ASSESSING NITROGEN FERTIGATION STRATEGIES FOR DRIP IRRIGATED SUGARCANE IN SOUTHERN AFRICA

D W F Butler[1], J H Meyer[2] and A W Schumann[3]

[1]Swaziland Sugar Association, PO Box 367, Simunye, Swaziland
[2]SASA Experiment Station, Private Bag X02, Mount Edgecombe, 4300
[3] University of Florida,700 Experiment Station Rd,Lake Alfred,FL.,33850
E-mail: butler@ssa.co.sz

Abstract

Standard nutritional advice for irrigated sugarcane in South Africa and Swaziland is based on soil sample analysis and threshold values that have been determined experimentally over many years with surface-applied fertilisers. Fertilisers are normally applied in solid form during the early stages of crop development and watered in by the next irrigation cycle. The increasing popularity of subsurface drip irrigation in the Southern African sugar industries raises opportunities for improved fertiliser management. However, without appropriate recommendations there could be a tendency towards leaching and denitrification associated with poor timing and excessive application of fertilisers by fertigation.

While little active research has been carried out on the fertigation requirements of sugar cane in Southern Africa, the results of studies of nutrient uptake patterns in irrigated sugarcane have been used to formulate monthly fertigation programmes that account for seasonal variation in nutrient demand within a single crop cycle ("growth curve nutrition"). This paper reports the initial results of two experiments established in Swaziland to test the benefits of using such an approach against more conventional principles of fertiliser application, with specific reference to nitrogen. Cumulative nitrogen uptake curves were tested for a summer cycle plant crop and for a winter cycle first ratoon crop. Results indicated that the winter nitrogen uptake curve correctly predicted the proportional monthly nitrogen demand of a winter ratoon crop but did not account for the effect of late nitrogen application on cane quality. The summer nitrogen uptake curve appeared to underestimate the nitrogen demand of a summer plant crop between January and April. Splitting nitrogen applications evenly over the first four months of crop development led to more efficient and productive use of nitrogen than the growth curve nutrition approach.

Keywords: Nutrition, nitrogen, fertigation, drip irrigation

Introduction

There are approximately 5,500 ha of subsurface drip irrigation (SDI) in the Swaziland sugar industry, comprising 11 % of the industry area (Magwenzi, 2001). Most of this development has taken place since 1998 and it is anticipated that a further 3,500 ha of SDI will be installed over the next four years. Similarly growers in the South African sugar industry have recognised the need for improved water use efficiency and the area under drip has expanded to well over 7,000 ha with approximately 30 % of the area under SDI.

The advantages of SDI in principle have been well documented (Hutmacher *et. al.*, 1993; Haynes, 1985). The main benefit is considered to be more accurate, frequent and uniform water application than can usually be achieved with conventional irrigation systems. This facilitates accurate and flexible fertigation of soluble fertilisers through the irrigation system according to the requirements of the crop. Water and nutrients are applied directly to the root zone, leading to greater efficiencies of application and uptake. This has been substantiated for sugarcane in studies carried out in Mauritius (Ng Kee Kwong *et. al.*, 1999) and Australia (Dart *et. al.*, 2000; Ridge and Hewson, 1995), where results indicated increases in nitrogen (N) fertiliser use efficiency of up to 30 %.

Standard nutritional advice for irrigated sugarcane in South Africa and Swaziland is based primarily on soil sample analysis and threshold values that have been determined experimentally over many years with surface-applied fertilisers. Fertilisers are normally applied in dry solid form during the early stages of crop development and watered in by the next irrigation cycle. The increasing popularity of SDI in the Southern African sugar industries undoubtedly raises opportunities for improved fertiliser management. However, without appropriate recommendations there is the potential for nutrient wastage, particularly through leaching and denitrification (Thorburn *et. al.*, 1998; Dart *et. al.*, 2000), associated with poor timing and excessive application of fertilisers by fertigation.

There are few sources of information on which to base practical guidelines for the fertigation of sugarcane (Thorburn *et. al.*, 1998). Issues that remain unexplored include optimal timing of fertiliser application to exploit the degree of control that the SDI system affords. Untimely N fertiliser application in sugarcane reduces its efficiency and compounds N losses to the environment (Ng Kee Kwong and Deville, 1987). Timing fertigation to coincide with periods of demand from the crop (growth curve nutrition) is a common method of maximising fertiliser efficiency in many high value crops with complex phenology and nutrient requirements, but there have been no formal field studies to assess the merits of this concept in sugarcane. This paper reports on the initial results of an experiment programme to test the benefits of the growth curve nutrition concept in order to produce preliminary guidelines for the fertigation of sugarcane in Southern Africa, with particular reference to nitrogen.

Procedure

Cumulative N uptake curves

In growth analysis lysimeter trials at Pongola, Thompson (1991) measured the biomass and accumulation of plant nutrients in the aerial parts of irrigated N14 at approximately six weekly intervals. These data were used by Schumann (2000) to generate cumulative nitrogen uptake curves for sugarcane accounting for the variable impact of season on crop removal of nutrients (Figure 1). To account for the period taken to germinate, plant crop uptake curves are assumed to be equivalent to the following month's ratoon crop uptake curve, with no uptake apportioned to the month of planting. These uptake curves provide the basis for monthly N application schedules suitable for fertigation (Table 1).

Nitrogen uptake validation experiments

Nitrogen uptake curves for a ratoon crop starting in June and a plant crop starting in September were selected for validation. Variety NCo376 was planted at 1.5 m spacing in two experiments in the Swaziland lowveld on 1st September 1998 (Experiment 1) and 1st September 1999 (Experiment 2). Each experiment comprised four N treatments split in various combinations as described in Table 2. All treatments other than the control received 80 kg N/ha in total, and all nitrogen was applied by fertigation. The experiments were randomised complete blocks with eight replications and were situated adjacent to each other on a well-drained shallow (200 – 400 mm) R set soil (Somerling form, Nixon *et. al.*, 1986), containing 2.6 % organic matter and 34 % clay. Gross plots were 153 m^2 and net plots were 39 m^2. The plant crop of Experiment 1 was harvested on 1st June 1999 at nine months of age, after which it was harvested on a 12-month cycle. Results of the plant crop were inconclusive because of the inherent fertility of the trial site and only the procedure and results of the first ratoon are presented in this paper. Experiment 2 was harvested on a 12-month cycle from the outset.

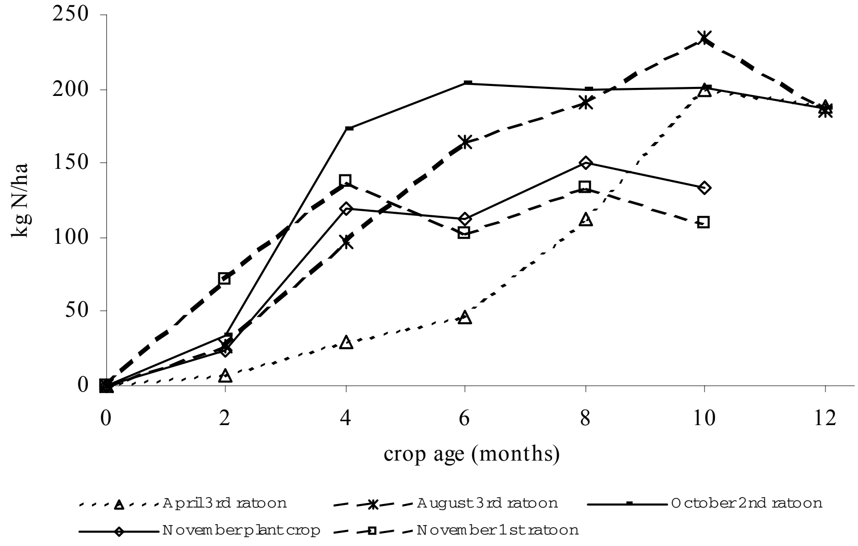

FIGURE 1. Comparison of N accumulation in above ground parts of irrigated N14 over different cropping cycles (Thompson, 1991)

	STARTING MONTH OF CROP																							
Crop Age	1		2		3		4		5		6		7		8		9		10		11		12	
(months)	R	P	R	P	R	P	R	P	R	P	R	P	R	P	R	P	R	P	R	P	R	P	R	P
0-1	29	0	22	0	13	0	3	0	1	0	2	0	5	0	10	0	16	0	21	0	27	0	30	0
1-2	20	22	13	13	5	5	2	1	2	2	7	6	12	10	17	16	22	21	27	27	27	30	26	29
2-3	10	13	4	5	1	1	2	2	7	7	12	12	16	17	19	22	22	27	21	27	18	26	15	21
3-4	3	4	2	1	2	2	7	7	12	12	16	16	18	19	19	22	17	21	14	18	11	15	7	10
4-5	1	2	2	2	6	7	11	12	15	16	17	18	17	19	15	17	11	14	8	11	5	7	2	3
5-6	1	2	5	6	10	11	15	15	17	17	17	17	13	15	10	11	7	8	4	5	2	2	0	1
6-7	4	5	8	10	14	15	17	17	17	17	13	13	9	10	6	7	3	4	2	2	0	0	2	1
7-8	6	8	11	14	15	17	16	17	13	13	9	9	5	6	3	3	1	2	0	0	1	2	2	4
8-9	8	11	12	15	15	16	13	13	9	9	5	5	3	3	1	1	0	0	0	1	2	2	4	6
9-10	9	12	12	15	11	12	9	9	5	5	2	2	2	1	0	0	0	0	1	2	3	4	6	8
10-11	9	12	9	11	8	9	5	5	2	2	0	2	0	0	0	0	1	1	2	3	4	6	6	8
11-12	0	9	0	8	0	5	0	2	0	0	0	0	0	0	0	1	0	2	0	4	0	6	0	9
TOTAL	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

P = Plant crop schedule
R = Ratoon crop schedule
(light grey) = Schedule used for Experiment 1
(dark grey) = Schedule used for Experiment 2

Table 1. Monthly nitrogen additions for irrigated ratoon and plant cane (% of total kg N/ha/year) - after Schumann (2000)

Irrigation management

Irrigation was applied with SDI delivering 2.1 mm/hr from emitters discharging 1.6 l water/hr spaced at 500 mm intervals. Drip tape was installed below each cane row at planting, at a depth of 150 - 200 mm below the surface and 50 - 100 mm below the cane sets. Irrigation was scheduled using a computerised water balance model incorporating the Penman-Montieth equation to estimate ET (Monteith, 1965) and thermal time to estimate canopy development (base temperature 11.5^{o}C). 60 mm irrigation was applied immediately after planting or harvest to replenish the total available moisture of the soil, after which 8 mm irrigation was applied at a soil moisture deficit of 10 mm. Where prolonged periods of rainfall coincided with a scheduled fertigation event, the crop was irrigated once there was sufficient soil water deficit to allow fertigation to proceed. This was as little as 2 mm on some occasions during the summer of 2000. All treatments received the same amount of irrigation water during any 24-hour period. N was injected as a 14.8 % solution pre-prepared by dissolving 450 g prilled urea (46 % N) per litre of water. The solution was injected by Amiad pump at a rate of 40 l/hr. Phosphorus (P) and potassium (K) were applied in the planting furrow or by fertigation in the ratoon crop according to soil test results.

Experiment 1 (1st June 2000 to 30th May 2001) - 1st ratoon

Treatment	Kg N/ha	Number of splits	Frequency of splits	Age at first application (months)	Age at last application (months)	Notes
N1	0	-	-	-	-	Untreated control
N2	80	2	Tri-monthly	0.2	3.0	"Conventional" split: 40% applied after harvest & 60% appplied at start of rapid stalk elongation
N3	80	5	Monthly	0.2	4.0	"Rational" split: 20% applied at monthly intervals for 5 months after harvest
N4	80	20	Fortnightly	0.2	9.5	"Growth Curve" split: monthly application schedule divided into fortnightly splits (see Table 1).

Experiment 2 (1st September 2000 to 31st August 2001) - plant crop

Treatment	Kg N/ha	Number of splits	Frequency of splits	Age at first application (months)	Age at last application (months)	Notes
N1	0	-	-	-	-	Untreated control
N2	80	2	Monthly	1.0	2.0	"Conventional" split: 40% one month after planting & 60% appplied at start of rapid stalk elongation
N3	80	4	Monthly	1.0	4.0	"Rational" split: 25% applied at monthly intervals starting one month after planting
N4	80	14	Fortnightly	1.0	7.5	"Growth Curve" split: monthly application schedule divided into fortnightly splits (see Table 1).

Table 2. Schedule of nitrogen treatments for Experiments 1 and 2

Soil and leaf sampling

Leaf samples were taken at monthly intervals until shortly before harvest. At least two weeks elapsed between fertigation and leaf sampling and results were compared against continuous leaf nitrogen thresholds (Schumann and Meyer, 1999).

Soil samples were taken from depths of 0 – 200mm, 200 – 400mm and 400 – 600mm midway between emitters from four replicates of Experiment 2 and analysed for plant available mineral nitrogen before planting and after harvest. Soil was also taken from each depth in a single plot before harvest to quantify the nitrogen mineralisation capacity of the experiment site. Soil bulk density was used to express the total nitrogen mineralised over an incubation period of 12 days as kg N/ha (after Wood, 1964). Total plant nitrogen was extrapolated from leaf analysis results at 11 months of age, assuming that foliar nitrogen comprised 48 % of total plant nitrogen (Thompson 1988a) and that foliage contributed 19 % of total dry matter in plant cane (Thompson, 1988b). Data were used to calculate a partial nitrogen balance for each treatment using the method described by Thorburn *et. al.* (2000a).

Two root profile pits were opened in treatments 1 and 4 in Experiment 2 during September 2001. Samples of roots were taken with a 25 cm^3 core at 100 mm intervals from a vertical 1m x 1m grid. Roots were separated from the soil, dried and weighed.

Crop measurements
Stalk growth was measured at monthly intervals and cane yield and quality were measured at harvest using well-established experimental methods.

Results

Experiment 1

Nitrogen application significantly increased cane yield but decreased cane quality (Table 3).
Treatment N4 resulted in a higher cane yield than treatment N2, while treatment N3 was intermediate. Prolonged N application reduced cane quality, especially in treatment N4, which produced significantly lower estimated recoverable crystal (erc) % cane, sucrose % cane and erc % dry matter (dm) than treatment N2 and the control ($P<0.05$). Reduced cane quality in treatment N4 was associated with increases in leaf nitrogen concentration (Table 4) and stalk growth up to 10 months of age (Table 5), corresponding with late additions of nitrogen.

There were no significant differences in leaf nitrogen concentration between the control and treatments N3 and N4 during September, suggesting that nitrogen supply from mineralised soil nitrogen was equivalent to the small additions of N fertiliser applied during winter in the two multiple-split treatments. There was progressively less distinction between leaf nitrogen in treatment N2 and the untreated control as available nitrogen was depleted by the crop or lost to the environment. On most occasions there were no statistically significant differences in leaf N concentration or stalk height between treatments N4 and N3.

Leaf nitrogen was marginal to deficient in all treatments after November. This may have been due to leaching following high rainfall in November, after the completion of the N fertigation schedules for treatments N2 and N3. Leaf nitrogen recovered slightly in treatment N4, possibly reflecting the continued application of nitrogen after November.

Table 3. Yield and cane quality at harvest for Experiments 1 and 2 (NS = not statistically significant, P > 0.05)

Experiment 1

Treatment	tc/ha	t dm/ha	s%c	s%dm	erc%c	erc%dm	ts/ha	t erc/ha
N1	81.6	22.7	13.8	49.4	12.3	44.0	11.2	10.0
N2	113.3	31.4	13.3	48.1	11.7	42.3	15.1	13.3
N3	116.0	32.1	12.9	46.6	11.3	40.7	15.0	13.1
N4	123.0	32.9	12.5	46.4	10.8	40.1	15.3	13.2
LSD (0.05)	11.84	3.10	0.73	1.70	0.76	1.88	1.42	1.28
LSD (0.01)	16.11	4.21	0.99	2.32	1.04	2.56	1.93	1.75
CV%	17.6	16.7	6.2	3.9	7.7	5.3	15.1	14.6

Experiment 2

Treatment	tc/ha	t dm/ha	s%c	s%dm	erc%c	erc%dm	ts/ha	t erc/ha
N1	112.1	32.5	15.2	52.2	13.9	47.8	16.9	15.5
N2	126.8	36.3	14.2	49.5	13.0	45.2	17.9	16.4
N3	138.7	39.4	14.4	50.9	13.1	46.3	20.0	18.2
N4	132.8	37.3	14.4	51.3	13.2	46.8	19.2	17.5
LSD (0.05)	14.91	4.33	NS	NS	NS	NS	2.03	1.87
LSD (0.01)	20.29	NS	NS	NS	NS	NS	NS	NS
CV%	14.5	14.0	5.8	4.7	6.4	5.2	13.0	13.0

Table 4. Leaf analysis results for Experiments 1 and 2 (NS = not statistically significant, P > 0.05). Thresholds after Schumann and Meyer, 1999.

Experiment 1

Date sampled	Age (months)	N%dm				Threshold N%dm	LSD (P<0.05)	LSD (P<0.01)	CV (%)
		N1	N2	N3	N4				
13-Sep-00	3.4	2.14	2.18	2.16	2.14	2.11	NS	-	2.3
27-Sep-00	3.9	2.08	2.18	2.14	2.14	2.05	0.066	NS	3.7
31-Oct-00	5.0	1.89	1.97	2.03	1.98	1.94	0.074	0.101	4.6
01-Dec-00	6.0	1.65	1.64	1.66	1.70	1.81	NS	-	2.3
04-Jan-01	7.1	1.49	1.51	1.59	1.64	1.69	0.049	0.067	5.4
29-Jan-01	8.0	1.45	1.45	1.47	1.50	1.58	0.033	NS	3.4
28-Feb-01	8.9	1.45	1.48	1.49	1.52	1.50	0.033	0.044	4.0
30-Mar-01	9.9	1.42	1.40	1.43	1.43	1.47	0.024	NS	4.0
30-Apr-01	11.0	1.52	1.52	1.53	1.52	1.49	NS	-	3.8

Experiment 2

Date sampled	Age (months)	N%dm				Threshold N%dm	LSD (P<0.05)	LSD (P<0.01)	CV (%)
		N1	N2	N3	N4				
04-Jan-01	4.1	2.13	2.26	2.28	2.27	1.91	0.093	0.127	5.0
30-Jan-01	5.0	1.88	1.95	2.04	1.98	1.75	0.109	NS	6.2
01-Mar-01	6.0	1.73	1.80	1.84	1.79	1.64	0.061	0.083	4.1
30-Mar-01	6.9	1.67	1.68	1.74	1.65	1.59	0.060	0.081	4.0
03-May-01	8.0	1.61	1.71	1.69	1.68	1.59	0.044	0.060	5.1
31-May-01	8.9	1.66	1.66	1.68	1.65	1.64	NS	-	4.2
02-Jul-01	10.0	1.61	1.61	1.65	1.63	1.69	NS	-	3.1
30-Jul-01	10.9	1.59	1.60	1.63	1.61	1.74	NS	-	3.3

Table 5. Stalk heights in Experiments 1 and 2 (NS = not statistically significant, P > 0.05).

Experiment 1

Date sampled	Age (months)	Stalk height to top visible dewlap (cm)				LSD (P<0.05)	LSD (P<0.01)	CV (%)
		N1	N2	N3	N4			
01-Dec-00	6.0	70.9	83.1	83.3	82.6	4.35	5.92	8.5
03-Jan-01	7.1	115.1	134.5	137.9	136.0	8.40	11.43	9.2
31-Jan-01	8.0	145.6	169.8	169.8	172.8	7.29	9.92	7.9
05-Mar-01	9.1	181.4	194.5	198.1	204.3	8.95	12.18	6.4
04-Apr-01	10.1	221.1	257.1	259.6	269.6	14.15	19.25	8.7
22-May-01	11.7	296.9	305.8	305.8	313.3	10.10	NS	4.2

Experiment 2

Date sampled	Age (months)	Stalk height to top visible dewlap (cm)				LSD (P<0.05)	LSD (P<0.01)	CV (%)
		N1	N2	N3	N4			
31-Jan-01	5.0	122.6	127.1	134.1	128.8	NS	-	8.4
01-Mar-01	6.0	159.5	167.1	171.9	168.8	NS	-	6.1
30-Mar-01	6.9	208.6	227.1	231.3	226.0	9.86	13.42	6.6
27-Apr-01	7.8	258.1	264.4	269.5	267.8	7.88	NS	3.5
07-Jun-01	9.2	275.4	284.3	285.8	283.6	7.18	NS	2.9
28-Jun-01	9.9	284.8	290.3	291.1	293.9	NS	-	3.2
02-Aug-01	11.0	278.4	288.0	291.5	289.8	9.52	NS	4.0

Experiment 2

Cane yield was increased by all three nitrogen treatments, but increases were significant only in treatments N3 and N4 (Table 3). Treatment N3 yielded best although the benefit was not significant when compared with either treatment N2 or N4. Cane quality was not significantly affected by N application and differences in yields of sucrose and erc corresponded with differences in cane yield.

Cane yield results were associated with increased stalk heights in all three N treatments throughout the sampling period (Table 5). There were no differences in stalk height among nitrogen treatments, suggesting that there was no added stalk growth in response to late applications of nitrogen. This contrasts with growth measurements in Experiment 1, where small additions of N were clearly reflected in stalk heights at nine months of age.

Differences in leaf N concentration were statistically significant on all five sampling occasions between January and May (Table 4). At five and seven months of age, treatments N1, N2 and N4 contained similar concentrations of leaf N. Treatment N3, however, contained significantly more leaf nitrogen than the control on all five sampling occasions during this period. Therefore the N uptake curve used to schedule splits for treatment N4 may have underestimated crop N demand in January, February and March. Leaching losses from heavy rainfall during this period may have compounded this effect, influencing the final cane yield of treatment N4 (Figure 2).

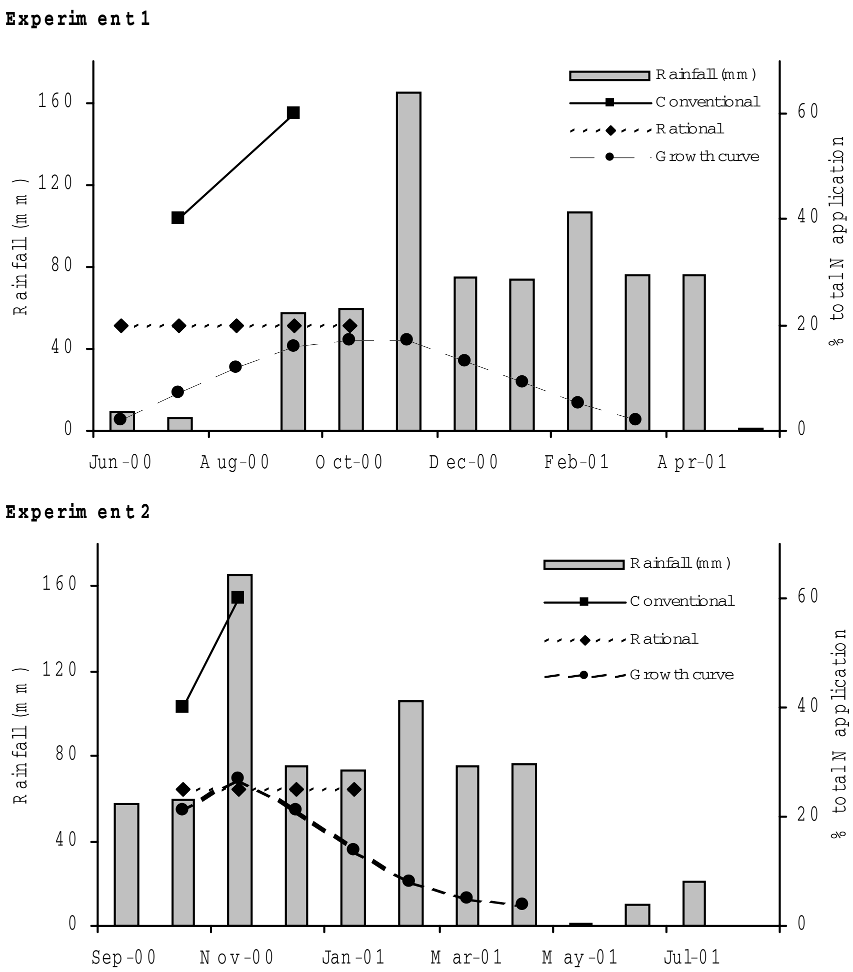

Figure 2. Timing of rainfall and N fertigation treatments in Experiments 1 and 2.

Nitrogen mineralised from soil organic matter equated to approximately 90 kg N/ha in the top 200 mm of soil and 248 kg N/ha in the full 600 mm soil profile over an incubation period of 12 days (after Wood, 1964). This was above average for the Shortlands soil form (Meyer *et. al.*, 1986), and explained the high leaf nitrogen in treatment N1 throughout the crop (Table 4). Plant available soil mineral nitrogen (SMN) in the top 200 mm of soil decreased from an average of 7.9 ppm before planting to 3.7 ppm after harvest over the experiment site. Levels of SMN at each depth were equivalent among all four treatments, although results were highly variable with coefficients of variance in excess of 60 %.

The nitrogen balance calculation indicated that up to 194 kg N/ha was supplied from mineralisation of soil organic matter during the crop (after Dart *et. al.*, 2000). A proportion of this may also have been derived from fixation of atmospheric nitrogen by non-symbiotic N-fixing bacteria (Dobereiner *et. al.*, 1995). Applied N was used most efficiently in treatment N3 (Table 6), adding to speculation that N application was affected by leaching losses in treatments N2 and N4. Losses may have been especially high during November when more than 160 mm rain coincided with the peak application for both treatments (Figure 2).

Table 6. Partial nitrogen balance for Experiment 2

Treatment	Total N inputs kg/ha[a]	Total N outputs kg/ha[b]	Balance kg/ha[c]	Apparent loss of applied N, kg/ha[d]	% fertiliser lost
N1	11	205	-194	-	-
N2	95	230	-135	59	73
N3	102	254	-152	41	52
N4	114	237	-123	70	88

Notes:
a Sum of nitrogen applied and depletion of plant available mineral nitrogen between planting and harvest
b Total plant nitrogen at harvest, extrapolated from leaf N (see Procedure)
c Nitrogen supplied by mineralisation of soil organic matter between planting and harvest (after Dart et.al., 2000)
d After Thorburn *et.al.*, 2000a

Roots were present to a depth of at least 1 m in treatments N1 and N4, despite the shallow, gravelly nature of the soil. Most roots were in the top 400 mm of soil, but there was no indication that they were limited to a wetted area surrounding each emitter (Figure 3). There was a substantially greater mass of roots in treatment N4, suggesting that nitrogen application enhanced root growth. Differences in root mass and distribution could not be attributed to individual N treatments because root profiles were sampled only in treatments N1 and N4.

(a) Control

(b) Fertigated (growth curve)

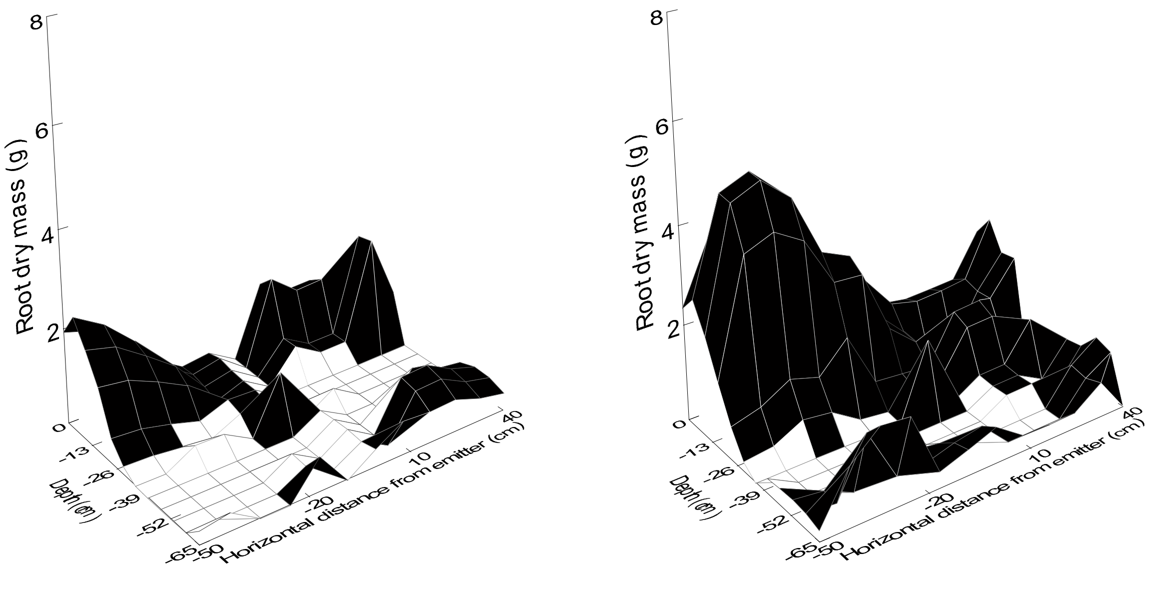

Figure 3. Root dry mass (g) per 25cm3 soil and distribution after harvest in Experiment 2

Discussion

Leaf analysis results in Experiment 1 indicated that the June N uptake curve correctly predicted the proportional monthly nitrogen demand of the crop, leading to better uptake of N fertiliser than the conventional approach. The September uptake curve for a plant crop (Experiment 2) was less precise and N fertiliser was used more efficiently when split rationally.

Improvements in leaf nitrogen were transitory in both experiments, and did not result in significant increases in cane yield among N treatments. This reflects results of previous experiments that showed increased fertiliser efficiency from fertigation but no associated yield benefit (Ng Kee Kwong *et. al.*, 1999; Dart *et. al.*, 2000; Ridge and Hewson, 1995). Soil tests indicated that the experiment site is highly fertile and justified the low rate of nitrogen used in the study (80 kg N/ha). The sensitivity of the crop to different fertigation regimes should increase as the fertility of the site decreases with each ratoon.

The nitrogen balance calculation depended on the extrapolation of plant nitrogen from third leaf nitrogen at 11 months of age. The extrapolation assumed that nitrogen concentration did not differ between the third leaf and the rest of the foliage, and therefore may have over-estimated plant removal of nitrogen. However, the calculation is likely to have given a fair representation of the relative efficiency of each treatment. Because all N treatments received 80 kg N/ha, apparent losses of N fertiliser were determined by the amount of plant available nitrogen used during the course of the crop. The large amount of SMN used in treatment N4 may have been a reflection of increased microbial activity associated with augmented root activity in response to frequent additions of fertiliser.

Adopting lower rates of N application in line with the high efficiency of fertigation increases the element of risk associated with rainfall, but judicious splitting of N application affords a greater spread of the risk provided yield and quality are not adversely affected. The timing and distribution of rainfall in relation to the timing of the various fertigation schedules will have determined its significance in terms of leaching losses. Rainfall between June 2000 and July 2001 was 6 % greater than the long-term mean, and under these conditions sucrose yields and nitrogen fertiliser uptake were optimised most by the rational approach to splitting. Schumann and Meyer's robust leaf thresholds (1999) proved to be an effective tool for monitoring the N status of the crop and could be used in conjunction with rational nitrogen splits to optimise nitrogen fertiliser management in drip-irrigated sugarcane.

The degree of exploitation of nutrients in the bulk soil and the distribution of nutrients applied by fertigation will have an important impact on the value of current representative soil sampling techniques for fertiliser advice. Experiment 2 was planted at the beginning of summer and developed rapidly over a period of seasonal rainfall that enhanced root development in the bulk soil, beyond the localised wetted zone of the drip tape. Root and fertiliser distribution may also have been affected by design parameters of the SDI system and the soil hydraulic properties of the experiment site (Thorburn *et. al.*, 2000b), although these effects are likely to be more significant in a winter-cycle crop when rainfall is restricted for the first period of growth.

This study has considered nitrogen fertiliser because it is subject to a greater range of losses than either P or K, and therefore offers more scope for improvements in management. Nitrogen fertiliser is available in readily soluble forms, such as prilled urea, at no additional cost over more conventional sources. In contrast, Schumann (2000) showed that the costs of water soluble sources of P and K fertiliser suitable for fertigation were approximately 80 % higher than those of conventional granular sources, requiring a substantial increase in sugar yield (1.45 t/ha in 2000) to break even when fertigating. There are sufficient data to develop the growth curve nutrition concept for P and K (Thompson, 1991; Meyer, 2000) but it is unlikely that the cost of fertigating with P and K fertiliser would be outweighed by increases in yield or efficiency.

The Somerling soil form in this study comprises over 20 % of the Swaziland sugar industry and approximately 40 % of cane in the irrigated South African industry. The results are therefore applicable to a significant area of both industries but cannot necessarily be applied to less fertile soils with limited rooting depth, or to older ratoons.

Soils that are highly susceptible to leaching or denitrification should benefit considerably from judicious N splitting programmes. However, Nixon and Workman (1987) showed that the performance of SDI on poorly drained saline/sodic soils was limited by the poor hydraulic conductivity of the soil. Significant benefits from fertigation cannot be expected unless the irrigation system design is optimised to meet local soil conditions (Thorburn *et. al.*, 1998 and 2000b), and this should be the first consideration when appraising fertigation strategies for poor soils.

Conclusions

- The winter nitrogen uptake curve correctly predicted the proportional monthly nitrogen demand of a winter ratoon crop but did not account for the effect of late nitrogen application on cane quality. The advantage of growth curve nutrition may only be realised with the use of chemical ripeners.
- The summer nitrogen uptake curve appeared to underestimate the nitrogen demand of a summer plant crop between January and April.
- Splitting nitrogen applications evenly over the first four months of crop development led to more productive and efficient use of nitrogen than the growth curve nutrition approach.
- This “rational split” strategy can be used in conjunction with leaf sampling to create a flexible and effective means of managing nitrogen fertigation for plant and first ratoon cane on well-drained soils with a high nitrogen mineralising capacity.

References

Dart, IK, Baillie, CP and Thorburn, PJ (2000). Assessing nitrogen application rates for subsurface trickle irrigated cane at Bundaberg. *Proc Aust Soc Sugar Cane Technol* 22: 230-235.

Dobereiner, J, Urquiaga, S and Boddey, RM (1995). Alternatives for nitrogen nutrition of crops in tropical agriculture. *Fert. Res.* 42: 339-346.

Haynes, RJ (1985). Principles of fertilizer use for trickle irrigated crops. *Fertil. Res.* 6: 235-255

Hutmacher, RB, Phene, CJ, Mead, RM, Davis, KR and Vail, SS (1993). Fertigation management with subsurface drip irrigation for efficient crop nutrient uptake. In: Jorgensen, GS and Norum, KN (eds). Subsurface drip irrigation: Theory, Practices and Application. 26th February 1993, Visali, California.

Magwenzi, OE (2001). Efficiency of subsurface drip irrigation in commercial sugarcane fields in Swaziland. In: Proceedings of the annual general meeting of the South African Sugarcane Agronomists Association. Mount Edgecombe, November 2001.

Meyer, JH, Wood, RA and Leibbrandt, NB (1986). Recent advances in determining the N requirement of sugarcane in the South African sugar industry. *Proc S Afr Sug Technol Ass* 60: 205-211.

Meyer, JH (2000). A perspective on the nutrient requirement of sugarcane for fertigation. In: Proceedings of the fertigation symposium 25 August 2000. Fertiliser Society of South Africa, Lynnwood Ridge, South Africa.

Monteith, JL (1965). Evaporation and environment. In: The Sate and Movement of Water in Living Organisms. pp 205-234. (Ed) GE Fogg. Academic Press, New York.

Ng Kee Kwong, KF and Deville, J (1987). Residual nitrogen as influenced by timing and nitrogen forms in a silty clay soil under sugarcane in Mauritius. *Fertil. Res.* 14: 219-226.

Ng Kee Kwong, KF, Paul, JP and Deville, J (1999). Drip-fertigation – a means for reducing fertilizer nitrogen to sugarcane. *Expl Agric.* 35: 31-37.

Nixon, DJ, Workman, M, and Glendinning, PJ (1986). Soil and land classification in Swaziland. *Proc S Afr Sug Technol Ass* 60: 216–222.

Nixon, DJ and Workman, M (1987). Drip irrigation on a poorly draining saline/sodic soil. *Proc S Afr Sug Technol Ass* 61: 140-145.

Ridge, DR and Hewson, SA (1995). Drip irrigation management strategies. *Proc Aust Soc Sugar Cane Technol* 17: 8-15.

Schumann, AW (2000). Fertigation for sugarcane. In: Proceedings of the fertigation symposium 25 August 2000. Fertiliser Society of South Africa, Lynnwood Ridge, 0040, South Africa.

Schumann, AW and Meyer, JH (1999). Robust leaf N thresholds for foliar diagnosis based on exponential-fourier functions. *Proc S Afr Sug Technol Ass* 73: 73-74.

Thompson, GD (1988a). The composition of plant and ratoon crops of variety N14 at Pongola. *Proc S Afr Sug Technol Ass* 62: 185-189.

Thompson, GD (1988b). Comparisons of the growth of plant and first ratoon crops of sugarcane at Pongola. *Proc S Afr Sug Technol Ass* 62: 180-184.

Thompson, GD (1991). The growth of sugarcane variety N14 at Pongola. *Mount Edgecombe Research Report No.7*. SASA Experiment Station, Mount Edgecombe, South Africa. December 1991.

Thorburn, PJ, Sweeney, CA and Bristow, KL (1998). Production and environmental benefits of trickle irrigation for sugarcane: a review. *Proc Aust Soc Sugar Cane Technol* 20: 118-125.

Thorburn, PJ, Dart, IK and Baillie (2000a). Nitrogen balances in trickle irrigated sugarcane. In: Proceedings of the 6th international micro-irrigation congress, Cape Town, October 2000. ASAE, Michigan.

Thorburn, PJ, Cook, FJ and Bristow, KL (2000b). Assessing soil wetting patterns for improved design of trickle irrigation. *Proc Aust Soc Sugar Cane Technol* 22: 236-243.

Wood, RA (1964). Assessing the potential of sugarbelt soils to supply nitrogen for plant cane. *Proc S Afr Sug Technol Ass* 38: 176-179.