# SIGNIFICANCE OF LESION AND SPIRAL NEMATODES IN *CROTALARIA*–MAIZE ROTATION IN WESTERN KENYA

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## ABSTRACT

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*Crotalaria* species used in rotations with maize to replenish soil fertility have been noted to host high populations of lesion (*Pratylenchus* spp.) and spiral nematodes (*Helicotylenchus* spp. and *Scutellonema* spp.). Thus, there is a need to identify *Crotalaria* species resistant to lesion and spiral nematodes to reduce their detrimental effect on maize. Eight *Crotalaria* species (*C. agatiflora, C. grahamiana, C. laburnifolia, C. ochroleuca, C. paulina, C. incana, C. pychnostachya* and *C. striata*) were evaluated along with maize, *Sesbania sesban* and *Tephrosia vogelii* to determine their effects on nematodes in two trials. Maize was grown subsequent to one-or two-seasons growth of each *Crotalaria* spp. These tests were conducted in randomized complete blocks replicated on farms near Yala town in western Kenya. The response of *Crotalaria* spp. to *Pratylenchus* spp. was not consistent across the two trials. In soils containing high initial *Pratylenchus* spp. populations, *S. sesban* and *T. vogelii* supported low nematode populations. All *Crotalaria* spp. and maize hosted high nematode populations. *Pratylenchus* and spiral nematodes did not affect the biomass production of *Crotalaria* species that produced good early growth, indicating the need for good early management. Poor plant stand was noted for *C. agatiflora, C. grahamiana* and *C. paulina* which had high root infection by *Pratylenchus* spp. In soils containing low initial populations of *Pratylenchus* spp., *Crotalaria* spp. caused only small changes in the nematode populations. Maize yields were not reduced by spiral nematodes in any of the studies. Maize yields, however, were negatively correlated to the *Pratylenchus* spp. populations in the highly infested soils. Despite increasing lesion and spiral nematodes, *Crotalaria* cover crops may not pose a threat to subsequent maize in the short-term. However, in the long-term, or when pre-existing *Pratylenchus* populations are already high, maize following *Crotalaria* cover crops may suffer from the nematode damage.

*Key words:* cover crops, *Crotalaria*, maize, *Pratylenchu*s, soil fertility, spiral nematodes, tree-fallow.

## RESUMEN

Desaeger, J. y M. R. Rao. 2003. Importancia de los nematodos lesionadores y de espiral en rotaciones de *Crotalaria* y maíz en el occidente de Kenya. Nematropica 34:27-39.

Se ha notado que especies de *Crotalaria* usadas en rotaciones con maíz para restaurar la fertilidad del suelo tienden a hospedar poblaciones altas de nematodos lesionadores (*Pratylenchus* spp.) y de espiral (*Helicotylenchus* spp. y *Scutellonema* spp.). Por lo tanto hay necesidad de identificar especies de *Crotalaria* que sean resistentes a nematodos lesionadores y de espiral para reducir su efecto perjudicial en maíz. Ocho especies de *Crotalaria* (*C. agatiflora, C. grahamiana, C. laburnifolia, C. ochroleuca, C. paulina, C. incana, C. pychnostachya* y *C. striata*) fueron evaluadas con maíz, *Sesbania sesban* y *Tephrosia vogelii* en dos experimentos para determinar sus efectos en nematodos. Se plantó maíz después de una o dos temporadas de haber plantado *Crotalaria* spp. Estos experimentos se llevaron a cabo en bloques randomizados replicados en fincas cerca a la ciudad de Yala en el occidente de Kenya. La respuesta de *Crotalaria* spp. a *Pratylenchus* spp. no fué consistente en los dos experimentos. En suelos con altas poblaciones iniciales de *Pratylenchus, S. sesban* y *T. vogelii* tuvieron bajas poblaciones de nematodos. Todas las especies de *Crotalaria* y maíz tuvieron altas poblaciones de nematodos. *Pratylenchus* y los nematodos de espiral no afectaron la producción de biomasa de las especies de *Crotalaria* que produjeron buen crecimiento en los estadíos tempranos de crecimiento, indicando la necesidad de un buen manejo temprano. Conteos pobres de plantas se notaron para *C. agatiflora, C. grahamiana* y *C. paulina* las cuales tuvieron infecciones radiculares altas por *Pratylenchus* spp. En suelos que contenían bajas concentraciones iniciales de *Pratylenchus* spp., *Crotalaria* spp. causó solo cambios pequeños en las poblaciones de nematodos. La producción de maíz no fueron reducidas por los nematodos de espiral en ninguno de los estudios. Sin embargo, la producción de maíz fué correlacionada negativamente con las poblaciones de *Pratylenchus* spp. en los suelos con altas infestaciones. A pesar de los aumentos en nematodos lesionadores y de espiral, puede que las cosechas de cubierta con *Crotalaria* no sean una amenaza para plantaciones posteriores de maíz a corto plazo. Sin embargo, a largo plazo, o cuando las poblaciones pre-existentes de *Pratylenchus* son ya altas, el plantar maíz después de cosechas de cubierta con *Crotalaria* puede sufrir por el daño de los nematodos.

*Palabras claves*: cosechas de cubierta, *Crotalaria*, maíz, *Pratylenchus*, fertilidad de suelos, nematodos de espiral, barbecho de árboles.

## INTRODUCTION

Low soil fertility in smallholders' farms is the fundamental cause of low crop yields in sub-Saharan Africa (Sanchez *et al.*, 1996). Small-scale farmers cannot afford to buy fertilizers, thus alternative strategies to replenish soil fertility need to be identified. Rotations with cover crops of leguminous trees or shrubs have been demonstrated to replenish nitrogen-depleted soils with mineral N and increase yields of subsequent cereal crops (ICRAF, 1997). *Crotalaria grahamiana* Wight and Arn and *C. agatiflora* Schweinf. are being promoted for short-rotations in western Kenya because of their high biological nitrogen fixation, rapid growth, and high biomass production (Niang *et al.*, 1996). However, the same *Crotalaria* spp. have been observed to host high populations of *Pratylenchus* spp. Filipjev, *Helicotylenchus* Steiner and *Scutellonema* spp. Andrássy (Desaeger and Rao, 1999, 2000, 2001). These nematodes are commonly associated with maize (*Zea mays* L.) and their high populations have the potential to cause losses in maize yields. In the USA, *Pratylenchus brachyurus* (Godfrey) Filipjev and Schuurmans Stekhoven and *P. zeae* Graham are a major cause of maize yield losses (Brown, 1987). Annually in South Africa, 12% of the maize yield is lost due to *Pratylenchus* spp. infection (Keetch, 1989).

Maize is a staple food to the people in East Africa and is planted on over 90% of arable land in western Kenya. *Pratylenchus* spp. are the most important nematode parasites of maize in Kenya (Kimenju *et al.*, 1998), and were observed to reduce yields up to 50% (Desaeger and Rao, 2000). *Pratylenchus* spp., *Helicotylenchus* spp. and *Scutellonema* spp., therefore, may limit the benefits and pose a potential threat to the sustainability of *Crotalaria*–maize rotations.

Experiments were conducted in western Kenya with the objectives of determining: a) the capacity of different *Crotalaria* spp. to serve as a host to the *Pratylenchus* spp., *Helicotylenchus* spp. and *Scutellonema* spp. and b) the pathogenic effects of these nematodes on *Crotalaria* and maize.

## MATERIALS AND METHODS

### *Trial 1: Ochinga farm*

A field experiment was conducted from March 1999 to January 2000 at Ochinga farm, near Yala town in western Kenya (0°6'N, 34°35'E, 1430 m elevation) in a randomized complete block design with four replications. The farm was previously cropped with maize and *C. grahamiana.* The soil was a clay loam with 36% sand, 27% silt, 37% clay and pH 5.9.

The treatments during the 'long rains' from April 1 to September 10, 1999 (i.e. cover crop phase) consisted of *Crotalaria agatiflora, C. grahamiana, C. ochroleuca* G. Don, *C. paulina* Schrank and *C. striata* DC. Benth., *Sesbania sesban* (L.) Merr., and *Tephrosia vogelii* Hook. f., and maize (two plots in each replication). The plots were 8 m by 6 m and separated by 1 m paths on all sides. *Crotalaria ochroleuca* was harvested on August 9 due to earlier maturity but other species were harvested on September 10. Cover crop biomass was removed from plots and maize was grown in all the plots during the 'short rains' from September 30, 1999 to January 13, 2000 (i.e. crop phase). Nematode control was attempted in one of the maize plots using the nematicide Vydate (a.i. 24% oxamyl) at 10 l ha$^{-1}$ just before sowing, and 1 and 2 months after sowing. The chemical was sprayed on the soil surface in 400 l ha$^{-1}$. Galvanized iron sheets were installed up to 0.3 m depth around the plots that received the nematicide to avoid contamination of neighboring plots. Rainfall during the cover crop phase was 1303 mm and during the crop phase 562 mm.

*Trial 2: Multiple farms*

A second field experiment was conducted from April 10, 1999 to August 1, 2000 on four closely located farms near Yala town in a randomized complete block design with two replications each at Khumusalaba, Nyabeda 1 and 2, and one at Dudi. While the soil at Khumusalaba was clay loam with 47% sand and 35% clay, those at Dudi and Nyabeda were clays with 24% sand and 53% clay. The farms were previously cropped with maize and bean (*Phaseolus vulgaris* L.).

From April 10, 1999 to March 1, 2000, the treatments consisted of *Crotalaria agatiflora, C. laburnifolia* L., *C. grahamiana, C. incana L., C. ochroleuca, C. paulina, C. pycnostachya* Benth., *C. striata*, and maize. The plots were 6 m by 6 m and separated by 1 m paths on all sides. While *C. incana* and *C. ochroleuca* grew only 6 months, other *Crotalaria* species were grown for nearly 11 months until March 1, 2000. After harvest, *Crotalaria* biomass was removed from plots and maize grown in the subsequent long rains from March 20 to August 1, 2000. The average rainfall across farms during the cover crop phase was 2000 mm and during the crop phase 1100 mm.

*Plot design and crop management*

In both the studies, blocks were delineated on the basis of initial populations of *Pratylenchus* spp. in composite soil samples collected at ten locations from the top 0–30 cm soil in each plot. The fields were manually cultivated at the beginning of the rainy seasons. The cover crops were established by direct seeding at 0.75 m between rows and 0.50 m within the rows. Maize (H 611 during the long rains and H 511 during the short rains) was sown at the recommended spacing of 0.75 m between rows and 0.25 m between plants within the rows. The maize in rotation with cover crops was fertilized with 120 kg N ha$^{-1}$, 50 kg P ha$^{-1}$ and 50 kg K ha$^{-1}$ to eliminate the effect of potential differences in the residual fertility effects of different cover crops. One-half of N rate, through urea, and the entire P and K rates, through triple superphosphate and potassium chloride, respectively, were incorporated in the soil during land preparation. The crop was topdressed with urea to supply the balance amount of N one month after sowing. The plots were hand-weeded three times each season to reduce weed competition and potential alternative hosts to nematodes.

*Data collection and analyses:*

In trial 1, biomass of cover crops was estimated at 180 days after planting (DAP) by harvesting 37 $m^2$ net area. In trial 2, biomass of cover crops was assessed at 180 DAP by harvesting two rows (9 $m^2$ net area) and at 320 DAP by harvesting four rows (15 $m^2$ net area). Maize yields in both these trials were determined by harvesting 15 $m^2$ net area. Dry weights were estimated based on the per cent dry matter determined on sub-samples dried at 70°C for a constant weight. Maize yields were adjusted to 15% moisture.

Nematode populations were determined at harvest of the cover crops, and at sowing and tasseling or harvest of maize. Soil was collected from the top 30-cm soil layer between rows at 12 locations systematically covering the whole plot. The soil from each plot was thoroughly mixed and nematodes were extracted from a 100 $cm^3$ soil sample using a modified Baermann method (Hooper, 1993). Nematode root infection of the cover crops was assessed at 60 and 180 DAP in trial 1 and at 180 and 320 DAP in trial 2. Nematode infection of maize roots was assessed at tasseling (56 DAP) and at harvest. Cover crop and maize roots were sampled by uprooting five plants per plot at each sampling date. A randomly selected 10 g fresh root sample was washed, cut into 0.5- to 1-cm pieces, and nematodes were extracted using the modified Baermann method (Hooper, 1993). The same root pieces were subjected to further extraction using the sodium hypochlorite method (Hussey and Barker, 1973). The additional nematodes thus obtained were added to the counts from the Baermann extraction.

The biomass data were subjected to analysis of variance (ANOVA) and standard error of difference among treatment means was provided. ANOVA was conducted on the data of nematode populations following log transformation. In trial 2, a combined ANOVA was conducted on the data of different farms, as the $\chi^2$ test indicated homogeneity of error variances for farms that had each two replications. Where F test was significant, treatment means were compared based on LSD ($P \leq 0.05$).

## RESULTS

*Host-status of different Crotalaria spp.*

In the first study at Ochinga, the initial plant-parasitic nematode populations were dominated by lesion and spiral nematodes, with 467 ± 41 lesion and 242 ± 28 spiral nematodes per 100 $cm^3$ soil, respectively. Lesion nematodes were predominantly *Pratylenchus zeae* mixed with *P. scribneri* Steiner, and spiral nematodes were *Scutellonema brachyurus* (Steiner) Andrássy, *S. clathricaudatum* Whitehead and *Helicotylenchus* spp. Steiner.

At 60 DAP, *C. agatiflora, C. paulina* and *C. grahamiana* had high *Pratylenchus* spp. populations of 356, 302 and 151 nematodes per g root, respectively. These *Crotalaria* spp. had experienced 11 to 32% stand loss (Table 1). In contrast, *C. ochroleuca, C. striata, S. sesban* and *T. vogelii* had low *Pratylenchus* nematode populations ranging from 1 to 71/g root and experienced only 3 to 5.8% stand mortality. Maize hosted 163 *Pratylenchus* spp. per g root. At harvest, all *Crotalaria* species hosted statistically similar numbers of *Pratylenchus* spp. in the range of 429 to 1269 /g root (Table 1). *Sesbania sesban* and *T. vogelii* had significantly

Table 1. Lesion and spiral nematode populations in roots and soil of the cover crops of *Crotalaria* spp., *Sesbania sesban* and *Tephrosia vogelii* at 60 and 180 days after planting (DAP) and effects of nematode infection on stand mortality and biomass production during the 1999 long rains (March-August) at Ochinga in western Kenya.

|  |  |  |  | Nematodes[x]/100 cm$^3$ soil |  | Biomass at harvest 180 DAP (ton/ha) |
|---|---|---|---|---|---|---|
|  | Mortality (%) | Lesion nematodes/g root |  | 180 DAP |  |  |
| Cover crops | 60 DAP | 60 DAP | 180 DAP | Lesion | Spiral |  |
| *C. agatiflora* | 32.1 | 356 a | 860 a | 263 bc | 278 b | 2.04 |
| *C. grahamiana* | 11.4 | 151 a | 1253 a | 175 cd | 189 b | 4.12 |
| *C. ochroleuca*[y] | 2.8 | 9 a | 1269 a | 349 bc | 241 b | 3.93 |
| *C. paulina* | 14.4 | 302 ab | 429 ab | 306 bc | 194 b | 2.63 |
| *C. striata* | 5.8 | 71 a | 1002 a | 421 b | 102 b | 7.15 |
| *S. sesban* | 3.0 | 1 b | 145 b | 114 cd | 331b | 3.93 |
| *T. vogelii* | 5.8 | 16 b | 62 b | 93 d | 442 b | 6.56 |
| Maize[y] | — | 163 ab | 658 ab | 1126 a | 861 a |  |
| SED[z] | 5.8 | — | — | — | — | 0.81 |
| *F* probability | <0.01 | <0.01 | <0.01 | <0.01 | 0.02 | <0.01 |

[x] Initial populations of lesion and spiral nematodes were 467 ± 41 and 242 ± 28 nematodes per 100 cm$^3$ soil, respectively; lesion nematodes were *Pratylenchus zeae* and *P. scribneri*, spiral nematodes were *Scutellonema brachyurus*, *S. clathricaudatum* and *Helicotylenchus* spp.

[y] *C. ochroleuca* and maize were harvested and sampled 5 weeks earlier than other species.

[z] Standard error of difference of means (SED) not given, where ANOVA was conducted on log (x + 1) transformed data; similar letters within each column do not differ significantly ($P = 0.05$) from each other.

lower *Pratylenchus* numbers than all *Crotalaria* species, except *C. paulina* and maize. Based on harvest populations, the cover crop species ranked as hosts for *Pratylenchus* spp. as follows: *C. ochroleuca* = *C. grahamiana* = *C. agatiflora* = *C. striata* > maize = *C. paulina* > *S. sesban* = *T. vogelii.* Root infection by *Scutellonema* and *Helicotylenchus* spp. was not reported, as their populations in all the test species were low, in the range of 3 to 68 /g root.

At harvest (180 DAP), *Pratylenchus* spp. in the soil were greatest under maize with over two times the initial population (Table 1). The soil under *T. vogelii*, *S. sesban* and *C. grahamiana* had significantly lower *Pratylenchus* spp. than at the beginning, but other *Crotalaria* species did not alter the initial nematode populations. The soil under maize contained the greatest number of *Scutellonema* and *Helicotylenchus* spp. (861 per 100 cm$^3$ soil) and differed significantly from all the cover crops. However, the cover crops with 102 to 442 *Scutellonema* and *Helicotylenchus* spp. per 100 cm$^3$ soil, did not differ significantly from each other.

*Crotalaria agatiflora* and *C. paulina* produced less than 3 t /ha of biomass (Table 1). *Crotalaria striata* and *T. vogelii* produced the highest biomass at 7.2 and 6.6 t /ha, respectively. *Crotalaria grahamiana*, *C. ochroleuca* and *S. sesban* produced moderate yields averaging 4 t /ha.

In the second trial on multiple farms, lesion and spiral nematodes initially averaged 53 ± 11 and 50 ± 8 per 100 cm$^3$ soil, respectively. The lesion nematodes at Dudi were identified as *P. zeae*, and at Nyabeda and Khumusalaba, *P. zeae* was mixed with *P. brachyurus* (Godfrey) Filipjev and Schuurmans Stekhoven. The spiral nematode *Scutellonema brachyurus* was present in all the farms. Additionally, the Dudi farm had *S. clathricaudatum*, the Nyabeda farms had *S. clathricaudatum* and *Helicotylenchus pseudorobustus* (Steiner) Golden, and the Khumusalaba farm had *S. clathricaudatum*, *H. pseudorobustus* and *H. dihystera* (Cobb) Sher.

The interaction of treatments x farms was not significant for the parameters monitored, so the results were averaged over farms (Table 2). At 180 DAP, maize, *C. ochroleuca* and *C. striata* had the highest *Pratylenchus* infection levels with 240, 175, and 155 nematodes per g root, respectively. *Crotalaria laburnifolia* and *C. pycnostachya* had the lowest *Pratylenchus* infection levels with 2 and 5 nematodes per g root, respectively. Other *Crotalaria* species had on average 50 nematodes per g root. At 320 DAP, *Pratylenchus* spp. populations appeared to be similar to those at 180 DAP for most species, except for *C. striata,* which contained one-third of those at 180

Table 2. Root infection by lesion nematodes, lesion and spiral nematodes in soil at harvest of 11-month-old *Crotalaria* spp. and their effects on cover crop biomass production near Yala in western Kenya (April 1999-August 2000). Results were averaged over four locations.

| | Lesion nematodes/g root | | Nematodes[w] at 320 DAP/100 cm$^3$ soil | | Biomass (ton/ha) | |
|---|---|---|---|---|---|---|
| Cover crops | 180 DAP | 320 DAP | Lesion | Spiral | 180 DAP | 320 DAP |
| *C. agatiflora* | 47 c | 11 c | 58 | 446 bc | 3.32 | 9.85 |
| *C. laburnifolia* | 2 d | 10 c | 6 | 52 c | 4.11 | 5.04 |
| *C. grahamiana* | 52 c | 83 abc | 54 | 1142 a | 3.64 | 7.93 |
| *C. incana*[x] | 54 c | — | 41 | 113 c | 1.88 | 0[y] |
| *C. ochroleuca*[x] | 175 ab | — | 19 | 94 c | 2.43 | 0[y] |
| *C. paulina* | 34 c | 54 bc | 26 | 905 ab | 1.82 | 4.43 |
| *C. pychnostachya* | 5 d | 12 c | 11 | 344 c | 1.60 | 2.10 |
| *C. striata* | 155 ab | 54 bc | 45 | 452 bc | 4.00 | 8.77 |
| Maize[x] | 240 a | — | 14 | 150 c | — | — |
| SED[z] | — | — | — | — | 0.42 | 1.18 |
| *F* probability | <0.01 | 0.07 | 0.26 | <0.01 | <0.01 | <0.01 |

[w] Initial populations of lesion and spiral nematodes were 53 ± 11 and 50 ± 8 nematodes per 100 cm$^3$ soil, respectively; lesion nematodes were *Pratylenchus zeae* and *P. brachyurus*, spiral nematodes were *Scutellonema brachyurus*, *S. clathricaudatum, Helicotylenchus pseudorobustus* and *H. dihystera.*

[x] Root infection by lesion nematodes and soil nematode populations in these species were determined at 180 days after planting (DAP).

[y] Zero values were excluded from ANOVA.

[z] Standard error of difference of means (SED) not given where ANOVA was conducted on log (x + 1) transformed data; similar letters within each column do not differ significantly ($P = 0.05$) from each other.

DAP (Table 2). Maize hosted the greatest *Pratylenchus* spp. populations, closely followed by *Crotalaria ochroleuca* and *C. grahamiana*. Root infection by *Scutellonema* and *Helicotylenchus* spp. was not reported, as the nematode populations were low and similar among species, ranging from 3 to 58 per g root.

At cover crop harvest (320 DAP), *Pratylenchus* spp. in the soil were similar to or slightly lower than those at the start of the study, and differences among *Crotalaria* spp. were not significant (Table 2). However, spiral nematode populations increased in the presence of all *Crotalaria* species. Greatest populations were noted under *C. grahamiana* and *C. paulina*, which differed significantly ($P \leq 0.05$) from other *Crotalaria* spp.

At 180 DAP, *C. laburnifolia*, *C. striata*, *C. grahamiana* and *C. agatiflora* were the most productive species with total biomass yields varying from 3.3 to 4.1 t /ha (Table 2). *Crotalaria incana* and *C. ochroleuca* had a short life cycle of only 180 days and produced the lowest yields of 1.9 and 2.4 t /ha, respectively. By 320 DAP the other *Crotalaria* species also completed their life cycle with a high proportion of senesced plants. At this stage, *C. agatiflora*, *C. striata* and *C. grahamiana* produced 8 t/ha or more of total biomass, *C. laburnifolia* and *C. paulina* produced 4 to 5 t /ha, and *C. pycnostachya* the lowest biomass at 2 t /ha.

### *Nematode infection and maize yields*

At Ochinga farm, *Pratylenchus* spp. populations in the soil increased during the 20-day interval between harvest of cover crops and maize sowing in the case of *C. striata*, *C. paulina* and *C. grahamiana* by 76%, 71% and 198%, respectively (Tables 1 and 3). Populations of *Pratylenchus* spp. remained stable in the case of *S. sesban* and *T. vogelii*. In contrast, *Pratylenchus* spp. populations decreased by 74% in the continuous maize system. Excluding *C. ochroleuca*, which was harvested earlier than other species, *Pratylenchus* spp. soil populations at maize sowing were positively and linearly related to the biomass production by the *Crotalaria* cover crops (Fig. 1). Although *Scutellonema* and *Helicotylenchus* spp. in the soil also increased at maize sowing compared to those at the harvest of cover crops, differences among cover crops were not significant (Tables 1 and 3).

At maize harvest, the continuous maize was heavily infected by *Pratylenchus* spp. with 634 nematodes per g root (Table 3). The addition of oxamyl significantly reduced *Pratylenchus* spp. populations to 76 nematodes per g root. Maize following *C. striata* had the greatest *Pratylenchus* populations. Maize following *T. vogelii* and *C. paulina* also were heavily infected and did not differ from the continuous system (Table 3). Differences among cover crops were not significant for *Scutellonema* and *Helicotylenchus* spp. Despite fertilizer application, maize yields averaged just over 2 t / ha (Table 3). Maize yields in rotation with *C. striata* and *T. vogelii* were significantly lower ($P \leq 0.05$) than that of oxamyl-treated continuous maize. Maize yield was greatest in rotation with the earliest harvested *C. ochroleuca*. Maize yields were inversely related to *Pratylenchus* spp. populations in the roots at tasseling and harvest stages (Fig. 2). *Scutellonema* and *Helicotylenchus* spp. did not influence maize yields ($P > 0.05$).

*Pratylenchus* spp. populations in the soil, even in the trial on multiple farms, generally increased during the 20-day interval between the harvest of *Crotalaria* spp. and subsequent maize sowing (Tables 2 and 4). Soil populations of *Pratylenchus* spp. did not differ among *Crotalaria* spp. and continuous maize at maize sowing, nor did root populations differ at tasseling

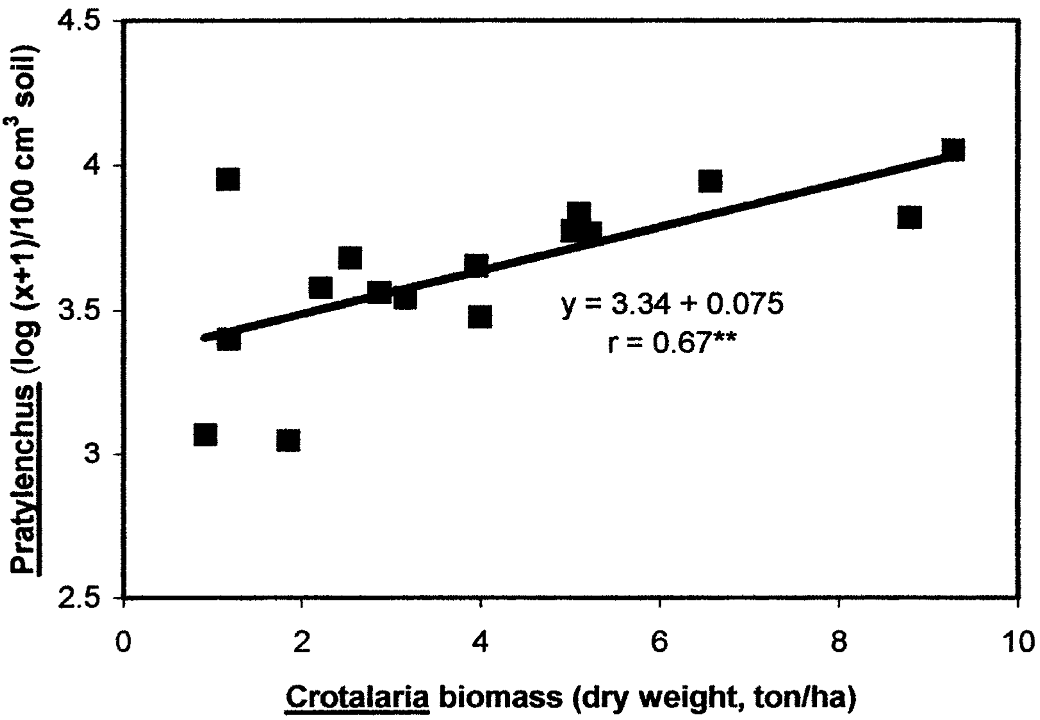

Fig. 1. Relationship between *Pratylenchus* soil populations at maize sowing and biomass of the preceding cover crops of *Crotalaria* spp. at Ochinga in western Kenya, September 1999.

(Table 4). *Scutellonema* and *Helicotylenchus* spp. populations increased for some *Crotalaria* species and they decreased for others. Maize yields ranged from 3.7 to 5.2 t/ha for *C. laburnifolia* and *C. agatiflora* respectively (Table 4). Maize following *C. laburnifolia* hosted the least number of *Pratylenchus* spp. at cover crop harvest and produced a greater yield ($P \leq 0.05$) than continuous maize. No other *Crotalaria* spp. increased ($P > 0.05$) maize yields. *Scutellonema* and *Helicotylenchus* spp. did not influence maize yields.

## DISCUSSION

The high populations of *P. zeae* relative to other *Pratylenchus* spp. in these tests confirm the reports of De Waele and Jordaan (1988) and Kimenju *et al.* (1998) that *P. zeae* is the most common lesion nematode associated with maize in Africa. Results further confirm the earlier reports that *Crotalaria* species are good hosts to *Pratylenchus* spp. (Jensen, 1953; Luc, 1968; Desaeger and Rao, 2000) and that *S. sesban* and *T. vogelii* support low populations (Desaeger and Rao, 2000). Another *Sesbania* species, *S. rostrata,* commonly planted along rice paddies, is similarly known to reduce populations of *Hirschmanniella* spp., which belongs to the same family as *Pratylenchus* spp. (Germani *et al.*, 1983; Pariselle and Rinaudo, 1988). Sivapalan (1972), however, reported that *T. vogelii* was a good host of *Pratylenchus loosi.*

The lack of significant relationship between *Pratylenchus* spp. populations and

Table 3. Population development of lesion and spiral nematodes in maize after six-month-old *Crotalaria*, *Sesbania* and *Tephrosia* cover crops and subsequent effects on maize grain yield at Ochinga during the 1999 short rains in western Kenya.

| | Nematodes[x]/100 cm$^3$ soil | | | | | |
|---|---|---|---|---|---|---|
| | Maize sowing | | Maize harvest | | | |
| Cover crops | Lesion | Spiral | Lesion | Spiral | Lesion nematodes at harvest/g root | Maize grain yields (ton/ha) |
| *C. agatiflora* | 268 b | 244 | 987 b | 824 | 186 d | 2.74 |
| *C. grahamiana* | 522 a | 348 | 983 b | 733 | 246 cd | 2.37 |
| *C. ochroleuca*[y] | 247 b | 253 | 652 bc | 993 | 162 d | 3.18 |
| *C. paulina* | 523 a | 444 | 1102 b | 1212 | 530 abc | 1.79 |
| *C. striata* | 743 a | 290 | 2193 a | 584 | 998 a | 1.05 |
| *S. sesban* | 133 b | 203 | 870 bc | 1359 | 304 bcd | 2.17 |
| *T. vogelii* | 94 b | 566 | 1116 b | 1621 | 650 ab | 1.29 |
| Maize[y] | 302 b | 201 | 1435 ab | 723 | 634 ab | 1.98 |
| Maize+ oxamyl | — | — | 157 c | 200 | 76 d | 2.86 |
| SED[z] | — | — | — | — | — | 0.70 |
| *F* probability | <0.01 | 0.47 | <0.01 | 0.23 | <0.01 | 0.08 |

[x] Species of lesion and spiral nematodes were the same as in Table 1.

[y] Maize in rotation was planted 7 weeks after harvest of *C. ochroleuca* and maize, and 3 weeks after harvest of other cover crops.

[z] Standard error of difference of means (SED) not given where ANOVA was conducted on log (x + 1) transformed data; similar letters within each column do not differ significantly ($P = 0.05$) from each other.

biomass production across *Crotalaria* spp. was possibly due to the tolerance of *Crotalaria* spp. to *Pratylenchus* spp. infection over time and/or differences in the production potential of different species. High biomass production by *C. striata* and *C. grahamiana* in six months despite being excellent hosts to *Pratylenchus* spp. indicates their tolerance to the nematode. However, reduced growth of *C. agatiflora, C. paulina* and *C. grahamiana* at Ochinga indicate that lesion nematodes have the potential to reduce *Crotalaria* biomass. Inadequate plant stand and reduced early growth severely restrict biomass production of short rotation *Crotalaria* cover crops (Desaeger and Rao, 2001). A significant negative relationship was reported between *P. zeae* populations and biomass production in *C. agatiflora* in western Kenya (Desaeger and Rao, 2000). On the other hand, the good overall performance of *C. striata* stresses the importance of good stand establishment and rapid early growth in overcoming the nematode damage over time.

*Pratylenchus* spp. soil populations at the 6-month cover crop harvest (trial 1) were low possibly because the nematodes were colonizing the roots. As the roots decomposed after harvest the nematode levels increased by the time of maize sowing. However, the increase of nematode populations in the soil after harvest of the 11-

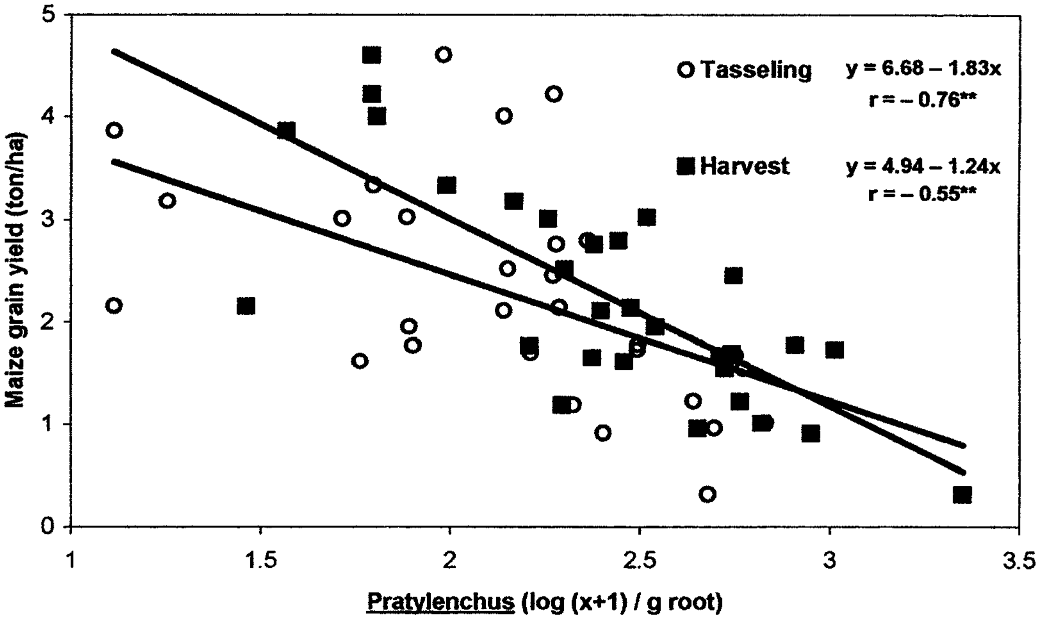

Fig. 2. Effect of root infection by *Pratylenchus* spp. at tasseling and at harvest on maize grain yields at Ochinga during the 1999 short rains in western Kenya.

month-old *Crotalaria* fallows (trial 2) was small because the stands of most species died naturally before harvest. All the *Crotalaria* species in our tests are considered short-duration cover crops with optimal harvest at 5 to 7 months after sowing. When a one-year cover cropping rotation is desired, planting *Crotalaria* in the two consecutive rainy seasons appears attractive for greater biomass production compared with a single crop. However, such a system builds up *Pratylenchus* spp. For a one-year cover cropping rotation, the longer lasting *S. sesban* and *T. vogelii* can be grown. Maize root infection was severe following *Crotalaria* cover crops that left a high number of *Pratylenchus* spp. in the soil. Greater nematode levels in the soil following high biomass producing cover crops such as *C. striata* and *C. grahamiana,* was probably due to larger root systems favoring the multiplication of nematodes. Lower maize root infection following *C. ochroleuca* was possibly due to the shorter growing period. The prolonged interval from harvest of *C. ochroleuca* to maize sowing allowed for greater nematode mortality. This implies that any detrimental effect of *Pratylenchus* spp. associated with *Crotalaria* covers can be reduced by extending the interval between harvest of *Crotalaria* and sowing of the subsequent maize crop.

Lower maize yields at Ochinga (trial 1) than at the other sites (trial 2) was likely due to greater *Pratylenchus* spp. populations and the short rains season in which maize was grown, when rainfall was low and erratic. Lower maize yields in rotation with *S. sesban* and *T. vogelii,* despite these cover crops hosting lower *Pratylenchus* spp. populations, were probably due to factors other than nematodes. The negative rela-

Table 4. Development of lesion and spiral nematode populations in maize after 11-month old *Crotalaria* cover crops and subsequent effects on maize grain yield during the 2000 long rains (March-August) on farms near Yala in western Kenya. Results were averaged over four locations.

| | Nematodes[y]/100 $cm^3$ soil | | Nematodes/g root | |
|---|---|---|---|---|
| | At maize sowing | | At maize tasseling | |
| Cover crops | Lesion | Spiral | Lesion | Grain yield (ton/ha) |
| *C. agatiflora* | 160 | 396 | 91 | 3.72 |
| *C. laburnifolia* | 79 | 152 | 122 | 5.18 |
| *C. grahamiana* | 189 | 397 | 50 | 4.20 |
| *C. incana* | 71 | 203 | 66 | 3.70 |
| *C. ochroleuca* | 75 | 143 | 122 | 4.65 |
| *C. paulina* | 108 | 515 | 109 | 4.46 |
| *C. pychnostachya* | 49 | 106 | 212 | 3.69 |
| *C. striata* | 305 | 295 | 242 | 4.17 |
| Maize | 101 | 452 | 40 | 3.73 |
| SED[z] | — | — | — | 0.55 |
| *F* probability | 0.50 | 0.52 | 0.89 | 0.26 |

[y] Species of lesion and spiral nematodes were the same as in Table 2.

[z] Standard error of difference of means (SED) not given where ANOVA was conducted on log (x + 1) transformed data.

tionship between *Pratylenchus* spp. root infection and maize yield in trial 1 was very similar to the results reported earlier (Desaeger and Rao, 2000).

Decreasing farm size and a strong emphasis on maize production has increased monocropping and severe nutrient depletion in many parts of western Kenya. The effect of plant-parasitic nematodes is generally confounded with nutrient depletion on farms and given the apparent importance of high soil fertility for good crop growth, the nematode problem is ignored (Hillocks *et al.*, 1995). When trials were conducted with adequate soil fertility, maize was often found to tolerate nematode infection without significant effects on yield (Norton, 1983). Improvement in the growth of *Pratylenchus*-infested crops by application of fertilizers was reported for tea in Sri Lanka (Sivapalan, 1972) and wheat in Mexico (Van Gundy *et al.*, 1974). It is probable that the fertilizer applied to maize in our trials to equalize fertility among the different cover crops reduced the negative effect of *Pratylenchus* spp.

Although small yield reductions due to spiral nematodes were reported previously (Desaeger and Rao, 2001), it appears that *Scutellonema* and *Helicotylenchus* spp. are not economically important to maize in *Crotalaria*-maize rotations. However, repeated cycles of *Crotalaria*-maize rotations over time may increase *Pratylenchus* spp. and jeopardize the sustainability of the system. *Sesbania sesban* and *T. vogelii* have a comparative advantage over *Crotalaria* cover crops for soils infested by *Pratylenchus* spp. provided the subsequent crop is pure maize or a maize-groundnut intercrop. However, *Crotalaria* cover crops are appropriate if the subsequent crop is a maize-bean intercrop, as both *S. sesban* and *T. vogelii* increase the risk of root-knot nematode (*Meloidogyne* spp.) damage to bean (Desaeger and Rao, 2001).

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