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EFFECT OF ANHYDROUS AMMONIA ON CANE YIELD, NEMATODES AND ELDANA

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Abstract

Anhydrous ammonia has higher concentrations of nitrogen (82% N) than urea (46% N), is usually more economical, has lower labour requirements for application and is less prone to volatilisation. It has also been shown that ammonia has nematicidal properties. It would be of great benefit to the sugar industry if anhydrous ammonia could be applied as both a fertiliser and as a nematicide for the sugarcane crop. Three field trials (one plant crop and two ratoons) were conducted to compare the effects of four different rates of anhydrous ammonia and urea (82, 120, 196, 260 kg N/ha) on the yield of sugarcane, nematode populations and eldana numbers. These were compared to the 'control treatment' of 120 kg N/ha of urea as well as a 'best management treatment' of 120 kg N/ha of urea with a nematicide (Temik®, 20 kg/ha), usually recommended for sandy soils. Sugarcane yields (tc/ha and t ERC/ha) in plots treated with ammonia were mostly greater than those of plots treated with urea. Anhydrous ammonia treatments generally had lower ERC% (cane quality) values than the urea treatments. In two of the trials, plots of sugarcane treated with ammonia had greater stalk borer damage than plots treated with urea. Compared with urea, treatment with ammonia reduced the number of *Meloidogyne* (root-knot nematode) and total numbers of nematodes in the soil in one of the trials.

Keywords: sugarcane, anhydrous ammonia, urea, yield, nematodes, eldana

Introduction

According to Batchelor and Shipley (1991), anhydrous ammonia (AA) gas has several characteristics which make it an efficient nitrogenous fertiliser: it can be applied to a wide range of soil types, it may be applied to soils without climatic constraints (contrary to some forms of urea which have to be applied under certain conditions to avoid volatilisation) and it is an economical source of nitrogen and has a low labour requirement. In some countries, such as the USA, it has been one of the predominant nitrogen carriers for many years (Smiley *et al*. 1970; Weber *et al*. 1995; Vitosh *et al*. 2000; Kyveryga *et al*. 2004).

In the South African sugar industry, the most widely used sources of nitrogen are urea and limestone ammonium nitrate (LAN) (Anon, 1997). Urea typically contains 46% N and LAN 28% N. They are applied as granules during and after planting and after harvesting successive ratoon crops (Anon, 1997). Not much has been reported on the use of anhydrous ammonia as a nitrogen source for sugarcane in southern Africa. The only publicised report to date is that of Batchelor and Shipley (1991), who detail the use of AA at Ubombo ranches in Swaziland.

There is some evidence in other crops that ammonia has nematicidal properties. Eno *et al*. (1955) found that increased levels of ammoniacal nitrogen decreased numbers of plant-parasitic nematodes. Vassalo (1967) and Birchfield *et al*. (1969) demonstrated the nematicidal potential of ammonia. Rodriguez-Kabana *et al*. (1981, 1982) looked at combinations of anhydrous ammonia for controlling nematodes of soybeans. Oka and Pivonia (2003) found that including a nitrification inhibitor (Nitrapyrin) increased nematicidal activity. However, there is not a large body of literature to support this and not much research conducted on anhydrous ammonia as a nematicide.

It would be advantageous to sugarcane farmers if anhydrous ammonia could be applied to fields and act as both a fertiliser and as a nematicide. Hence the objectives of this work were to assess the merits of using anhydrous ammonia to control plant-parasitic nematodes and improve the growth of sugarcane, and to determine the optimum rate of application.

Materials and Methods

Three trials (one plant crop and two ratoons) were conducted between 2004 and 2007. All three trials were conducted on the farm of Mr WAM Clewlow at Zinkwazi on the north coast of KwaZulu-Natal. The soils were all sandy with <10% clay and had many of the plant-parasitic nematodes commonly found associated with such soils, *viz.* species of *Helicotylenchus, Meloidogyne, Paratrichodorus, Pratylenchus* and *Xiphinema*.

Trials 1 and 3 were randomised complete block designs with six replications per treatment. Plots consisted of five rows x 10 m with a net plot of three rows x 10 m and two outer guard rows. Trial 2 had four bigger plots of five rows x 50 m for each treatment with two net plots of three rows x 10 m in each, resulting in eight replicates per treatment. Four different rates of N were tested: 65, 120, 196 and 260 kg/ha for the plant crop and 82, 120, 196 and 260 kg/ha for the ratoon trials. The dates of treatment and harvesting, amount of rainfall and different treatments are shown in Table 1.

For the plant crop trial, the anhydrous ammonia gas was applied subsoil via injectors on tractor mounted tines. The gas was applied one week before planting. At planting, the urea was applied in the furrow as an initial application of 65 kg/ha for all the rates of urea and the remainder applied as a split application over the row at four and 10 weeks after planting. Phosphorus was applied at a rate of 53 kg/ha in the furrow at planting and potassium at 175 kg/ha as a split application at planting (75 kg/ha), and four (50 kg/ha) and 10 weeks (50 kg/ha) later. For ratoon trial 2, the anhydrous ammonia gas was applied below the soil surface on both sides of the row via injectors on tractor mounted tines and the urea was applied by hand over the row 25 days after harvest. No phosphorus or potassium fertiliser was necessary (analysis by the South African Sugarcane Research Institute (SASRI) Fertiliser Advisory Service (FAS)). However, one ton of dolomitic lime was recommended and applied to the interrows of all rows of all plots. For ratoon trial 3, the anhydrous ammonia gas was applied as before and the urea applications were split, with half applied on the day of treatment and the remaining half applied two weeks later. All plots received three tons of dolomitic lime alongside the row on the day of treatment and a top dressing of 20 kg/ha phosphorus and 175 kg/ha potassium (according to FAS recommendations). All of the plots not receiving anhydrous ammonia gas were also ripped with the tines. Temik® (15% aldicarb) was applied at 20 kg/ha with a wheel barrow applicator in the planting furrow (for the plant crop) and over the cane row, but away from the dolomitic lime (for the ratoon trials).

Table 1. Details of the three trials.

	Trial 1	Trial 2	Trial 3
Crop stage	Plant crop	Ratoon	Ratoon
Variety	N12	N19	N27
Planting/Harvest date	13 December 2004	12 November 2004	27 October 2006
Date of treatment	07 December 2004	07 December 2004	16 November 2006
Date of harvest	18 April 2006	10 November 2005	05 November 2007
Age of crop	16 months	12 months	12 months
Rainfall (first 4m)	505 mm (103% LTM)	508 mm (105% LTM)	584 mm (122% LTM)
Rainfall (crop)	1261 mm (82% LTM)	838 mm (81% LTM)	1264 mm (104% LTM)
Treatment 1	AA at 65 kg N/ha	AA at 82 kg N/ha	AA at 82 kg N/ha
Treatment 2	AA at 123 kg N/ha	AA at 123 kg N/ha	AA at 123 kg N/ha
Treatment 3	AA at 197 kg N/ha	AA at 197 kg N/ha	AA at 197 kg N/ha
Treatment 4	AA at 262 kg N/ha	AA at 262 kg N/ha	AA at 262 kg N/ha
Treatment 5	Urea at 65 kg N/ha	Urea at 82 kg N/ha	Urea at 82 kg N/ha
Treatment 6	Urea at 120 kg N/ha	Urea at 120 kg N/ha	Urea at 120 kg N/ha
Treatment 7	Urea at 196 kg N/ha	Urea at 196 kg N/ha	Urea at 196 kg N/ha
Treatment 8	Urea at 260 kg N/ha	Urea at 260 kg N/ha	Urea at 260 kg N/ha
Treatment 9	Temik 150G at 20 kg/ha + Urea at 120 kg N/ha	Temik 150G at 20 kg/ha + Urea at 120 kg N/ha	Temik 150G at 20 kg/ha + Urea at 120 kg N/ha
Treatment 10	-	-	Temik 150G at 20 kg/ha + AA at 123 kg N/ha

Soil samples were collected at the time of treatment (time = 0 weeks) and at 6, 10 and 20 weeks for trial 1, at 4, 12 and 24 weeks for trial 2, and at 14 and 26 weeks for trial 3 to measure the effect of treatments on the plant parasitic nematodes. Soil was collected to a depth of 200 mm, from the base of sugarcane stools, along the guard row of each plot, and nematodes were extracted from 200 cm^3 soil sub-samples with the Seinhorst (1962) sieving and elutriation technique. All extracted nematodes were enumerated under the microscope. These data were transformed to $\log_{10}(x+1)$ to remove the inherent variability and analysed by Means ANOVA, Student t-test (JMP Software, SAS Institute).

At harvest, the cane was burnt and stalks in the three net rows cut, stacked and weighed. Twelve representative stalks from each plot were collected for NIR analyses for sucrose and various quality parameters, and another 15 stalks from each plot were examined to determine the proportion of stalks and internodes that were bored by the stalk borer *Eldana saccharina* Walker (Lepidoptera: Pyralidae) (eldana). The effects of treatments on cane, sugar yield and cane quality was analysed by Means ANOVA, Student t-test (JMP Software, SAS Institute).

Results

Cane and sucrose yield

In the plant crop, there were significant differences in cane yield (t cane/ha) between different rates of N and whether AA or urea was applied (Table 2). Applying AA at 123 kg N/ha and 262 kg N/ha resulted in significantly ($P<0.05$) higher cane yields than the ‘control’ treatment (120 kg N/ha from urea). No differences in sugar yield (t ERC/ha) were noted between treatments and different rates. In the ratoon crops, for trial 2, there was no significant effect of N-source or N-rate on cane or sucrose yield (Table 2). However, for trial 3, there were significant increases in both cane and sucrose yields where Temik had been applied to both urea and AA-treated plots. Overall, application of AA resulted in slightly higher cane and sucrose yields for all three trials, significantly so for cane yield in trial 2, although the results were not always significant (Table 2).

Table 2. Effect on different rates of anhydrous ammonia and urea and Temik on cane and sucrose (ERC) yield.

	Trial 1		Trial 2		Trial 3	
	t cane/ha	t ERC/ha	t cane/ha	t ERC/ha	t cane/ha	t ERC/ha
AA 65 (PC)/AA 82 (R)	128.9 abc	12.57	70.6	8.49	30.2 d	3.17 d
AA 123	157.8 ab	13.93	76.9	9.04	24.0 def	2.61 de
AA 196	152.3 abc	14.12	72.8	8.76	22.8 def	2.39 de
AA 262	162.1 a	13.69	76.5	8.94	22.0 def	2.31 de
Urea 65 (PC)/Urea 82 (R)	125.5 bc	11.93	59.2	7.91	17.1 f	1.71 e
Urea 120	119.2 c	11.73	65.4	8.56	18.0 def	1.90 e
Urea 196	138.6 abc	12.71	65.1	8.38	26.5 de	2.96 d
Urea 260	145.3 abc	14.45	70.4	8.80	25.9 de	2.63 de
Temik + Urea 120	128.8 abc	12.51	68.2	8.56	44.1 c	4.89 c
Temik + AA 123	-	-	-	-	54.9 b	6.33 b
Probability (ANOVA individual treatments)	*0.05*	nsd	nsd	nsd	*0.05*	*0.05*
AA (average of all rates)	150.3	13.57	74.2	8.81	24.8	2.62
Urea (average of all rates)	132.2	12.70	65.0	8.41	21.9	2.30
Probability (averages for AA and Urea)	nsd	nsd	*0.0034*	nsd	nsd	nsd

Numbers with different letters are significantly different ($P<0.05$) to the control treatment (Urea at 120 kg N/ha)

nsd' mean 'not significantly different'

Cane quality

Various components of sugarcane quality were measured (Table 3). The one component which was consistently not affected by either N-source or N-rate in any of the three trials was purity. In addition, when comparing individual treatments, dry matter % cane was not affected in any of the trials. When comparing AA vs urea, fibre % cane was not affected. Conversely, the quality component which was affected in all three trials was ERC%, with AA treatments generally having lower ERC% than the control treatment (Table 4). In the plant crop, AA at 262 kg N/ha resulted in significantly ($P<0.05$) lower ERC% and in the ratoon crop of trial 2, AA at all four rates resulted in significantly ($P=0.0013$) lower ERC% (Table 4). Trial 2 exhibited the most changes in sugarcane quality with significantly reduced dry matter % cane, brix % cane, pol % cane and ERC% when comparing AA vs urea (Table 3).

Table 3. Effect on different rates of anhydrous ammonia and urea and Temik on different components of cane quality. Probability (P) values are shown. Those quality components where significant differences occur between treatments are shown as numbers. Those components which do not show any significant differences are shown as 'nsd' (no significant difference).

		Trial 1	Trial 2	Trial 3
Dry Matter % cane	Individual treatments: 4 different rates of N, 2 different carriers	nsd	nsd	nsd
Fibre % cane		0.05	nsd	0.003
Brix % cane		0.05	nsd	0.01
Purity		nsd	nsd	nsd
Pol % cane		nsd	nsd	0.03
ERC %		0.05	0.001	0.03
Dry Matter % cane	Average of all rates: AA vs. Urea	nsd	0.0001	nsd
Fibre % cane		nsd	nsd	nsd
Brix % cane		nsd	0.0001	nsd
Purity		nsd	nsd	nsd
Pol % cane		nsd	0.0001	nsd
ERC %		nsd	0.0001	nsd

Table 4. Effect on different rates of anhydrous ammonia and urea and Temik on ERC%.

	Trial 1	Trial 2	Trial 3
AA 65 (PC)/AA 82 (R)	9.72 ab	12.07 bcd	10.71 bc
AA 123	8.89 ab	11.72 cd	10.76 abc
AA 196	9.28 ab	11.99 cd	10.15 c
AA 262	8.53 b	11.59 d	10.50 bc
Urea 65 (PC)/Urea 82 (R)	9.46 ab	13.33 a	10.21 c
Urea 120	9.85 a	13.03 a	10.56 bc
Urea 196	9.36 ab	12.88 ab	10.91 abc
Urea 260	10.01 a	12.54 abc	10.16 c
Temik + Urea 120	9.83 ab	12.54 abc	11.18 ab
Temik + AA 123	-	-	11.66 a
Probability (ANOVA individual treatments)	*0.05*	*0.0013*	*0.03*
AA (average of all rates)	9.10	11.84	10.53
Urea (average of all rates)	9.67	12.94	10.46
Probability (averages for AA and Urea)	nsd	*0.0001*	nsd

Numbers with different letters are significantly different ($P<0.05$) to the control treatment (Urea at 120 kg N/ha)

nsd' mean 'not significantly different'

Eldana saccharina

In trials 1 and 2 there were significant effects of N-source and N-rate (Table 5). In trial 1, reducing the rate of urea to 65 kg N/ha resulted in significantly less % stalks bored and % internodes bored than the 'control' treatment of 120 kg N/ha. In trial 2, there were significant differences between treatments, but none of the treatments resulted in significantly less or more damage than the control treatment (Table 5). Similarly for trials 1 and 2 there was a trend of increased % stalks and internodes bored for AA application vs urea, with significant increases (P>0.001) for trial 2.

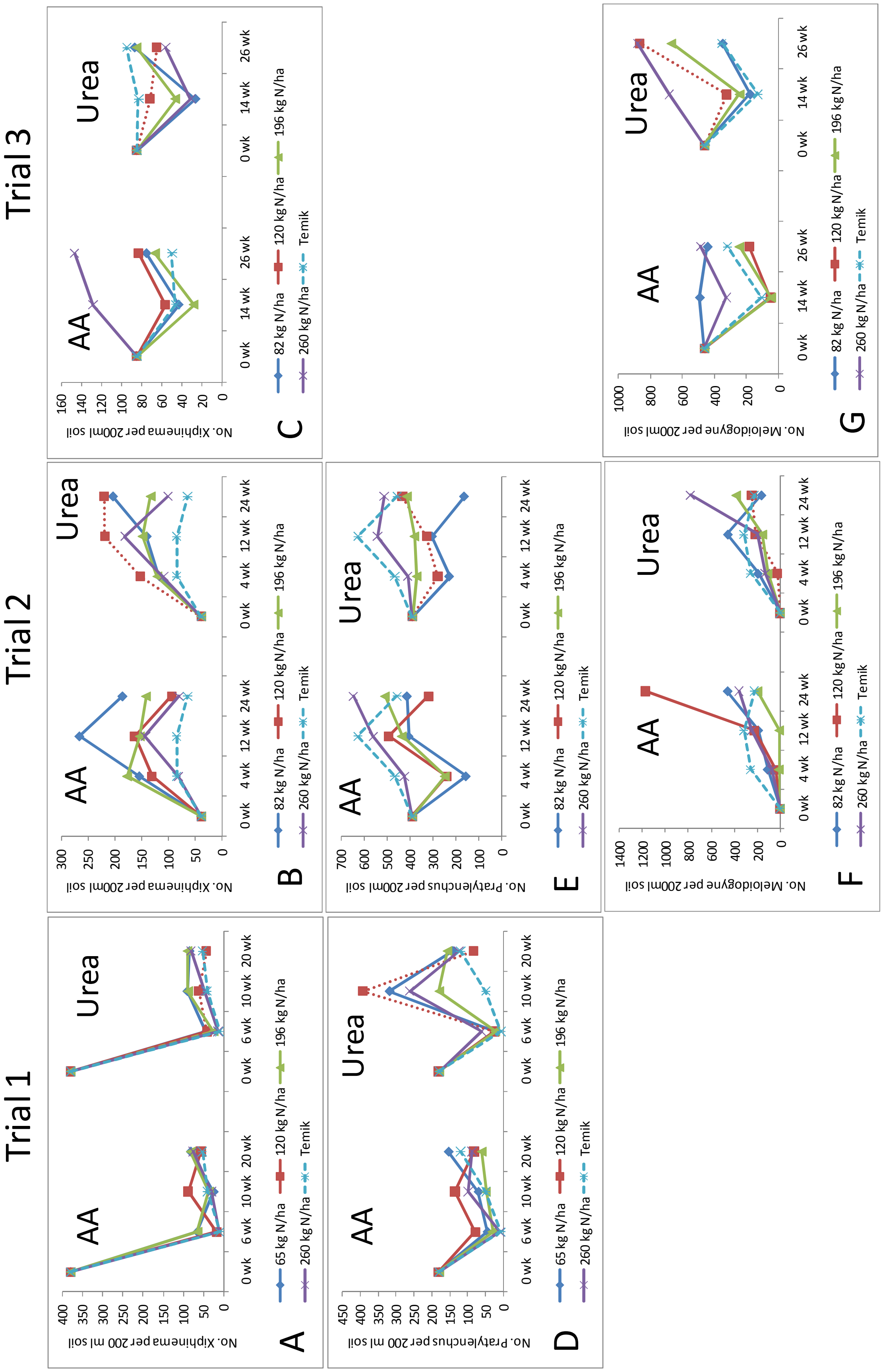
Table 5. Effect on different rates of anhydrous ammonia and urea and Temik on stalk borer (*Eldana saccharina*) damage.

	Trial 1		Trial 2		Trial 3	
	% stalks bored	% internodes bored	% stalks bored	% internodes bored	% stalks bored	% internodes bored
AA 65 (PC)/AA 82 (R)	18.9 bc	2.3 bc	56.7 ab	7.8 abc	62.2	9.2
AA 123	35.6 bc	4.8 a	53.6 abc	7.0 abcde	50.0	8.9
AA 196	33.3 a	3.5 abc	60.0 a	8.3 ab	57.8	10.3
AA 262	31.1 ab	3.5 abc	61.7 a	9.2 a	58.9	9.6
Urea 65 (PC)/Urea 82 (R)	14.4 c	1.6 c	41.8 bc	5.1 cde	56.7	10.4
Urea 120	32.2 ab	4.4 ab	52.0 abc	5.9 bcde	62.7	12.7
Urea 196	31.1 ab	3.7 ab	40.8 c	4.7 e	54.4	9.5
Urea 260	22.2 abc	2.4 bc	51.7 abc	7.3 abcd	68.9	12.2
Temik + Urea 120	30.0 ab	3.3 abc	42.5 c	5.3 de	50.0	7.6
Temik + AA 123	-	-	-		42.2	6.5
Probability (ANOVA individual treatments)	*0.05*	*0.05*	0.01	0.0006	nsd	nsd
AA (average of all rates)	29.7	3.5	58.0	8.1	57.2	9.5
Urea (average of all rates)	25.0	3.0	46.6	5.7	60.7	11.2
Probability (averages for AA and Urea)	nsd	nsd	*0.001*	0.0004	nsd	nsd

Numbers with different letters are significantly different (P<0.05) to the control treatment (Urea at 120 kg N/ha)

Plant-parasitic nematodes

Nematode samples were taken at regular intervals to assess the effect of treatments on different nematode genera. Statistical analyses showed that for all three time periods for trial 1 (6, 10, 20 weeks) and for all three time periods for trial 2 (4, 12, 24 weeks) there was no significant difference between treatments, and between treatments and the control for any of the nematode genera as well as for total plant-parasitic nematodes (PPN) and free-living (non plant-parasitic) nematodes (Figure 1 A-P). However, there were some significant results from trial 3. At both 14 and 26 weeks, the number of total PPN in the AA at 120 kg N/ha and 196 kg N/ha treatments were significantly (P<0.04) lower than that of the control treatment (Figure 1M). Similarly for trial 3, the number of *Meloidogyne* at 14 weeks was significantly lower (P=0.02) for the same two treatments (AA at 120 kg N/ha and 196 kg N/ha) than the control (Figure 1G). For all of the other nematode genera (*Xiphinema*, *Pratylenchus*, *Helicotylenchus*) as well as the free-living nematodes, there were interesting trends but no significant differences (up or down) for the different rates of N and two different sources of N.


Trial 1
Trial 2
Trial 3
A
B
C
D
E
F
G
AA
Urea
No. Xiphinema per 200 ml soil
No. Xiphinema per 200ml soil
No. Pratylenchus per 200 ml soil
No. Pratylenchus per 200ml soil
No. Meloidogyne per 200ml soil
0 wk
4 wk
6 wk
10 wk
12 wk
14 wk
20 wk
24 wk
26 wk
0
50
100
150
200
250
300
350
400
450
500
600
700
800
1000
1200
1400
20
40
60
80
120
140
160
65 kg N/ha
82 kg N/ha
120 kg N/ha
196 kg N/ha
260 kg N/ha
Temik

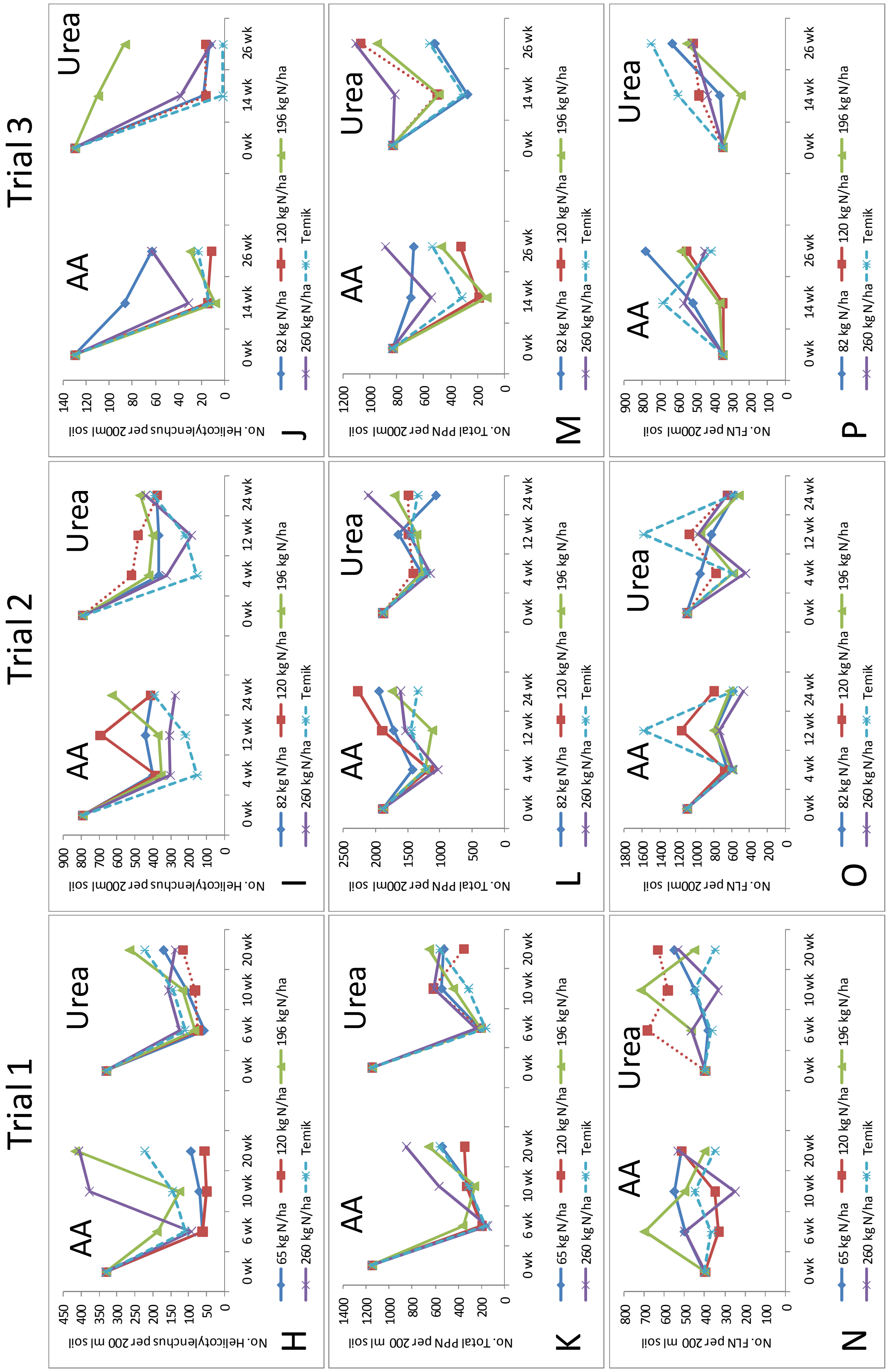

Trial 1
Trial 2
Trial 3
AA
Urea
H
No. Helicotylenchus per 200 ml soil
450 400 350 300 250 200 150 100 50 0
0 wk 6 wk 10 wk 20 wk
65 kg N/ha
120 kg N/ha
196 kg N/ha
260 kg N/ha
Temik
I
No. Helicotylenchus per 200ml soil
900 800 700 600 500 400 300 200 100 0
0 wk 4 wk 12 wk 24 wk
82 kg N/ha
J
140 120 100 80 60 40 20 0
0 wk 14 wk 26 wk
K
No. Total PPN per 200 ml soil
1400 1200 1000 800 600 400 200 0
L
No. Total PPN per 200ml soil
2500 2000 1500 1000 500 0
M
1200 1000 800 600 400 200 0
N
No. FLN per 200 ml soil
800 700 600 500 400 300 200 100 0
O
No. FLN per 200ml soil
1800 1600 1400 1200 1000 800 600 400 200 0
P
900 800 700 600 500 400 300 200 100 0

Figure 1. A-P: Changes in nematode numbers over time for the different treatments. The different nematodes studied were *Xiphinema* (1A-C), *Pratylenchus* (1D-E), *Meloidogyne* (1F-G), *Helicotylenchus* (1H-J), total plant-parasitic nematode (PPN) numbers (1K-M) and free-living (FLN) nematodes (1N-P). The 'control' treatment of 120 kg N/ha urea is shown as a dotted (...) line and the nematicide treatment of Temik at 20 kg/ha is shown as a dashed (- -) line.

Discussion

To be an effective nematicide for sugarcane, it is not necessary for a chemical to eliminate all of the plant-parasitic nematodes for the duration of the whole crop. However, it is important to protect the newly forming roots for the first two months of growth (Spaull and Cadet, 1990). The widely-recommended nematicide, Temik, at the registered rate of 20 kg/ha is neither completely nematicidal as it does not eliminate all of the nematodes nor suppresses the numbers for more than four to six weeks. From the results obtained from these trials, anhydrous ammonia did not show any overall significant reduction of nematode numbers. Except for the one trial (trial 3), where numbers of *Meloidogyne* and total PPN were reduced, there was no consistent effect in the other two trials nor for any of the other nematode genera. In addition, the typical dosage response curve that would be expected from a nematicidal agent at different rates (i.e. decreased nematode numbers with increased amount of N) was not observed. Other researchers have found similar inconsistencies when using anhydrous ammonia as a nematicidal agent for maize (Lamprecht *et al*. 2007, 2008, 2009). Whereas anhydrous ammonia has been shown to be a popular N source in many parts of the country and proved to be very effective in reducing certain root diseases (e.g. root and crown rot severity of maize) as well as enhancing grain yield in maize (with substantial economic implications), its effectiveness as a nematicidal agent remains questionable with plots having received anhydrous ammonia often having the highest nematode counts.

Even though anhydrous ammonia is not recommended for use to control nematodes it could be used as an alternative source of nitrogen for sugarcane. However, results from these trials showed that caution should be taken as in some cases anhydrous ammonia resulted in reduced ERC% and increased eldana infestation, both of which can result in reduced cane quality and reduced payment for the grower. This nitrogen carrier also needs specialised equipment for application, can only be used in the absence of a trash blanket and is not recommended where soil texture makes sealing of the tine furrow difficult; for example, on very heavy or sandy soils (Anon, 1997). On the other hand, Weber et al. (1995) stated that anhydrous ammonia application below the surface, although requiring more energy to place the material below ground (compared to conventional broadcast or banding applications), requires less overall energy for fertiliser production, transportation and application compared to other forms of nitrogen fertiliser.

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