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LONG TERM EFFECTS OF NEMATODES ON SIX SOUTH AFRICAN SUGARCANE VARIETIES

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Abstract

Newly released sugarcane varieties are routinely screened on sandy soils to assess their tolerance to nematodes. A site at Compensation in KwaZulu-Natal, South Africa, was chosen to assess the tolerance of N12, N31, N39, N41, N42 and NCo376. Varieties were either treated with Temik® at 20 kg/ha or left untreated. Yield, nematodes and soil and leaf nutrient status were assessed annually for seven years. Nematicide treated plots showed, on average, a 10 ton increase in cane yield and 1.3 ton increase in ERC yield per hectare over the seven year period, with the highest increase of 22 tc/ha in the fourth ratoon. All varieties tested responded to nematicide application and were rated as intermediate due to the 9-18% increase in yield. While yield differences were demonstrated between control and nematicide treated plots, differences in nematode community and nutrient status were not as distinct. Differences in yield between varieties were also observed. A difference of 8 tc/ha between N31 (lowest yielding) and N39, N41 and N42 (highest yielding) was noted in untreated plots. In general, varieties grouped together in couples with respect to the nematodes and nutrients associated with them. These groupings were NCo376 and N41, N31 and N42 and N12 and N39. Over time, the yield declined and this decline was consistent with climatic potential. A positive change in nematode community was also noted over time as the numbers of the plant parasitic (harmful) nematode *Pratylenchus* decreased and the free-living (beneficial) nematodes increased. All leaf nutrients except for nitrogen and silicon were present in sufficient amounts and therefore not growth limiting. Nitrogen levels however, were below critical levels from the second ratoon, and this could have affected yields. The data from this trial clearly illustrate the impact of nematodes on yields and the benefits of applying a nematicide.

Keywords: plant-parasitic nematodes, sugarcane yield, varieties

Introduction

Loss caused by nematodes to the South African sugar industry amounts to 1.6 million tons of cane annually, which is equivalent to about R450 billion (Spaull, 1995). Due to its significant contribution to reduction in yields, efforts are constantly being made to control this pest and thus reduce losses in revenue.

The most common way of controlling nematodes in this industry is with the use of chemical nematicides. Application of a nematicide at planting and to each of the subsequent ratoons can considerably increase plant growth and yield (Donaldson, 1987; Cadet and Spaull, 2003). Application of a nematicide can also favour more rapid canopy development, development of a more extensive root system and enhanced weed suppression. Fertilisers and moisture in the soil can therefore be used more efficiently (Barnes, 1974; Cadet and Spaull, 2003). Nematicides are thus an excellent way of controlling nematodes and increasing yields.

Various factors such as clay content, soil pH and harvest age can, however, affect the response to nematicide. Donaldson (1985) reported that the response due to nematodes was 37% greater in the Fernwood series soil (<6% clay) than in the Clanthal series soil (6-9% clay). However, the common misconception is that because the response to nematicide is smaller in soils with a higher clay percentage, nematodes are not a problem in these soils. That this is not the case is clearly illustrated by Spaull (1995), where his revised estimate of crop loss due to nematodes was based on data obtained from the slightly better soils (10-19% clay). It is therefore important to assess the use of a nematicide in the better soils and, should this not be economical, alternative methods of control should be investigated.

One such method of control could be the use of resistant varieties. Cook and Evans (1987) suggested that growing resistant varieties is the best method of control against nematodes. However, with the diversity of nematodes associated with sugarcane, finding a variety that is resistant is highly unlikely (Luc and Reversat, 1985; Cadet and Spaull, 2005; Spaull and Cadet, 2003; Berry *et al*., 2008b). Using varieties that are tolerant to nematodes is therefore more practical. Rutherford *et al*. (2003) and Spaull and Cadet (2003) outlined the difference in yield loss between a susceptible and a tolerant variety, with the tolerant variety increasing yields by between 25-124% over the susceptible variety.

All post-release varieties are therefore routinely screened by the Nematology section at the South African Sugarcane Research Institute (SASRI) for their reaction to nematodes, and are rated accordingly as highly susceptible, susceptible, intermediate or tolerant. The results from such trials have been reported in Cadet *et al*. (2000), Spaull and Cadet (2003), Cadet *et al.* (2005) and Spaull *et al*. (2005).

This paper reports on a trial conducted on one of the slightly better soils in the sugar industry. Six varieties were planted under rainfed conditions and their responses to nematodes and nematicide application over time were assessed. This trial enabled valuable monitoring of soil and leaf nutrient status over time.

Materials and Methods

Trial site and layout

The trial was planted on 6 October 2004 on a sandy Kroonstad form soil at Compensation on the KwaZulu-Natal north coast (29° 30’ S, 31° 08’ E) in South Africa. The soil composition was 11% clay, 4% silt, 16% fine sand, 34% medium sand and 35% coarse sand. Each plot was made up of three net rows and two guard rows, each row 10 m long with 1 m row spacing. There was a 1 m break between each plot, in which no cane was planted. Plots were arranged in a split plot design with six replicates of each treatment. Cane was planted double stick and cut into 3-4 budded setts before covering. The trial was harvested annually for a plant crop and six ratoons, it was rainfed, it was fertilised each year according to recommendations from the SASRI Fertiliser Advisory Service (FAS) and was weeded as per farm practice.

Treatments

Six varieties were planted: NCo376, N12, N31, N39, N41 and N42. Each variety was either left untreated or was treated with Temik® at 20 kg/ha. The nematicide was applied once a year, either in the furrow at planting or applied over the row within one month of harvest of the subsequent ratoon.

Sampling and processing

Every year, six months after planting/harvesting, soil samples were taken for nutrient and nematode analysis. At the same time leaf samples were also taken for nutrient analysis. Using a spade, soil samples were taken from the outer row of each plot at two spots along the row. These were taken to a depth of 5-15 cm and both subsamples were pooled into one sample per plot. Nematodes in the soil were extracted from a 200 cm^2 subsample of soil using the Seinhorst (1962) elutriation technique. Nematodes were enumerated and identified to genus level using a dissecting microscope. A composite soil sample was submitted to the Nematology Unit, Biosystematics Division, Agricultural Research Council-Plant Protection Research Institute (ARC-PPRI) in Pretoria, for nematode species identification.

The same soil samples were also analysed for phosphorus (P), potassium (K), aluminium (Al), calcium (Ca) and magnesium (Mg), and determination of pH. The third leaf of 30 plants within each plot were collected, mid-ribs stripped off and the leaf blades analysed for nitrogen (N), iron (Fe), copper (Cu), zinc (Zn), phosphorus (P), potassium (K), sulphur (S), calcium (Ca), magnesium (Mg), manganese (Mn) and silicon (Si). All nutrient analyses were conducted using the methods described in Barnard *et al*. (1990). At harvest of each crop, the three net rows of each plot were harvested by hand and weighed. The yield of each plot was calculated and expressed as tons cane per hectare (tc/ha). From each plot, 12 random stalks were milled and sucrose (ERC) yield was determined using near-infrared reflectance (Van Staden and Mdlalose, 2000).

Data analysis

The following species were found in more than 70% of the samples and used for further analyses: *Pratylenchus zeae*, *Helicotylenchus dihystera*, *Xiphinema louisi*, *Paratrichodorus* spp., *Criconemoides curvatus*, *Scutellonema brachyurus* and *Tylenchorhynchus* spp. To analyse the nematode community composition, each plant-parasitic nematode (PPN) genus was expressed as a percentage of the total PPNs. Free-living nematodes (FLN) as a group was expressed as a percentage of total nematodes. Yield data were subjected to analysis of variance (ANOVA) and treatment means were separated from the control means using the Student's t-test (JMP Software, SAS Institute). Soil, leaf and nematode data were analysed using principal component analysis (PCA) (Hotelling, 1933; ADE4 software, Thioulouse *et al.*, 1997). Factorial maps, drawn using PCA, highlighted the effect of nematicide treatment, varieties and crop age on leaf and soil nutrient status and nematode community composition.

Simulations

The DSSAT Canegro model (Singels *et al.*, 2008) was used to simulate the NCo376 treatment (a plant crop followed by five ratoons). The soil profile described for the trial site by Berry *et al.* (2008a) was used, along with weather data from the Tongaat/Klipfontein weather station (29° 34' S, 31° 8' E), approximately 10 km away from the trial site. The distance from the trial site reduces the potential accuracy of the simulations. The model assumes ideal field management; yields are determined by radiation interception and air temperature, and limited by water stress. The model therefore provided an indication of maximum climatic potential yield per season for the trial. As plant crops take longer to germinate and emerge than ratoon crops, they tend to intercept less radiation over a given time period, and so lower yields are typically simulated for plant crops compared with ratoon crops. Ratoon crops are, however, assumed to have equal vigour, so successive ratoon crops do not have decreased climatic potential.

Results

Effect of nematicide on yield, nematodes and nutrient status

All varieties showed an increase in average cane (Figure 1) and ERC (data not shown) yields when treated with nematicide at 20 kg/ha. Variety N39 showed the smallest increase of 6 tc/ha with all the other varieties producing an increase of between 10 and 11 tc/ha. Although not significantly different, these increases were substantial.

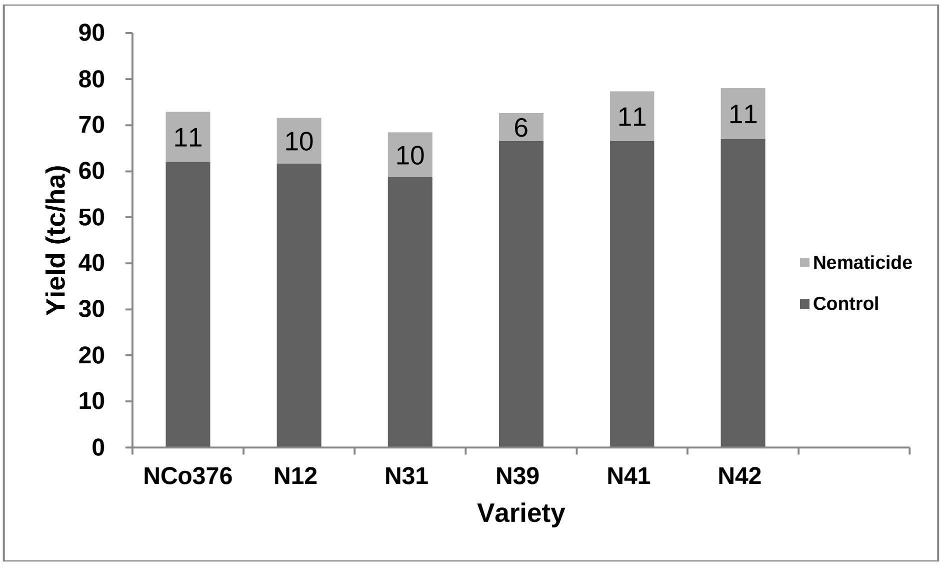

Figure 1. Average cane yield and increases due to nematicide application for the six varieties tested over the seven year period.

Each year, an increase in cane (Figure 2) and ERC (data not shown) yield was noted in the nematicide treated plots. This increase ranged from 3 tc/ha in the second ratoon to 22 tc/ha in the fourth ratoon. The difference in cane yield due to nematicide was significant ($P<0.05$) in ratoons one, three and four. In addition, the difference in ERC yield was also significant ($P<0.05$) in the fifth ratoon.

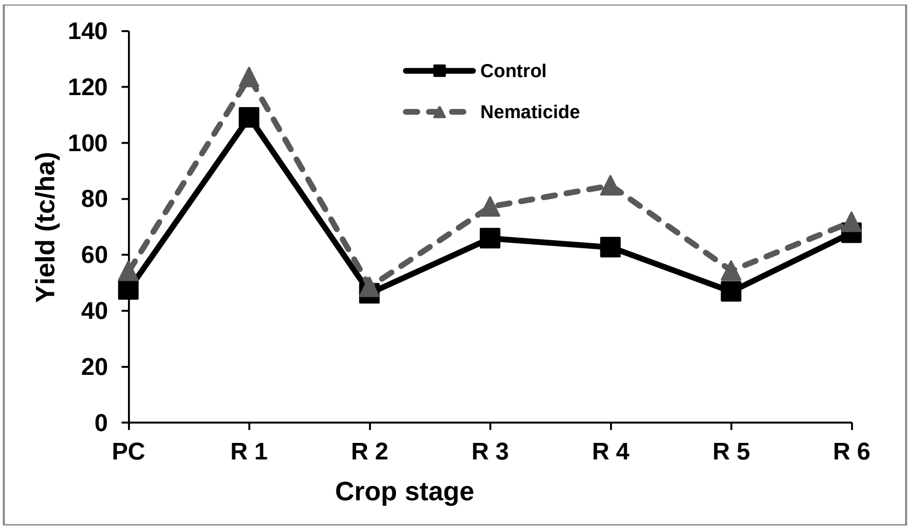

Figure 2. Cane yields obtained annually in control and nematicide treated plots over the seven year period. Yield = combined pooled average of all six varieties tested.

Of the 25 variables tested, six showed significant differences between the control and nematicide treated plots. Control plots were associated with significantly higher levels of the PPN *Pratylenchus*, Mg in the soil and Zn in the leaf. On the other hand, nematicide treated plots were associated with higher proportions of the PPNs *Paratrichodorus* and *Criconemoides* and higher proportions of FLNs (Figure 3, Table 1).

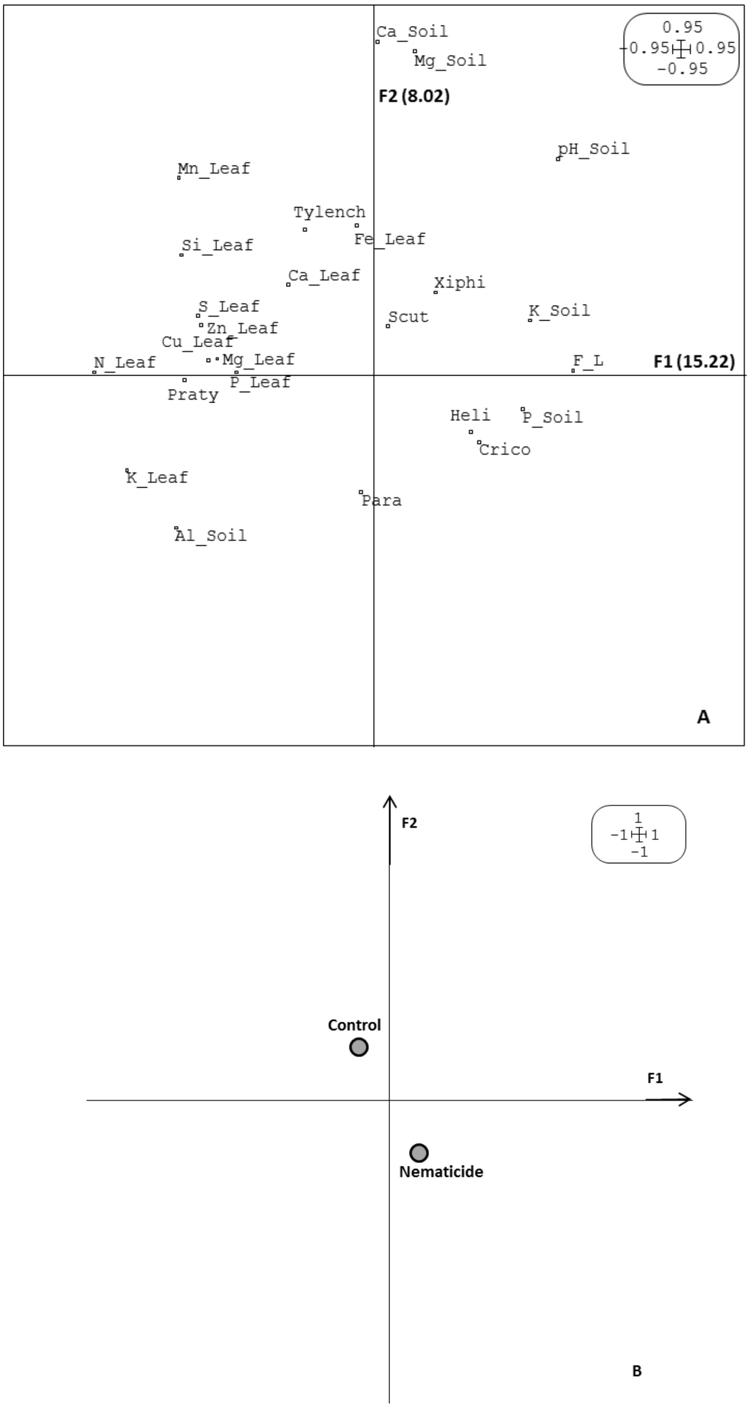

Figure 3. Principal component analysis of nematode, soil and leaf nutrient status of the plant. A: Factorial map showing the relationship between the variables. B: Factorial map showing the difference between the control and nematicide treated plots. Variables and treatments in the same quadrant are related and exhibit similar properties. The relationship along the horizontal (F1) axis (i.e. left to right) is stronger than the relationship along the vertical (F2) axis (up and down).

Table 1. One-way analysis of variance of control and nematicide treated plots showing variables exhibiting significant differences (P<0.05) between treatments. Means with the same letter are not significantly different.

Variable	Control	Nematicide	P-value
Praty (%)	21.5[a]	18.0[b]	0.03
Para (%)	12.1[b]	16.3[a]	0.002
Crico (%)	2.1[b]	4.3[a]	0.01
Free-living (%)	28.8[b]	32.4[a]	0.02
Mg Soil (ppm)	27.0[a]	23.0[b]	0.02
Zn Leaf (ppm)	16.2[a]	15.9[b]	0.02

Effect of varieties on yield, nematodes and nutrient status

The varieties could be split into two groups: the higher yielding (and newer) varieties N39, N41 and N42 (all yielding on average 67 tc/ha) and the lower yielding (and older) varieties NCo376, N12 and N31 (yielding between 59 and 62 tc/ha) (Figure 1). Over time, the varieties differed in ERC (Figure 4) and cane (data not shown) yields per crop; however, all varieties followed the same trend. Except in the first ratoon, N31 was consistently the worst performer. No variety could be singled out as the best performer, although N39 and N41 performed consistently well over the seven year period.

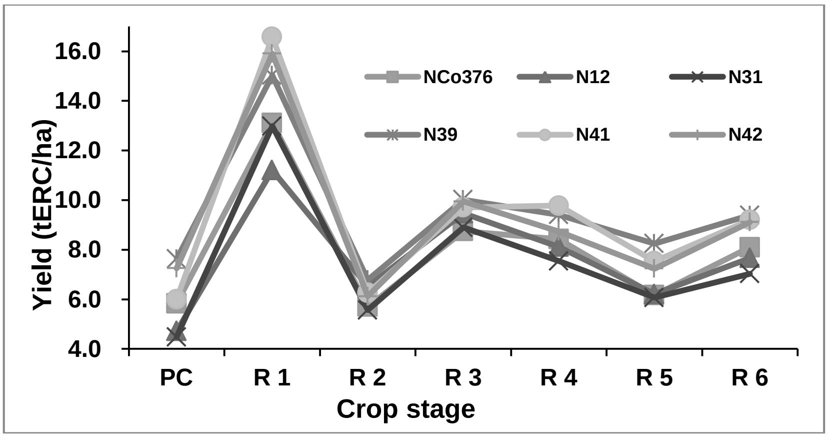

Figure 4. Estimated recoverable crystal (ERC) yields obtained annually in the control plots for the six varieties tested over the seven year period.

Significant differences between varieties were observed in 18 out of the 25 variables tested (Table 2). Variety NCo376 and N41 supported significantly higher levels of the PPN *Pratylenchus* (Table 2). Proportions of the PPN *Helicotylenchus* were highest in N12, followed by N42 and N39 (Table 2, Figure 5). Variety N31 supported the highest proportions of the PPNs *Paratrichodorus*, *Criconemoides* and *Scutellonema* (Table 2). The highest proportions of the PPN *Tylenchorhynchus* were found in varieties NCo376 and N41 (Table 2, Figure 5). In addition, varieties NCo376 and N41 showed similar responses to 12 other tested variables (Table 2). This similarity was further confirmed by their grouping pattern on the factorial map (Figure 5B). Varieties N31 and N42 also exhibited similarity (Figure 5B) but this relationship was less strong as only seven variables were found to be the same (Table 2). Most of these similar associations (six) were with soil and leaf factors (Table 2). Although not grouped very closely together on the factorial map (Figure 5B), varieties N12 and N39 also behaved similarly with similarities exhibited in 12 variables (Table 2). Key differences between them include the PPN *Paratrichodorus*, Al in the soil, and N, K and Zn in the leaf, with all variables showing higher levels in N39 (Table 2).

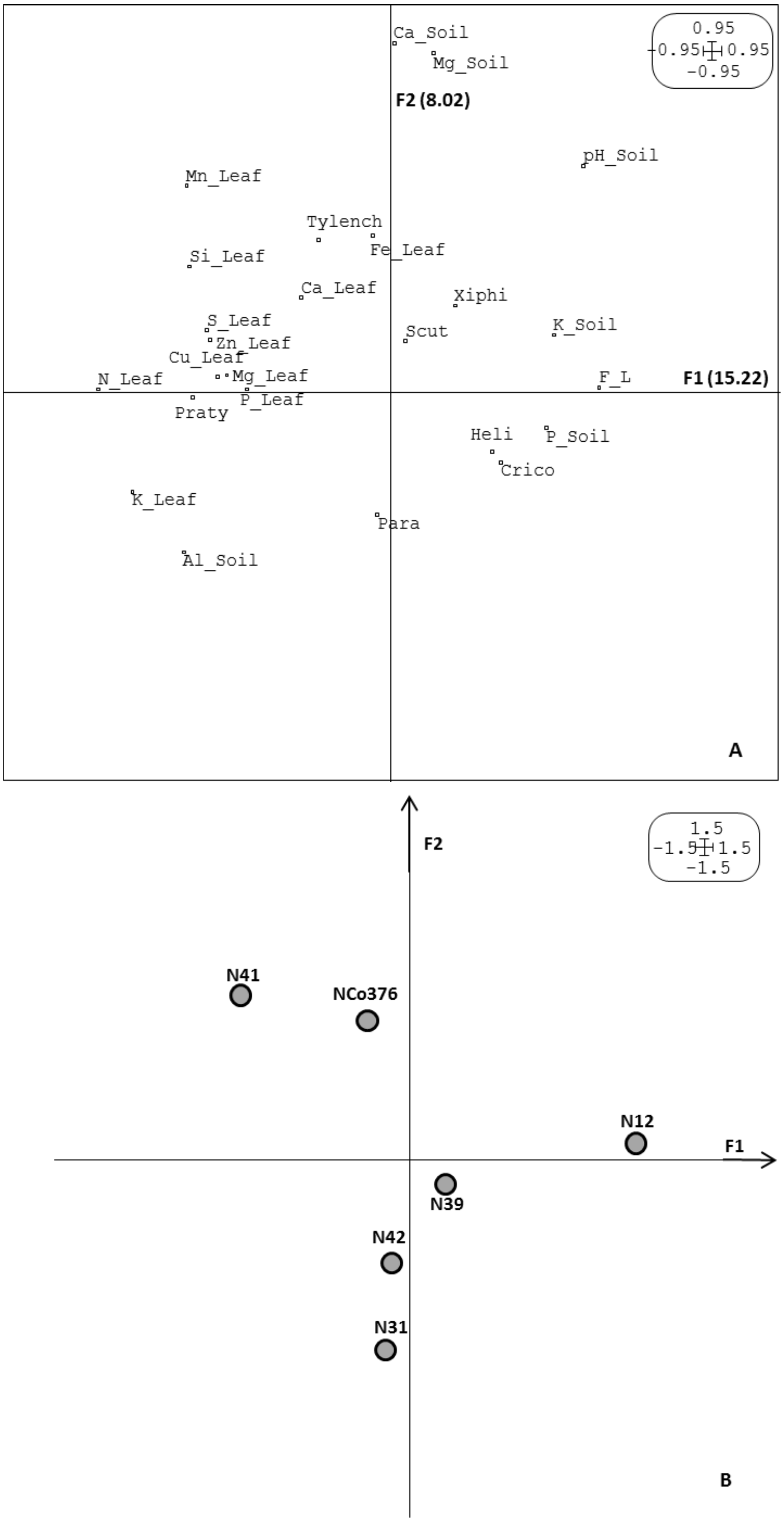

Figure 5. Principal component analysis of nematode, soil and leaf nutrient status of the plant. A: Factorial map showing the relationships between nematode, soil and leaf variables. B: Factorial map showing the difference between the six different varieties tested in the trial. Variables and varieties in the same quadrant are related and exhibit similar properties. The relationship along the horizontal (F1) axis (i.e. left to right) is stronger than the relationship along the vertical (F2) axis (up and down).

Table 2. One-way analysis of variance of varieties tested in the trial showing variables exhibiting significant differences (P<0.05) between varieties. Means with the same letter are not significantly different.

Variable	NCo376	N12	N31	N39	N41	N42	P value
Praty (%)	26.6^{a}	14.2^{b}	15.2^{b}	18.4^{b}	26.4^{a}	17.9^{b}	<0.001
Heli (%)	34.0^{c}	59.4^{a}	31.0^{c}	46.2^{b}	26.3^{c}	51.2^{b}	<0.001
Para (%)	11.1^{c}	7.7^{c}	23.4^{a}	15.6^{b}	15.5^{b}	11.6^{bc}	<0.001
Crico (%)	4.8^{ab}	2.9^{bc}	6.4^{a}	1.3^{c}	1.5^{c}	2.3^{bc}	0.003
Scut (%)	2.0^{b}	2.0^{b}	5.3^{a}	1.4^{b}	2.5^{b}	1.3^{b}	0.010
Tylencho (%)	8.0^{ab}	2.2^{c}	3.2^{bc}	3.7^{bc}	11.4^{a}	6.1^{bc}	0.004
P Soil (ppm)	28.7^{c}	33.9^{ab}	28.4^{c}	32.3^{abc}	29.6^{bc}	35.4^{a}	0.010
K Soil (ppm)	57.3^{b}	75.5^{ab}	69.4^{ab}	89.3^{a}	66.0^{b}	76.3^{ab}	0.040
Ca Soil (ppm)	102.8^{a}	106.3^{a}	59.2^{b}	93.0^{a}	104.1^{a}	69.7^{b}	<0.001
Mg Soil (ppm)	26.4^{a}	29.6^{a}	16.9^{b}	28.0^{a}	29.6^{a}	19.6^{b}	<0.001
Al Soil (ppm)	33.6^{c}	41.5^{bc}	47.2^{ab}	51.1^{a}	49.9^{ab}	49.2^{ab}	0.001
N Leaf (%)	1.4^{a}	1.2^{b}	1.3^{ab}	1.4^{a}	1.4^{a}	1.4^{a}	0.0006
K Leaf (%)	1.3^{b}	1.3^{b}	1.4^{a}	1.4^{a}	1.3^{b}	1.3^{b}	<0.001
S Leaf (%)	0.1^{bc}	0.1^{bc}	0.1^{ab}	0.1^{c}	0.1^{a}	0.1^{c}	0.0005
Zn Leaf (ppm)	16.3^{b}	15.0^{e}	15.5^{d}	15.9^{c}	16.8^{a}	16.9^{a}	<0.001
Fe Leaf (ppm)	109.2^{a}	101.7^{b}	95.7^{c}	104.6^{b}	109.4^{a}	103.5^{b}	<0.001
Mn Leaf (ppm)	38.2^{a}	32.8^{b}	41.9^{a}	33.7^{b}	41.3^{a}	32.2^{b}	<0.001
Cu Leaf (ppm)	5.9^{a}	5.7^{b}	5.7^{b}	5.8^{b}	5.8^{ab}	5.9^{a}	0.0002

Effect of crop stage on yield, nematodes and nutrient status

Decreases in yield with subsequent ratoons are frequently observed, and a similar trend was noted in this trial (Figures 2, 4, 6). However, this trend was mostly consistent with simulated climatic potential except for the second ratoon (Figure 6). Yield trends closely follow variation in seasonal rainfall, suggesting that rainfall is the main climatic determinant of yield variability. Simulated yields were of similar magnitude to the control plots, while the nematicide treated plots exhibited a much higher yield.

Twenty out of the 25 variables showed significant differences between the different crop stages (Table 3), and there was a definite shift in nematode community, and leaf and soil nutrient status as the crop aged (Figure 7). The first two ratoons were fairly similar in terms of their nematode composition and soil factors, with the difference being mainly in the leaf elements. Numbers of free-living nematodes increased significantly over the crop life, from 20% in the first ratoon up to 44% in the sixth ratoon (Table 3).

Conversely, levels of the PPN *Pratylenchus* decreased significantly from 27% of the total PPNs in the first ratoon to 12% in the sixth ratoon. Levels of the PPNs *Paratrichodorus* and *Criconemoides* remained constant throughout, except for spikes in the fourth and sixth ratoons, respectively (Table 3). Phosphorus in the soil remained constant for the first three ratoons, but increased significantly with subsequent ratoons (Table 3). Soil pH increased significantly in the sixth ratoon (Figure 7, Table 3). Conversely, levels of Al in the soil decreased significantly in the sixth ratoon (Table 3). Leaf N was significantly lower in all subsequent ratoons, when compared to the first ratoon. Whereas soil K levels fluctuated over time, leaf K levels decreased significantly. Zinc and Cu levels remained relatively constant from the second ratoon. Leaf Ca levels remained constant throughout the crop life, while Mg, Mn and Si levels decreased significantly. Levels of Fe in the leaf fluctuated over time.

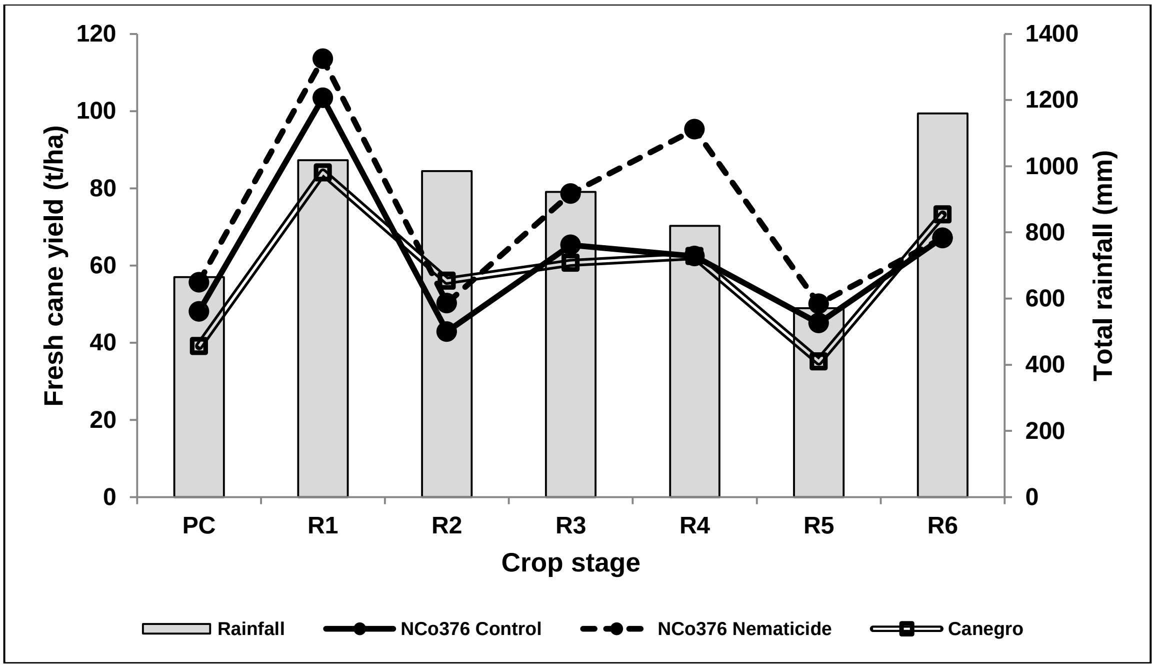

Figure 6. Relationship between yields of variety NCo376 for the control and nematicide treated plots, and rainfall and yields over time, simulated using the Canegro model.

Table 3. One-way analysis of variance of the different crop stages over the entire crop life showing variables exhibiting significant differences (P<0.05) between crop stages. Means with the same letter are not significantly different. (The plant crop and fifth ratoon are omitted due to missing data.)

Variable	R1	R2	R3	R4	R6	P value
Praty (%)	26.5^{a}	25.7^{a}	19.1^{b}	15.7^{bc}	12.2^{c}	<0.001
Xiphi (%)	7.5^{b}	9.2^{b}	8.7^{b}	9.2^{b}	16.2^{a}	<0.001
Para (%)	14.0^{b}	12.9^{b}	12.8^{b}	19.2^{a}	12.1^{b}	0.006
Crico (%)	2.3^{b}	1.8^{b}	2.7^{b}	2.9^{b}	6.1^{a}	0.010
Free-living (%)	20.6^{c}	27.7^{b}	28.0^{b}	31.9^{b}	44.0^{a}	<0.001
pH Soil	4.6^{bc}	4.6^{b}	4.5^{c}	4.5^{bc}	5.0^{a}	<0.001
P Soil (ppm)	26.2^{c}	27.2^{c}	28.0^{c}	34.0^{b}	41.2^{a}	<0.001
K Soil (ppm)	73.2^{b}	42.8^{c}	50.5^{c}	69.7^{b}	125.8^{a}	<0.001
Al Soil (ppm)	52.8^{a}	49.7^{a}	54.2^{a}	48.2^{a}	23.1^{b}	<0.001
N Leaf (%)	1.9^{a}	1.2^{c}	1.3^{b}	1.2^{c}	1.2^{c}	<0.001
P Leaf (%)	0.2^{a}	0.2^{b}	0.2^{c}	0.2^{c}	0.2^{c}	<0.001
K Leaf (%)	1.6^{a}	1.3^{b}	1.2^{c}	1.3^{b}	1.1^{d}	<0.001
S Leaf (%)	0.2^{a}	0.1^{b}	0.1^{cd}	0.1^{d}	0.1^{c}	<0.001
Ca Leaf (%)	0.3^{ab}	0.3^{ab}	0.3^{a}	0.3^{c}	0.3^{bc}	0.030
Mg Leaf (%)	0.2^{a}	0.2^{a}	0.1^{b}	0.1^{c}	0.1^{c}	<0.001
Zn Leaf (ppm)	16.5^{a}	15.8^{b}	16.7^{a}	15.6^{b}	15.8^{b}	<0.001
Fe Leaf (ppm)	108.1^{a}	95.9^{b}	108.1^{a}	97.8^{b}	110.2^{a}	<0.001
Mn Leaf (ppm)	43.7^{a}	43.4^{a}	33.9^{b}	32.9^{bc}	30.1^{c}	<0.001
Cu Leaf (ppm)	6.0^{a}	5.7^{b}	5.9^{a}	5.7^{b}	5.7^{b}	<0.001
Si Leaf (ppm)	0.5^{b}	0.7^{a}	0.3^{c}	0.3^{c}	0.2^{d}	<0.001

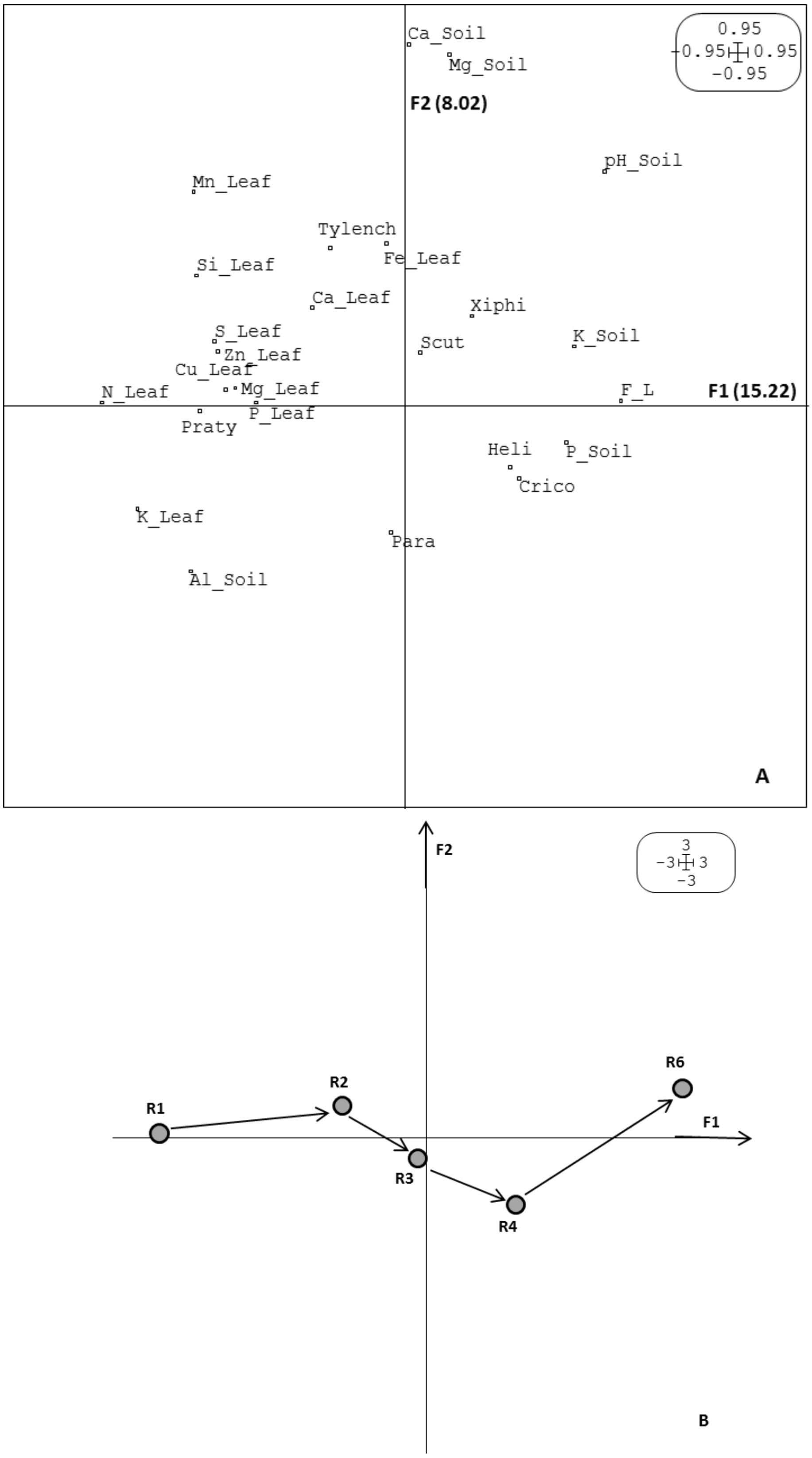

Figure 7. Principal component analysis of nematode, soil and leaf nutrient status of the plant. A: Factorial map showing the relationships between nematode, soil and leaf variables. B: Factorial map showing the difference between the plant crop and subsequent ratoons. Variables and treatments in the same quadrant are related and exhibit similar properties. The relationship of left to right (F1 axis) is stronger than the relationship between up and down (F2 axis).

Discussion

The Nematology section at SASRI routinely screens new post-release varieties in field trials to test their susceptibility/tolerance to nematodes. These trials are usually planted on nematode infested sandy soils (<6% clay), and yield comparisons are made between control and nematicide treated cane (usually with Temik® at 20 kg/ha). The larger the yield response in the treated cane, the more susceptible the variety. The Nematology section has recently decided on criteria for assigning ratings to varieties based on yield losses. According to this rating, a variety with 0-5% yield loss would be classified as tolerant, 6-20% as intermediate and >21% as susceptible (unpublished data[1]).

According to these criteria, all the varieties in this trial were rated as 'intermediate' (yield loss of between 6 and 20%). However, despite this, use of a nematicide was still beneficial (Figures 1, 2). Except for variety N39, all varieties tested showed an average increase of between 10 and 11 tc/ha, translating into an increase in yield of 9 to 18%. The yield benefit of nematicide application has been consistently demonstrated since the 1970s, when a 35 tc/ha (84%) increase in the plant crop and 39 tc/ha (173%) increase in ratoon crops were noted in the poor sandy soils (average clay <6%) of the Natal coastal belt (Moberly *et al*., 1974; Rau and Moberly, 1975). However, the response demonstrated in this trial was well below that described in those soils. This could be due to two reasons, the first being the higher clay content of 11% exhibited in this trial. Donaldson (1985) reported that the response to nematicide is reduced as the clay percentage increases. He reported an increase of 27 tc/ha (55%) between cane treated with a nematicide grown in a Fernwood series soil (<6% clay) and 13.1 tc/ha (18%) in a Clansthal series soils (6-9% clay). This is consistent with the results of this trial, where on average a yield increase of between 9 and 18% was noted. The second reason could be due to the absence of the PPN *Meloidogyne* from this trial. Cadet and Spaull (2003) reported on the '*Meloidogyne* effect' in sugarcane, where this PPN alone was responsible for 30% of total yield loss. There was also a particularly large difference in yield between the control and nematicide treated plots in the third and fourth ratoons (11 and 22 tc/ha, respectively).

There could be many reasons for this. Examination showed no difference in climatic conditions for those two years. Numbers of the borer *Eldana saccharina* Walker (Lepidoptera: Pyralidae) were also not particularly different those two years. One possible explanation could be the presence of high numbers of *Fulmekiola serrata* (Kobus) (Thysanoptera: Thripidae) (thrips) during those seasons (van den Berg *et al*., 2009). Temik®, used in this trial, was applied to the ratoon crop in November, which coincides with the peak thrips population (van den Berg *et al*., 2009; Way *et al*., 2011). It is registered for use against thrips in tomatoes, cotton and citrus (see Temik® label). So, in addition to controlling the nematodes, the nematicide could also have provided some measure of control against thrips, resulting in greater yield increases.

Although differences in yield were noted between the control and nematicide treated plots (Figures 1, 2), differences in nematode communities and soil and leaf nutrient status were not as obvious, despite the long term nature of the study (Figure 3, Table 1). This result was confirmed by Cadet *et al*. (2004) and Bond *et al*. (2000), who also reported minimal change in nematode community between control and nematicide treated plots. This could be because systemic nematicides protect the plant only during the initial stages of growth and do not

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completely eradicate nematodes from the soil (Sipes and Schmitt, 1998; Cadet *et al*., 2004). The nematodes recover and multiply again and, although the plant has been protected during its early, criticial, stage of growth, the nematode community later on in the crop is different to that at the beginning (Bunt, 1987; Cadet *et al*., 2004). Hence, when the soil samples were collected from the trial at six months, the nematode populations had recovered and there were no differences in numbers between the treated and control plots.

In terms of nematode profiles of the different varieties, N12 was associated with high numbers of the PPN *Helicotylenchus*, which is consistent with other reports (Cadet *et al*., 2000; Rutherford *et al*., 2003). N31 supported the highest proportions of the PPNs *Paratrichodorus*, *Criconemoides* and *Scutellonema* (Table 2), and N41 and NCo376 supported the highest proportions of the PPN *Tylenchorhynchus* (Figure 5, Table 2). The principle of particular nematodes being associated with particular varieties has been illustrated in other studies, where high numbers of *Meloidogyne* were associated with N19 and N27, high numbers of *Helicotylenchus* were associated with N12 and N16, and N17 promoted higher numbers of *Xiphinema* (Rutherford *et al*., 2003; Cadet *et al*., 2000, 2004). However, it is not yet known whether particular varieties are always associated with particular nematodes and what other factors (chemical, biological, physical) are associated with high numbers of a particular nematode.

The yields of all the varieties tested in this trial exhibited similar seasonal trends (Figure 4). The lower yields associated with varieties N12 and N31 could be attributed to the early harvest of these varieties. The preferred harvest ages recommended for these two varieties are 16-22 months and 18-24 months, respectively (Anon, 2006a,b). The higher yields associated with N39, N41 and N42 could be attributed to their suitability to a wider range of soils (N39) and average potential soils (N41 and N42) (Anon, 2006c,d,e). N39 and N42 also supported high numbers of the PPN *Helicotylenchus,* which has been associated with better growth of sugarcane (Cadet, 1986; Cadet *et al*., 2002; Dana, 2004).

The trend in yield over time was generally consistent with climatic potential (Figure 6) and therefore the seasonal variations in control and treated plots could be mostly attributed to climatic variability, primarily rainfall. Although this is not the case in this trial, yield decline is a common phenomenon in sugarcane and is attributed to soil degradation associated with the long term monoculture of sugarcane (Prammanee *et al.*, 1993, 1995; Henry and Ellis, 1995; Meyer, 1995; Leslie and Wilson, 1996; Schumann *et al*., 2000). To break this monoculture, a bare fallow or green manure crop is recommended before replanting. This could increase yields by as much as 11-29% (bare fallow) and 10-54% (green manure crop) in the subsequent plant crop (Nixon, 1992). Although the residual response in the ratoon is minimal (Nixon, 1992), a higher plant crop yield provides a good base for subsequent ratoons (Garside *et al*., 2007). Controlling pests and diseases, ensuring that the crop is adequately fertilised and that weeds are controlled, are ways of alleviating ratoon yield decline once the cane has been planted and is being ratooned. Cadet and Spaull (2003) showed that just by controlling nematodes with the addition of a nematicide every year, sugarcane can be grown for up to 20 years longer before the 40 tc/ha threshold is reached, depending on the variety, soil type and nematode community.

The nematode community changed from a more pathogenic community to a less pathogenic community over time (Figure 7, Table 3). This is illustrated by the increase in the proportions of FLNs and the decrease in the proportions of the PPN *Pratylenchus* with each subsequent ratoon. Free-living nematodes contribute to nutrient recycling as they feed on bacteria, fungi, decaying organic matter and other nematodes in the soil. Through their feeding, digestion and excretion process, minerals and nutrients are recycled back into the soil (McSorley, 2004). In this way FLNs contribute to a healthier soil. *Pratylenchus* is the most common PPN associated with sugarcane and together with *Meloidogyne* is considered the most damaging of the PPNs associated with sugarcane (Cadet and Spaull, 2005). It is not clear from this study what the impact of a change in nematode community is on yield, but this could be a topic for further investigation in another paper. Whether this change will occur in other soil types under different conditions has also not been established and should also be investigated further. Various differences in leaf and soil nutrient levels were observed over time (Figure 7, Table 3).

This study again confirmed the inversely proportional relationship between soil pH and Al (Turner *et al.*, 1992; Cadet *et al*., 2004). Even though the crop was fertilised every year, leaf N levels decreased over time to below the critical value of 1.8% (Elwali and Gascho, 1983, 1984) from the first ratoon onwards. Because N is critical to sugarcane growth and is a large determinant in eventual yield (Holford, 1968; Brüggemann *et al*., 2001; Miles, 2010), the decrease in yield could in part be attributed to the decrease in N levels. According to leaf critical levels, P and K were not growth limiting (Elwali and Gascho, 1983, 1984). All other leaf nutrients tested, except Si which was low, showed marginal to satisfactory levels (Miles and Rhodes, 2008). This problem of low leaf Si levels is widespread in the dryland areas (van der Laan and Miles, 2010).

Conclusions

The data from this paper clearly illustrates the yield benefit of treating sugarcane with a nematicide. It also highlights that, although the response to nematicide may be reduced in the slightly better soils, losses due to nematodes do still occur. Therefore, if the use of a nematicide is not economical in these soils, other methods of control should be used. These include planting tolerant varieties, green manuring, organic amendments and time of planting. This paper also highlights the importance of leaf sampling. Although the crop was fertilised each year, leaf N values were below thresholds for most of the crop’s life. Leaf sampling allows the identification of low nutrient status and allows timely corrective action to be taken to ultimately maximise yields.

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