

PRELIMINARY OBSERVATIONS ON THE ROOTING HABIT OF SOME SUGARCANE VARIETIES IN SOUTH AFRICA

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Abstract

A study was made of the root development of twelve sugarcane varieties, some of which are known to differ in their response to nematodes. The number and mass of sett and shoot roots produced by the varieties were recorded at intervals up to 14 weeks after planting in pots. Root length was estimated and indices of root hair abundance and frequency of branching were calculated. Number and mass of sett roots generally increased up to 10 weeks and then declined. In NCo 382 and N6 however, there was a progressive increase up to 14 weeks. Shoot root production was initiated after 2 weeks. The number and mass of shoot roots of each variety increased with time but there were relatively large differences between varieties. Shoot root mass was greatest in N55/805 and NCo310 and least in N6. Estimated total root length at 14 weeks was greatest in N55/805 and Co331 and least in CB36/14 and NCo293. In most varieties the number of root hairs per unit length of sett or shoot root decreased from 6 to 14 weeks. There was little difference in the degree of branching of the sett or shoot roots between varieties. Varieties that generally grow well on soils subject to moisture deficiency tended to have a greater total root length than those that require better growing conditions. The variety N8, which has shown some degree of tolerance to nematode damage in field trials, did not develop more roots nor a greater mass or length of roots than some other less tolerant varieties.

Introduction

A large number of nematodes feed on and cause damage to the roots of sugarcane in South Africa. The damage, especially to crops growing on the poor coastal sands, is often sufficient to reduce the yield of cane. In these poor sands some varieties, in particular N8, appear to be less affected by nematodes than others (Anon¹). This could be due to resistance to or tolerance of nematodes, or possibly to differences in the rate and extent of root development in these varieties on the coastal sands. Assuming there was no biochemical difference in their reaction to nematodes, a variety that rapidly develops an extensive root system would presumably be less affected by a given number of nematodes than another variety in which root development proceeds more slowly. Resistance to drought would presumably also be greater in the former variety. Thus a study of the cane root system could contribute towards an understanding of the relative performance of different varieties in the poor soils where nematodes may be a problem. However, apart from the work of Glover^{4,7} and Wood and Wood¹⁰, little attention has been given to sugarcane root development in South Africa.

The data presented in this paper are the results of a preliminary investigation of the rooting habit of twelve varieties. Before describing the work it is relevant to mention briefly the two types of roots produced by the sugarcane plant. In commercial practice sugarcane is propagated vegetatively from stalk cuttings, or setts, each usually bearing three or more buds. These buds develop to form the new primary shoots. Immediately above each node of the sett lie a number

of root primordia. At an early stage in the life of the plant these primordia give rise to the *sett* roots. These sett roots are gradually replaced by the *shoot* roots, which originate from similar root primordia on the newly developed shoots. In the course of time secondary shoots (tillers) develop from buds on the lower nodes of the primary shoots and these then develop their own shoot roots. A more detailed account of root development in sugarcane has been given by Dillewijn³.

Methods

Single-budded setts of twelve varieties, Co331, NCo293, NCo310, NCo334, NCo339, NCo376, NCo382, N6, N8, N50/211, N55/805 and CB36/14, were pre-germinated in vermiculite. Two weeks after planting, 150 well grown plants of each variety were carefully lifted and the numbers of sett and shoot roots per plant in a sample of 50 plants per variety were recorded. All the plants were then replanted in plastic pots containing 5 litres of river sand with two plants per pot. The mechanical composition of the sand was 51% coarse sand, 43% medium sand, 4% fine sand and 2% clay. The pots were arranged in a randomised block design on a concrete floor outdoors. The pots were automatically irrigated twice daily and a hydroponic nutrient solution was added once a week. Synthetic shade cloth suspended 3 metres above the pots provided 35% shade.

At 6, 10 and 14 weeks after the initial planting 50 plants of each variety were lifted, the roots cut off and the number and fresh mass of sett and shoot roots per plant were recorded. On each occasion the sett and shoot roots from five randomly selected plants were preserved in alcohol. The remaining roots were bulked according to their origin and dried at 100°C for 24 hours. After root removal the 6-, 10- and 14-week old plants were immediately replanted in trays of sand and after a further 8 weeks the number of new sett and shoot roots was recorded.

Estimates of the length of sett and shoot roots per plant as well as indices of root hair abundance and root branching were obtained from the alcohol preserved material. The sett and shoot roots were bulked according to their origin and dried with absorbent paper. Root volume was determined by displacement in water. No difference was found between the volume of roots measured in water or kerosene. The roots were then chopped into approximately 10-20 mm lengths and a small subsample was spread in a thin layer of water in a petri dish. Scratched across the dish were two parallel lines, 80 mm long and 6 mm apart. Using a dissecting microscope the diameter of every portion of root that crossed or touched one line was recorded. Root hair abundance on the same root pieces was scored on a scale of 25, when root hairs were very abundant; 20, when root hairs were numerous; 10, when root hairs were moderately numerous; 1, when root hairs were infrequent and 0, when root hairs were absent. After all the roots on one line had been measured and scored the number of branches on the roots between the two lines was recorded. Further subsamples were taken until measurements from approximately 200 root pieces had been recorded.

Estimates of root length per plant were made from the volume and diameter of roots of a known dry mass, assuming

that the roots were cylindrical. Root hair scores and the number of branches were related to the number of root pieces measured to give indices of root hair abundance and branching. No estimates were made of root hair length.

Results

Number of primary roots per plant (Tables 1 and 2).

After 6 weeks of growth N50/211 and NCo293 had produced more and N8 and Co331 less sett roots than any other variety, (Table 1). Thereafter the number of sett roots of most of the varieties slowly declined, presumably due to some roots dying back. Maximum sett root production in varieties NCo334, CB36/14 and NCo293 had occurred by the 2nd week and in all other varieties except N6 and N8, by the 6th week (Table 1). Maximum root production in N6 and N8 had occurred by the 10th week.

No shoot roots had developed in any variety up to 2 weeks after planting.

TABLE 1
Number of primary sett roots per plant

| Variety | Weeks after planting | | | |
|----------------|----------------------|------|------|------|
| | 2 | 6 | 10 | 14 |
| N55/805 | 28,7 | 36,4 | 27,3 | 31,2 |
| NCo 310 | 40,6 | 42,2 | 35,2 | 36,4 |
| NCo 376 | 35,0 | 39,9 | 23,2 | 32,2 |
| CB 36/14 | 47,6 | 47,2 | 46,8 | 44,3 |
| N8 | 19,8 | 22,3 | 28,4 | 26,9 |
| NCo 382 | 28,6 | 32,3 | 23,6 | 27,5 |
| N50/211 | 54,1 | 56,0 | 48,5 | 46,7 |
| NCo 339 | 30,0 | 37,6 | 29,3 | 26,8 |
| NCo 334 | 47,8 | 37,4 | 39,6 | 36,4 |
| N6 | 28,2 | 30,0 | 32,4 | 30,9 |
| Co 331 | 24,9 | 27,5 | 23,1 | 21,6 |
| NCo 293 | 52,2 | 52,2 | 40,1 | 37,0 |
| Mean | 36,4 | 38,4 | 33,1 | 33,1 |
| LSD (p < 0,05) | 3,80 | 4,06 | 3,82 | 3,71 |
| LSD (p < 0,01) | 5,02 | 5,37 | 5,06 | 4,91 |
| CV | 26,5 | 19,0 | 20,7 | 20,1 |

Least significant differences between time intervals within varieties are 3,87 (p < 0,05) and 5,11 (p < 0,01), and the coefficient of variation is 19,9.

TABLE 2
Number of primary shoot roots per plant

| Variety | Weeks after planting | | | |
|----------------|----------------------|------|------|------|
| | 2 | 6 | 10 | 14 |
| N55/805 | 0 | 8,2 | 13,4 | 23,1 |
| NCo 310 | 0 | 4,7 | 10,1 | 18,0 |
| NCo 376 | 0 | 9,1 | 16,5 | 26,3 |
| CB 36/14 | 0 | 5,6 | 15,5 | 27,2 |
| N8 | 0 | 4,8 | 10,8 | 22,0 |
| NCo 382 | 0 | 4,9 | 8,7 | 15,5 |
| N50/211 | 0 | 3,4 | 11,9 | 19,8 |
| NCo 339 | 0 | 4,2 | 8,8 | 17,5 |
| NCo 334 | 0 | 4,7 | 8,9 | 16,0 |
| N6 | 0 | 0,2 | 6,0 | 9,8 |
| Co 331 | 0 | 4,1 | 8,9 | 15,3 |
| NCo 293 | 0 | 2,8 | 9,6 | 20,3 |
| Mean | 0 | 4,7 | 10,7 | 19,2 |
| LSD (p < 0,05) | — | 1,11 | 1,46 | 2,23 |
| LSD (p < 0,01) | — | 1,47 | 1,93 | 2,95 |
| CV | — | 42,2 | 24,4 | 20,8 |

Least significant differences between time intervals within varieties are 1,69 (p < 0,05) and 2,23 (p < 0,01) and the coefficient of variation is 26,3.

After 6 weeks all varieties had produced shoot roots with NCo376 and N55/805 having produced the most and N6 the least (Table 2). Subsequently CB36/14 and NCo376 were the two varieties with the greatest number of shoot roots. All varieties showed a progressive increase in number of shoot roots with time.

Root mass per plant (Figure 1).

Sett root mass was not recorded at 2 weeks. Generally there was an increase in sett root mass from 6 to 10 weeks then a decline from 10 to 14 weeks. Exceptions to this were N55/805, where there was a decline in mass after 6 weeks, and NCo382 and N6 where there was a notable increase up to 14 weeks. After 14 weeks of growth the mass of sett roots developed by NCo382 and N6 was considerably greater than that of any of the other varieties. In all varieties the mass of shoot roots increased with time, with N55/805 and NCo310 producing the greatest mass of root material and N6 the least.

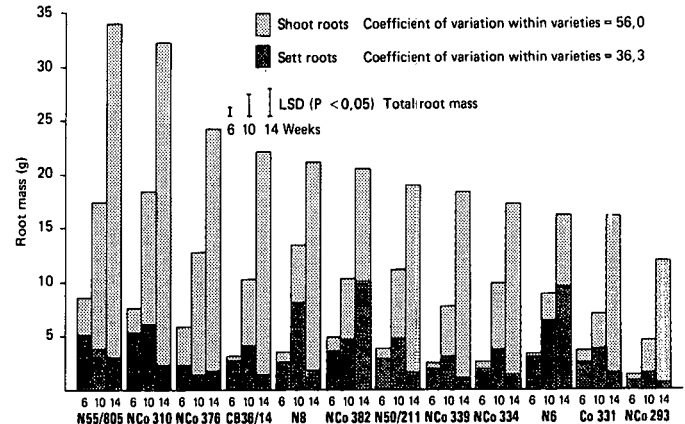


FIGURE 1 Root mass per plant at 6, 10 and 14 weeks.

There was an approximate two-fold increase in total root mass from 6 to 10 weeks and again from 10 to 14 weeks in varieties N55/805, NCo310, NCo376, NCo382 and Co331 (Figure 1). In the other varieties the increase in total root mass was nearer three-fold for the 6 to 10 week interval. On each occasion N55/805 and NCo310 had produced a greater mass of root material than any other variety.

The mass of individual sett roots varied to a greater extent than that of the shoot roots. This is illustrated by the following correlation coefficients relating number to mass of roots. The mean coefficients for the sett roots of the twelve varieties at 6, 10 and 14 weeks were 0,28, 0,22 and 0,23 respectively, while the corresponding correlation coefficients for the shoot roots were 0,77, 0,56 and 0,54.

Root length per plant (Figure 2).

Since the data presented in Figure 2 are based on a small sample of only five plants, they can only be considered as rather crude estimates. However, with a few exceptions, it appears that at 6 weeks the length of the sett or shoot roots for each variety was broadly similar. Sett root length, particularly that of NCo310, increased up to 10 weeks; then with the exception of NCo382 and N6, it declined. In these latter two varieties the sett roots formed the greater proportion of the root system at 14 weeks. Except for NCo382 shoot root length increased with time. At 14 weeks N55/805, N8, NCo339 and Co331 had a greater length of shoot roots than the other varieties. Total root length per plant at 14 weeks was greatest in N55/805 and Co331 and least in CB36/14 and NCo293 (Figure 2).

Apart from N55/805, varietal differences in total root mass at 14 weeks were not reflected by differences in total root length. This can largely be explained by the wide range in mean root diameters from which the length estimates were derived. Varieties with relatively thin shoot roots, such as N8, NCo339 and Co331, had a disproportionately longer root system than other varieties with a similar root mass. In addi-

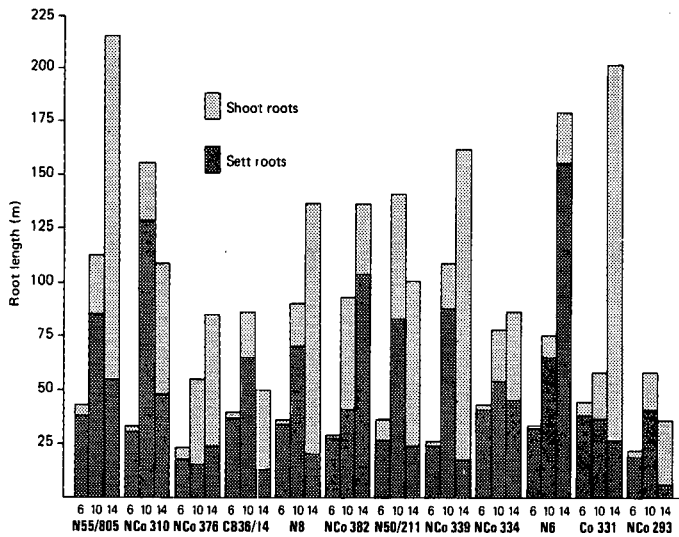


FIGURE 2 Root length per plant at 6, 10 and 14 weeks.

TABLE 3
Index of root hair abundance per unit root length

| Variety | Sett | | | Shoot | | |
|----------|---------|----------|----------|---------|----------|----------|
| | 6 weeks | 10 weeks | 14 weeks | 6 weeks | 10 weeks | 14 weeks |
| N55/805 | 1,2 | 1,4 | 2,1 | 2,6 | 1,6 | 2,1 |
| NCo 310 | 6,0 | 1,4 | 1,5 | 12,4 | 1,1 | 1,3 |
| NCo 376 | 1,7 | 1,0 | 5,3 | 2,3 | 4,5 | 2,3 |
| CB 36/14 | 5,1 | 2,1 | 2,1 | 16,0 | 3,3 | 1,8 |
| N8 | 8,0 | 2,0 | 1,9 | 14,7 | 4,3 | 2,1 |
| NCo 382 | 2,9 | 1,2 | 1,5 | 6,8 | 3,5 | 1,3 |
| N50/211 | 3,7 | 3,8 | 7,0 | 3,5 | 1,8 | 1,2 |
| NCo 339 | 3,2 | 7,2 | 1,0 | 6,6 | 1,8 | 1,9 |
| NCo 334 | 5,9 | 2,2 | 5,3 | 7,5 | 2,5 | 1,9 |
| N6 | 9,3 | 8,1 | 5,3 | NR* | 4,1 | 3,7 |
| Co 331 | 3,4 | 1,2 | 1,6 | 8,2 | 5,3 | 1,3 |
| NCo 293 | 10,5 | 4,4 | 2,4 | 6,8 | 2,9 | 1,3 |
| Mean | 5,1 | 3,0 | 3,1 | 7,9 | 3,0 | 1,8 |

* NR = not recorded

tion, since the diameter of the sett roots of all the varieties was smaller than that of the shoot roots then those varieties with an above average mass of sett roots, such as NCo382 and N6, also had a disproportionately longer root system.

Root hair abundance (Table 3).

The number of root hairs per unit length of sett or shoot root generally decreased from 6 to 14 weeks. Most of the varieties had more hairs on the shoot roots than the sett roots at 6 weeks and vice versa at 14 weeks. With a few exceptions N6 had as many or more root hairs than the other varieties. At 6 weeks root hairs were more numerous on the sett roots of NCo310, CB36/14, N8, NCo334, N6 and NCo293 than on the other varieties and they were particularly numerous on the shoot roots of NCo310, CB36/14 and N8 at this time.

Frequency of branching (Table 4).

There appeared to be little difference in the degree of branching of the sett or shoot roots between varieties. Branching of the sett and shoot roots was generally similar. The number of branches on the shoot roots at 10 and 14 weeks was greater than at 6 weeks.

Root regrowth (Table 5).

Variety N8 was the only variety to produce a notable number of new sett roots after the original roots had been removed. Plants of all the varieties that had had their roots

TABLE 4
Index of frequency of branching per unit root length

| Variety | 6 weeks | Sett 10 weeks | 14 weeks | 6 weeks | Shoot 10 weeks | 14 weeks |
|----------|---------|------------------|----------|---------|-------------------|----------|
| | N55/805 | 0,7 | 1,9 | 1,2 | 0,6 | 1,1 |
| NCo 310 | 1,1 | 1,2 | 0,8 | 1,1 | 1,1 | 1,3 |
| NCo 376 | 1,2 | 1,1 | 0,9 | 0,6 | 1,0 | 1,1 |
| CB 36/14 | 1,0 | 1,2 | 1,2 | 0,7 | 1,3 | 1,3 |
| N8 | 0,9 | 1,4 | 1,3 | 0,7 | 1,4 | 1,3 |
| NCo 382 | 0,8 | 1,3 | 1,0 | 0,4 | 1,2 | 1,6 |
| N50/211 | 1,0 | 1,3 | 1,0 | 1,1 | 1,5 | 1,4 |
| NCo 339 | 1,3 | 1,3 | 1,1 | 0,5 | 1,5 | 1,3 |
| NCo 334 | 0,9 | 1,5 | 1,5 | 0,9 | 1,3 | 1,4 |
| N6 | 0,6 | 0,9 | 1,0 | NR* | 1,1 | 1,8 |
| Co 331 | 1,3 | 1,4 | 1,2 | 0,9 | 1,9 | 1,1 |
| NCo 293 | 0,8 | 1,1 | 1,3 | 0,7 | 1,4 | 1,3 |
| Mean | 1,0 | 1,3 | 1,1 | 0,7 | 1,3 | 1,3 |

* NR = not recorded

TABLE 5
Number of new roots formed per plant eight weeks after original excision

| Variety | First batch of roots cut at: | | | | | |
|----------|------------------------------|----------|----------|---------|----------|----------|
| | Sett | | | Shoot | | |
| | 6 weeks | 10 weeks | 14 weeks | 6 weeks | 10 weeks | 14 weeks |
| N55/805 | 0 | 0 | 0 | 18,5 | 27,7 | 23,6 |
| NCo 310 | 0 | 0 | 0 | 17,4 | 24,2 | 28,2 |
| NCo 376 | 0 | 0 | 0 | 22,3 | 30,6 | 27,2 |
| CB 36/14 | 0,1 | 0 | 0 | 21,1 | 25,6 | 24,0 |
| N8 | 5,2 | 2,4 | 1,1 | 18,9 | 25,5 | 24,3 |
| NCo 382 | 0 | 0,1 | 0 | 16,9 | 21,0 | 20,6 |
| N50/211 | 0,5 | 0,1 | 0 | 21,4 | 23,1 | 25,9 |
| NCo 339 | 0 | 0 | 0 | 14,8 | 22,2 | 23,5 |
| NCo 334 | 0 | 0 | 0 | 15,6 | 20,1 | 23,1 |
| N6 | 0,2 | 0 | 0 | 11,5 | 23,4 | 23,7 |
| Co 331 | 0 | 0 | 0 | 15,2 | 19,1 | 19,9 |
| NCo 293 | 0 | 0 | 0 | 18,3 | 23,9 | 22,4 |
| Mean | 0,5 | 0,2 | 0,1 | 17,6 | 23,9 | 23,9 |

removed at 6 weeks possessed about as many new shoot roots 8 weeks later as undisturbed plants of the same age (compare Tables 2 and 5). For all the varieties the average mortality of plants following complete root excision was less than 5 percent.

Discussion

The data obtained from this preliminary study are, not unexpectedly, rather elementary. However, they have shown that large differences do exist between varieties in the number and mass of sett and shoot roots, root hair abundance and, if the estimates can be relied on, root length.

In spite of the fact that setts of all the varieties originated from cane growing in the same small plot the variation in both root number and root mass within varieties was large. However, differences in stalk diameter and position on the stalk from which the sett is taken in relation to the apical meristem are known to affect root development. Since these were not standardised the large coefficients of variation are not unexpected.

Results of field trials with a nematicide on sandy soils have indicated that N8 is, in some way, less susceptible to nematodes than NCo382, which in turn is less susceptible than N55/805 and NCo376 (Anon¹). All four of these varieties are probably less susceptible than NCo339 (unpublished data). At any one time the number, mass and estimated length of sett and shoot roots of N8 were generally no

greater than those of NCo382, N55/805, NCo376 or NCo339 (see Tables 1 and 2 and Figures 1 and 2). It appears, therefore, that the better growth of N8 in nematode infested soil is not simply a result of inherently more rapid root development. Possibly this variety is resistant to, or tolerant of the damage caused by, one or more of the pathogenic species of root-feeding nematodes occurring in sandy soils.

N8 was the only variety in which a noteworthy proportion of the sett root primordia did not germinate until after the first 6 weeks of growth (see Tables 1 and 5). Dillewijn³ suggested that delayed development of sett roots would be of considerable importance in regions where cane was exposed to root injury by insects, bacteria, fungi and cultivating implements. This may be true for damage from implements and, presumably, also from a short period of moisture stress, but not for damage from soil organisms. As many if not more of the organisms that caused the original root damage would probably still be in the root zone and likely to cause further damage when the new sett roots germinated.

Each of the twelve varieties was able to compensate for the loss of all its roots by developing about as many new shoot roots as undisturbed plants of the same age; but since shoot measurements were not taken the effect of such extreme root damage on top growth is not known.

Glover⁴ found that sett root growth of NCo376 and N50/211 ceased 11 days after planting and at 8 weeks no sett roots were found. In the present study sett roots were still present 14 weeks after planting. Normally the importance of sett roots to the cane plant declines after 2 to 3 months as they are replaced by the shoot roots (see Dillewijn³). There appears to be some variation in the rate at which this transition takes place. For example in most of the varieties there was a much greater mass and length of sett roots than shoot roots at six weeks while the reverse was true at 14 weeks (see Figures 1 and 2). However, in two of the varieties, NCo382 and N6, sett roots still formed about 50% or more of the total root mass at 14 weeks and over 75% of the total root length. Presumably in NCo382 and N6 the sett roots continue to play an important rôle for a longer period than in the other varieties.

The primary function of sugarcane roots is the absorption of water and nutrients from the soil. This takes place via the surface of the root hairs and, to a lesser extent, the surface of young non-suberized roots. Evans² found that in 12 to 14 month old cane the surface area of the roots and root hairs available for absorption of moisture and nutrients bore no relationship to root length or mass. However, he did suggest that in very young root systems root length would be related to its absorbing capacity. Circumstantial evidence indicates that this may be true for at least some of the twelve varieties studied; some varieties which are adapted to conditions where moisture stress is often a limiting factor have a more extensive root system than others that require a more favourable soil environment. For example, N55/805, N8, NCo382, N6 and Co331 are all hardy varieties that generally perform better than others on poor, shallow or sandy soils in rainfed areas in South Africa. These same varieties had each produced a relatively extensive root system within 14 weeks (Figure 2). In contrast CB36/14 and NCo334, which only grow well under good soil moisture conditions, both produced a relatively limited root system in this study.

However, the supposition that the surface area available for absorption is related to root length and that root length in some varieties is indicative of the habitat in which the plant grows well is confounded when the indices of root hair abundance are considered. Assuming that the abundance of

root hairs is related to their total surface area, it might be expected that varieties which are adapted to soils where moisture deficiency may occur would have a greater index of root hair abundance. It might also be expected that the product of the index of root hair abundance and root length would be greater in varieties that are adapted to an unfavourable habitat. However, the expected differences do not necessarily occur (Table 3). The product of index of root hair abundance and total root length for each of the varieties at 14 weeks is, in descending order: N6 (895); N55/805 (452); NCo334 (316); NCo339 (314); N8 (282); Co331 (271); NCo376, (268); N50/211 (263); NCo382 (198); NCo310 (151); CB36/14 (94); NCo293 (52). While the product values for N6, N55/805 and CB36/14 are as might be expected, that of NCo334 is much higher and those of NCo382 and Co331 much lower than expected.

Variety NCo376 presently accounts for approximately 65% of the cane crushed in South Africa (Lamuse⁹) and is grown successfully in a range of environments in Southern Africa. It is probably the most adaptable of the varieties grown in this region. It is perhaps surprising therefore that NCo376 was not outstanding in any of the features studied in this investigation (see Tables 1-5 and Figures 1 and 2).

Humbert⁸ reported that cane subjected to short periods of drought had a much more extensive root system than cane from an irrigated soil where no such stress occurred. In the present study the plants were watered twice daily and it is unlikely that any moisture stress was experienced. Perhaps greater differences in root development would have occurred between varieties if the plants had been grown under conditions of intermittent moisture stress. Such conditions would have been more representative of the poor coastal sands where nematode damage is most likely.

It must be emphasized that the data obtained in this study are of a preliminary nature. Further work is obviously needed, for example, to confirm the differences in root length and to determine whether the differences between the rooting habit of varieties change during the later development of the root system, as was found for some Mauritian varieties by Evans². Root development of both plant and ratoon cane under different soil moisture conditions also requires investigation.

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REFERENCES

1. Anon. (1979). Sugarcane diseases. Questions and answers. *S. Afr. Sug. J.* **63**, (3), 91-95.
2. Evans, H. (1938). Studies on the absorbing surface of sugarcane root systems. 1. Method of study with some preliminary results. *Ann. Bot. NS* **2**: 159-182.
3. Dillewijn, C. van, (1952). Botany of sugarcane. Chronica Botanica Co., Waltham, Mass. 371 pp.
4. Glover, J. (1967). The simultaneous growth of sugarcane roots and tops in relation to soil and climate. *SASTA Proc* **41**: 143-159.
5. Glover, J. (1968). Further results from the Mount Edgecombe root laboratory. *SASTA Proc* **42**: 123-132.
6. Glover, J. (1968). The behaviour of the root system of sugarcane at and after harvest. *SASTA Proc* **42**: 133-135.
7. Glover, J. (1970). Soil sterilization and the growth of tops and roots at the Mount Edgecombe root laboratory. *SASTA Proc* **44**: 162-168.
8. Humbert, R. P. (1968). The growing of sugarcane. Elsevier, Amsterdam, 779 pp.
9. Lamuse, J. P. (1979). Fifty-fourth annual review of the milling season in Southern Africa (1978-1979). *SASTA Proc* **53**: 21-44.
10. Wood, G. H. and Wood, R. A. (1967). The estimation of cane root development and distribution using radiophosphorus. *SASTA Proc* **41**: 160-168.