RESEARCH/INVESTIGACIÓN

POPULATION RESPONSES OF PLANT-PARASITIC NEMATODES IN SELECTED CROP ROTATIONS OVER FIVE SEASONS IN ORGANIC COTTON PRODUCTION

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ABSTRACT

Van Biljon E. R., A. H. Mc Donald†, and H. Fourie. 2015. Population responses of plant-parasitic nematodes in selected crop rotations over five seasons in organic cotton production. Nematropica 45:102–112.

Crops with resistance or tolerance to the root-knot nematode, *Meloidogyne incognita* race 4, were evaluated for management of plant-parasitic nematodes in organic cotton production for five consecutive seasons. During the first two summers, *Sesamum indicum* L. (sesame), *Tagetes erecta* L. (marigold), *Crotalaria juncea* L. (sunn hemp), *Avena sativa* L. (oat), and *Gossypium hirsutum* L. (cotton) were grown. During the winter, oat followed sesame, marigold, sunn hemp, and one of the cotton regimes, while the summer oat was followed by *Crambe abyssinica* Hochst. ex R.E. Fries (*Abyssinian crambe*) during spring. The other cotton regime was left fallow during the winter. During the third summer, cotton was grown in all the rotations. The results showed that rotations such as sesame/oat, marigold/oat, and sunn hemp/oat can be beneficial in reducing *M. incognita* race 4 population densities. *Pratylenchus zeae* population densities increased following sunn hemp in summer. Cotton is not a good host for this lesion nematode species. Cotton in the sesame/oat rotation gave a higher yield than in the other rotations. Development of effective crop rotation systems becomes difficult when crop choices increase and fields are infested with multiple plant-parasitic nematode species.

Key words: cover crops, *Gossypium hirsutum*, *Meloidogyne incognita*, *Pratylenchus zeae*, rotation.

RESUMEN

Van Biljon E. R., A. H. Mc Donald† y H. Fourie. 2015. Respuesta de las poblaciones de nemátodos parásitos de plantas a rotaciones de cultivos seleccionadas durante cinco estaciones en producción ecológica de algodón. Nematropica 45:102–112.

Se evaluaron cultivos con resistencia o tolerancia al nemátodo formador de agallas en las raíces, *Meloidogyne incognita* raza 4, para el manejo de los nemátodos parásitos de plantas en producción ecológica durante cinco estaciones de cultivo consecutivas. Durante los dos primeros veranos se cultivaron, *Sesamum indicum* L. (sésamo), *Tagetes erecta* L. (caléndula), *Crotalaria juncea* L. (cáñamo de Bengala), *Avena sativa* L. (avena), y *Gossypium hirsutum* L. (algodón). Durante el invierno, avena seguida de sésamo, caléndula, cáñamo de bengala y uno de los cultivos de algodón, mientras que la avena de verano fue seguida de *Crambe abyssinica* Hochst. ex R.E. Fries (*Crambe abisínica*) durante la primavera. El otro cultivo de algodón se dejó en barbecho durante el invierno. Durante el tercer verano, se cultivó algodón en todas las rotaciones. Los resultados mostraron que las rotaciones sésamo/avena, caléndula/avena y cáñamo de Bengala/avena pueden ser beneficiosas al reducir las densidades de población de *M. incognita* raza 4. Las densidades de población de *Pratylenchus zeae* se incrementaron tras el cultivo de cáñamo de Bengala en verano. El algodón no es un buen hospedante de este nematodo lesionador. El algodón tras la rotación sésamo/avena produjo una mayor cosecha que en las otras rotaciones. El desarrollo de rotaciones de cultivos efectivas se dificulta cuando las opciones de elección de cultivos se incrementan y cuando los campos se encuentran infestados por múltiples especies de nemátodos parásitos de plantas.

Palabras clave: cultivos de cobertura, *Gossypium hirsutum*, *Meloidogyne incognita*, *Pratylenchus zeae*, rotación.

INTRODUCTION

World cotton (*Gossypium hirsutum* L.) production was almost 26 million tons in 2012, with slightly below 3.1 million tons recorded for the southern hemisphere (FAO, 2014). South African cotton production decreased from 58,798 tons in 1980 to 12,100 tons in 2012 (FAO, 2014) mainly due to the adverse impact that the international market has on local cotton production (Anonymous, 2014a). Factors contributing to lower local cotton prices include increasing world supplies of cotton, poor demand from yarn mills, decreased demand from the Chinese market, bumper crops in India, and increased cotton production in the U.S.

Profitability of cotton is, therefore, questionable under local conventional production conditions that require high-input costs to which the use of synthetically derived nematicides contributes. Organic cultivation is an option to be considered because input costs could be reduced substantially using non-synthetic fertilizers and non-chemical pest control technology. The goal of organic farming includes reducing the effects of industrial chemicals and fertilizers on topsoil while enhancing soil fertility, preventing soil erosion, promoting and enhancing biological diversity, and minimizing the risk to human and animal health and natural resources (Treadwell *et al.*, 2010). Small scale farming methods that include growing a variety of crops on smaller plots, rotating crops to maintain soil quality, and managing pests while avoiding the overuse of chemicals are still among the best ways to conserve land and contribute toward sustainable agricultural practices (Benson, 2012, Anonymous, 2014b). Organic farming excludes the application of synthetic chemicals to the environment (Seaman, 2011).

Plant-parasitic nematodes are a known constraint in cotton production, and it is important to reduce the occurrence of these pests in organic cotton-production systems (Starr *et al.*, 2005). Root-knot nematodes (*Meloidogyne* spp.) are among the most damaging and economically important pests of subtropical and tropical crops throughout the world (Stirling and Stirling, 2003; Perry *et al.*, 2009). Certain *Meloidogyne* spp. are major parasites of cotton and cause significant crop losses either directly by suppressing plant growth and development or indirectly through interactions with certain soil-borne fungal pathogens (Starr *et al.*, 2005).

Meloidogyne acronea Coetzee is known to parasitize cotton in some regions but *M. incognita* (Kofoid and White) Chitwood is considered the most important pest of cotton worldwide (Starr *et al.*, 2005). Four host races are recognized within *M. incognita* (Kirkpatrick and Sasser, 1984; Hartman and Sasser, 1985; Maqbool, 1992) of which races 3 and 4 are adapted to parasitize cotton (Starr and Veech, 1986; Robinson, 2007). In South Africa, only race 4 is known to parasitize cotton crops (Kleynhans *et al.*, 1996; Van Biljon, 2004). Results over the years have indicated that the damage done by *M. incognita* race 4 can be severe and cotton yield losses in sandy soils with a heavy infestation of this pest species can be as much as 40% (Van Biljon, 2007).

In addition to *Meloidogyne* spp., *Pratylenchus* spp. also parasitize cotton and are worldwide in their distribution (Duncan and Moens, 2006). Globally, *P. brachyurus* (Godfrey) Filipjev and Schuurmans Stekhoven, *P. neglectus* Rensch, *P. penetrans* (Cobb) Chitwood and Oteifa and *P. zeae* Graham have been associated with cotton (Kleynhans *et al.*, 1996; Starr *et al.*, 2005). Another lesion nematode species, *P. teres* Khan and Singh was first reported in South Africa from the Vaalharts irrigation area in the Northern Cape Province from soybean (Fourie *et al.*, 2001) and cotton (Carta *et al.*, 2002). The pathogenicity of this nematode species on cotton is, however, unknown. *Nanidorus* and *Paratrichodorus* spp. have also been reported from areas under local cotton production where high numbers of *P. lobatus* (Colbran) Siddiqi and *N. minor* in particular have been found (Kleynhans *et al.*, 1996; Van Biljon and Swanepoel, 2007). Various crops including tobacco (*Nicotiana tabacum* L.), wheat (*Triticum aestivum* L.), onion (*Allium cepa* L.), lettuce (*Latuca sativa* L.), and cotton were investigated as hosts for *P. meyeri* (Van Biljon, 1992; Kleynhans *et al.*, 1996). The latter authors reported damage symptoms inflicted by *P. meyeri* on cotton plants. Similar symptoms have been reported for other species in this genus, including poor top growth, wilting, and stubby roots (Christie and Perry, 1951).

Crop rotation, either during winter or summer, may seem to be a straightforward method for managing plant-parasitic nematodes. The development of crop rotation programs, however, is often confounded by external factors including: specialized cropping practices in certain geographic regions, the nature of climate patterns in an area, markets for rotation crops, and requirements for specialized equipment to grow and harvest rotation crops (Thomason and Caswell, 1987). For rotation crops to be practical, they should provide an adequate income to the producer (Ingham *et al.*, 1999; Starr *et al.*, 2007). From a nematology perspective, rotation crops should be considered based on particular nematode species that are present in a field, the host ranges of the crops to be planted, desired level of nematode population decline, and the availability of resistant crop varieties (Caswell-Chen and Westerdahl, 2004). Since cotton is often grown in monoculture in South Africa, it is a challenge to identify a range of suitable rotation crops considering the abovementioned requirements for this cultivation strategy. Crops such as *Phaseolus vulgaris* L. (dry bean), *Zea mays* L. (maize), *Solanum tuberosum* L. (potato), *Glycine max* L. Merr (soybean), *Helianthus annuus* L. (sunflower) and *Triticum aestivum* L (wheat) that may be attractive for their rotation attributes in local cotton production systems can be highly susceptible to a wide range of *Meloidogyne* and *Pratylenchus* spp. (Kleynhans *et al.*, 1996; Keetch and Buckley, 1984). Thus, to enable the sustainable production of cotton in local regions where nematode pests pose problems, such as the Vaalharts Irrigation Scheme, crops that are known for their adverse effects on nematode development and reproduction should be considered as potential cover or rotational crops. One such crop is sesame (*Sesamum indicum* L.), a crop valued for its oil and seed with suppressive activity against *M. arenaria* and *M. incognita* (Rodríguez-Kábana *et al.*, 1994; Walker *et al.*, 1998). Abyssinian mustard or crambe (*Crambe abyssinica* Hochst. ex R.E. Fries) also significantly suppressed numbers of *M. incognita* in soil and roots in comparison with a susceptible intercrop (Curto *et al.*, 2005), and sunn hemp, (*Crotalaria juncea* L.) is reported to suppress plant-parasitic nematodes in several field tests (Sipes and Arakaki, 1997; Robinson and Cook, 2001; Wang *et al.,* 2002; Adegbite *et al.*, 2005; Wang *et al.*, 2007). Cover crops, including sunn hemp were found to be resistant to populations of *M. arenaria* (Neal) Chitwood, *M. incognita* and *M. javanica* (Treub) Chitwood (McSorley, 1999; Akhtar and Malik, 2000). Also, marigolds (*Tagetes minuta* L.; *T. patula* L.) are known antagonists to plant-parasitic nematodes (McSorley, 1999; Mc Sorley *et al.*, 2009), and potential cover crops such as crambe, marigold, and oat (*Avena sativa* L.) produce chemicals that are toxic to nematodes (Volkmar, 1991; Donkin *et al.*, 1995; Hagan *et al.*, 1998; Mitkowski and Abawi, 2004).

The purpose of this study was to evaluate the effect of several potential rotation crops in different, practically applicable crop regimes for their effect on nematode populations in an organic cotton-farming system over several seasons.

MATERIALS AND METHODS

A field study was conducted for five consecutive seasons (October 2008 to April 2011) at a site near Jan Kempdorp (27.95764 °S; 24.83881 °E) that is situated in the Vaalharts Irrigation Scheme in the Northern Cape Province of South Africa.

Before beginning the study, the field was ploughed and disced to obtain a fine tilth. Analyses of soil particle size were done according to the hydrometer method of Day (1965) modified from Bouyoucos (1951). The experiment site had 83% sand, 5% silt, and 11% clay. The soil pH was 6.7, the electrical resistance 765 ohms, and carbon content 0.32% (Walkley and Black,1934) at a depth of 30 cm.

The different regimes used, as well as the planting and harvesting dates for each crop and season, are listed in Table 1. Sesame, marigold, oat, and sunn hemp were grown as summer rotation crops with cotton. During the winter, oat was grown as a cover crop in four of the crop regimes. One regime was left fallow during winter, and crambe was planted in the spring in a summer-oat regime. A fallow regime served as the control. In this study, cotton was grown as the final crop in all the regimes.

Six crop regimes were arranged in a randomized complete block design (RCBD) with six replicates each. Plot size was 6 m x 5 m, with 2-m bare strips left between plots to minimize inter-plot effects. The number of rows planted for each of the crops varied as follows: 6 for cotton, marigold, and sunn hemp and 37, 35, and 10 for crambe, oat, and sesame, respectively. Intra-row spacings for cotton, crambe, oat, and sesame were 20, 10, 5, and 3 cm and inter-row spacings for these crops were 1 m, 60 cm, 16 cm, and 17 cm, respectively. Marigold and sunn hemp seeds were broadcasted by sprinkling the seeds proportionally across a 300-mm wide area over the rows, with 1 m inter-row spacings. The seeding rates for cotton, crambe, marigold, oat, sesame, and sunn hemp were 150 seed plot^{-1}, 17 kg ha^{-1}, 5 kg ha^{-1}, 75 kg ha^{-1},3,3 kg ha^{-1} and 75 kg ha^{-1}, respectively. Except for cotton and sesame, which were harvested at maturity at the end of each season and before physiological seed maturity, the aerial parts of all crops were cut and incorporated into the soil. The remaining stalks of the cotton and sesame were incorporated directly after harvest. All plants were harvested in each plot to minimize the effect of compensation where plants were previously removed for nematode assessments.

Weed control practices included shallow soil cultivation using hoes, combined with selective hand-weeding to ensure weed-free plots. No inorganic fertilizers or insecticides were used for the duration of the study. Matured, composted cow manure provided by a nearby commercial supplier was applied on all plots before planting at a rate of 20 t ha^{-1} every summer and 10 t ha^{-1} every winter (Ratter, 2004). The trial received supplementary, overhead sprinkler irrigation as rainfall in the region is too low for sustainable crop production under rainfed conditions.

To assess nematode population densities before planting the initial crops, soil samples were obtained by taking 20 cores, 30-cm deep and 5-cm in diam., arbitrarily within the middle 4 rows or 1 m inside the

Table 1. Rotation regimes studied over five consecutive seasons (2008 to 2011) for the control of plant-parasitic nematodes in an organic cotton field study at Jan Kempdorp, Northern Cape Province of South Africa.

Crop regime	Summer 1 (2008/9) [planted 22/10/2008; slashed and ploughed 29/4/2009][z]	Winter 1 (2009) [planted 15/06/2009; slashed and ploughed 21/9/2009][z]	Summer 2 (2009/10) [planted 28/10/2009; slashed and ploughed 19/4/2010][z]	Winter 2 (2010) [planted 18/06/2010; slashed and ploughed 8/9/2010][z]	Summer 3 (2010/11) [planted 20/10/2010; harvested 8/5/2011]
Sesame/Oat	Sesame [harvested 22/4/2009]	Oat	Sesame [harvested 12/4/2010]	Oat	Cotton
Marigold/Oat	Marigold	Oat	Marigold	Oat	Cotton
Sunn hemp/Oat	Sunn hemp	Oat	Sunn hemp	Oat	Cotton
Oat/Crambe	Oat	Crambe [planted 17/08/2009]	Oat	Crambe [planted 19/08/2010]	Cotton
Cotton/Oat	Cotton [harvested 22/10/2008]	Oat	Cotton [harvested 12/4/2010]	Oat	Cotton
Cotton/Fallow	Cotton [harvested 22/10/2008]	Fallow	Cotton [harvested 12/4/2010]	Fallow	Cotton

[z]Except where indicated otherwise in the same column

perimeter of each plot. The soil samples from each plot were combined and thoroughly mixed to obtain one composite sample. Nematodes were extracted according to the procedure of Jenkins (1964) from one 250-ml subsample taken from the composite sample from each plot for identification and quantification of all plant-parasitic nematodes that were recovered. To determine nematode root infection, 4 randomly selected plants from the 4 center rows of each plot or from the area 1 m inside the perimeter of plots of crops that were broadcast seeded (marigold and sunn hemp) were sampled 12 wk after planting. The roots from each plot were excised, combined, and cut into approximately 1-cm sections. A 10-g subsample was taken after thorough mixing. Nematodes were extracted from the excised roots by maceration and sugar-centrifugal flotation (Coolen and D'Herde, 1972) for identification and quantification of nematodes that were present. The soil samples from the fallow plots in winter were taken, and nematodes were extracted as described earlier.

The nematode numbers from soil and roots were subjected to a $\log_e(x+1)$ transformation before factorial analysis of variance (ANOVA) was performed. The different crop regimes served as the main effects, while the five seasons (time) represented the sub factors (Little and Hills, 1972). Shapiro-Wilk's test was performed on the standardized residuals to test for deviations from normality (Shapiro and Wilk, 1965). Student's t-LSD (least significant difference) was calculated at a 5% level to compare means for significant effects (Snedecor and Cochran, 1967). All the statistical procedures were done with SAS Version 9.2 statistical software (SAS Institute, Inc. 1999). The initial (before planting) soil nematode counts from each plot and the yield data were analyzed using Genstat 13 (VSNi International, 2010) and were subjected to an ANOVA. Means were compared by Tukey's Multiple Range Test ($P \leq 0.05$).

RESULTS

Nematode taxonomists at the Nematology Unit at the Agricultural Research Council-Plant Protection Research Institute's (ARC-PPRI) National Collections in Pretoria identified the *Meloidogyne* and *Pratylenchus* spp. present in soil and root samples obtained at the study site as *M. incognita* and *P. zeae*. These endoparasitic species were present in all the experimental plots throughout the study. Ectoparasitic nematode species such as *Paratrichodorus lobatus* (stubby-root nematode), and *Hoplolamus* spp. (lance nematodes) were present in low numbers for the duration of this study and warrant no further discussion. Race differentiation by means of the North Carolina Differential Host Test (Taylor and Sasser, 1978) indicated that *M. incognita* race 4 was present at the study site. This biotype was also the predominant nematode pest in all plots before the initial crops were planted (Table

Table 2. *Meloidogyne incognita* (RKN) and *Pratylenchus zeae* (LESN) population densities in the soil (250 ml) before planting (October 2008) in various cropping regimes in an organic cotton field study near Jan Kempdorp, Northern Cape Province of South Africa.

	Sesame/Oat	Marigold/ Oat	Sunn hemp/ Oat	Oat/ Crambe	Cotton/Oat	Cotton/ Fallow[z]	CV	LSD
RKN[w]	4.78[y] (145±83)	4.65 (117±62)	4.62 (138±91)	4.67 (117±64)	4.88 (200±154)	5.30 (272±229)	17.0	n/s
LESN[x]	1.09 (3±4)	1.16 (3±2)	1.05 (3±3)	1.22 (3±2)	1.90 (7±6)	1.02 (2±2)	29.6	n/s

[w]RKN = root-knot nematodes (*Meloidogyne incognita* race 4)
[x]LESN = lesion nematodes (*Pratylenchus zeae*)
[y]$Log_e(x + 1)$ transformed; real means followed by standard deviations in parenthesis
[z]Clean fallow = without the presence of any weeds/plants on the plot (weed free)

2). At the beginning of the study lesion nematodes were present in comparatively lower numbers than root-knot nematodes (Table 2). All plant-parasitic nematodes were, however, comparable across the plots according to the ANOVA. Only root-knot and lesion numbers were subjected to ANOVA analyses at the 12-wk samplings because the other nematode numbers were too low and variable.

A significant interaction ($P \leq 0.0001$; F ratio = 4.77) existed between the crop regimes and seasons (time) for *M. incognita* population levels 10 g^{-1} roots, indicating that this population reacted differently to the different crop regimes over time. Root-knot nematode population densities at 12 wk after planting differed substantially between the respective crops for each of the growing seasons (winter and summer). Crops that were grown in summer had significantly ($P \leq 0.05$) higher population levels in general compared to their counterparts grown during both winter seasons (Fig. 1). The only exceptions were the sesame/oat and marigold/oat regimes, which did not differ in terms of root-knot nematode numbers among the first two summer and both winter seasons.

Among the crops tested, cotton supported the highest ($P \leq 0.05$) density of *M. incognita* after marigold and oat during the final summer season. Sunn hemp and oat also supported relatively high numbers of root-knot nematodes during the first summer while sesame and marigold were relatively poor hosts to this nematode pest. There was a decline in root-knot numbers in all the winter crops in 2009, with even lower numbers the following winter (2010) in all regimes (Fig. 1). Although *M. incognita* populations in the sesame/oat and marigold/oat regimes were relatively low throughout the study, the nematodes increased to a limited degree when cotton was planted on these plots during the final summer (2010/2011). Although final root-knot nematode numbers in cotton roots were still significantly ($P \leq 0.05$) lower for plots, they did not differ significantly from the marigold/oat, sunn hemp/oat, oat/crambe as well as the cotton/fallow regimes (Fig. 1). The sunn hemp/oat regime did not support *M. incognita* during the second summer, which was in contrast with the high population densities it maintained during the initial summer. In the final summer (2010/2011), the sunn hemp/oat and sesame/oat regimes had the lowest root-knot nematode populations detected in cotton roots. Although the oat/crambe regime supported less ($P \leq 0.05$) root-knot nematodes than the cotton-dominated regimes during the first two summers, it maintained similar population levels during the final summer and thus did not seem to have a suppressive effect on this nematode pest in the long term. The cotton/oat and cotton/fallow regimes showed similar trends in terms of maintaining high root-knot numbers in summer, although in the cotton/fallow regime, the numbers were always lower, but not significantly lower, than in the cotton/oat regime. Low winter population levels of *M. incognita* did not seem to have a great effect on their establishment in cotton even after two winters of cover cropping or clean fallow. Although root-knot nematodes were present in cotton in all regimes during the final growing season (2010/2011), infestation levels were lower on average than those in the cotton during the previous two growing seasons (Fig. 1). Higher ($P \leq 0.05$) root-knot nematode population levels were present in cotton/oat regimes during the first two summers compared to the final summer season. In contrast, population levels in cotton/fallow regimes varied among the three summer seasons with those during the first summer being the highest

A significant interaction ($P \leq 0.0001$; F ratio = 27.2) existed between the respective crop regimes and seasons (time) for *Pratylenchus zeae* population levels 10 g^{-1} roots, indicating that this nematode pest reacted differently to the different crop regimes and also over time. Lesion nematode numbers (Fig. 2) also varied among the crop regimes, particularly

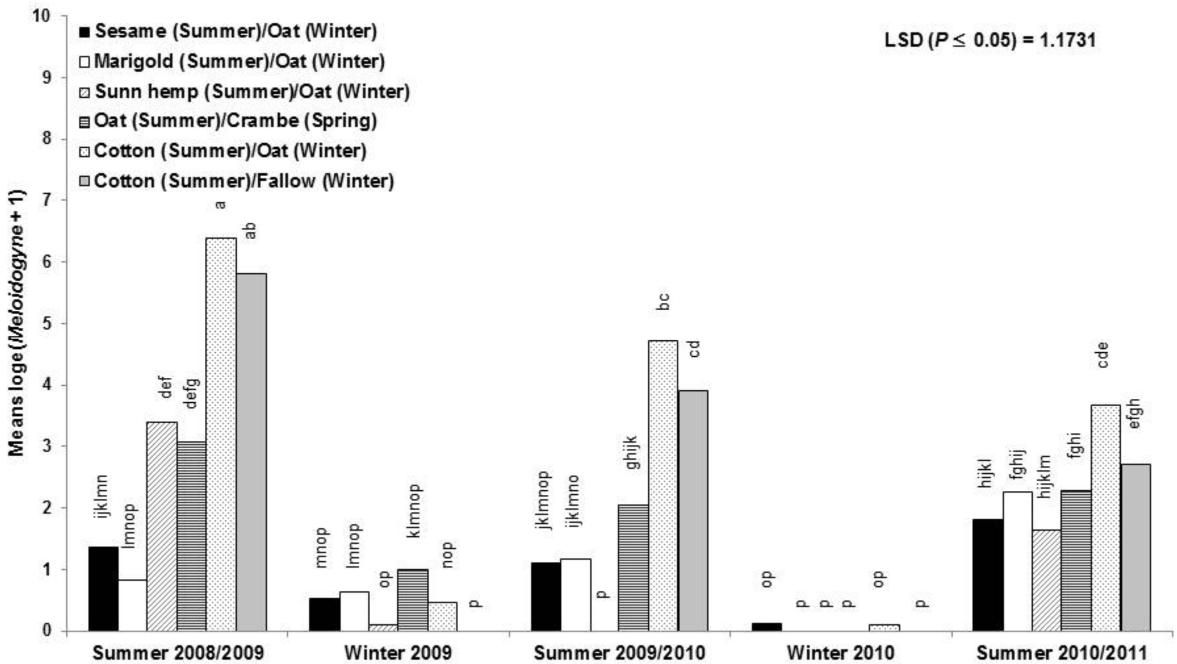

Fig. 1. The effect of crop rotation regimes over time (summer 2008/2009 to summer 2010/2011) on a *Meloidogyne incognita* race 4 population in roots (10 g) of crops at 12 wk after planting in an organic cotton-farming study at Jan Kempdorp, Northern Cape Province of South Africa. Means of treatments designated with the same letter on top of each column do not differ significantly (Tukey's multiple range test; $P \leq 0.05$).

during the first two summers and first winter. The sunn hemp/oat rotation regime and to a lesser extent the sesame/oat regime increased lesion nematode population densities, particularly during the summer of 2009/2010 when higher ($P \leq 0.05$) nematode numbers were present in both regimes. Lesion nematode numbers were also higher in sunn hemp than in sesame during the summers of 2008/2009 and 2009/2010 and the winter of 2009 (Fig. 2). Oat in winter and crambe planted in the spring supported more lesion nematodes than root-knot nematodes during the cool season. Cotton was a poor host for this lesion nematode species (Fig. 2) and population levels remained low throughout the study in the cotton regimes. In contrast with root-knot nematodes during the final summer, lesion nematode numbers were low in cotton in all crop regimes. Although sunn hemp seemed to be a better host than sesame to lesion nematodes in the preceding summers where cotton was grown as the final crop, population densities were higher than in the marigold/oat, cotton/oat, and cotton/fallow regimes and similar to those in the sunn hemp/oat and oat/crambe regimes (Fig. 2).

Significantly ($P \leq 0.05$) higher cotton yields were obtained in the final summer (2010/11) in the sesame/oat, marigold/oat, and cotton/oat regimes than in the sunn hemp/oat, oat/crambe, and cotton/fallow regimes (Fig. 3). There was, however, no significant correlation (data not shown) between root-knot or lesion nematode numbers and yield of cotton in the final season of this study.

DISCUSSION

In this study, *M. incognita* race 4 was the dominant plant-parasitic nematode on cotton in the experimental site at the Vaalharts Irrigation Scheme, followed by *P. zeae*. The general decline in *M. incognita* race 4 and *P. zeae* numbers over the five seasons in this study was interesting. Seasonal fluctuations in precipitation are unlikely to have contributed towards the latter scenario because of the supplementary irrigation that was applied. However, soil temperature and other edaphic factors such as pH or carbon content might have changed during the time that the experiment was conducted but these were only measured before onset of the experiment and not at termination, so no conclusions can be drawn. Long-term studies, measuring a broader set of soil parameters, will be needed to obtain an accurate picture of the population dynamics of plant-parasitic nematodes over time under different crop regimes

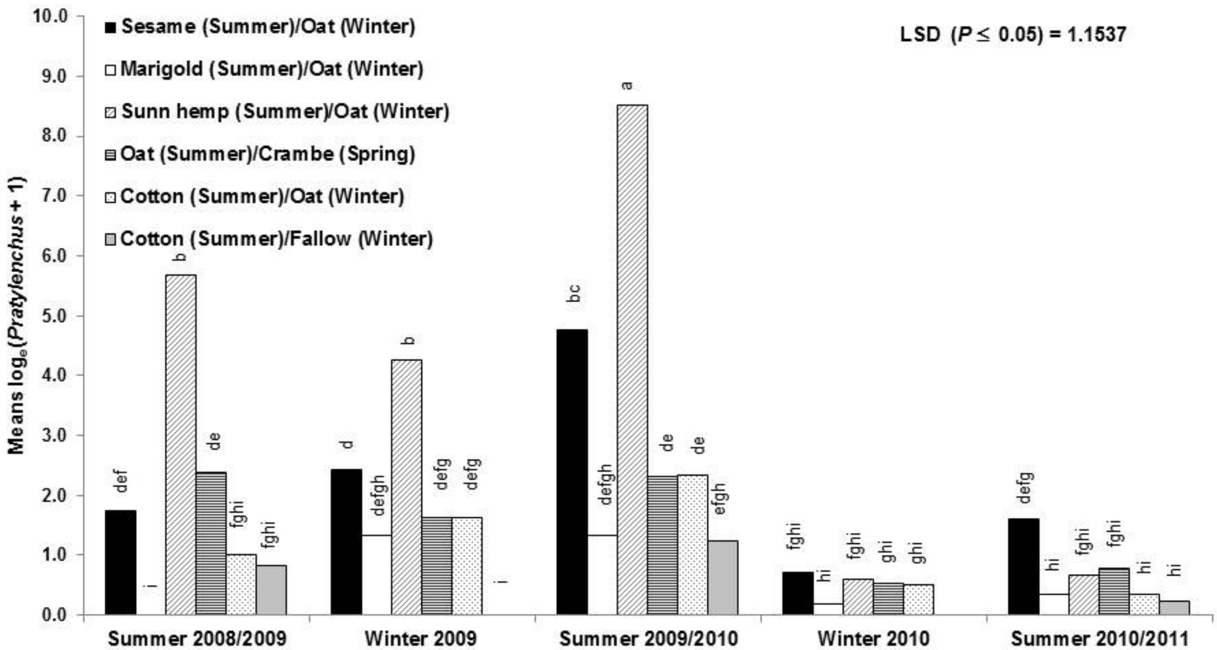

Fig. 2. The effect of crop rotation regimes over time (summer 2008/2009 to summer 2010/2011) on a *Pratylenchus zeae* population in roots (10 g) of crops at 12 wk after planting in an organic cotton-farming study at Jan Kempdorp, Northern Cape Province of South Africa. Means of treatments designated with the same letter on top of each column do not differ significantly (Tukey's multiple range test; $P \leq 0.05$).

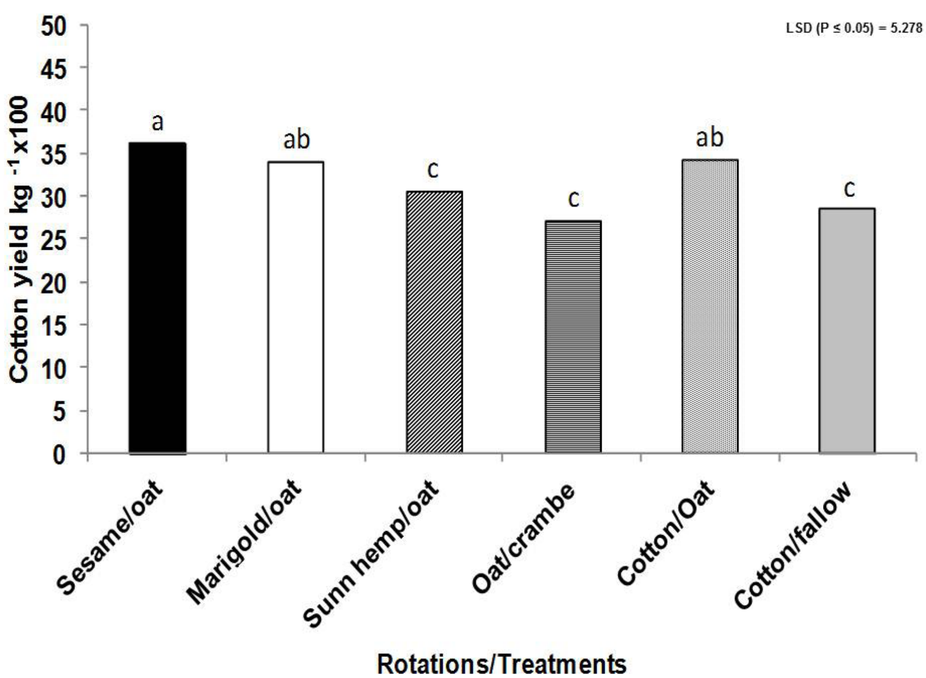

Fig. 3. Cotton yield at the end (summer 2010/2011) of an organic cotton-farming study on the effect of crop rotation regimes on the Vaalharts Irrigation Scheme at Jan Kempdorp, Northern Cape Province of South Africa. Means of treatments designated with the same letter on top of each column do not differ significantly significantly (Tukey's multiple range test; $P \leq$ 0.05).

(Thoden *et al.*, 2011).

These results, however, showed that certain rotation regimes could be beneficial in reducing numbers of *M. incognita* that could be harmful to cotton. Our results showing that sunn hemp supported high root-knot nematode numbers in the first season are contradicted by Marla *et al.* (2008) and McSorley (1999), who found very low reproduction on *C. juncea*. Akhtar and Malik (2000) also found sunn hemp to be a poor host to populations of *M. arenaria*, *M. incognita*, and *M. javanica*. McSorley (1999) and McSorley *et al.* (2009) concluded that sunn hemp performed well as a root-knot nematode resistant crop, although they suggested that low numbers of certain plant-parasitic nematodes might survive or even increase on sunn hemp. It is possible that sunn hemp cultivars may differ in their suitability to *M. incognita* or that the population that was present in soil at our study site was more aggressive than the isolates in studies by the other researchers.

In our study, sesame was a poor host to *M. incognita*, which agrees with an earlier report by Walker *et al.* (1998), who introduced sesame accessions resistant to *M. incognita* into the USDA Plant Introduction Collection. Starr and Black (1995) found sesame to be resistant to *M. incognita* races 1 and 3, and our results suggest that *M. incognita* race 4 could be added to that list.

Curto *et al.* (2005) found that crambe significantly suppressed *M. incognita* second-stage juveniles in soil and nematodes in roots in comparison with a susceptible intercrop. Our results were similar as summer rotation of oat and cotton with crambe resulted in root-knot population densities that were comparable to the non-cotton combinations tested.

Susceptibility of oat cultivars to *Meloidogyne* spp. has been demonstrated by several authors, including Pederson and Rodríguez-Kábana (1987), Johnson and Motsinger (1989) and Carneiro *et al.* (2006). To our knowledge, however, this is the first report of an oat cultivar being reported as a suitable host to *M. incognita* race 4. While our results confirm that *M. incognita* becomes largely inactive during winter (Timper *et al.,* 2006), our data indicates that rotation of susceptible cotton with a susceptible oat cultivar in the summer or with bare fallow in winter, might take longer to be effective in suppressing race 4 on cotton in a summer-winter rotation regime. Although small-grain winter cover crops are hosts to many plant-parasitic nematode species, nematode reproduction is, in most instances, suppressed by low soil temperatures (Ploeg and Maris, 1999; Starr *et al.*, 2007).

Da Rosa *et al.* (2003) found that sunn hemp reduced population densities of *Meloidogyne* spp. but also increased *P. zeae* numbers. However, in spite of this increase in population density, Dinardo-Miranda and Gil (2005) found that crop rotation with *C. juncea* contributed to increased sugarcane yield. Rhodes *et al.* (2009) also found that green manures of oat and sunn hemp suppressed numbers of undisclosed *Pratylenchus* spp. in sugarcane. Both the marigold/oat and oat/crambe regimes lowered lesion nematode numbers in our study. Marigolds grown throughout the summer suppressed root-knot, lesion, and stunt (*Tylenchorhynchus* spp.) nematodes (Hagan *et al.* 1998), as well as *P. penetrans* on potato (LaMondia, 2006). Our results with *P. zeae* contradict the results of the latter author in terms of lesion nematode susceptibility of oat. The study by LaMondia (2006) showed that oat rotations suppressed a *P. penetrans* population, while in our study, oat, as well as sesame and sunn hemp, resulted in a significant increase in the the *P. zeae* population that was present at the experimental site at Vaalharts. It is possible that this contradiction could be explained by Mc Donald and Nicol (2005), who reported that cultivar differences, as well as differences in the aggressiveness of lesion nematode species might have an effect on susceptibility of oat to these pests. Thus, cotton appeared to be a poor host to *P. zeae*, and the population density declined to almost zero in all the rotation regimes during the last summer of 2010/2011 when cotton was grown. It is unknown why *P. zeae* was the only lesion nematode species that was present in the field where we did our study, particularly given a past cropping history of cotton production. Weed hosts and *P. zeae*'s ability to survive in winter, as confirmed by our study, might be contributing factors.

Our results do not provide any evidence that incorporating the aerial parts of the rotation crops into the soil had any greater effect than had they been left for harvest. Rhodes *et al.* (2009) suggested that effects of green-manure fallowing would only be significant after at least 6 mon. The effects of green-manure fallow versus rotation with antagonistic crops should be studied separately and over a prolonged period to obtain more meaningful and accurate results.

Cotton yield in the final season of our study was not related to either the final root-knot nematode or lesion nematode numbers or the population dynamics of these nematode species in the respective crop regimes. Yield effects after cover crop treatments are sometimes inconsistent and not always attributed to a specific factor (McSorely *et al.*, 2009). This study, however, confirmed the importance of accurate nematode species identification in planning cropping regimes. Economically important species may differ greatly in their pathogenicity to particular crops (Webster, 1987). Some crop rotation schemes can be complicated by the presence of different species and races in the same field because nematode reproduction can vary with crop and cultivar (Fortnum *et al.*, 2001). It is, therefore, imperative that the major economically important nematodes that are present in a field are identified to species, and even race level, before developing a crop rotation strategy.

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