# CANE ROOT DEVELOPMENT AND CROP MODELLING

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**Abstract**

Data from pot and field trials were analysed to provide information on cane root length to root mass ratio and maximum water uptake per unit root length. These studies showed that the root length to root mass ratio decreased with an increase in crop age and varied between 300 and 1 100 cm/g. The uptake of water per unit root length increased with depth and was not proportional to root distribution. Coefficients of equations describing the root system in the CANEGRO model were adjusted in accordance with this new information. Data from two irrigation experiments were selected from the literature to test the ability of the model to simulate yield response on a Hutton form sand and Milkwood form clay. Simulated yields conformed more closely to observed yields when the root length to mass ratio was changed from 300 to 500 cm/g and maximum root water uptake was increased from 0,030 to 0,035 $cm^3$/cm/day.

## Introduction

Computer simulation of agronomic practices has been an important component of agricultural research and technology transfer. In the South African sugar industry the CANEGRO model (known previously as CANESIM) was recently made available to sugarcane technologists (Inman-Bamber, 1991). Despite the good progress that has been made in developing the detailed balances for carbon and soil water, the parameters required for characterising sugarcane root growth still need to be verified. The values currently used to determine the root length to mass ratio (300 cm/g) and root water use efficiency (maximum 0,03 cm/g) are largely empirically based, and there is a need to quantify these parameters before photosynthate can be correctly allocated between the above ground portion of the crop and the roots. Various workers (Van Dillewijn, 1952; Glover, 1967; Baran *et al.*, 1974; Ball-Coelho *et al.*, 1992) have shown that the root systems of young cane consist mostly of fine sett roots which have a greater length per unit mass than the larger and deeper buttress and rope roots. Sett root mass values reported by Van Dillewijn (1952), indicated that the mass of sett roots declined sharply 58 days after planting, whereas that of the shoot roots increased. Studies conducted on the root system of sugarcane grown on an ultisol in north eastern Brazil (Ball-Coelho *et al.*, 1992) showed that root length to mass ratios ranged from 627 to 2 261 cm/g, which are considerably higher than the values used in CANEGRO. The length to mass ratio is also considered to be a function of growth stage, soil depth, and soil physical and chemical properties (Anderson, 1987; Barber, 1971).

Roots deep within the profile are often considered less effective than those near the soil surface. Taylor and Klepper (1973, 1975), reported that cotton and corn roots deep in the profile were as effective and more effective, respectively, in the uptake of water per unit root length than shallow roots, probably because they were younger and were found in wetter soil. According to Jones (1985) the major exception to the proportionality between water uptake and root length occurs when some soil layers are drier than others.

This paper reports the results of an investigation that was conducted to determine the root length to mass ratios and water use efficiency factors that are the most appropriate for inclusion in CANEGRO.

## Methods and materials

CANEGRO is a version of the CERES-MAIZE model (Jones and Kiniry, 1986) which has been modified to simulate the growth and yield of sugarcane over a wide range of climatic and soil conditions in South Africa (Inman-Bamber, 1991). The model simulates rooting depth, total dry mass and distribution of root mass within the soil profile. With increase in age, root biomass declines as a fraction of total biomass.

*Procedure*

The investigation was divided into two phases: 1) calibration of the equations used to describe root growth in the CANEGRO model, with special reference to the root length/mass ratio and water use per unit root length measurements, 2) validation of the model by comparing simulated yields with observed above ground dry matter production (t/ha) using data from independent field trials.

*Calibration*

a) *Source of data*

Data on above ground dry matter accumulation and root production were obtained mainly from a growth analysis glasshouse trial, and a limited amount of data were obtained from a lysimeter and from three field trials. Selected characteristics of the trials are summarised in Table 1.

In the pot trial, pre-germinated single eyed setts of cane variety NCo376 were planted in pots containing a Hutton form sand (Clansthal series). The trial was harvested on 13 occasions. Yield and root density data were obtained also from the following sources:

- an irrigated growth analysis trial at the Central Field Station (CFS) which was established to determine the relative proportion of photosynthate allocated to the root system of variety NCo376.
- an irrigated growth analysis trial established at the old root laboratory site at the Experiment Station, with the object of determining the shape of the root growth curve in three soil forms (Cartref, Shortlands and Hutton)
- the ninth ratoon crop of a rainfed ridging trial at Mtunzini on a Westleigh form soil where seven cane varieties were established
- a watertable depth experiment that was conducted at the Experiment Station using variety N12 planted in lysimeters.

b) *Crop water use*

Plant available water capacity of the soil used in the pot trial was determined in the laboratory on disturbed samples between 10 and 1 500 kPa. The 10 kPa values were used as an indication of field water capacity (FC). The

Table 1

Selected characteristics of trial sites

| Trial No. Trial name | 1 Pot trial | 2 Lysimeter | 3 Mtunzini | 4 CFS '92 | 5 Rootlab '92 | | |
|---|---|---|---|---|---|---|---|
| Trial type | Pot | Pot | Field | Field | Field | | |
| Variety | NCo376 | N12 | NCo376 | NCo376 | NCo376 | | |
| Crop | Plant | Plant | 9th ratoon | Plant | Plant | | |
| Water | Irrigation | Irrigation | Rainfed | Irrigation | Irrigation | | |
| Soil depth (mm) | 600 | 1 200 | 400–700 | >2 000 | 1 800 | | |
| Soil form | Hutton | Tukulu | Westleigh | Hutton | SH | CR | HU |
| Clay (%) * | 6 | 11 | 14 | 7 | 32 | 7 | 4 |
| Silt (%) * | 3 | 8 | 9 | 3 | 14 | 5 | 2 |

* Mean % to the respective soil depths

SH = Shortlands; CR = Cartref and HU = Hutton

amount of water held by the soil between these two limits was used to calculate the plant available moisture capacity (AMC). The AMC and FC values were 97 and 149 mm/m respectively. Water content during the trial was determined by weighing the pots. Moisture content for the trial at Mtunzini was determined gravimetrically and the neutron moisture gauge was used for the other trials. Soil texture was determined by the hydrometer method described by Day (1965).

c) *Root measurements*

Root length was determined for the whole root system in the pot trial, and from core samples taken in the remaining trials. Roots were separated from the soil by flotation and the stirring action of water entering a washing pot. The roots left the pot through an overflow and were collected on a 0,5 mm sieve. A modified line intersection counter, based on the design of Rowse and Phillips (1974), was used to determine root length (cm). Root mass (g) was determined after drying at 50°C for 24 hours.

Table 2

Mean root length to mass ratio (L/Lm, cm/g) of sugarcane a) younger and b) older than 50 days

a) younger than 50 days

| Trial No. | 1 | 4 | 5 | Mean |
|---|---|---|---|---|
| Oldest cane (days) | 42 | 42 | 40 | |
| Mean L/Lm ratio (cm/g) | 680 | 684 | 1 070 | 811 |
| STD | 390 | 312 | 264 | |
| CV % | 57 | 46 | 25 | |
| n | 20 | 10 | 30 | |

b) older than 50 days

| Trial No. | 1 | 2 | 3 | 4 | Mean |
|---|---|---|---|---|---|
| Oldest cane (days) | 181 | 90 | 365 | 117 | |
| Mean L/Lm ratio (cm/g) | 369 | 469 | 504 | 527 | 467 |
| STD | 105 | 222 | 130 | 154 | |
| CV % | 28 | 47 | 25 | 29 | |
| n | 15 | 34 | 24 | 12 | |

N = number of data setts used

STD = standard deviation

The root length to mass ratio (L/Lm, cm/g) was calculated from the following equation: $(L/Lm)_x$ = mean $L_x$/mean $Lm_x$ where $x$ denotes roots collected on day x. All $(L/Lm)_x$ values from a trial were then added together and divided by the number of values added to calculate the mean L/Lm per trial. Average root length to mass ratios obtained from the various trial sites are summarised in Table 2.

Water uptake per unit root length (RWU, $cm^3$/cm/day) was calculated for each soil depth and period by dividing water withdrawal by roots (Ov, $cm^3/cm^3$), by rooting density (Lv, $cm/cm^3$) and the time in days (Taylor and Klepper, 1975).

*Validation*

In order to evaluate the experimentally derived root length to mass ratio and water use per unit root length coefficient on the performance of the CANEGRO model, data were used from two irrigation trials conducted by Thompson *et al.* (1967) and Thompson and de Robillard (1968). The trials were carried out near Mount Edgecombe on a deep Hutton form sand and a shallow Milkwood form clay. Daily rainfall and weekly means of daily maximum and minimum screen temperatures, class A-pan evaporation, and solar radiation were available and were used to generate the simulation. The root length to mass ratios tested ranged from 50 to 811 cm/g. The statistical technique of Wilmott (1982) was used to select the ratio that provided the best agreement between simulated and observed yields. The sensitivity of the CANEGRO model to changes in the soil water conductivity factor ($SWC_f$), using a revised root length to mass ratio, was also tested.

## Results

*Root extension*

Total root length obtained in the pot trial was correlated with the quantity of cumulative heat units (CHU) recorded for the 181 day cropping period (Figure 1). Initially the rate of root growth was slow and averaged 0,0044 $mm/mm^2$/day for the period covering the first 500 CHU, but the rate increased almost four fold to an average value of 0,0189 mm/$mm^2$/day for the 500 to 2 000 CHU period.

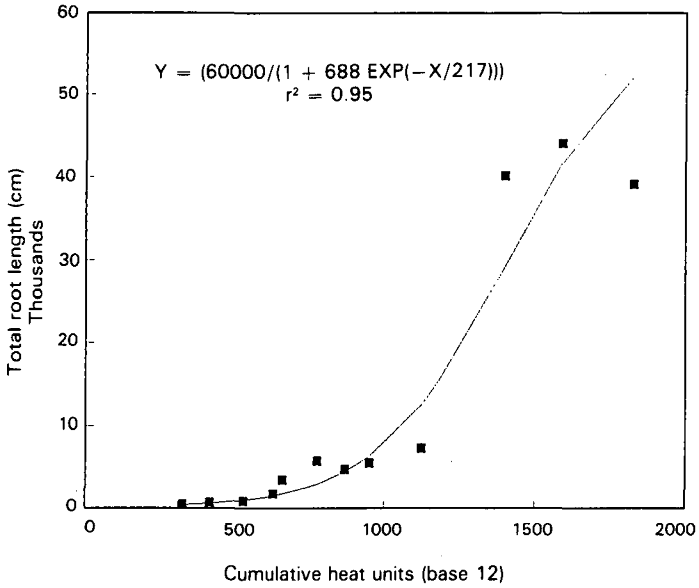


**FIGURE 1** The relationship of total root length with cumulative heat units for variety NCo376 in pots.

The mean root length to mass ratio varied from 368 to 1 070 cm/g for cane produced in the pot trial (see Figure 2). An examination of results obtained from the various trials suggested that the root length to mass ratio was mainly a function of crop age. The average ratio declined from 811 cm/g for cane younger than 50 days, to 467 cm/g for cane older than 50 days. The dependence of root length to mass ratio on stage of crop development was clearly illustrated by the data obtained from the pot trial (Figure 2). The decline in the ratios was most marked during the first 50 days following planting.

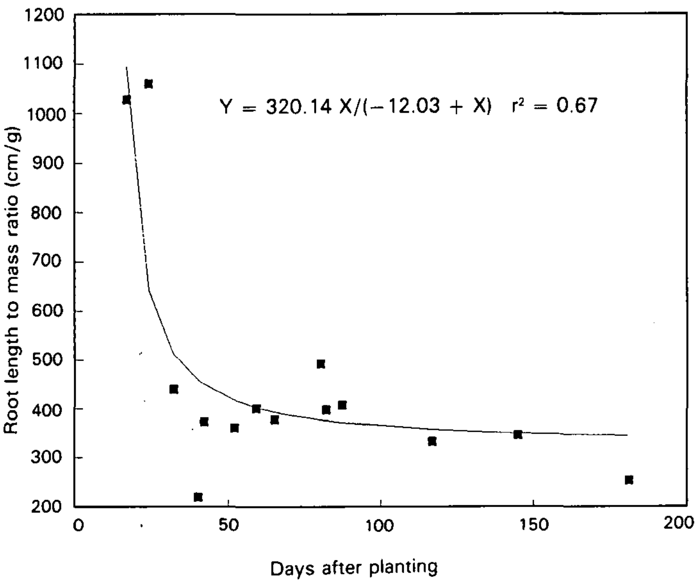


**FIGURE 2** Change in the root length to mass ratio with time for variety NCo376 grown in pots.

## *Root water use efficiency*

Root water use efficiency as measured by root water uptake (RWU, $cm^3$/cm/day) was positively correlated with soil moisture measurements from various trial sites (Figure 3). Of interest was the relationship obtained between root water use efficiency and soil depth using data from the CFS trial.

For both the sampling dates, water uptake increased from levels below 0,01 $cm^3$/cm/day in the surface soil layers, to values between 0,03 and 0,07 $cm^3$/cm/day for soil depths in excess of 800 mm (Figure 4). The increase in root water use efficiency between the two sampling dates (curves A and B) was consistent with the increase in soil moisture content in the soil profile between these two dates (curves C and D). However, no relationship was found between soil moisture content and root water use efficiency in any soil layer on either sampling date.

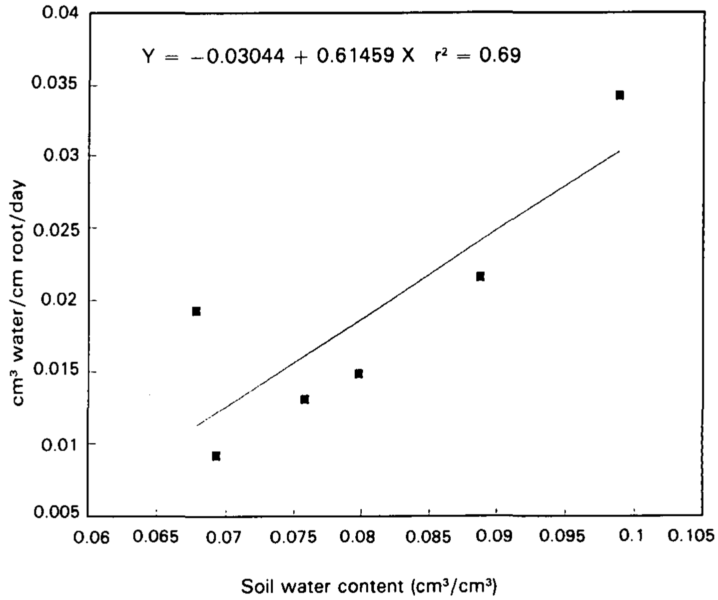


**FIGURE 3** The relationship between root water use efficiency and soil water content for variety NCo376.

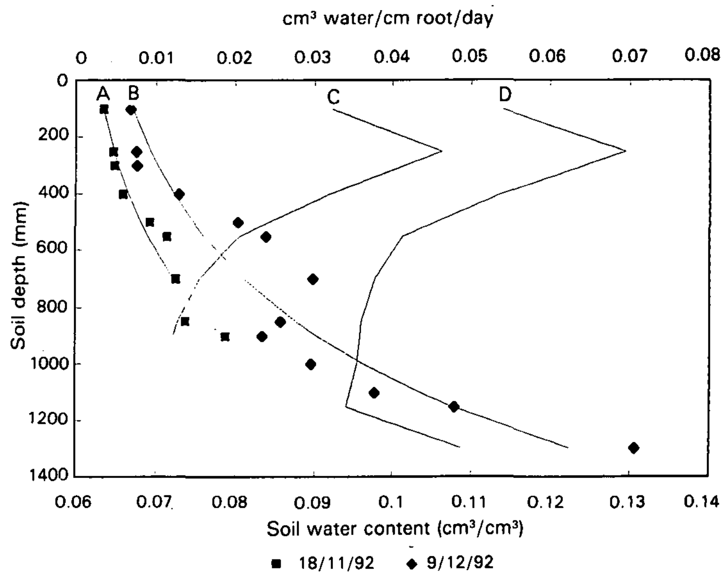


**FIGURE 4** Root water efficiency expressed as a function of soil depth (curves A and B). Curves C and D are the mean soil water content for the periods used to calculate curves A and B. Data for variety NCo376 from the CFS field trial.

**Table 3**

**Comparison of the sensitivity of predicted response to changes in root length to root mass ratios for Hutton and Milkwood form soils**

| Soil type | Observed mean yield dry matter (t/ha) | Simulated yields (dry matter, t/ha) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | L/Lm (cm/g) | | | | | | | |
| | | 50 | 100 | 300 | 400 | 467 | 500 | 800 | 811 |
| | | $SWC_f$ | | | | | | | |
| | | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 |
| Hutton sand | 36,10<br>D-index* | 38,88<br>0,96 | 38,62<br>0,96 | 36,97<br>0,95 | 36,63<br>0,95 | 36,21<br>0,94 | 36,15<br>0,94 | 35,64<br>0,93 | 35,64<br>0,93 |
| Milkwood clay | 29,72<br>D-index* | 19,90<br>0,72 | 23,69<br>0,81 | 28,10<br>0,85 | 29,09<br>0,85 | 29,30<br>0,85 | 29,43<br>0,85 | 30,41<br>0,82 | 30,43<br>0,82 |

* Index of Agreement (Willmott, 1982)

**Table 4**

**Sensitivity of the CANEGRO model to changes in the soil water conductivity factor ($SwC_f$)**

| Soil type | Observed mean yield dry matter (t/ha) | Simulated yields (dry matter, t/ha) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | L/Lm (cm/g) | | | | | | |
| | | 467 | 467 | 467 | 467 | 467 | 467 | 467 |
| | | $SWC_f$ | | | | | | |
| | | 40 | 60 | 120 | 140 | 160 | 180 | 240 |
| Milkwood clay | 29,72<br>D-index* | 29,29<br>0,85 | 29,29<br>0,85 | 29,78<br>0,85 | 30,01<br>0,85 | 29,92<br>0,85 | 29,77<br>0,85 | 29,60<br>0,85 |
| Hutton sand | 36,10<br>D-index* | 38,64<br>0,96 | –<br>– | 36,21<br>0,94 | –<br>– | 33,89<br>0,91 | 33,25<br>0,89 | –<br>– |

* Index of Agreement (Willmott, 1982)

### *Validation*

Measured and simulated yield responses, using root length to mass ratios varying from 50 to 811 cm/g, and a soil water conductivity factor of 80 for the Hutton form sand and Milkwood form clay, are shown in Table 3. In general, predicted yields on the Milkwood form soil were more sensitive to increasing root length to mass ratios than those obtained from the Hutton form soil. Of interest is that predicted yields on the Milkwood form soil increased with increasing root length to mass ratio, whereas those yields on the Hutton form soil declined. The simulated yields that agreed most closely with the observed yields, coincided with a root length to mass ratio of 500 cm/g for both soil types. Increasing the root length to mass ratio to above 500 cm/g had little effect on predicted yields in either the Hutton or Milkwood form soils.

The sensitivity of CANEGRO to changes in the soil water conductivity factor ($SWC_f$) was also tested for the soils, using a revised root length to mass ratio value of 500. In terms of the simulated yield data shown in Table 4, the model was more sensitive to changes in this factor on the sandy Hutton form soil when compared with the Milkwood form clay soil. Changing the value of the factor from 80 to 120 improved yield prediction on the clay soil but had little or no effect in improving yield on the sandy soil.

## Discussion

The results have clearly shown that the root length to mass ratios used in CANEGRO are too low and need to be changed to 500 cm/g for cane growing on either sandy or clay soils. The revised value will be more in line with the higher root length to mass ratios of 780 and 412 cm/g that were obtained respectively by Ball-Coelho *et al.* (1992) and van Dillewijn (1952). The results have also shown that the length to mass ratio is a function of crop age. Cognisance of this relationship should be taken in modifying CANEGRO by using the appropriate coefficients in the equation that describes this relationship. There was, however, insufficient evidence to justify the use of different length to mass ratios for different soil types and for different soil depths. However, further work will be required to test the effect of soil depth and soil physical and chemical properties on the root length to mass ratio. The results obtained by Ball-Coelho *et al.* (1992) showed that the mean root length to mass ratio of roots in the top metre of soil was 780 cm/g and increased to 1 745 cm/g in the one to two metre soil depth. It may be inferred that the root length to mass ratio may be variety dependent, as shown by the mean values of 780 cm/g for Co997 (Ball-Coelho *et al.*, 1992), 341 cm/g for variety POJ2878 (van Dillewijn, 1952) and 469 cm/g for N12 and 515 cm/g for NCo376 that were obtained in this investigation.

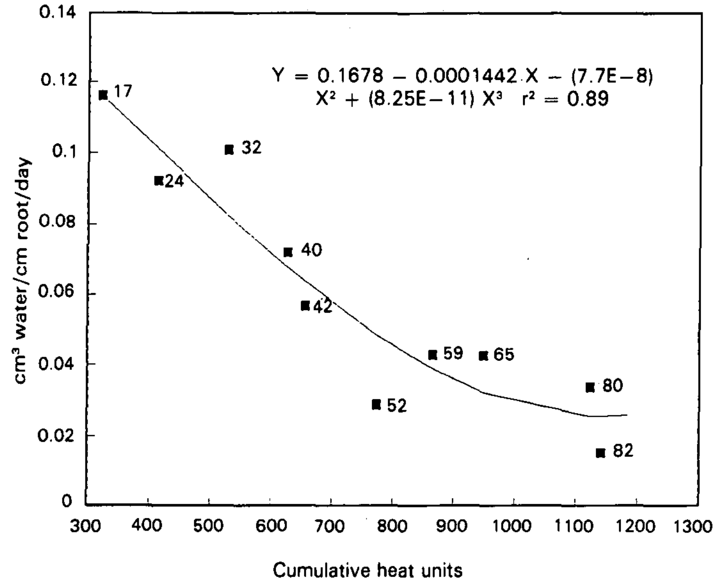


**FIGURE 5** Root water uptake rate (*cm³*/cm/day) as a function of time (cumulative heat units) for variety NCo376 grown in pots. Data labels indicate days after planting.

It is evident from the various relationships obtained that root water use efficiency increases with increasing soil moisture content and depth (Figure 4) but decreases with increasing crop age (Figure 5). It may also be inferred from the data that young sugarcane roots can apparently withdraw water at a higher rate than older roots, even at depths where moisture contents may be lower than in the topsoil. The results suggest that the maximum root water uptake value used in CANEGRO should be increased from 0,030 to 0,035 $cm^3$/cm/day. As crop water use is also a function of crop age and soil depth, there is a need to modify the model to include these variables. The regression equations associated with the relationships shown in Figures 1, 2 and 3 will provide a satisfactory basis for introducing these changes. However, further field work will be needed to confirm these relationships.

## Conclusions

The CANEGRO model simulates the depth, total dry mass and distribution of root mass within the profile. Changing the values for root length to mass ratio, as recommended, will help to provide a more realistic allocation of new root length to each soil layer, and will improve the prediction of the model in simulating biomass production. Potential root system biomass maintains a dynamic equilibrium with the total crop biomass. With increasing age, the root length to mass ratio declines, which implies that the root biomass declines in relation to the total biomass. As predicted root growth is a function of water extraction; inclusion of factors such as crop age and soil depth in calculating root water uptake will assist in improving the prediction capability of CANEGRO. Future work will be needed to consider the effect of factors such as variety, stage of crop (plant or ratoon) and physical factors such as texture on root proliferation. The allocation of photosynthate to the root system also needs to be verified.

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