding of the role of biophysical processes. Variables were expressed as multiples of the value at 2.66m RS. These responses were compared to the amount of seed cane planted at each RS. Relative seed cane is defined as the amount of seed cane planted, expressed as a multiple of the amount planted at the 2.66m RS.

Final response of the different variables to row spacing at the last sampling date was defined as the average response per unit reduction in row spacing (units of $\%m^{-1}$). This was taken as the slope of a linear regression between the relative variable and row spacing.

Results

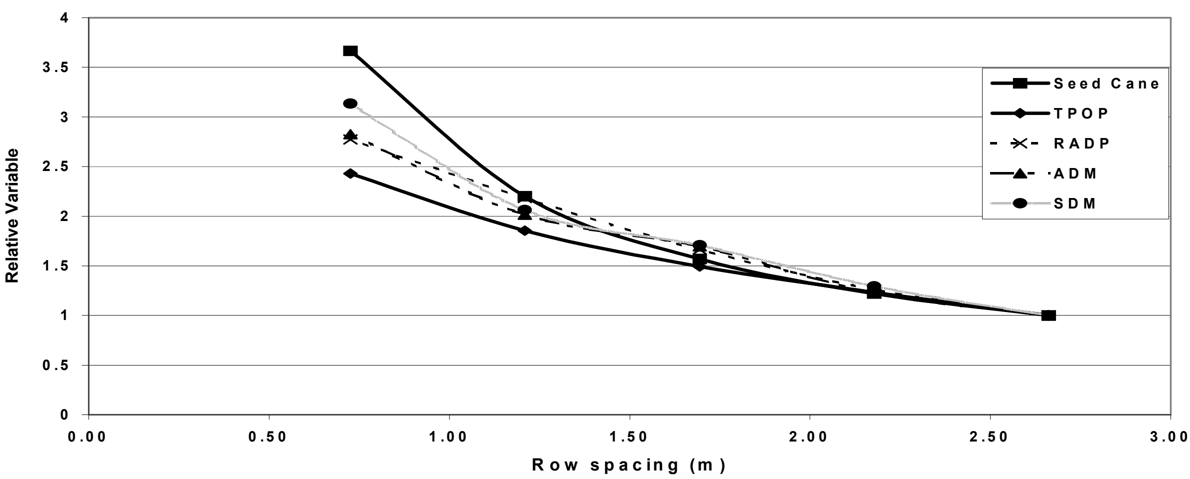
Radiation interception

The largest differences in FI_{PAR} occurred early in the growing period (Figure 2). At 102 DAE, FI_{PAR} ranged from 0.5 at 0.73m RS to 0.14 at 2.66m RS. It took 140 and 215 DAE to reach 0.80 FI_{PAR} at 0.73m and 2.66m RS respectively. The average response in time to reach 80% canopy was 44 days per one metre reduction in RS. This response constitutes a 26% reduction when decreasing row spacing from 1.5 to 0.5m.

The thermal time (base 16 ^{o}C) required from emergence to 50% cover varied from 862 ^{o}Cd at 2.66m RS to 415 ^{o}Cd 0.73m RS, an average response of $26\%m^{-1}$. It increased on average with 230 ^{o}Cd per metre reduction in RS which is much higher than the value of 125 $^{o}Cdm^{-1}$ found by Singels and Donaldson (2000).

The values of FI_{PAR} for the wide RS towards the end of the experiment were unexpectedly high (>0.95). This could be because FI readings were all taken on the north-eastern half of the inter-row space, thereby introducing possible bias.

a) 173 Days after emergence



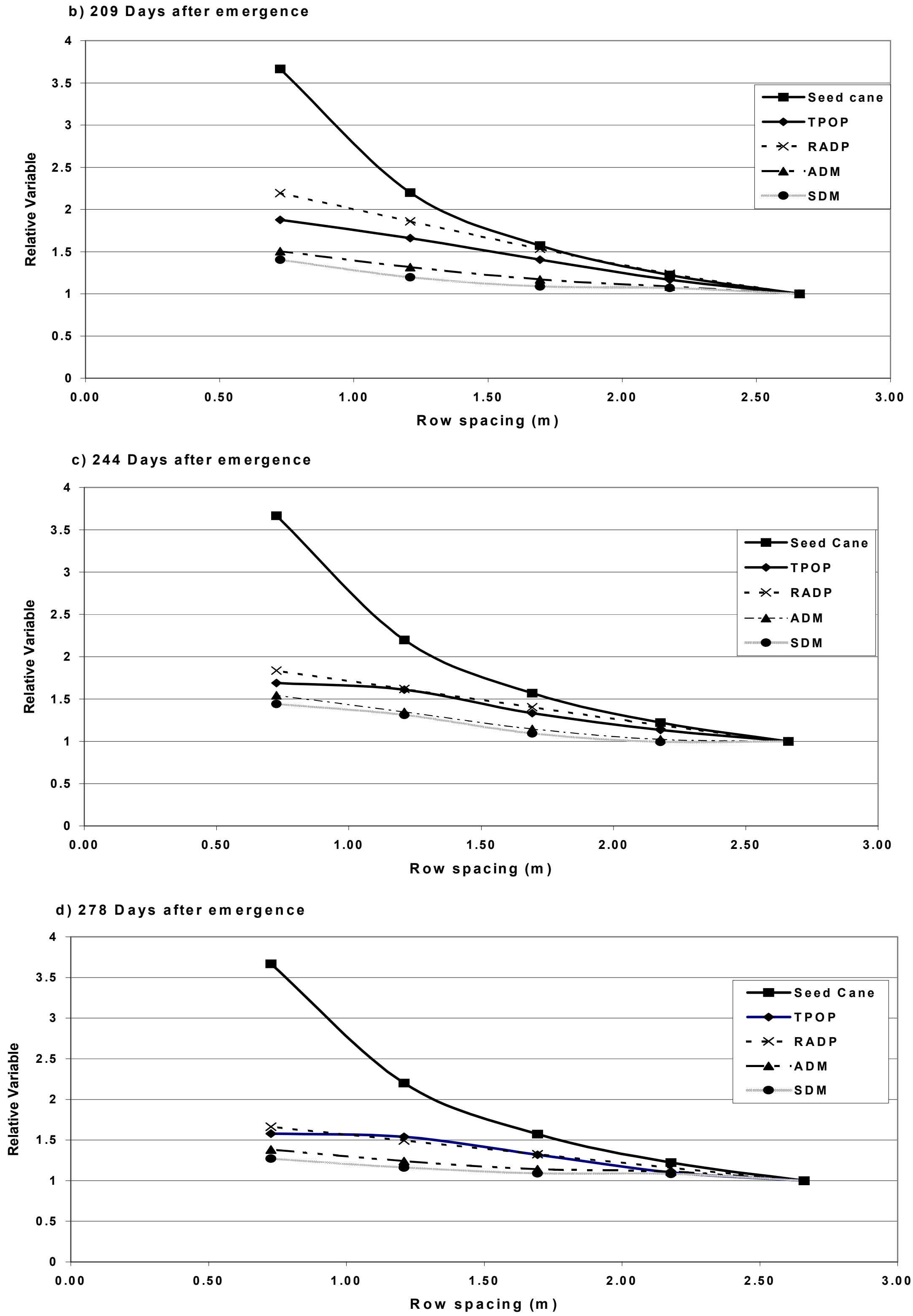


Figure 1: Values relative to that for 2.66m RS for intercepted radiation (PARI), tiller population (TPOP), aerial dry mass (ADM) and stalk dry mass (SDM) for different row spacings.

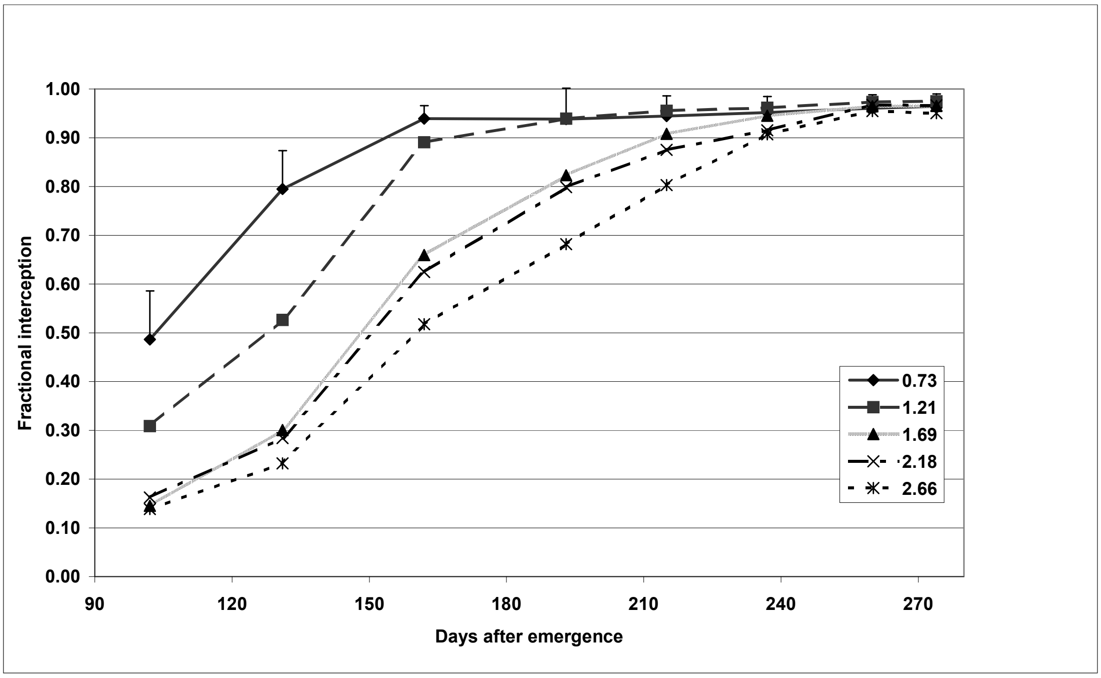


Figure 2. Fractional interception of photosynthetic active radiation for different row spacings. Bars indicate one standard error of measurement.

The response of PARI to RS was greatest early on with relative values directly related to the relative amount of seed cane (Figure 1). These responses diminished as the canopy of the wider RS's caught up. The PARI at the last sampling date 278 DAE ranged from 1534 MJm^{-2} for 0.73m RS, to 922 MJm^{-2} for 2.66m RS. Total accumulated incident PAR above the canopy at 278 DAE was 2886MJm^{-2} giving a seasonal PAR interception efficiency of 0.53 and 0.32 for 0.73m and 2.66m RS respectively. The corresponding interception efficiencies for global radiation were 0.49 and 0.26. These values are much lower than those reported by Muchow *et al.* (1997) and were presumably caused by the very slow emergence observed in this study.

The average response of PARI to row spacing at 278 DAE was 34.32% m^{-1} .

Tiller population

The initial rate of increase in TPOP was directly related to the amount of seed cane used (Figure 3). Competition for light had almost no effect on tiller production. A linear regression of relative peak TPOP versus relative seed cane show that 94% of additional viable buds germinated and developed as tillers.

The peak TPOP ranged from 43.95m^{-2} (36.17m^{-1} row) for 0.73m RS to 13.59m^{-2} (31.90m^{-1} row) for 2.66m RS.

Peak TPOP occurred at approximately 131 DAE or 542°Cd (base16) after emergence (500°Cd was reported for a ratoon NCo376 crop by Inman-Bamber, 1994). The timing of the peak TPOP for the different row spacings did not relate to FI_{PAR}. Tiller population for all row spacings started to decline when FI_{PAR} reached 0.74 for 0.73m RS which corresponds with the findings of Inman-Bamber (1994) for a 1.2m spaced ratoon crop. In the APSIM model, light competition is simulated to induce senescence once FI_{PAR} reaches 0.85 (Keating et al., 1999). Results from the reported study confirm that the light environment within the stool zone, rather than in the inter-row zone, dictates tiller phenology.

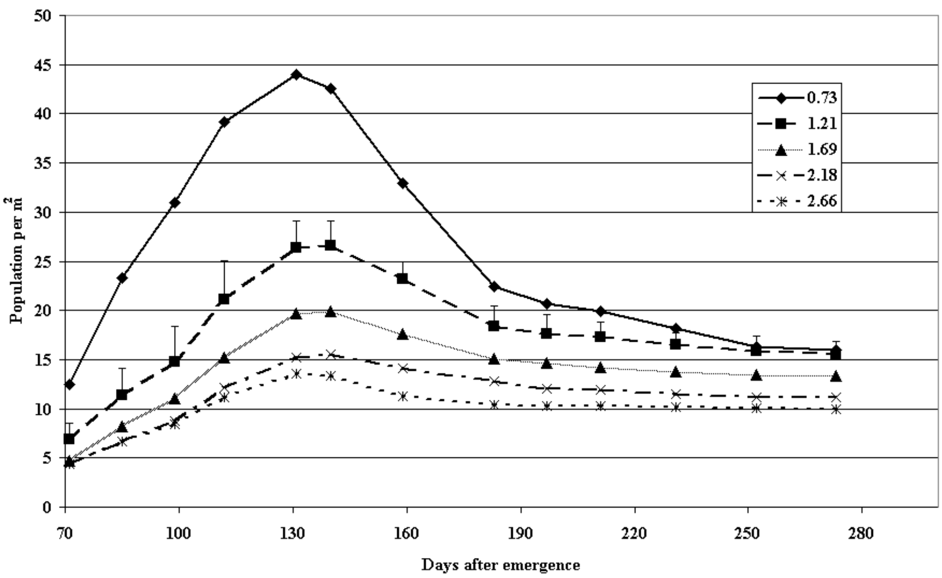


Figure 3: Time progression of tiller population for different row spacings. Bars indicate one standard error of measurement.

After reaching a peak population, tillers senesced back at a rate inversely related to RS (Figure 3). During the phase of tiller senescence, the relative TPOP response to RS declined to levels directly proportional to the relative response in PAR interception (Figure 1). This seems to indicate that the amount of PAR intercepted (source strength) dictated the number of tillers that could be maintained by the crop (sink size). Final TPOP ranged from 15.80m^{-2} at 0.73m RS to 10.01m^{-2} at 2.66m RS. The average response in TPOP at the last sampling date was 29% m^{-1}.

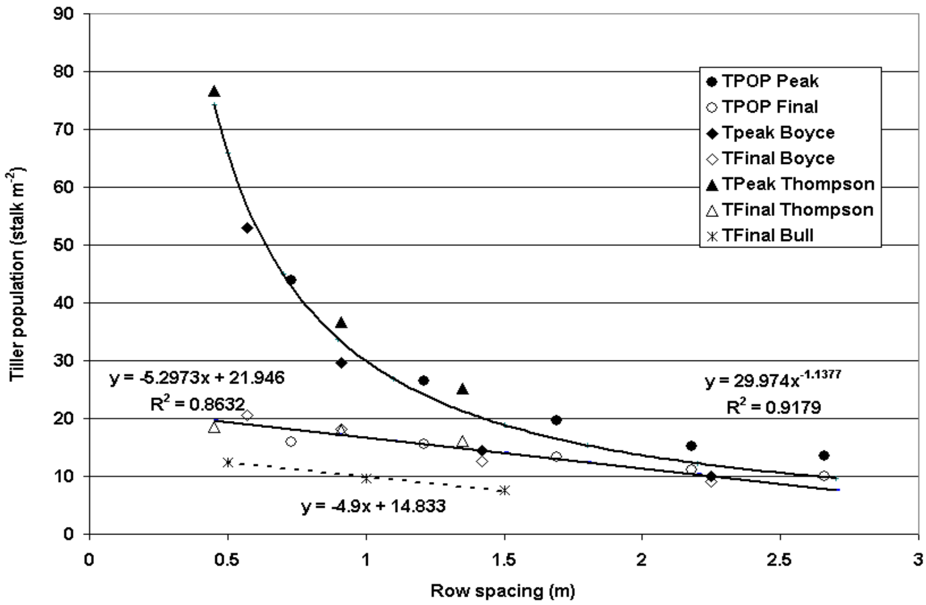


Figure 4. Response of peak and final NCo376 tiller populations to row spacing measured in this study and reported by Boyce (1968) and Thompson and Du Toit (1965). The broken regression line represents mean final tiller population for Australian genotypes reported by Bull and Bull (1996).

There is a high degree of similarity between tiller populations for irrigated NCo376 (plant crop of similar age) reported by Boyce (1968), Thompson and du Toit (1965) and this study (Figure 4). It seems that the wide range of planting dates for these trials had little effect on the response. Based on the pooled data presented in Figure 4, an increase of 5.29 tillers m^{-2} can be expected for every 1m decrease in RS. The response is quite similar for the data of Bull and Bull (1996) at 4.9 tillers m^{-2}.

Biomass accumulation and partitioning

Total ADM responded less to RS than did TPOP or PARI at the last three sampling dates (Figure 1). This suggests that wider rows have higher RUE's which in fact is the case (Figure 5). The RUE (slope of the regression line) ranged from $1.72gMJ^{-1}$ for 2.66m RS to $1.24gMJ^{-1}$ for 0.73m RS. Possible explanations for this could be because wider rows intercepted more radiation than actually measured or because narrow rows experienced water and/or nutritional stress through increased intra-row competition. The measured RUEs are similar to those ($1.26MJ^{-1}$-$1.8gMJ^{-1}$) reported by Muchow *et al.* (1997) for Australian and Hawaiian studies.

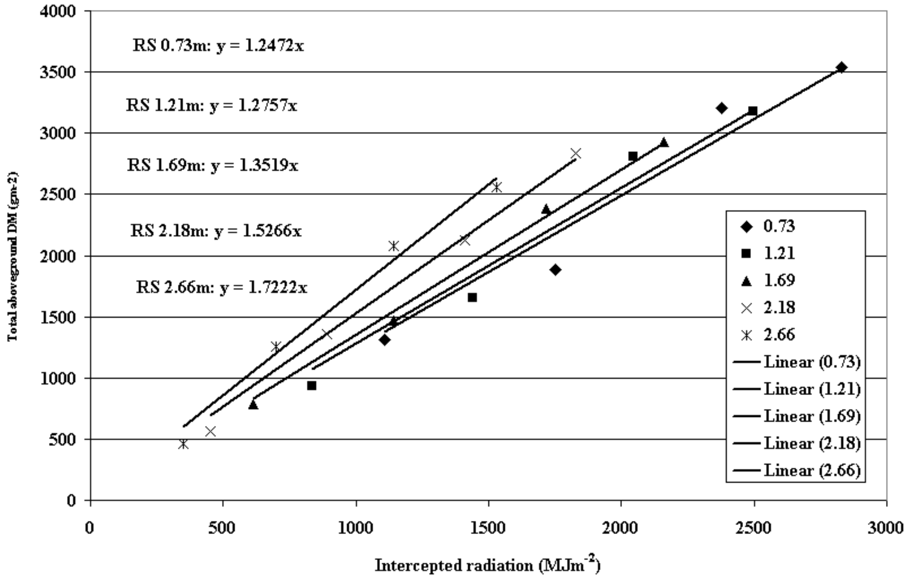


Figure 5. Aboveground dry mass as a function of global radiation intercepted for different row spacings. The lines are linear regression forced through the origin (the slope is indicated and equals the radiation use efficiency; RUE).

Stalk dry mass (SDM) had lower relative values than ADM (Figure 1). This was because of progressively less partitioning to stalks in the narrower rows. This trend is supported by the observation that mass per stalk decreased as RS decreased (Figure 6), as also found in other studies (Table 1). The tendency was more prevalent and significant at the later samplings. This appears to indicate a shift in partitioning priority away from stalks to leaves as row spacing decreases.

Sucrose and dry matter content of stalks showed no significant response to RS. Responses in sucrose mass and stalk fresh mass were therefore similar to the stalk dry mass response at 12 months of 13% per 1m decrease in row spacing. This response is very similar to that reported by Boyce (1968) and Thompson and du Toit (1965). The very large responses reported by Bull and Bull (1996) were the result of tiller population responses similar in magnitude to the response measured in this study (approx 5 tillers.m^{-1}), but from a very low base of 7.6 tillers.m^{-2} (compared to 13 tillers.m^{-2} for the SA data) at 1.5m row spacing.

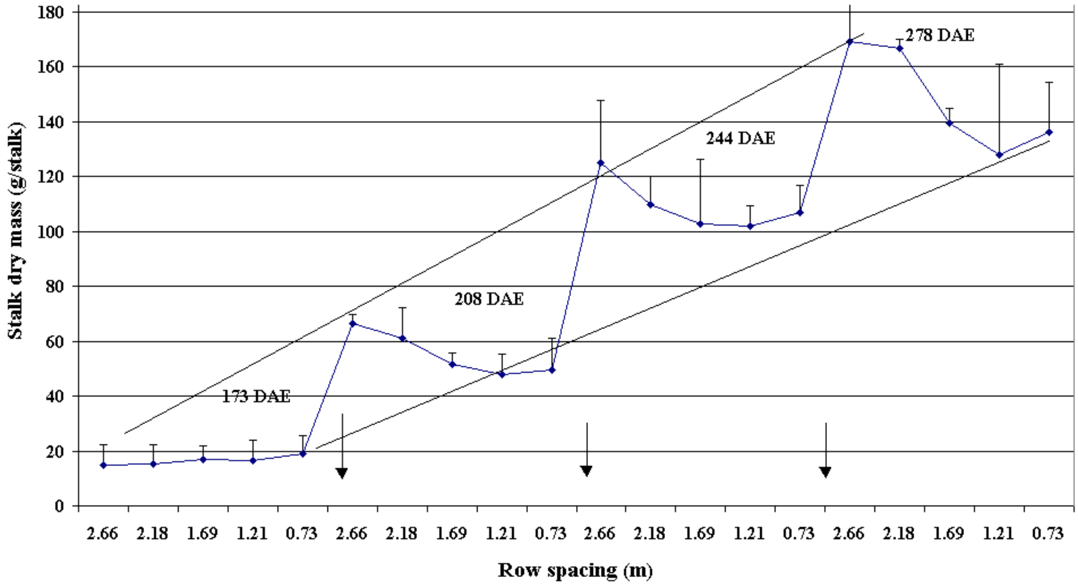


Figure 6. Dry mass per stalk for different row spacing and at different sampling dates. Bars indicate one standard error of measurement.

Conclusions

The following relationships were identified and could be used as a framework for modelling the effect of RS on sugarcane growth under non-limiting conditions:

- The rate of canopy closure has a direct linear relationship with row spacing (and not amount of seed cane) and increased by 26% per metre reduction in row spacing.
- Tiller production rate per unit area is strongly related to the amount of seed cane planted per unit area.
- The peak tiller population is reached at a light interception within the stool zone of 72%.
- The rate of tiller senescence is strongly related to an apparent imbalance between sink and source. When the sink (represented by TPOP) is much larger than that which can be maintained by the source (PARI), tillers are senesced at a high rate. The accurate simulation of the tiller senescence process is very important in predicting final tiller population, which is a key component of yield potential.
- There appears to be a decrease in RUE with decreasing RS.
- There is a decrease in the stalk fraction with decreasing RS. The magnitude of this decrease increases with age.

This information could be used to improve crop models' ability to simulate crop response to row spacing. These models could then be applied to identify optimal row spacing for irrigated and dry land scenarios.

This study demonstrated significant responses to row spacing (at a standard seed rate per planted row) in canopy development and stalk dry mass for non-limiting water and nutrient conditions. It is estimated that under these conditions canopy closure at a row spacing of 0.5m will be 26% faster than at a row spacing of 1.5m. This could have a significant impact on weed control costs. The average yield response was 13% per metre reduction in row spacing. This response was confounded by an exponential increase in the amount of seed cane. A cost:benefit analysis is required to determine whether reduced row spacing under irrigation is economically feasible. The economic impact of a lower seed cane density in narrow rows should also be investigated.

These results are specific to a plant crop of NCo376 with optimal water and nutrient status. It is important that the effect of ratoon stage and variety on these relationships be investigated in future.

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REFERENCES

Bezuidenhout, CN (2000). A model review and proposed mechanistic tiller model for the Canegro Sugarcane Crop Model. M Tech Thesis, Technikon Natal, Durban.

Boyce, JP (1968). Plant crop results of a row spacing experiment at Pongola. *Proc S Afr Sug Technol Ass* 42: 136-142.

Braunack, MV and Hurney, AP (2000). The position of harvesting traffic does affect yield. *Proc Aust Soc Sug Cane Technol* 22: 126-132.

Bull, TA and Bull, JK (1996). Increasing sugarcane yields through higher planting density – preliminary results. pp 166-168 In: Wilson, JR., Hogarth, DM, Campbell, JA and Garside, AL (Eds). *Sugarcane: Research Towards Efficient and Sustainable Production*. CSIRO Div of Tropical Crops and Pastures, Brisbane, Australia.

Bull, TA and Bull, JK (2000). High density planting as an economic production strategy: (b) Theory and trial results. *Proc Aust Soc Sug Cane Technol* 22: 104-112.

Bull, TA and McLeod, R (2000). High density planting as an economic production strategy: (d) Economic assessment and industry implications. *Proc Aust Soc Sug Cane Technol* 22: 119-125.

Bull, TA, Norris, CP, Robotham, BG and Braunack, MV (2001). New farming systems for sugarcane production. *Proc Int Soc Sug Cane Technol* 24: 52-57.

Garside, AL, Bell, MJ and Magarey, RC (2001). Monoculture yield decline – Fact not fiction. *Proc Int Soc Sug Cane Technol* 24: 16-21.

Irvine, JE and Brenda, GTA (1980). Sugarcane spacing I: Historical and theoretical aspects. *Proc Int Soc Sug Cane Technol* 17: 350-355.

Inman-Bamber, NG (1991). A growth model for sugarcane based on a simple carbon balance and CERES-Maize water balance. *S Afr J Plant Soil* 8: 93-99.

Inman-Bamber, NG (1994). Temperature and seasonal effects on canopy development and light interception of sugarcane. *Field Crop Res* 36: 41-51.

Javanovic, NZ and Annandale, JG (1998). Measurement of radiant interception of crop canopies with the LAI-2000 plant canopy analyser. *S Afr J Plant Soil* 15(1): 6-13.

Keating, BA, Robertson, MJ, Muchow, RC and Huth, NI (1999). Modelling sugarcane production systems 1: Development and performance of the sugarcane module. *Field Crop Res* 61: 253-271.

Mali, AL and Singh, PP (1988). Studies on growth analysis of sugarcane varieties in relation to row spacing. *Proc Sug Technol Ass India* 50: 59-64.

McGlinchey, MG and Inman-Bamber, NG (1996). Predicting sugarcane water use with the Penman-Monteith equation. pp 592-598 In: Evapotranspiration and irrigation scheduling: Proc Int Conf, Nov 3-6. San Antinio. CR Camp, EJ Sadler and RE Yoder (Eds) ASAE, St Joseph, Michigan.

Moberly, PK (1971). The nitrogen requirements of ratoon crops of sugarcane in relation to age and time of harvest. *Proc S Afr Sug Technol Ass* 45: 205-210.

Moberly, PK and Stevenson, DWA (1971). An evaluation of poultry manure as a sugarcane fertiliser. *Proc S Afr Sug Technol Ass* 45: 136-141.

Muchow, RC, Evensen, CI, Osgood, RV and Robertson, MJ (1997). Yield accumulation in irrigated sugarcane: II: Utilization of intercepted radiation. *Agron J* 89: 646-652.

SASEX (2001). Varieties. In: Senior Certificate Course Notes, South African Sugar Association Experiment Station, Mt Edgecombe.

Singels, A, Bezuidenhout, CN and Schmidt, EJ (1999). Evaluating strategies for scheduling supplementary irrigation of sugarcane in South Africa. *Proc Aust Soc Sug Cane Technol* 21: 219-226.

Singels, A and Donaldson, RA (2000). A simple model of unstressed sugarcane canopy development. *Proc S Afr Sug Technol Ass* 74: 151-154.

Singels, A, Kennedy, AJ and Bezuidenhout, CN (1998). IRRICANE: A simple computerised scheduling method for sugarcane. *Proc S Afr Sug Technol Ass* 72: 117-122.

Spitters, CJT, Toussaint, HAJM and Goudriaan, J (1986). Separating the diffuse and direct component of global radiation and its implications for modeling canopy photosynthesis. Part 1: Components of incoming radiation. *Agric For Meteorol* 38: 217-229.

Thomas, JR, Salinas, FG and Namken, LN (1978). Growth and yield of sugarcane as affected by row spacing and irrigation regime. *J Am Soc Sug Cane Technol* 7(NS): 129-135.

Thompson, GD (1965). The effect of trash conservation on soil moisture and the sugarcane crop in Natal. *Proc S Afr Sug Technol Ass* 39: 143-157.

Thompson, GD and du Toit, JL (1965). The effects of row spacing on sugarcane crops in Natal. *Proc Int Soc Sug Cane Technol* 12: 103-111.

Van Dillewijn, C (1952). Botany of Sugarcane. The Chronica Botanica Co, Book Department. Waltham, Mass, USA.