EFFECT OF INTERCROPPING ON NEMATODES IN TWO SMALL-SCALE SUGARCANE FARMING SYSTEMS IN SOUTH AFRICA

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ABSTRACT

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Two trials were planted on sandy soils on small-scale grower farms to study the effect of intercropping on the nematode fauna, soil and plant fertility and sugarcane yield. Peanut (*Arachis hypogaea*) and sugar bean (*Phaseolus limensis*) were intercropped between the sugarcane rows in the first trial; velvet bean (*Mucuna deeringiana*) and sweet potato (*Ipomoea batatas*) were intercropped in the second trial. These practices were compared to a standard aldicarb (nematicide) treatment and an untreated control. In the first trial (irrigated sugarcane), peanut grew well as an intercrop, however, 70% of the sugar bean died before producing seeds. Intercropping with sugar bean had no effect on initial sugarcane stalk number whereas peanut reduced initial sugarcane stalk number by 30%. In the second trial (non-irrigated sugarcane), both velvet bean and sweet potato grew well as intercrops. Intercropping resulted in initial reduction in sugarcane stalk number of 30% for sweet potato and 70% for velvet bean. However, for both trials, and for all intercrops (except peanut), the sugarcane stalk number at harvest was the same as that of the control. Intercropping with velvet bean, peanut and sweet potato increased *Meloidogyne javanica* and *Pratylenchus zeae* infestation of the sugarcane sett roots; conversely, intercropping with sugar bean reduced nematode infestation. Intercropping with velvet bean, sugar bean and sweet potato had no effect on sugarcane yield, whereas intercropping with peanut reduced sugarcane yield by 22% and sucrose yield by 29%. Intercropping with velvet bean increased levels of some nutrients in the soil and leaves of sugarcane. These results show that intercropping can be used by small-scale growers to: manage nematodes (sugar bean), provide nutrients to the sugarcane crop (velvet bean), provide alternative food source and/or income (sweet potatoes) and to improve the overall productivity of the land without being detrimental to sugarcane cultivation.

Key words: Intercropping, nematodes, small-scale farming, soil fertility, South Africa, sugarcane.

RESUMEN

Berry, S. D., P. Dana, V. W. Spaull, and P. Cadet. 2009. Efecto del intercultivo sobre los nematodos en dos sistemas de producción de caña de azúcar a pequeña escala en Sudáfrica. Nematropica 39:11-33.

Se sembraron dos pruebas en suelos arenosos en sistemas de producción a pequeña escala para estudiar el efecto del intercultivo sobre la nematofauna, la fertilidad del suelo y plantas, y el rendimiento de la caña de azúcar. Se sembró maní (*Arachis hypogaea*) y fríjol de Lima (*Phaseolus limensis*) intercalados con la caña de azúcar en el primer ensayo, y se sembró vitabosa (*Mucuna deeringiana*) y batata (*Ipomoea batatas*) intercaladas con la caña en el segundo ensayo. Se compararon estas prácticas con un tratamiento con aldicarb (nematicida) y un control no tratado. En el primer ensayo (caña de azúcar con irrigación), el maní creció bien como intercultivo, pero el 70% del fríjol murió antes de producir semilla. El intercultivo con fríjol no tuvo efecto sobre la cantidad inicial de cañas mientras que el maní redujo las cañas en un 30%. En el segundo ensayo (caña de azúcar sin irrigación), tanto la vitabosa como la batata crecieron bien como intercultivos. El intercultivo causó una reducción inicial en la cantidad de cañas del 30% con la batata y del 70% con la vitabosa. Sin embargo, en ambos ensayos, y para todos los cultivos (excepto el maní), la cantidad de cañas al momento de la cosecha fue igual que en el control. El intercultivo con vitabosa, maní y batata aumentó la infestación de las raíces de caña con *Meloidogyne javanica* y *Pratylenchus zeae*. El intercultivo con fríjol de Lima redujo la infestación con nematodos. El intercultivo con vitabosa, fríjol de Lima y batata no tuvo ningún efecto sobre el rendimiento de la caña, mientras que el intercultivo con maní redujo el rendimiento de la caña en un 22% y la producción de sucrosa en un 29%. El intercultivo con vitabosa aumentó los niveles de algunos nutrientes en el suelo y en las hojas de la caña. Estos resultados demuestran que le intercultivo se puede utilzar en plantaciones pequeñas para: manejar nematodos (fríjol de Lima), suministrar nutrientes al cultivo de la caña (vitabosa), tener otras fuentes de alimento o de ingreso (batata), y para mejorar la productividad de la tierra sin afectar el rendimiento del cultivo de la caña de azúcar.

Palabras clave: caña de azúcar, cultivos a pequeña escala, fertilidad del suelo, intercultivo, nematodos, Sudáfrica.

INTRODUCTION

When planting sugarcane in South Africa, the normal row-spacing ranges between 1 and 1.5 m and the growth of this perennial plant is relatively slow compared to many annual food crops (Allison *et al.,* 2007). From the theoretical point of view, intercropping, that is, planting other crops in the space between the rows, would appear to be an ideal practice in sugarcane to optimize land use and land preparation. From the practical point of view, intercropping may complicate or reduce the weeding (through allelopathic effects) and may create competition, resulting in reduced production of both crops, aggravated by unavoidable physical damage during the harvesting of the short cycle crop (Ofori and Stern, 1987). However, for a resource poor sugarcane farmer, the opportunity of getting an intermediate income soon after the expense incurred from planting a field of sugarcane could be a determining factor in farming sustainably. Certainly, intercropping of sugarcane is widely practiced in Mauritius, India and Pakistan (Sathyavelu *et al.,* 1991; Khakwani *et al.,* 2001). From the agronomical point of view, the decomposition of crop residues or green manure left on the soil surface should provide additional nutrients to the sugarcane crop. An additional benefit would result from intercropping a legume crop to improve the nitrogen status of the soil (Clermont-Dauphin, 1995). The economic and fertilizing aspects of intercropping appear positive for small-scale farmers. From the sanitary point of view, intercropping is regarded with caution. A companion crop could contract diseases and attract or multiply pathogens and herbivores to which the principal crop is susceptible (Sumner *et al.,* 1981; Fargette and Fauquet, 1988). This could reduce the benefit of the intercrop. However, in practice there are many examples showing that correct intercropping can mitigate disease and nematode susceptibility (Sharma and Bajaj, 1998; Sinha *et al.,* 2004). Moreover, recent work has shown that plant diversity could reduce pathogen and disease pressure compared to a single crop (Cardinale *et al.,* 2003). In addition, the microbial decomposition of the crop residues could provide nutrients to the plant, which could limit soilborne pathogens, such as nematodes, by releasing humic acids and enhancing the multiplication of antagonistic microflora (Bridge, 1987).

This study was conducted to identify the effect of intercrops on sugarcane yield, soil and plant fertility and nematode reproduction on both irrigated and non-irrigated crops managed by two small-scale farmers in South Africa.

MATERIALS AND METHODS

Sites

Both trials were planted within existing sugarcane fields. The irrigated field was located near Boschfontein, Tonga, in Mpumalanga (31°35'E—26°25'S). The soil was sandy: 7.5% clay, 5.2% silt, 25.6% fine sand, 30.4% medium sand and 29.5% coarse sand with a pH of 7.0. The non-irrigated field was situated in the Amatikulu district of KwaZulu Natal (31°33'E—29°01'S). The soil was sandy: 3.8% clay, 3.7% silt, 11.8% fine sand, 64.2% medium sand and 15.7% coarse sand with a pH of 5.3. At Boschfontein and Amatikulu, the planting furrows were 1.3 and 1.1 m apart respectively, into which 3-4 budded stalk cuttings (setts) of sugarcane cultivar N32 and N12 respectively were planted in September. The sugarcane was harvested after 12 and 20 months respectively. The rainfall between planting and harvesting was approximately 80% of the long-term mean at both sites (735 mm $year^{-1}$ at Boschfontein and 1110 mm $year^{-1}$ at Amatikulu). However at Boschfontein, the rainfall was supplemented by regular irrigation as needed.

At Boschfontein, the trial was planted as a randomized block design with 4 treatments and 6 replicates. Each plot was 65 m^2 (5 rows × 10 m length × 1.3 m width). At Amatikulu, the field was too small to plant a conventional trial thus the treatments were applied to 40 row × 5 m strips, perpendicular to the row, except the nematicide treatment, which was 12 rows × 13 m long. In each strip, 6 sub-plots of 16 m^2 were delimited as replicates.

Treatments

The intercrops investigated were peanut (*Arachis hypogaea*) and sugar bean (*Phaseolus limensis*) in the Boschfontein trial and velvet bean (*Mucuna deeringiana*) and sweet potato (*Ipomoea batatas*) in the Amatikulu trial. These crops were chosen after consultation with the growers. Details of the treatments and their application procedure are given in Table 1. The intercrops were sown at the same time as sugarcane planting and harvested 3-4 months later. Because the velvet bean vines invaded the sugarcane row, they were cut back at 4 months and left on the soil in the interrow as green manure. The sweet potato vines were also left on the soil surface when the tubers were harvested, between 3 and 4 months after planting.

The inorganic fertilizer rates applied to all the plots were calculated from the soil chemical analysis: 140 kg N/ha, 40 kg P/ha and 175 kg K/ha at Boschfontein and 120 kg N/ha, 60 kg P/ha and 175 kg K/ha at Amatikulu. The granular fertilizer was applied over the sugarcane setts before covering. An additional 50% of N, P and K was scattered between the cane rows on the sweet potato cuttings. For the legumes, no extra N was applied. Weeding was done by hand except at 3 months at Amatikulu, when metribuzin herbicide was applied at 1.44 kg ha^{-1} in the inter row, except for plots where the intercrops were planted. The carbamate nematicide, aldicarb, was applied by an applicator, in the furrow, over the setts, to selected plots at 3 kg/ha (20 kg Temik 15 G) before covering with soil.

Sampling

At 1.25 and 2.5 months at Boschfontein and at 0.75, 1.5, 2.25 and 3 months at

Table 1. Detail of the treatments and their application procedure.

Trial	Treatment no.	Treatment	Dose per row	Dose ha-1	Application procedure
Irrigated	1	Control	—	—	—
	2	Nematicide	3.9 g of Aldicarb	3 kg Aldicarb ha-1	Over the sugarcane setts, before covering
	3	Peanut	—	—	1 seed per hole, every 15cm, along both sides of the cane row (130 holes per 10 m inter row)
	4	Sugar bean	—	—	1 seed per hole, every 10 cm, along the middle of the inter row (100 holes per 10 m inter row)
Non-irrigated	1	Control	—	—	—
	2	Nematicide	3.3 g of Aldicarb	3 kg Aldicarb ha-1	Over the sugarcane setts, before covering
	3	Velvet bean	—	—	2 seeds per hole, every 50 cm (11 holes per 5 m inter row)
	4	Sweet potato	—	—	1 cutting every 50 cm (11 cuttings per 5 m inter row

Amatikulu, all plots were sampled. Samples consisted of a single sugarcane sett (stalk cutting) dug per plot and the sett, along with 400 cm^3 rhizospheric soil, placed in plastic bags. In the laboratory, the sett roots of germinated nodes were separated from the shoot roots. At the same time, a single intercropped plant was removed from the soil, from the inter-row of each plot along with its rhizospheric soil. In the laboratory, the roots and soil were separated and processed for nematode extraction.

At 3.5, 4.5, 5.5, 7, 9 and 11 months at Boschfontein and 4, 6, 7, 9 and 11 months at Amatikulu, after the sett roots had disappeared, sugarcane shoot roots were collected from between 5 and 20 cm underneath the sugarcane stool with rhizospheric soil.

A representative sample of 30 third-stage sugarcane leaves was collected from each plot, 7 months after planting for nutrient analyses.

Nematode processing and analysis

Nematodes were extracted from a 200 cm^3 soil sample with Seinhorst's elutriation technique (1962). One to 30 g fresh weight of roots were washed and cut and placed in a mist chamber as described by Seinhorst (1950). All extracted nematodes were enumerated under the microscope. Roots were oven dried and the number of nematodes extracted was adjusted to per g of dry weight. The relative proportion of each ectoparasitic species was calculated according to the total number of ectoparasites in the soil. A similar calculation was made for the endoparasitic species in the soil and in the roots. The percentage of free-living nematodes was calculated from all soil nematodes (including ecto- and endoparasites). To compare the nematode species status in soil and roots for all of the different treatments during the sett root development period (first three months), the average of the relative proportions at 1.25 and 2.5 months for Boschfontein and at 0.75, 1.5, 2.25 and 3 months for Amatikulu were used. For the shoot roots, the average of the relative proportions at 3.5, 4.5, 5.5, 7, 9 and 11 months for Boschfontein and at 4, 6, 7, 9 and 11 months for Amatikulu were used.

Soil, leaves and yield

Chemical analysis was conducted on soil and leaves collected at 7 months after planting at both locations. From a subsample of the soil collected at 7 months, the pH (water) and ppm of P, K, S, Ca, Mg, Al, Mn, Zn, Fe, as well as the percentage of C were analysed (Barnard *et al.,* 1990). At the same time, analysis was made of the levels of N, P, K, S, Ca, Mg and Si (%), and Fe, Zn, Mn and Cu (ppm) in the leaves (Wood *et al.,* 1985). The cane was harvested from the 3 central rows of 10 m for each of the 6 replicates at Boschfontein after 12 months, and from 6 sub-plots comprising three rows each 5 m long in each treatment area at Amatikulu after 20 months. The harvested cane stalks from each plot were weighed and the yields converted to t cane ha^{-1}. Twelve representative stalks were collected from each plot and milled to measure the sucrose yield, expressed as tons estimated recoverable crystal (t ERC ha^{-1}) and sucrose quality, expressed as %ERC.

Statistical analysis

To describe the effect of the treatments on the nematodes and to exclude temporal nematode variations induced by season and rainfall, the proportion of plant-parasitic or free-living nematodes in the various treated plots was calculated according to the corresponding proportions in the control plots, for the same sampling dates.

Multivariate analyses were performed with ADE4 software (Thioulouse *et al.*, 1997) on the soil, leaf and nematode data to study the changes in nematode communities and soil and leaf chemical elements relative to different treatment effects. The average proportions of each genus were calculated from the total numbers of ecto- and endoparasitic nematodes and the data transformed to arcsin (square root (x)) prior to ANOVA and student t-test (JMP software, version 5.0).

RESULTS

Effect of treatments on nematode abundance in soil and roots

In the rhizosphere of the intercrops, and of the irrigated sugarcane (Boschfontein), the number of free-living nematodes was similar to the control throughout the crop cycle (Fig. 1A). The same situation was observed for non-irrigated cane (Fig. 1B), except at the first month after planting, where the number of free-living nematodes associated with sugarcane intercropped with velvet bean was 5 times higher than in the control plots. Nematicide treatment had no effect on free-living nematodes.

For the first 3 months at the irrigated site, numbers of plant parasitic nematodes in the peanut and sugar bean rhizospheres showed contrasting population development, with a marked reduction then an increase with the peanut, and the reverse with the sugar bean (Fig. 1C). Both were different to the sugarcane (control) rhizosphere. At the fourth month, the plant parasitic nematode community was slightly greater (+150%) in the sugarcane that had been intercropped than in the control, and was similar to that of the nematicide treatment (Fig. 1C). For non-irrigated cane, an increase ($P < 0.05$) (+500%) in numbers of plant parasitic nematodes occurred in the rhizosphere of the velvet bean within the first 3 months compared to the control sugarcane; but this did not occur with the sweet potato (Fig. 1D). Conversely to the irrigated situation, and compared with the control, the plant-parasitic community increased markedly from 5 to 7 months in the sugarcane rhizosphere, in plots previously intercropped with sweet potato (+500%) and in plots treated with a nematicide (+400%). Numbers in sugarcane that had been intercropped with velvet bean were similar to those in the control plots.

Under irrigated conditions, the roots of sugar bean were more infested (+100 to 400%) than the sett roots of sugarcane in the intercropped plots (Fig. 2A). The reverse was true for the peanut intercropped plots. Treatment with nematicide almost completely reduced sett root infestation. The shoot roots in the nematicide treated plots were also less infested than the control. However the shoot roots of sugarcane from intercropped plots were almost twice as infested as those in the control plots (Fig. 2A). In the non-irrigated trial, a marked increase in infestation occurred in the sett roots of sugarcane intercropped with sweet potato (+1500%) and velvet bean (+600%) (Fig. 2B). This was most prevalent at 1.5 months after planting, thereafter there was a marked reduction, presumably due to the natural death of the sett roots and emergence of new shoot roots. Few nematodes were recovered from the intercrops roots. The least infested sett roots were those from sugarcane treated with nematicide (Fig. 2B). As soon as the sugarcane

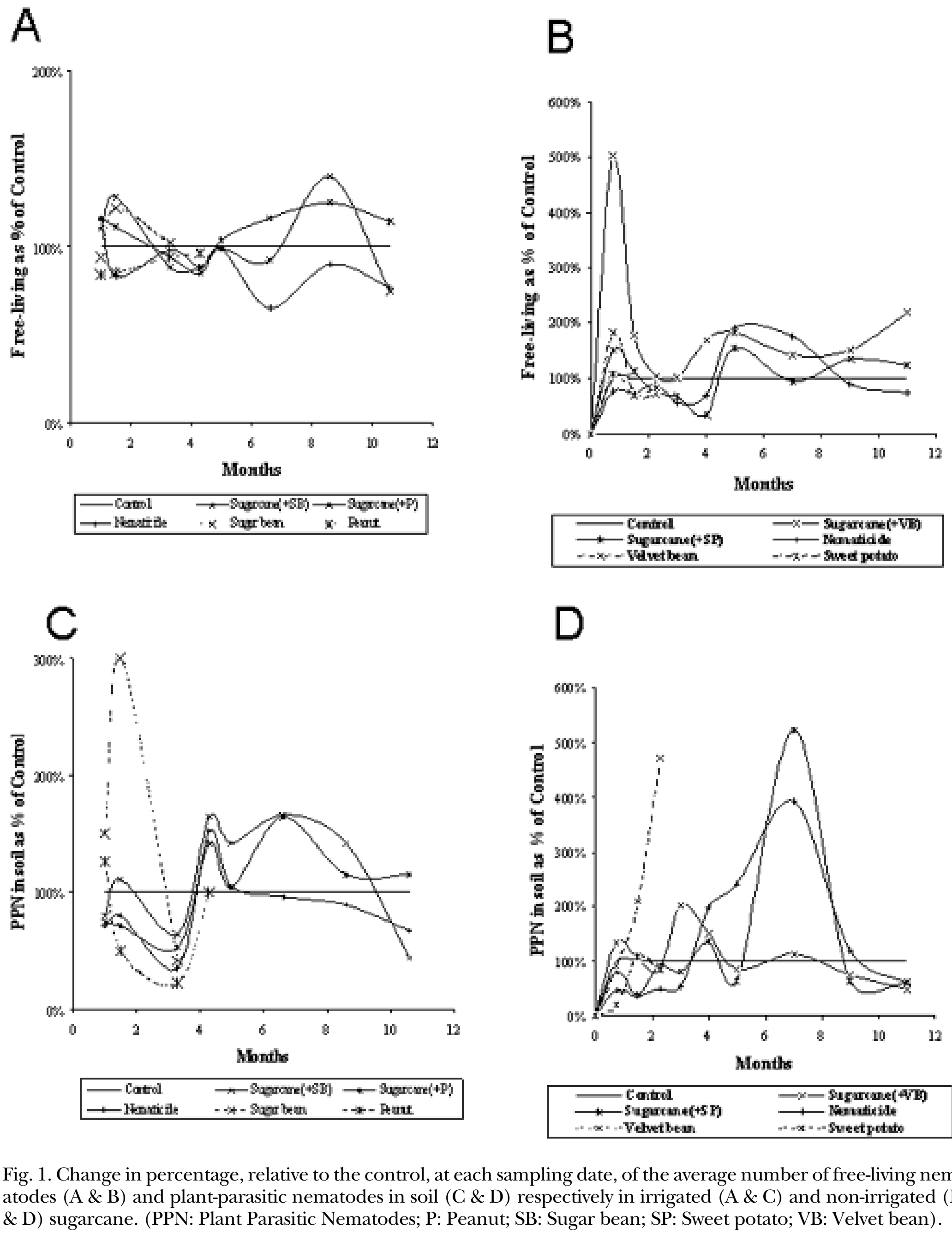

Fig. 1. Change in percentage, relative to the control, at each sampling date, of the average number of free-living nematodes (A & B) and plant-parasitic nematodes in soil (C & D) respectively in irrigated (A & C) and non-irrigated (B & D) sugarcane. (PPN: Plant Parasitic Nematodes; P: Peanut; SB: Sugar bean; SP: Sweet potato; VB: Velvet bean).

shoot roots appeared, 2 months after planting, they were invaded by large numbers of nematodes in both intercropped plots, but especially where sweet potato had been planted (+1800%) (Fig. 2C). After several months, the plant-parasitic

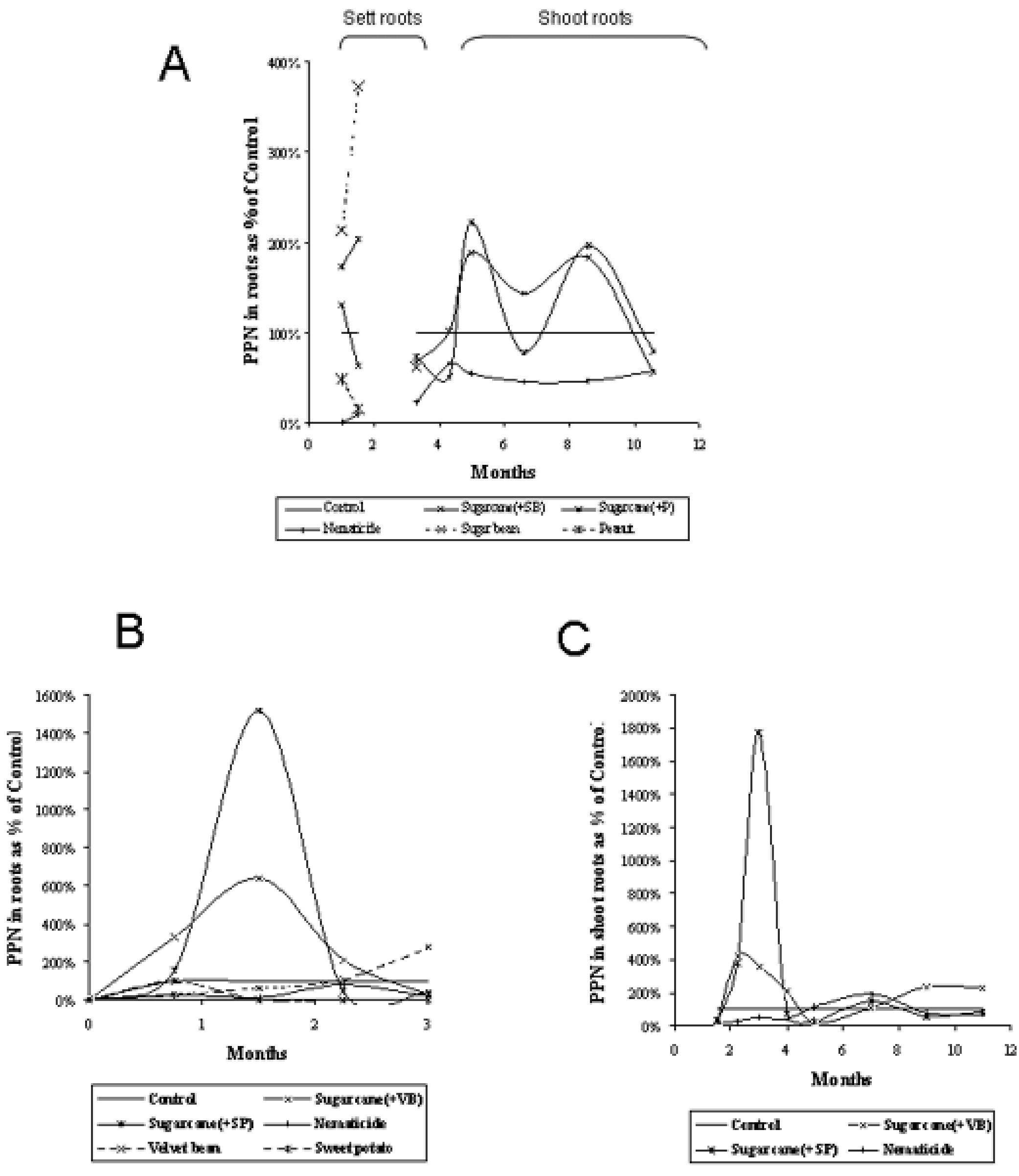

Fig. 2. Change in percentage, relative to the control, at each sampling date, of the average number of plant-parasitic nematodes in sett roots (A & B) and shoot roots (A & C) in irrigated sugarcane (A) and non-irrigated (B & C) sugarcane and in roots of intercrops (A & B). (PPN: Plant Parasitic Nematodes; P: Peanut; SB: Sugar bean; SP: Sweet potato; VB: Velvet bean).

nematodes were still more abundant in the shoot roots of sugarcane intercropped with velvet bean, but less so where sweet potato had been grown.

Effect of treatments on the balance between nematode species

The statistical analyses were performed on the most abundant and frequent nematode species recovered from the soil and roots: At Boschfontein, the most common nematodes were: Criconematids, *Helicotylenchus dihystera*, *Meloidogyne javanica*, *Paratrichodorus minor*, *Pratylenchus zeae*, *Scutellonema* spp. (with a majority of *S. africanum*), *Tylenchorhynchus goffarti*, *Xiphinema coomansi*, plus the free-living nematodes counted together as a single ecological group. At Amatikulu, the same species were found except *S. africanum* and *X. coomansi* were replaced by *S. truncatum* and *X. elongatum.* A few *Tylenchorhynchus* sp., *Paratrichodorus minor*, *Hemicycliophora* sp., *Longidorus* sp., *Rotylenchulus parvus* and *Hoplolaimus pararobustus* were also present in the soil, but in less than 10% of the samples and were not taken into consideration for the statistical analysis.

The correlation circle of the Principal Component Analysis (PCA) performed on the average relative proportions of the different species and free-living nematodes at the irrigated site, showed, on the first axis (F1) the opposition between *Meloidogyne* (right) and *Pratylenchus* (left) (Fig. 3A). When the factorial values corresponding to each of the plots were projected on the same factorial plan and grouped per treatment, a difference could be discerned between the nematode communities recovered from soil and the roots of sugarcane in plots intercropped with peanut and sugar bean (Fig. 3B). More *Meloidogyne* and fewer *Pratylenchus* were recovered from the roots and rhizosphere soil of sugarcane grown in peanut-intercropped plots, compared to the control. Conversely, sugarcane grown in sugar bean-intercropped plots exhibited the reverse situation, as did sugarcane in plots treated with nematicide (Figs. 3A & B; Table 2). These latter plots also had significantly greater numbers of the Criconematid species and free-living nematodes relative to the control (Table 2).

In the non-irrigated trial, the first factor (F1) was again characterized by the opposition between *Meloidogyne* and *Pratylenchus.* However, unlike the irrigated trial, there was marked opposition along the second factor between *Xiphinema* (top) and *Helicotylenchus* (bottom) in the soil (Fig. 4A). When the points corresponding to the plots were projected on the same factorial plan and grouped per treatment, the two intercropping treatments were both on the left part of the F1 axis (Fig. 4B). The velvet bean treatment resulted in greater proportions of *Meloidogyne*, whereas the sweet potato treatment, when compared with the control, had little or no effect on the nematode community (Figs. 4A and B, Table 2). The nematicide-treated plots, located on the right side of the F1 axis, was in contrast to the control and intercropping treatments, with a significantly lower proportion of *Meloidogyne* and consequently a higher proportion of *Pratylenchus* (Figs. 4A and B, Table 2).

Compared with the early period, there were smaller differences between the nematode communities later on in the crop cycle. This is shown by the closer clustering of the stars corresponding to the treatments on the factorial plan derived from the analysis of the 5-11 months data for both the irrigated (Fig. 3D) and non-irrigated sites (Fig. 4D). At the irrigated site, the peanut intercropped plots were slightly offset from the other treatments due to higher proportions of Criconematid species (Figs. 3C and D; Table 2). At the non-irrigated site, intercropping with velvet bean promoted communities with significantly more free-living nematodes and significantly lower proportions of *Xiphinema* (Figs. 4C and D; Table 2). The relative proportions of *Xiphinema* were highest in the control plots.

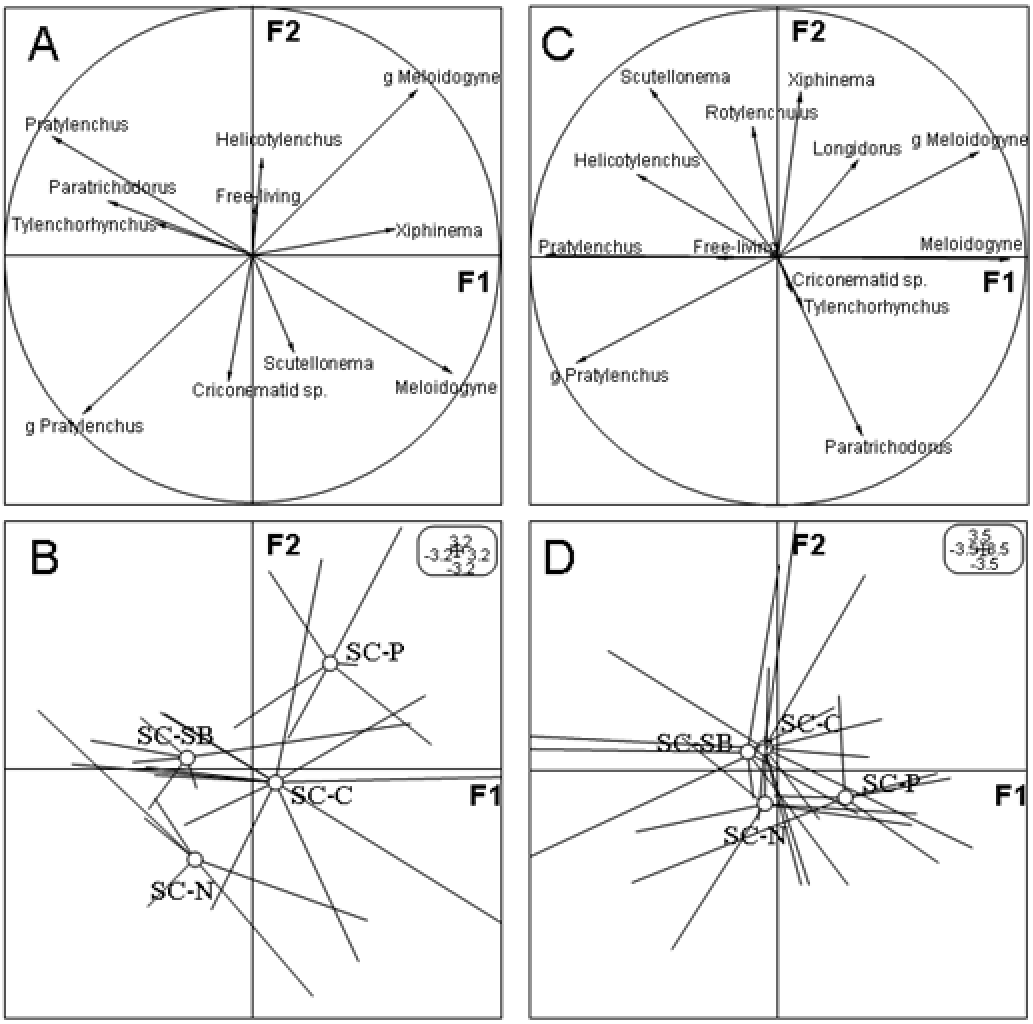

Fig. 3. Impact of treatments on the specific structure of the nematode community in irrigated sugarcane. Correlation circles (A & C) and F1 × F2 factorial plans (B & D) issued from the PCA of the nematode data collected between 0-3 months (A & B) and after 5 months (C & D). In the factorial plans, each treatment has been represented as a star, the branches of which link the position of each plot to the gravity centre of the corresponding treatment. (SC-C: Sugarcane Control; SC-N: Sugarcane+Nematicide; SC-SB: Sugarcane+Sugar bean; SC-P: Sugarcane+Peanut).

Effect of treatments on soil and leaf chemical characteristics

On the correlation circle of the PCA performed on the soil parameters at the irrigated site (Boschfontein) at 7 months (Fig. 5A), most of the soil chemical elements were on the positive part of the F1 axis. In the factorial plan for comparison of treatments, the gravity centers of the stars corresponding to the four treatments were clumped in the center indicating little distinction between them (Fig. 5B). The only significant difference was a slight increase

Table 2. Average relative proportions of the main nematode species in sugarcane soil and roots, which best explain, among a group of other nematode variables, the location of the stars corresponding to the different treatments in the factorial plan (c.f. Fig. 3 & 4), for the two different periods and for each trial. (mo: month). Numbers were changed to arcsin (square root (x)) prior to ANOVA or t-test. Numbers in rows in bold and followed by different letters were significantly different ($p < 0.05$).

	Irrigated sugarcane				Non-irrigated sugarcane			
	SC (Control)	SC (Nematicide)	SC + Sugar bean	SC + Peanut	SC (Control)	SC (Nematicide)	SC + Velvet bean	SC + Sweet Potato
Endoparasities								
Pratylenchus in soil								
0-3 mo	76 b	77 ab	**94 a**	78 ab	4 b	**69 a**	**21 c**	38 b
>5 mo	51 a	53 a	48 a	40 a	43 ab	25 b	52 a	56 a
Pratylenchus in roots								
0-3 mo	93 b	**99 a**	97 ab	**84 c**	57 a	56 a	52 a	50 a
>5 mo	42 a	45 a	42 a	30 a	58 a	44 a	70 a	57 a
Meloidogyne in soil								
0-3 mo	24 a	23 ab	**6 b**	22 ab	58 b	**31 c**	**79 a**	62 b
>5 mo	49 a	47 a	52 a	60 a	57 ab	75 a	48 b	44 b
Meloidogyne in roots								
0-3 mo	7 b	**0 c**	3 c	**15 a**	37 a	44 a	48 a	50 a
>5 mo	58 a	55 a	58 a	70 a	42 a	56 a	30 a	42 a
Ectoparasities								
Helicotylenchus								
0-3 mo	37 a	24 a	34 a	39 a	26 a	55 a	63 a	30 a
>5 mo	3 ab	2 ab	4 a	1 b	41 a	59 a	61 a	53 a
Xiphinema								
0-3 mo	20 a	10 a	23 a	25 a	37 a	23 a	17 a	29 a
>5 mo	3 a	3 a	1 a	2 a	35 a	**11 b**	**12 b**	**25 b**

Table 2. (Continued) Average relative proportions of the main nematode species in sugarcane soil and roots, which best explain, among a group of other nematode variables, the location of the stars corresponding to the different treatments in the factorial plan (c.f. Fig. 3 & 4), for the two different periods and for each trial. (mo: month). Numbers were changed to arcsin (square root (x)) prior to ANOVA or t-test. Numbers in rows in bold and followed by different letters were significantly different ($p < 0.05$).

	Irrigated sugarcane				Non-irrigated sugarcane			
	SC (Control)	SC (Nematicide)	SC + Sugar bean	SC + Peanut	SC (Control)	SC (Nematicide)	SC + Velvet bean	SC + Sweet Potato
Paratrichodorus								
0-3 mo	19 a	15 a	23 a	25 a	—	—	—	—
>5 mo	62 a	69 a	53 a	67 a	—	—	—	—
Scutellonema								
0-3 mo	8 a	5 a	8 a	2 a	9 a	13 a	4 a	7 a
>5 mo	16 a	10 a	21 a	5 a	10 a	17 a	12 a	11 a
Criconematid spp.								
0-3 mo	14 b	**42 a**	10 b	8 b	28 a	9 a	16 a	34 a
>5 mo	3 b	4 ab	13 ab	**14 a**	13 a	12 a	15 a	10 a
Free-living nematodes								
0-3 mo	64b	**78 a**	72 ab	75 ab	89 a	93 a	91 a	91 a
>5 mo	44 a	43 a	39 a	42 a	40 b	39 b	**62 a**	45 b

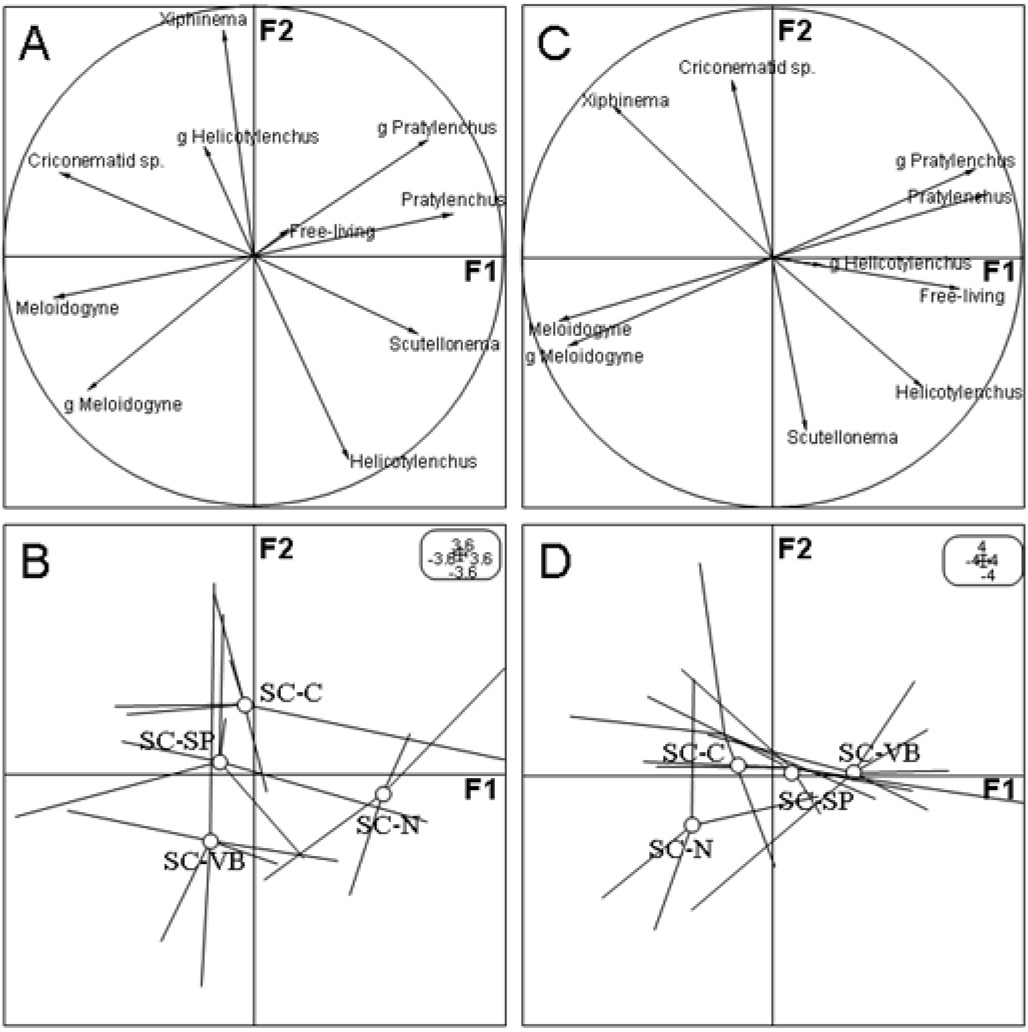

Fig. 4. Impact of treatments on the specific structure of the nematode community in non-irrigated sugarcane. Correlation circles (A & C) and F1 × F2 factorial plans (B & D) issued from the PCA of the nematode data collected between 0-3 months (A & B) and after 5 months (C & D). In the factorial plans, each treatment has been represented as a star, the branches of which link the position of each plot to the gravity centre of the corresponding treatment. (SC-C: Sugarcane Control; SC-N: Sugarcane+Nematicide; SC-SP: Sugarcane+Sweet potato; SC-VB: Sugarcane+Velvet bean).

in levels of S in the nematicide-treated plots (Table 3). As found at the irrigated site, PCA of the soil parameters at non-irrigated site (Amatikulu) placed most of the variables, except pH and S, in the positive region of the F1 axis (Fig. 5C). In the factorial plan for comparison of treatments, the gravity centres of the stars corresponding to nematicide-treated and control plots were located on opposite sides of the F1 axis (Fig. 5D). This was as a result of the lower Mg and Mn levels in the nematicide-treated plots (Table 3). Both gravity centers of the intercropped plots were located

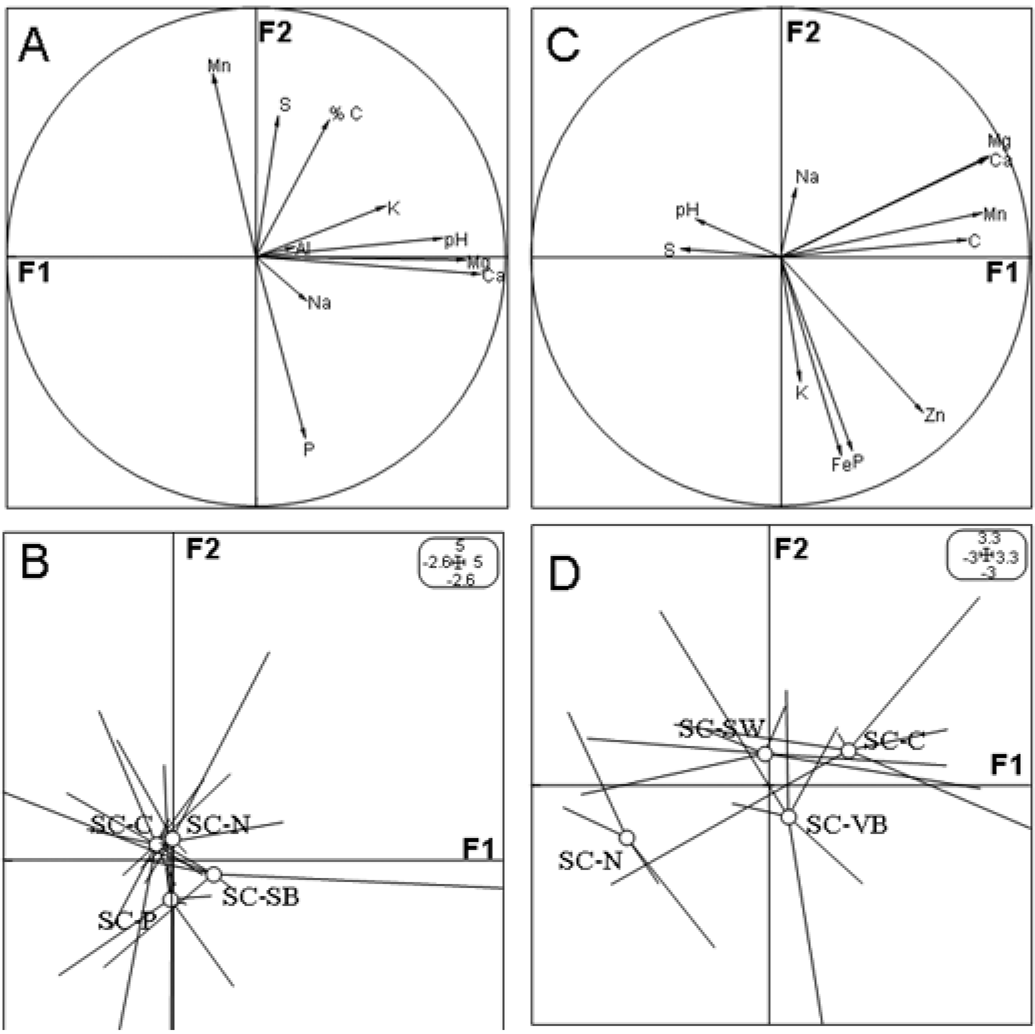

Fig. 5. Impact of treatments on the soil chemical characteristics in irrigated (A & B) and non-irrigated (C & D) sugarcane. F1 × F2 correlation circles of the PCA (A & C) and factorial plans (B & D) with each treatment represented as a star, the branches of which link the position of each plot to the gravity centre of the corresponding treatment. (SC-C: Sugarcane Control; SC-N: Sugarcane+Nematicide; SC-SB: Sugarcane+Sugar bean; SC-P: Sugarcane+Peanut; SC-SP: Sugarcane+Sweet potato; SC-VB: Sugarcane+Velvet bean).

near the origin of the factorial plan (Fig. 5D). Soils from plots intercropped with velvet bean had a significantly higher pH and higher levels of K (Table 3).

On the correlation circle of the PCA performed on the leaf chemical parameters at the irrigated site (Fig. 6A), the differences between treatments were most evident along the F1 axis (Fig. 6B). The control was located near the center of the factorial plan with the nematicide-treated and the two intercrop treatments on opposite ends. However the magnitude of these differences was small for most elements, except for increased P levels in leaves of sugarcane intercropped with peanut (Table 4).

Table 3. Average levels of the main soil elements, which best explain, within the group of soil variables, the location of the stars corresponding to the different treatments in the factorial plan, for each trial. (cf Fig. 5).

	Irrigated sugarcane				Non-irrigated sugarcane			
	SC (Control)	SC (Nematicide)	SC + Sugar bean	SC + Peanut	SC (Control)	SC (Nematicide)	SC + Velvet bean	SC + Sweet Potato
pH	7.0 a	7.4 a	7.1 a	7.0 a	5.3 b	4.4 ab	**5.5 a**	5.4 ab
P (ppm)	33.7 a	42.0 a	47.5 a	51.0 a	19.5 a	21.3 a	21.2 a	18.7 a
K (ppm)	36.5 a	28.8 a	35.8 a	32.8 a	23.1 b	22.7 b	**33.6 a**	24.6 b
Ca (ppm)	297.6 a	331.7 a	639.2 a	352.0 a	62.0 a	37.5 a	50.8 a	62.2 a
Mg (ppm)	100.6 a	106.3 a	105.7 a	103.2 a	42.8 a	**19.3 b**	36.0 ab	38.5 a
Na (ppm)	48.5 a	47.1 a	53.6 a	50.5 a	14.2 a	9.3 a	21.3 a	13.7 a
Zn (ppm)	—	—	—	—	1.7 a	1.0 a	1.7 a	1.4 a
Fe (ppm)	—	—	—	—	24.3 a	27.8 a	26.5 a	25.0 a
Mn (ppm)	57.6 a	57.5 a	50.2 a	52.2 a	19.0 a	**12.3 b**	15.7 ab	17.5 ab
S (ppm)	9.2 b	**11.3 a**	10.0 ab	9.3 ab	11.1 ab	12.7 ab	9.6 b	13.1 a
Al (ppm)	17.2 ab	17.8 a	16.5 b	18.5 a	—	—	—	—
% C	0.4 a	0.4 a	0.5 a	0.4 a	0.4 a	0.3 a	0.4 a	0.3 a

Numbers in bold and followed by different letters were significantly different from the corresponding control. (ANOVA; $P < 0.05$).

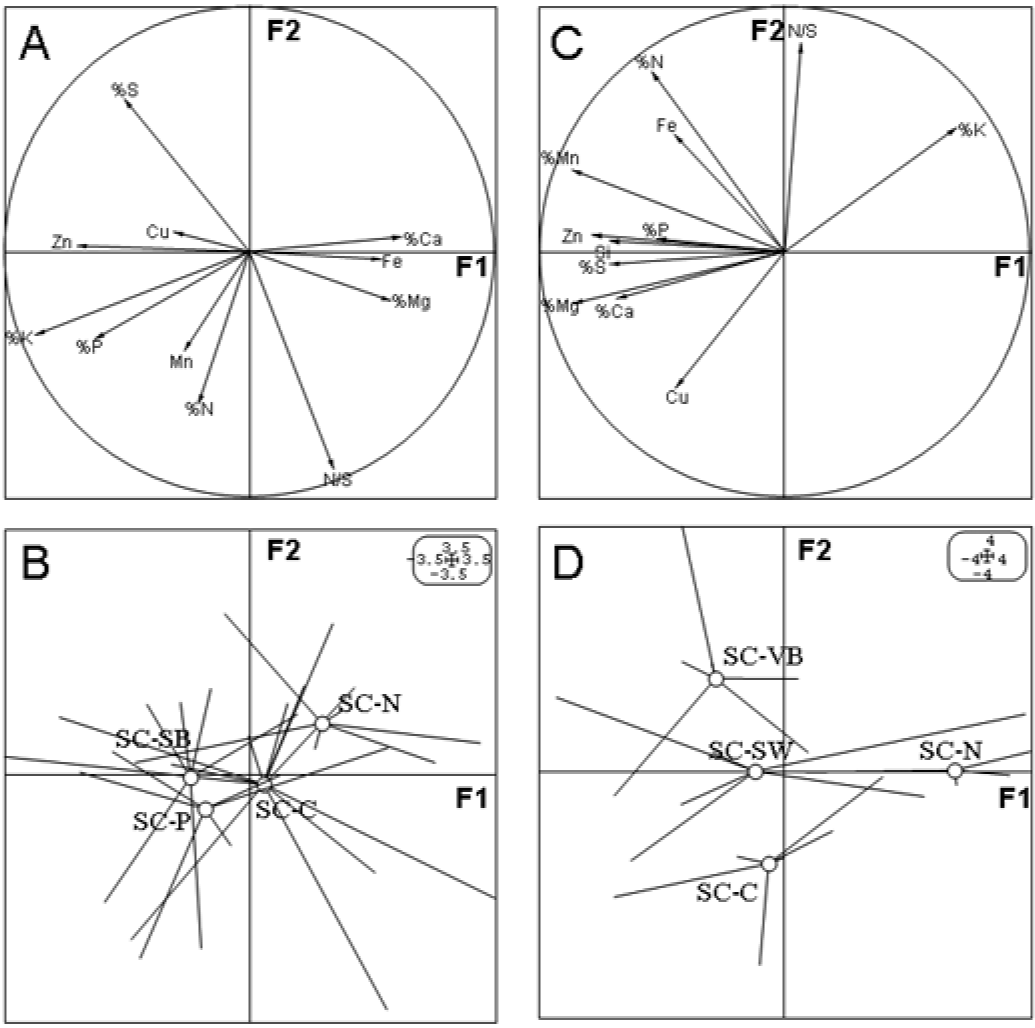

Fig. 6. Impact of treatments on the leaf chemical characteristics in irrigated (A & B) and non-irrigated (C & D) sugarcane. F1 × F2 correlation circles of the PCA (A & C) and factorial plans (B & D) with each treatment represented as a star, the branches of which link the position of each plot to the gravity centre of the corresponding treatment. (SC-C: Sugarcane Control; SC-N: Sugarcane+Nematicide; SC-SB: Sugarcane+Sugar bean; SC-P: Sugarcane+Peanut; SC-SP: Sugarcane+Sweet potato; SC-VB: Sugarcane+Velvet bean).

On the correlation circle of the PCA of leaf chemical parameters at non-irrigated site (Fig. 6C), K was opposed to all other elements. The location of the gravity center of plots intercropped with velvet bean in the positive part of F2 (Fig. 6D) can be explained by higher levels of N, K, Mn and Fe and a greater N/S ratio in the sugarcane leaves (Table 4). The nematicide treated plots were strongly correlated with the positive part of F1 (Fig. 6D) due to higher levels of K, and lower levels of Mg and Zn in the leaves (Table 4).

Table 4. Average levels of the main leaf chemical elements, which best explain, within the group of leaf variables, the location of the stars corresponding to the different treatments in the factorial plan, for each trial. (cf Fig. 6).

	Irrigated sugarcane				Non-irrigated sugarcane			
	SC (Control)	SC (Nematicide)	SC + Sugar bean	SC + Peanut	SC (Control)	SC (Nematicide)	SC + Velvet bean	SC + Sweet Potato
N %	2.20 ab	2.13 b	2.19 ab	2.25 a	1.55 b	1.56 b	**1.74 a**	1.60 b
P %	0.17 b	0.17 b	0.18 ab	**0.19 a**	0.14 a	0.14 a	0.14 a	0.14 a
K %	0.95 a	0.88 a	1.00 a	1.00 a	0.71 c	**1.12 a**	**0.92 b**	0.86 bc
Ca %	0.31 a	0.32 a	0.31 a	0.33 a	0.23 a	0.22 a	0.23 a	0.22 a
Mg %	20.00 a	21.00 a	20.00 a	20.00 a	0.21 a	**0.16 b**	0.19 a	0.20 a
S %	0.17 a	0.17 a	0.17 a	0.17 a	0.14 a	0.14 a	0.14 a	0.14 a
Mn %	87.90 a	74.10 a	85.10 a	72.00 a	87.80 bc	73.30 c	**117.20 a**	99.00 ab
Zn (ppm)	19.90 a	19.80 a	20.80 a	21.30 a	18.60 a	**15.70 b**	19.80 a	19.30 a
Cu (ppm)	5.20 a	5.30 a	5.50 a	5.10 a	5.30 a	5.00 a	5.10 a	5.10 a
Fe (ppm)	184.50 a	197.60 a	177.80 a	170.50 a	98.00 b	100.70 b	**125.80 a**	112.10 ab
N/S	13.10 a	12.60 a	12.90 a	13.10 a	10.90 b	11.30 ab	**11.80 a**	11.40 ab

Numbers in bold and followed by different letters were significantly different from the corresponding control. (ANOVA; $p < 0.05$).

Yield of intercrops and effect of intercropping on cane yield

The yield of the sweet potato when harvested between 3 and 4 months was more than 12 t tubers/ha. The mass of the velvet bean was not recorded but there was sufficient growth to provide thick mulch when they were cut back at 4 months. The peanut was pilfered before they could be weighed. Most of the sugar beans died from a foliar fungal infection before seeds were produced and no weights were recorded.

Intercropping sugarcane with sweet potato or sugar bean had no significant effect on cane or sucrose yield or quality at harvest, even though with the sweet potato there was some effect on early growth (data not shown). Intercropping with velvet bean reduced the sucrose content (%ERC) of the cane ($P<0.05$) and while tons ERC was 2 t/ha lower than the control, the difference was not significant. Intercropping with peanut was associated with a significant reduction in %ERC (-1.1%), tons cane (-18 tc/ha) and tons ERC (-3.3 t ERC/ha) (Table 5).

DISCUSSION

It has been shown that intercropping, while improving the overall sustainability and viability of the sugarcane farming enterprise, could sometimes result in even more deleterious conditions, such as increasing the populations of damaging plant parasitic nematodes when planting a nematode-susceptible intercrop (e.g. many vegetables) (Netscher and Sikora, 1990) or by increasing the levels of insect pests (Pitan and Odebiyi, 2001). Previous work by Parsons in South Africa (2003), showed the economic potential of growing various intercrops between sugarcane rows. However, in Parsons' work no data were presented on the effect of these practices on soil health or their effect on pests and diseases. Data from the current work indicated that of the four intercrops tested sugar bean was clearly different. The roots of sugar bean were more attractive to *Meloidogyne* and *Pratylenchus* nematodes than those of sugarcane, with the resultant decrease in infestation of sugarcane sett roots. However later on in the crop cycle, after the sugar bean had died, shoot roots of the sugarcane were more heavily infested than those of the control plots. This was possibly due to the larger root system of sugarcane that developed as a result of reduced nematode infestation and reduced damage of sett roots in the early phases of growth. A large number of nematodes is often indicative of the presence of a large and physiologically active root system. Fewer nematodes could indicate the presence of small and deteriorated roots with a limited host capacity because nematode are not attracted by dead roots (Lavallee and Rhode, 1962; Spaull and Cadet, 1991). Also a smaller number of nematodes may be the direct consequence of a nematicide treatment, whatever the size of the root system (Crow *et al.*, 2003). Due to the attractiveness of sugar bean to nematodes, this particular crop could be useful as a 'trap crop'. This method of nematode management has been widely used in other crops for managing, amongst others, root-knot nematodes (*Meloidogyne* spp.) and potato cyst nematodes (*Globodera* spp.) (Bridge, 1996; Akhtar, 1997). In contrast, the other three intercrops (velvet bean, peanut and sweet potato) exhibited little infestation of their roots and increased infestation of sugarcane sett and shoot roots. The reasons for this are not entirely clear. Possible explanations could be that these plants are resis-

Table 5. Effect of the nematicide and intercrop treatments on the yields (t cane ha^{-1} and t ERC ha^{-1}) and quality (%ERC) for both trials.

	t cane/ha	SE	t ERC/ha	SE	% ERC	SE
Irrigated						
SC (Control)	82.0 a	8.1	11.4 a	1.0	13.9 a	0.3
SC (Nematicide)	90.1 a	6.5	12.5 a	1.1	13.8 ab	0.4
SC + Sugar bean	82.4 a	5.1	11.3 a	0.9	13.7 ab	0.3
SC + Peanut	**64.3 b**	4.0	**8.1 b**	0.4	**12.8 b**	0.4
Non-irrigated						
SC (Control)	126.9 a	8.6	15.4 a	1.4	12.1 a	0.3
SC (Nematicide)	154.9 a	28.3	17.2 a	4.5	10.6 ab	0.8
SC + Velvet bean	129.4 a	11.1	13.4 a	1.4	**10.3 b**	0.6
SC + Sweet Potato	131.4 a	11.4	14.8 a	1.4	11.2 ab	0.3

Numbers in bold and followed by different letters were significantly different from the corresponding control. (ANOVA; $p < 0.05$).

tant to nematode invasion and reproduction or they exude allelochemicals that alter the behavior of the nematodes (Kokalis-Burrelle and Rodriguez-Kabana, 2006). Earlier work in pot trials did show that velvet bean and peanut exhibited no galling on their roots and were resistant to infestation by *M. javanica* (Berry and Wiseman, 2003), which may explain their low infestation in these field trials. The production of allelochemicals by crops such as *Mucuna deeringiana, M. pruriens, Crotalaria juncea, Brassica napus* and *Tagetes erecta* affect certain nematode species (Vargas-Ayala *et al.,* 2000; Wang *et al.,* 2003; Zasada *et al.,* 2006). Other studies showed that the effect of intercropping on nematode infestation in the principal crop was erratic and contradictory, sometimes increasing the level of infestation by certain species, as in this study, or decreasing the nematode population (Sharma and Bajaj, 1998; Sinha *et al.,* 2004). It is strongly dependent on the choice of principal and companion crops, the nematode species and on the edaphic environment.

In addition to their effect of increasing or decreasing infestation in the roots and soil, the growing of intercrops can also affect the balance of species within a nematode community. The nematode communities between 0 and 3 months showed that intercropping with sugar bean had a similar effect as using a nematicide viz. an alteration of the endoparasitic nematode community with significant reductions in *Meloidogyne* and significant increases in *Pratylenchus.* Intercropping with peanut and velvet bean had the opposite effect. Intercropping with sweet potato had little effect on nematode species balance. These effects had largely disappeared by the time sugarcane reached maturity at the fifth month. At this stage, there were significant increases in the Criconematid species for peanut and significant increases in free-living nematodes for velvet bean, however the proportions of the other major nematode species were largely unaffected. Other researchers (Wang *et al.,* 2002) have also found the residual effect to only last a few months. This suggests that using intercropping to effectively manage nematodes requires longer periods of crop growth, although this may be complicated by the sugarcane cultivation system where once the sugarcane has canopied (at approximately 6 months), the inter-rows are relatively shaded out, preventing growth of most intercrops. Thus the replanting of shade tolerant crops may be a possibility. However at this stage of sugarcane growth, the damage to the crop from plant parasitic nematodes is relatively minimal compared to that at the initial stages of growth (Cadet, 1985). Thus a reversion of the nematode community back to that in the beginning may not be that detrimental. Growing a suitable intercrop at the beginning of the growth cycle would be more beneficial.

It may be inferred that the multiplication of nematodes on the intercrop added to the infestation of the sugarcane roots, leading to a potentially disadvantageous situation for the sugarcane. This might have been expected to have a negative influence on the subsequent yield of the sugarcane. But, except for the peanut-intercropping, this was not the case, possibly because the additional organic material, brought into the row by the harvesting of the intercrops, later in the cycle, could have favoured sugarcane growth and compensated for the nematode damage. Such a green manure effect was observed with sunn hemp hay amendment by Wang *et al.,* (2003) independently of a negative effect on nematode populations. However, *Crotalaria* leaves have been shown to develop a temporary nematostatic effect (Jourand *et al.,* 2004). The increased N in the leaves of velvet bean-intercropped sugarcane at 7 months suggests that extra microfloral activity occurred in these plots. Three possibilities can be made to explain this: (i) soil nitrogen-fixing activity of the legume plant increased levels of N in the soil to the benefit of the sugarcane (Bandyopadhyay, 1986; Govinden and Ramasamy, 1994); (ii) decomposition of the vines, and (iii) the abrupt multiplication of free-living nematodes immediately after planting suggested that the inoculation of the velvet bean seeds by *Rhizobium* could have triggered an instant multiplication of bacteria, which would have increased soil N (Yanni *et al.,* 1997; West *et al.,* 2002). A large number of free-living nematodes mirror the parallel multiplication of the microflora (bacteria and fungi), on which these nematodes feed (Zunke and Perry, 1997). In Egypt, sugarcane intercropped with mung bean also resulted in improved soil fertility, particularly in increased levels of N and P in the soil (El-Hafiez *et al.,* 2003). However, high levels of soil N although increasing sugarcane growth can also retard sucrose accumulation (Muchow *et al.,* 1996). Thus the depressed %ERC of sugarcane in plots intercropped with velvet bean could be explained by the increase in the levels of N in the leaves associated with the N fixation by the intercrop.

These increased levels of nutrients, along with the presumed organic amendment effect, may explain why for three of the intercropping treatments, there was no significant reduction in final sugarcane and sucrose yield even though the early growth was seemingly retarded. Similar work on sandy clay loam soils in Kenya found that intercropping with maize and soybean, regardless of the planting pattern, significantly decreased sugarcane tillering at the beginning of the cycle. However, yields at harvest were not affected. Intercropping with beans did not affect sugarcane tillering, yield or quality at harvest. Sugarcane yield was also better when intercropped with common bean or soybean than in a pure stand (Anon., 1999). In Pakistan, intercropping with berseem and wheat in ratoon crops reduced sugarcane yield by 3 and 9% respectively. However, the overall income per hectare was substantially increased (Solangi *et al.,* 1987). Further optimization of the intercropping technique for sugarcane cultivation could include: planting these intercrops every alternate row (as suggested by Parsons, 2003), increasing the row spacing, planting these crops in the inter-row and not adjacent to the sugarcane row, and reducing the amount of seed sown per inter-row.

Sowing an appropriate intercrop between sugarcane rows seems to be an efficient way of utilizing limited resources for small-scale farmers in particular. However, additional knowledge needs to be gained on the best intercrops. Whereas the success of sugarcane cultivation is based on monocropping, the success of intercropping is based on crop diversity, to avoid punctual overflow of similar products on the market and reduce pest and disease build-up. Biologically related practices, such as intercropping, can lead towards the establishment of a more balanced nematode community, often dominated by less damaging species. Such a re-balancing effect is likely to be a long-term process. Thus in the short term, often the economical profit is considered advantageous to the grower. However, in the long term, this diversity-based system will be of greater benefit particularly in terms of overall improvement in soil quality and better management of nematode losses.

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LITERATURE CITED

Akhtar, M. 1997. Current options in integrated management of plant-parasitic nematodes. Integrated Pest Management Reviews 2:187-197.

Allison, J. C. S., N. W. Pammenter, and R. J. Haslam. 2007. Why does sugarcane (*Saccharum* sp. hybrid) grow slowly? South African Journal of Botany 73:546-551.

Anonymous. (1999). http://www.kari.org/1999AReport/Sugarcane.htm

Bandyopadhyay, S. K., and R. De. 1986. N relationship in a legume-non legume association grown in an intercropping system. Fertilizer Research 10:73-82.

Barnard, R. O., A. J. Buys, J. G. K. Coetzee, C. C. Du Prees, J. H. Meyer, J. A. J. van Vuuren, J. E. Volschen, F. Bessinger, and J. J. N. Lambrechts. 1990. Handbook of standard soil testing methods for advisory purposes. 132 pp. South African Sugarcane Experiment Station, Mount Edgecombe, South Africa.

Berry, S., and E. J. Wiseman. 2003. The effect of cover crops on plant parasitic nematodes in the South African Sugar Industry. Proceedings of the 77th Congress of the South African Sugar Technologists Association, pp. 114-117.

Bridge, J. 1987. Control strategies in subsistence agriculture. Pp. 389-420 *in* R. H. Brown, and B. R. Kerry, ed. Principles and Practice of Nematode Control in crops. Academic Press, Australia.

Bridge, J. 1996. Nematode management in sustainable and subsistence agriculture. Annual review of Phytopathology 34:201-225.

Cadet, P. 1985. Incidence des nématodes sur les repousses de canne à sucre au Burkina Faso et en Côte d'Ivoire. Revue de Nématologie 8:277-284.

Cardinale, B. J., C. T. Harvey, K. Gross, and A. R. Ives. 2003. Biodiversity and biocontrol: emergent impacts of a multi-enemy assemblage on pest suppression and crop yield in an agroecosystem. Ecology Letters 6:857-865.

Clermont-Dauphin, C. 1995. Relationship between beans and maize intercropped in a ferrallitic soil in Haiti. Pp. 445-454 *in* H. Sinoquet, and P. Cruz ed. Ecophysiology of tropical intercropping. INRA Editions, Paris.

Crow, W. T., R. M. Giblin-Davis, and D. W. Lickfeldt. 2003. Slit injection of 1,3-Dichloropropene for management of *Belonolaimus longicaudatus* on established bermudagrass. Journal of Nematology 35:302-305.

El-Hafiez, A., A. Zohry, and A. I. N. A. El-Aal. 2003. Soil morphological features and competition of intercropping mung bean with sugarcane in upper Egypt. Egyptian Journal of Agricultural Research 81:1-14.

Fargette, D., and C. M. Fauquet. 1988. A preliminary study on the influence of intercropping maize and cassava on the spread of African cassava mosaic virus by whiteflies. Annals of Applied Biology 17:195-202.

Govinden, N., and S. Ramasamy. 1994. Indexing of sugar cane lands in Mauritius: I. Food crop suitability and production potential of miller-planters lands. Revue Agricole Sucriere de l'Ile Maurice 73:11-20.

Jourand, P., S. Rapior, M. Fargette, and T. Mateille. 2004. Nematostatic effects of a leaf extract from *Crotalaria virgulata* subsp. grantiana on *Meloidogyne incognita* and its use to protect tomato roots. Nematology 6:79-84.

Khakwani, A. A., H. K. Ahmad, G. Hassan, and F. U. Khan. 2001. Studies on sugarcane-sunflower intercropping system at different geometrical patterns and NPK levels during autumn planting. Pakistan Journal of Biological Sciences 4:1209-1211.

Kokalis-Burelle, N., and R. Rodriguez-Kabana. 2006. Allelochemicals as biopesticides for management of plant parasitic nematodes. Pp. 15-29. *in* Inderjit and K. G. Mukerji, Ed. Disease Management of Fruits and Vegetables-Volume 2. Allelochemicals: Biological Control of Plant Pathogens and Diseases. Springer, Netherlands.

Lavallee, W. H., and R. A. Rohde. 1962. Attractiveness of plant roots to *Pratylenchus penetrans* (Cobb). Nematologica 8:252-260.

Muchow, R. A., M. J. Robertson, A. W. Wood, and B. A. Keating. 1996. Effect of nitrogen on the time-course of sucrose accumulation in sugarcane. Field Crops Research 47:143-153.

Netscher, C., and R. A. Sikora. 1990. Nematode parasites of vegetables. Pp. 237-284 *in* M. Luc, R. A. Sikora, J. Bridge, Ed. Plant parasitic nematodes in subtropical and tropical agriculture. CAB International, United Kingdom.

Ofori, F., and W. R. Stern. 1987. Cereal-legume intercropping systems. Advances in Agronomy 141:41-89.

Parsons, M. J. 2003. Successful intercropping of sugarcane. Proceedings of the South African Sugar Technologist Association 77:77-98.

Pitan, O. O. R., and J. A. Odebiyi. 2001. The effect of intercropping with maize on the level of infesta-

tion and damage by pod-sucking bugs in cowpea. Crop Protection 20:367-372.
Sathyavelu, A., K. Chinnasamy, and S. Rajasekaran. 1991. Studies on intercropping in sugarcane with pulses and oilseeds. Sissta Sugar Journal of Sugarcane Research, Tamil Nadu, India 19:35-37.
Seinhorst, J. W. 1950. De betekenis van de toestand van de grond voor het optreden van aantasting door het stengelaaltje (*Ditylenchus dipsaci* (Kühn) Filipjev). Tijdschrift over Plantenziekten 56:289-348.
Seinhorst, J. W. 1962. Modifications of the elutriation method for extracting nematodes from soil. Nematologica 8:117-128.
Sharma, G. C., and B. K. Bajaj. 1998. Effect of intercropping bell-pepper with ginger on plant parasitic nematode populations and crop yields. Annals of Applied Biology 133:199-205.
Sinha, U. P., M. G. Haidar, and D. Kumkum. 2004. Effect of intercropping of mustard (*Brassica campestris* var. Toria/B. *campestris* var. Sarson) with sugarcane on nematode population and yield of crop. Indian Journal of Nematology 34:160-164.
Solangi, G. Y., G. M. Rajper, and N. K. Udhejo. 1987. Studies on some economic aspects of intercropping in sugarcane. Pakistan Journal of Agricultural Research 8:379-382.
Spaull, V. W., and P. Cadet. 1991. Studies on the relationship between nematodes and sugarcane in South and West Africa: Ratoon Cane. Revue de Nematologie 14:183-186.
Sumner, D. R., B. Doupnik, and M. G. Boosalis. 1981. Effects of reduced tillage and multiple cropping on plant diseases. Annual Review of Phytopathology 19:167-187.
Thioulouse, J., D. Chessel, S. Dolédec, and J. M. Olivier. 1997. ADE-4: a multivariate analysis and graphical display software. Statistics and Computing 7:75-83.
Vargas-Ayala, R., R. Rodríguez-Kábana, G. Morgan-Jones, J. A. McInroy, and J. W. Kloepper. 2000. Shifts in soil microflora induced by velvetbean (*Mucuna deeringiana*) in cropping systems to control root-knot nematodes. Biological Control 17:11-22.
Wang, K. H., B. S. Sipes, and D. P. Schmitt. 2002. *Crotalaria* as a cover crop for nematode management: A review. Nematropica 32:35-57.
Wang, K. H., R. McSorley, and R. N. Gallaher. 2003. Effect of *Crotalaria juncea* amendment on nematode communities in soil with different agricultural histories. Journal of Nematology 35:294-301.
West, S. A., E. T. Kiers, E. L. Simms, and R. F. Denison. 2002. Sanctions and mutualism stability: why do rhizobia fix nitrogen? Proceedings of the Royal Society of Biological Sciences 269:685-694.
Wood, R. A., J. H. Meyer, and M. Govender. 1985. A rapid system of cane leaf analysis using x-ray spectrometry and infra-red reflectance. Proceedings of the South African Sugar Technologists Association 59:195-201.
Yanni, Y. G., R. Y. Rizk, V. Corich, A. Squartini, K. Ninki, S. Philip-Holingsworth, G. Orgambide, F. de Bruijn, J. Stoltzfus, D. Buckley, T. M. Schmidt, P. F. Mateos, J. K. Ladha, and F. B. Dazzo. 1997. Natural endophytic association between *Rhizobium leguminosarum* bv. *trifolii* and rice roots and assessment of its potential to promote rice growth. Plant and Soil 194:99-114.
Zasada, I. A., W. Klassen, S. L. F. Meyer, M. Codallo, and A. A. Abdul-Baki. 2006. Velvetbean (*Mucuna pruriens*) extracts: impact on *Meloidogyne incognita* survival and on *Lycopersicon esculentum* and *Lactuca sativa* germination and growth. Pest Management Science 62:1122-1127.
Zunke, U., amd R. N. Perry. 1997. Nematodes: Harmful and beneficial organisms. Pp. 85-133 *in* G. Benckiser, ed. Fauna in soil ecosystems. Marcel Dekker Incorporated, New York, Basel, Hong Kong.

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