CONSUMPTIVE USE OF WATER BY A PLANT CROP OF SUGARCANE OF VARIETY N14

By G. D. THOMPSON

South African Sugar Association Experiment Station, Private Bag X02, Mount Edgecombe 4300

Abstract

Consumptive use of water by a plant crop of variety N14 was measured daily by means of three weighing lysimeters located in a field of irrigated sugarcane at Pongola from 12 November 1986 to 12 October 1987. The amount of evapotranspiration (E_t) was similar to that measured for a plant crop of variety NCo376 from 12 November 1967 to 8 October 1968. The mean ratio of E_t to Class A pan evaporation (E_o) was 0,78, compared with 0,82 for NCo376. Variety N14 produced 4,2 tons of above-ground dry matter per hectare per 100 mm E_t, which was not significantly different from 4,1 t produced by NCo376. Estimates of the gross amount of assimilate produced by N14, including dry matter content of roots and respiration, indicated that production per unit of E_t did not vary appreciably in successive periods after full canopy had been formed. The analyses of leachate from the lysimeters showed that losses amounted to 27 kg nitrogen (N), 0,084 kg phosphorus (P), 2,4 kg potassium (K), 125 kg calcium (Ca), and 59 kg magnesium (Mg) per hectare.

Introduction

Consumptive use of water by sugarcane crops has been measured in a number of countries during the past several decades. The literature has been reviewed (Thompson[5]) and it appears that the relation of evapotranspiration (E_t) to open Class A pan evaporation (E_o) is similar for different varieties growing under different climatic conditions. It might therefore be assumed that differences in the water requirements between varieties are likely to be small and precise measurements would be required to identify them.

Three weighing lysimeters were installed in a field on the Experiment Station farm at Pongola in 1967 (Thompson and Boyce[9]). Each had a surface area of 3,71 m^2 and water losses could be measured to the nearest 0,1 mm. These lysimeters have remained intact since 1967. Sugarcane variety NCo376 was planted in the lysimeters and the surrounding field in 1967 and 5 successive crops were harvested at approximately yearly intervals (Thompson[6]).

Variety N14 has succeeded NCo376 as the preponderant variety in the northern irrigated areas of the South African sugar industry. Since the facility was available, it was decided to measure the consumptive use of water by N14 to compare it with that previously measured for variety NCo376. Although different varieties could have been planted in each of the 3 lysimeters, it was decided to plant only N14 so that replicated results could be obtained.

Method

The experiment was planted on 12 November 1986 to coincide exactly with the time of planting of the NCo376 crop in 1967. Setts of variety N14, approximately 300 mm long, were planted in furrows 1,52 m apart. One row passed along the centre of the lysimeters which were 1,52 m wide and 2,44 m long (Figure 1). The layout of the field and the positions of the lysimeters were as previously described for the NCo376 crop (Thompson and Boyce;[9] Thompson[6]). The crop was fertilized with 53 kg nitrogen (N), 18 kg phosphorus (P), and 88 kg potassium (K) ha^{-1} in the furrow. A topdressing of 32 kg N and 64 kg K ha^{-1} was applied to the field on 19 December 1986, but because the growth in the lysimeters appeared to be slightly better than that in the surrounds, a similar topdressing to the cane in the lysimeters was delayed until 18 March 1987.

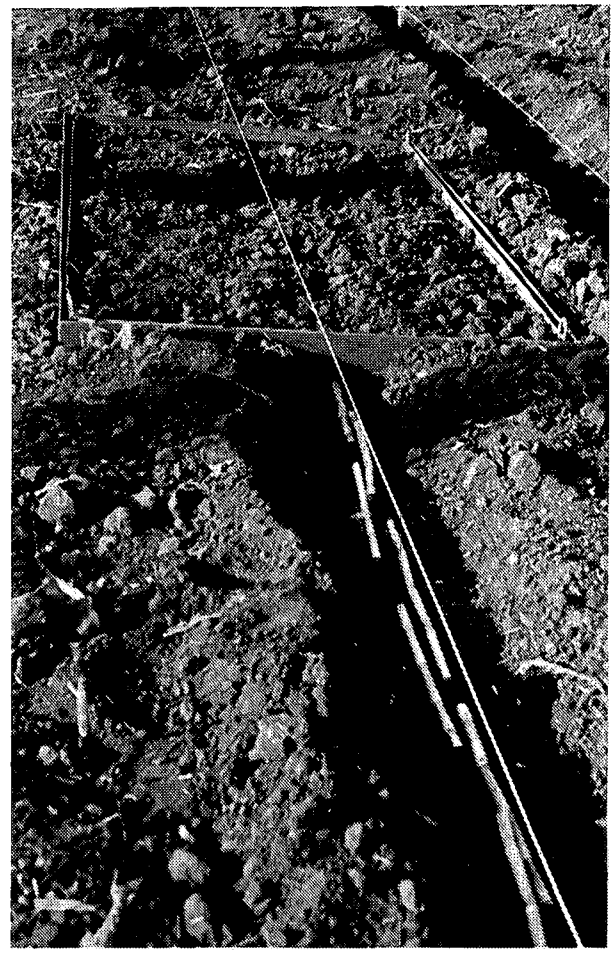

FIGURE 1 A weighed lysimeter showing direction of cane row along the centre line of the container.

On 9 April 1987 some of the cane in the lysimeter field lodged when heavy winds blew during the night. None of the cane in the lysimeters lodged, but it was necessary to lift some of the cane surrounding the lysimeters and to hold it erect by means of wire strands attached to metal standards. This procedure also had to be followed when the plant crop of NCo376 lodged in August 1968.

The construction of the lysimeters has also been described previously (Thompson and Boyce[9]). In their original design, provision was made to remove leachate from the false bottom by means of a hand-operated pump and a suction tube which was lowered through a pipe in the corner of each

lysimeter. This necessitated frequent activity near the lysimeter which must have interfered with crop growth and have caused soil compaction in the immediate vicinity of the lysimeters. Since access to the bottom of the lysimeters was achieved relatively easily through underground tunnels, it was decided to remove leachate by draining it through a nipple with an attached valve. Provision was also made to apply suction to the bottom of the lysimeters to accelerate the removal of water from the soil profile in order to inhibit waterlogging of the crop if this appeared to be likely.

The mass of leachate removed was determined by weighing the lysimeters immediately before and after each removal. A sample of the leachate was taken on each occasion and analysed for N, P, K, calcium (Ca), and magnesium (Mg) contents.

E_t was determined daily by recording the mass of each lysimeter to the nearest 0,45 kg at 08h00. Rainfall was measured daily at 08h00 in a raingauge located next to the field. Amounts of irrigation water applied were estimated by recording the mass of each lysimeter at 18h00 and at 06h00 on the following day on the occasions when irrigation was practised. Irrigation was always carried out for approximately 12-hour periods at night when the error due to unmeasured E_t while irrigation was in progress was likely to be small. Irrigation water was applied on 20 occasions to the plant crop.

Daily E_t from 08h00 on day 1 to 08h00 on day 2 was calculated by taking measurements of rainfall, irrigation and leachate into account, together with the change in mass of each lysimeter over the 24-hour period.

The numbers of shoots and stalks in each lysimeter were recorded on 11 occasions and at the time of harvest on 12 October 1987. The percentage of vertical ground-cover was estimated by taking 10 readings on 7 occasions with the device described by Cackett[2]. This was done at random over the 0,4 ha which comprised the lysimeter field, and not over the lysimeters themselves.

The crop was 334 days old when it was harvested. The cane in each lysimeter and from four 2,44 m lengths of row located at random in the lysimeter field was harvested separately. The dead leaves and shoots (trash) were removed first from the standing cane and sealed in polythene bags which had previously been weighed. The standing crop was then cut carefully at ground-level and delivered immediately to the millroom. After weighing, the foliage was separated from the stalks and the two components weighed again separately.

The stalks from the lysimeters were broken at the natural breaking point and the bottom sections (cane stalks) and top sections (apexes) were weighed and analysed separately. The whole stalks of the crops from the 4 extra plots were analysed as single samples. After disintegration of the stalk material sub-samples were taken for the determination of dry matter, brix, sucrose, and fibre content. The foliage was chopped in a chaff cutter and a sub-sample taken for the determination of dry matter content. In some instances the foliage included a few mainly senescent flowers. The total amount of trash from each plot (2,44 m of cane row) was weighed before oven-drying to determine the dry matter content. The total amount of dry matter produced in each lysimeter and in each of 4 sub-plots could then be calculated. Estimates of the total amounts of dry matter production, or gross assimilation, including allowances for roots and respiration, were also determined (Thompson[7]).

On the meteorological site near the lysimeter experiment, sunshine hours, maximum and minimum temperatures, and run of wind were recorded daily, as were wet and dry bulb temperatures at 08h00 and 14h00 daily. From these data and some crop parameters measured previously at Pongola with reference to NCo376 (Thompson[6]), estimates of daily E_t from a fully canopied crop could be calculated using the following equations:

$$E_t(\text{Penman}^4) = \frac{\Delta R_n + \gamma(e_a - e_d)0{,}26\left(1 + \frac{u}{160}\right)}{\Delta + \gamma} \quad (1)$$

$$E_t(\text{Monteith}^3) = \frac{\Delta R_n + \gamma(e_a - e_d)B_v}{\Delta + \gamma(1 + r_s/r_a)} \quad (2)$$

where Δ = slope of the saturated vapour pressure curve at air temperature
R_n = net radiation
γ = psychrometric constant
e_a = saturated vapour pressure of air at dry bulb temperature
e_d = vapour pressure of air at dry bulb temperature
u = run of wind
B_v = wind function (Businger[1])
r_s = surface resistance (0,75 sec cm^{-1})
r_a = aerodynamic resistance (1/0,01437u)

Results and discussion

Crop characteristics

Vertical ground-cover by the crop of variety N14 developed as shown in Figure 2 from the time of planting until the end of February 1987. The crop was considered to be fully canopied from 1 February onwards. The figure includes the data obtained for NCo376 in 1967–68 and it can be seen that N14 formed a canopy more slowly than did NCo376. The differences in the behaviour of the young crops may have been due in part to the fact that excellent germination was obtained from single-budded setts of NCo376 which were planted carefully at a spacing of 150 mm between the buds, whereas standard, many-budded setts of N14 were used and germination was not particularly good, although no replanting was necessary in the lysimeters themselves.

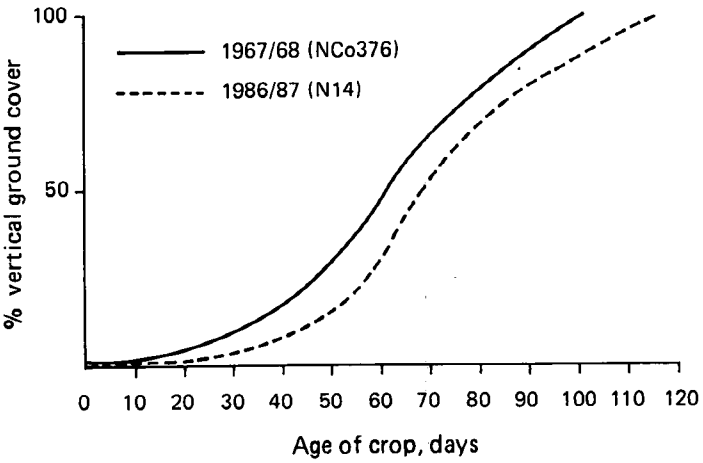

FIGURE 2 Development of vertical ground-cover of plant crops of two varieties planted on 12 November in different years on the same site at Pongola.

Variety NCo376 has a characteristically higher population of shoots and stalks than N14. This is confirmed by the data in Table 1, which show that there were more shoots and stalks of NCo376 at all stages of the plant crops, and 50% more at the time of harvest.

Table 1

Mean number of shoots or stalks per lysimeter for two varieties from January to October in different years

Month	Shoots or stalks per lysimeter	
	NCo376 (1968)	N14 (1987)
Jan	114	95
Feb	137	85
Mar	90	56
Apr	68	44
May	69	44
Jun	65	44
Jul	66	44
Aug	66	44
Sep	64	44
Oct	64	44

Measured E_t

Figure 3 illustrates the comparative cumulative amounts of E_t and E_o for NCo376 in 1967–68 and for N14 in 1986–87. Until mid-August there was no appreciable difference between the two values, but in September and October of 1987 the E_o was much lower than it was in 1968, and this was reflected in reduced E_t for N14 in these months. The crop of NCo376 was harvested when it was 332 days old and the N14 crop when it was 334 days old. Taking this difference into account, E_o in 1967–68 exceeded E_o in 1986–87 by 43 mm, and E_t was 92 mm greater.

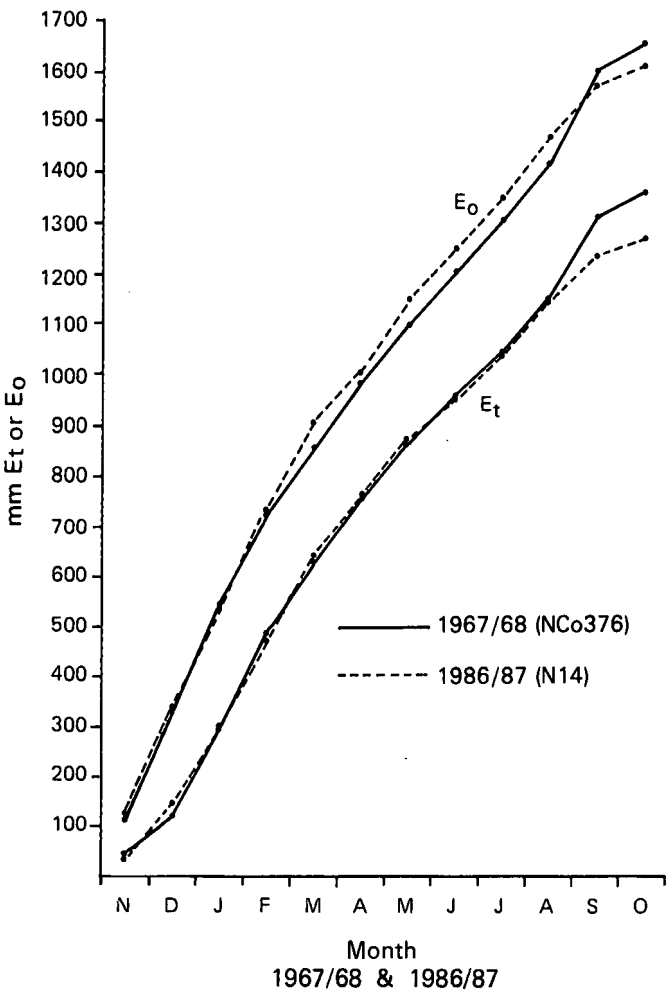

FIGURE 3 Cumulative amounts of E_t for plant crops of NCo376 and N14, and the associated amounts of Class A pan E_o.

The mean E_t/E_o ratio for NCo376 in 1967–68 was 0,82, while that for N14 in 1986–87 was 0,78. Figure 4 shows how similar the mean monthly values of the ratio were for the two crops until September and October.

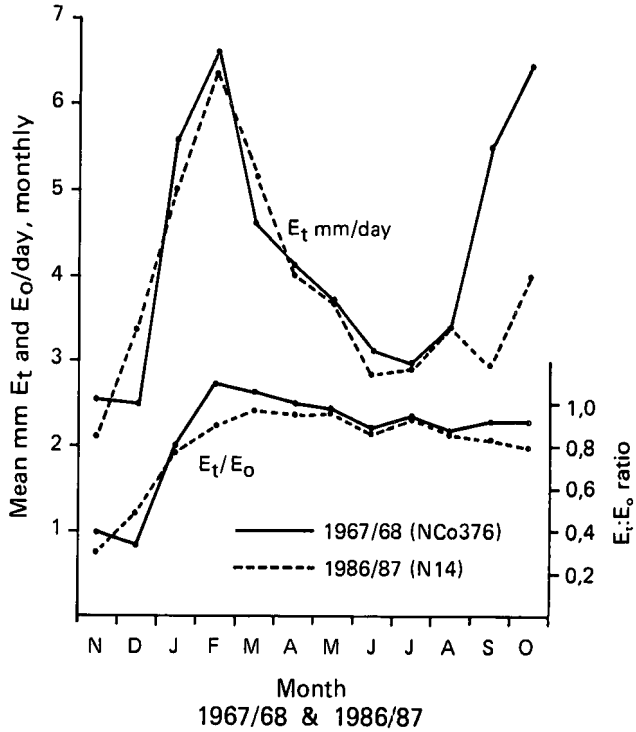

FIGURE 4 Mean monthly values of E_t d^{-1} for plant crops of NCo376 and N14 and the associated E_t : E_o ratios.

Mean monthly E_t d^{-1} reached a maximum for both varieties in February. The rates were 6,6 and 6,4 mm d^{-1} for the two varieties respectively.

During the period from 1 February to 31 August in the two seasons, when both the crops were considered to be fully canopied and the climatic conditions (E_o) were similar, the comparative data were:

Variety	Year of trial	No of days	E_t (mm)	E_o (mm)	E_t/E_o
NCo376	1968	213	860	878	1,02
N14	1987	212	852	932	0,91

Estimated E_t

For the 254 days from 1 February to 11 October inclusive, E_t was calculated for the N14 plant crop using equations (1) and (2). Figure 5 shows the relationships established between measured E_t and estimated E_t, and between measured E_t and measured E_o. The equations are:

$E_t = 1,08 + 0,83\ E_t$ (Penman[4]) $\quad r = 0,75$

$E_t = 0,96 + 0,80\ E_t$ (Monteith[3]) $\quad r = 0,73$

$E_t = 1,18 + 0,63\ E_o$ (Class A pan) $\quad r = 0,73$

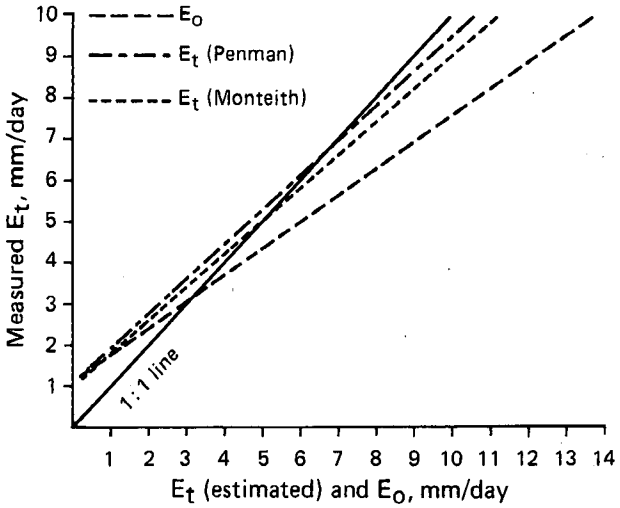

FIGURE 5 Relationships between E_t (measured) and E_t estimated from Penman and Monteith equations and E_o for a plant crop of N14 (1986-87).

The comparable data obtained using results for 251 days of the plant crop of NCo376 in 1968 are shown in Figure 6. The equations are:

$E_t = 0,25 + 1,20\ E_t$ (Penman[4]) $\quad r = 0,86$

$E_t = 0,36 + 1,00\ E_t$ (Monteith[3]) $\quad r = 0,84$

$E_t = 0,87 + 0,77\ E_o$ (Class A pan) $\quad r = 0,85$

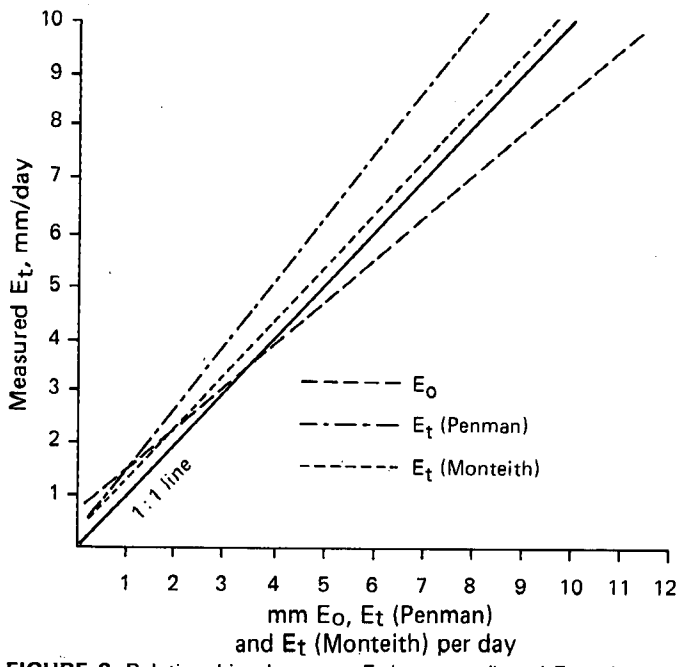

FIGURE 6 Relationships between E_t (measured) and E_t estimated from Penman and Monteith equations and E_o for a plant crop of NCo376 (1967-68).

Unlikely daily results were sometimes observed during the plant crop of N14. Weekly means were calculated for the 37 weeks of the fully canopied crop, and when the results for 3 outlying sets of data were omitted, the following relationships were calculated (n = 34):

E_t(measured), Lysimeter 1 $= 0,85 + 0,70\ E_o$(Class A pan) $r = 0,83$

E_t(measured), Lysimeter 2 $= 0,00 + 0,85\ E_o$(Class A pan) $r = 0,94$

E_t(measured), Lysimeter 3 $= 0,82 + 0,74\ E_o$(Class A pan) $r = 0,89$

E_t(measured), mean $= 0,55 + 0,77\ E_o$(Class A pan) $r = 0,92$

When the Monteith[3] equation was used to estimate E_t for the plant crop of N14, the crop parameters determined in 1968 for NCo376 were used (Thompson[6]). These were:

z_o (roughness length) = 5,7 cm
z-D (height of wind measurement above zero plane displacement) = 225 cm
r_s (surface resistance) = 0,75 sec cm^{-1}

It is possible that different values would be applicable to a variety such as N14 which has a significantly lower population of stalks than NCo376.

In general, the observation that the Monteith[3] estimate of E_t most closely approximates measured values over a wide range of conditions is confirmed. The ease with which E_o can be measured nevertheless makes the Class A pan the most convenient means of exercising good irrigation control in the field.

Yield data

The yield of NCo376 from the lysimeters in October 1968 was 166 tc ha^{-1}, which represented 12,1 tc ha^{-1} 100 mm E_t^{-1}. In 1987, the comparable figures for N14 were 124 tc ha^{-1} and 9,7 tc ha^{-1} 100 mm E_t^{-1}. This apparently poorer performance of N14 was at least partly due to the fact that only 62% of the total dry matter produced above-ground by N14 was in the stalks, whereas in NCo376 the proportion was 69%. Taking into account the dry matter in stalks, foliage and trash, N14 produced 4,2 t dm ha^{-1} 100 mm E_t^{-1}, compared with 4,1 t dm ha^{-1} 100 mm E_t^{-1} for NCo376. This is shown in Table 2 where it can be seen that the above-ground crop of NCo376 contained 26,2% dry matter, whereas the N14 contained 29,4% dry matter. This occurred despite the fact that the fresh trash from NCo376 contained only 29,1% moisture, compared with 45,6% moisture in the trash from N14 due to rain having fallen prior to and at times during the harvesting process. When the NCo376 was harvested in 1968, the apex of the stalks was included with the foliage, hence the data for the two varieties in Table 2 are not strictly comparable. However, the apexes of the stalks from the lysimeters comprised only 2% of the total stalk mass.

The mean yield of stalks from the 4 extra plots was 146 t ha^{-1}, compared with 127 t ha^{-1} from the lysimeters. Total

Table 2

Composition of above-ground components of crops of NCo376 and N14 at approximately 11 months of age

Component	NCo376				N14				
					Lysimeters				4 extra plots
	Wet (t ha^{-1})	Dm (%)	Dry (t ha^{-1})	Total dm (%)	Wet (t ha^{-1})	Dm (%)	Dry (t ha^{-1})	Total dm (%)	Dry (t ha^{-1})
Foliage	41	26,2	10,8	19	38	25,1	9,5	18	9,5
Stalks	166	23,6	39,2	69	127	26,7	34,0	62	36,1
Trash	10	70,9	6,8	12	20	54,4	10,9	20	7,1
Total	217	26,2	56,8	100	185	29,4	54,4	100	52,7

above-ground dry matter production in the extra plots is given in the final column of Table 2. The data show that the yields of dry matter from the lysimeters and the extra plots were fairly comparable. The tendency for the proportion of trash harvested from the lysimeters to be higher than that from other plots may have occurred partly because it was difficult to discriminate between dead leaves which had fallen from the cane in the lysimeters and that from adjacent cane rows. If the mean yield of dry matter from the extra plots is used instead of that from the lysimeters, the water use efficiency becomes 4,1 t dm ha^{-1} 100 mm E_t^{-1}, the same as that observed for NCo376 in 1968.

Some separate plots in the lysimeter block were harvested at intervals during the development of the plant crop of N14 (Thompson[7]). The results of this work were used to estimate the amounts of above-ground dry matter produced on the lysimeters during the successive periods. Table 3 shows that water use efficiency appeared to improve progressively until the final period from 21 July until 11 October, when dry matter production or net assimilation declined significantly. Gross assimilation, which included estimates of dry matter in roots and respiration losses during each period, was also calculated. The final column in Table 3 indicates that t gross assimilate ha^{-1} 100 mm E_t^{-1} changed little after a full canopy of leaves had formed.

It is of interest to note that almost one-third of the amount of N applied in the furrow and as a topdressing appeared in the leachate. In contrast, only 84 g, or less than 1% of the amount of P placed in the furrow, and only 1,6% of the K applied in the furrow and as a topdressing was leached. It should be noted that the Makatini sandy clay soil series on the Pongola farm has a P-desorption index (PDI) which varies between 0,5 and 0,7. P-fixation was therefore not a significant contributor to the small amount of P leached in the lysimeters. Ca and Mg comprised by far the greatest amounts of major elements contained in the leachate. Reference to Figure 7 shows that, while nutrient losses were generally proportional to the amount of leachate during successive 50-day periods, N losses were significantly higher during the initial stages of the crop growth than during later phases. Ca and Mg losses, on the other hand, tended to be much greater towards the end of the crop's growth than at the beginning.

Of the average of 26,8 kg N ha^{-1} in the leachate, 40% comprised NH_4-N and 60% NO_3-N.

Table 3

Estimated water use efficiency in terms of t dm ha^{-1} 100 mm E_t^{-1} for successive periods during the growth of a plant crop of N14

Period		No of days	Total E_t (mm)	Estimated (t dm ha^{-1})	Above-ground dm production (t ha^{-1} 100 mm E_t^{-1})	Gross assimilation (t ha^{-1} 100 mm E_t^{-1})
From	To					
12.11.86	20.01.87	70	238	1,5	0,62	1,00
21.01.87	16.03.87	55	328	15,7	4,77	7,02
17.03.87	18.05.87	63	271	14,0	5,17	9,31
19.05.87	20.07.87	63	181	12,1	6,66	10,33
21.07.87	11.10.87	83	261	11,1	4,27	9,43
12.11.86	11.10.87	334	1 280	54,4	4,25	7,34

Leachate

The amounts of leachate and the amounts of nutrients in the leachate from each lysimeter are given in Table 4. Since the soil profile in the lysimeters was only 1 m deep, it is likely that the crop growing in the surrounding field was able to take up some of the apparent nutrient losses at depths greater than 1 m. Thompson and Boyce[8] used gypsum blocks to show that the crop removed water from depths in excess of 2 m on an adjacent site. Thus the results given in Table 4 possibly represent an overestimate of nutrient losses due to leaching in the field on the site of the experiment.

Table 4

Amounts of leachate and the amounts of nutrients in the leachate from each lysimeter during the plant crop of the lysimeter experiment

Lysimeter no	Leachate (mm)	N (kg ha^{-1})	P (g ha^{-1})	K (kg ha^{-1})	Ca (kg ha^{-1})	Mg (kg ha^{-1})
1	453	34,1	79	1,59	80,7	40,2
2	598	20,3	86	2,52	128,9	79,8
3	566	25,9	88	3,15	166,3	59,0
Mean	539	26,8	84	2,42	125,3	59,7

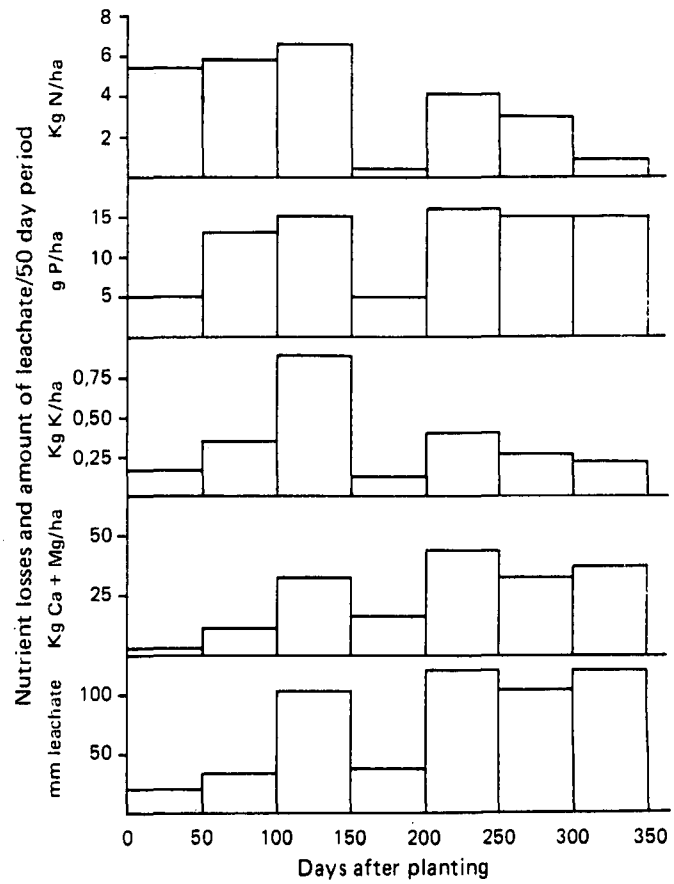

FIGURE 7 Average amounts of nutrients in leachate, and amounts of leachate in successive 50-day periods during plant crop of lysimeter experiment (1986-87).

Conclusions

It seems unlikely that differences between commercial varieties of sugarcane in terms of consumptive use of water can be identified in the field with the type of lysimetry used in this experiment. Measured E_t for a plant crop of N14 varied from lysimeter 2 to lysimeter 3 by 5,5%. The $E_t : E_o$ ratios for comparable plant crops of NCo376 and N14 differed by 5,1%.

Flowering of the plant crop may have affected the consumptive use of water by N14 when compared with NCo376, which did not flower. Its performance in successive ratoon crops will be studied before any suggestion can be made that the estimation of E_t from E_o for commercial irrigation control should be based on a ratio of E_t to E_o less than 1,0.

The Penman[4] equation, and more particularly the Monteith[3] equation, can be used to obtain good estimates of actual E_t, but the Class A pan remains the more practical and convenient basis for exercising irrigation control. The analysis of leachate from the lysimeters indicates that a soil series such as the Makatini sandy clay is likely to lose significant amounts of N through leaching, but applied amounts of P and K are apparently retained strongly in the surface to a depth of 1 m of the profile and should be available to the crop.

Acknowledgements

Mr K Soobramoney managed the experiment very capably and processed the raw data. Messrs G Ghumo, S Nxumalo, and Z Mngomezulu recorded data daily at Pongola. The Chemistry and Soils department analysed the samples of leachate.

REFERENCES

1. Businger, JA (1956). Some remarks on Penman's equation for the evapotranspiration. *Neth J agric Sci* 4: 77–80.
2. Cackett, KE (1964). A simple device for measuring canopy cover. *Rhod J agr Res* 2: 56.
3. Monteith, JL (1965). *Evaporation and environment. In* 'The state and movement of water in living organisms'. Edited by GE Fogg. Academic Press. New York, pp 205–234.
4. Penman, HL (1948). Natural evaporation from open water, bare soil and grass. *Proc R Soc* (A) 193: 120–145.
5. Thompson, GD (1976). Water use by sugarcane. *S Afr Sug J* 60 (11): 593–600.
6. Thompson, GD (1986). Agrometerological and crop measurements in a field of irrigated sugarcane. *MERR* 5.
7. Thompson, GD (1988). Comparisons of the growth of plant and first ratoon crops of sugarcane at Pongola. *Proc S Afr Sug Technol Ass* 62 (in press).
8. Thompson, GD and Boyce, JP (1968). The plant crop results of two irrigation experiments at Pongola. *Proc S Afr Sug Technol Ass* 42: 143–152.
9. Thompson, GD and Boyce, JP (1971). Comparison of measured evapotranspiration of sugarcane from large and small lysimeters. *Proc S Afr Sug Technol Ass* 45: 169–176.