# EFFECTS OF CROPPING SYSTEM ON NEMATODE POPULATION DENSITIES IN SMALL-SCALE HIGHLAND GUATEMALAN AGRICULTURE[†]

B. Larson,[1†] J. L. Stimac,[1] R. McSorley,[1] and C. MacVean[2]

Department of Entomology and Nematology, University of Florida, Gainesville, FL 32611, U.S.A.,[1] and Research Institute, Universidad del Valle de Guatemala, Aptdo. Postal 82, Guatemala, Guatemala.[2]

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## ABSTRACT

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The effects of adding selected intercrops to small-scale corn and bean cropping systems in the western Guatemalan highland state of Sololá were evaluated to determine if the associations would increase nematode damage to the principal crops and necessitate use of additional nematode management tactics. Nematode densities were sampled four times during a year-long crop sequence in small plots of corn (*Zea mays* L.) in monoculture; corn in association with black beans (*Phaseolus vulgaris* L.), faba beans (*Vicia faba* L.), and broccoli (*Brassica oleracea* L.); and corn in association with black beans, cilantro (*Coriandrum sativum* L.), and amaranth (*Amaranthus cruentus* L.). Corn crops were followed sequentially by black bean in monoculture, black bean in association with tomato (*Lycopersicon esculentum* L.), and black bean in association with husk tomato (*Physalis pruinosa* L.). The experimental design was a randomized complete block with six replicates. Nematode counts by genus and trophic group from each plot were subjected to analysis of variance. In the cropping systems tested, nematode densities either decreased or increased only slightly during the corn cycle but consistently increased during the bean cycle. Densities of all plant-parasitic nematode populations remained low throughout the study (less than 35 nematodes per 100 $cm^3$ soil), indicating no need for nematode management. Neither of the alternative cropping systems tested resulted in significant increases over the monoculture in population densities of nematodes considered to be economically damaging to either corn or beans.

*Key words*: *Amaranthus cruentus*, *Brassica oleracea*, *Coriandrum sativum*, cropping systems, Guatemala, intercrops, *Lycopersicon esculentum*, nematodes, *Phaseolus vulgaris*, *Physalis pruinosa*, *Vicia faba*, *Zea mays*.

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## RESUMEN

Larson, B., J. L. Stimac, R. McSorley y C. MacVean. 2000. Efectos de sistemas de cultivos sobre las densidades poblacionales de nemátodos dentro de la agricultura de pequeña escala en el altiplano de Guatemala. Nematrópica 30:177-191.

Se evaluaron los efectos en las poblaciones de nemátodos al agregar cultivos en asocio con maíz y frijol a pequeña escala en el departamento de Sololá, altiplano occidental de Guatemala. El objetivo fue determinar si las asociaciones aumentaban el daño causado por los nemátodos en los cultivos principales y si creaban mayor necesidad de manejo de los nemátodos. Las densidades de nemátodos fueron muestreadas cuatro veces durante el período de un año en parcelas pequeñas de maíz (*Zea mays* L.) en monocultura; maíz en asociación con frijol negro *(Phaseolus vulgaris L.),* habas *(Vicia faba L.)*, y brócoli *(Brassica oleracea* L.); y maíz en asociación con frijol negro, cilantro (*Coriandrum sativum*

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L.) y amaranto (*Amaranthus cruentus* L.). Los cultivos de maíz fueron seguidos en secuencia por frijol negro en monocultura; frijol en asociación con tomate (*Lycopersicon esculentum* L.); y frijol en asociación con mil-tomate (*Physalis pruinosa* L.). El diseño experimental consistió en bloques completos al azar con seis repeticiones. Se compararon los conteos de nemátodos en cada parcela por género y por grupo trófico, utilizando análisis de varianza. Las densidades de nemátodos dentro de los cultivos investigados disminuyeron o aumentaron poco durante el ciclo del maíz, pero aumentaron consistentemente durante el ciclo del frijol. Las densidades de todas las poblaciones de nemátodos fitoparasíticos estuvieron bajos durante todo el estudio (menos de 35 nemátodos por 100 $cm^3$ de suelo), indicando que no se necesitaba ningún tipo de manejo de nemátodos. Ninguno de los sistemas alternos de cultivos que se probaron resultó en aumentos significativos sobre la monocultura en términos de las densidades poblacionales de nemátodos que pueden causar daños económicos al maíz o el frijol.

*Palabras claves*: *Amaranthus cruentus*, *Brassica oleracea*, *Coriandrum sativum*, cultivos intercalados, Guatemala, *Lycopersicon esculentum*, nemátodos, *Phaseolus vulgaris*, *Physalis pruinosa*, sistemas de cultivos, *Vicia faba*, *Zea mays*.

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## INTRODUCTION

In the western Guatemalan highlands, small-scale farmers seeking greater income are increasingly tempted to plant export vegetables, reducing the production of staple food crops and increasing risk of greater dependency on synthetic pesticides (Morales *et al.*, 1993). Cropping systems that maintain the staples corn and beans and incorporate additional crops for their economic and nutritional benefits may be less risky for such farmers. Knowledge of nematode pests on cropping systems in the region is minimal, so when planting more intensive cropping systems to meet changing economic and sociological conditions of small-scale farmers in the area, it is important to determine the consequences in terms of pest populations. In Central America, chemical control of nematodes is generally not economically feasible for small-scale farmers and economic thresholds are difficult to establish (Pinochet, 1987; Sosa-Moss, 1985). Since small-scale farmers in the area cannot afford to implement nematode control measures, the use of any alternative cropping systems would have to preclude incurring those costs.

Crop rotations that are particularly suited to the needs of low-resource tropical farmers have long been promoted as one of the most effective tactics to avoid nematode population build-up (Noe, 1988; Noe *et al.*, 1991; Nusbaum and Ferris, 1973). Rotation crops have been tested for their effects on reducing *Meloidogyne* spp. numbers and increasing yields in peanut (*Arachis hypogaea* L.) (Rodriguez-Kabana *et al.*, 1988a; 1988b), soybean (*Glycine max* Merr.) (Minton and Bondari, 1994; Rodriguez-Kabana *et al.*, 1990; 1991b; Weaver *et al.*, 1988), tobacco (*Nicotiana tabacum* L.) (Fortnum and Currin, 1993), and vegetable crops (McSorley *et al.*, 1994a; 1994b). Although understanding of nematode population response to sequential crop arrangements that include non-host or poor host crops is increasing, the effects of adding such crops within a season are unclear. As has been observed for insect populations, the response of nematode populations, principally *Meloidogyne incognita* (Kofoid and White) Chitwood, to associations of susceptible and non-susceptible crops has varied in different cropping systems. Although there have been some reports of positive effects of crop associations in reducing damage from plant-parasitic nematodes (Hackney and Dickerson, 1975; Marban-Mendoza *et al.*, 1992; Raymundo, 1985; Tanda and Atwal, 1988), studies of other systems have not shown significant effects (Griffin and Jensen, 1997; Powers *et al.*, 1993; Sharma *et al.*, 1996).

The variable results from studies of nematode response to cropping system highlight the importance of evaluating proposed changes to specific cropping systems to determine possible changes in nematode population densities and subsequent crop damage consequences. Such evaluations are particularly important when additional crops are added to the system for purposes other than pest management. Given the tendency of small-scale farmers in the tropics to modify cropping systems based on economic value, food stability, and cultural traditions (Beets, 1982), rather than considerations of plant protection from pests, information pertinent to nematode management in individual cropping systems is valuable.

The present study sought to determine the effect of adding selected intercrops to corn and beans on nematode population densities in a selected tropical community. The additional crops were chosen for their potential economic and nutritional value and not for their value in suppressing pest populations. Therefore, it was unknown whether their inclusion in the cropping system would result in significantly higher nematode population densities that could lead to greater damage to the principal crops under the conditions of small-scale farmers in the study area.

Nematode population densities in corn (*Zea mays* L.) and black bean (*Phaseolus vuglaris* L.) monocultures were compared to those in selected intercrops. While corn and/or black beans are occasionally mixed with other crops, corn and bean intercrops or corn and bean monocultures are more typical in the study area. Corn and bean monocultures provide a stable but low income to the local farmers. The high-risk intercrop treatment includes crops that are likely to provide higher but less stable returns over time, as a result of both greater pest problems and variability in market prices. The low-risk intercrop includes crops likely to provide returns over time that are intermediate between the monoculture and high-risk treatments. Compared to the high-risk treatment, the low-risk treatment is expected to provide lower but more stable returns over time, due to lower pest damage levels and more stable market values for those crops. Crops were chosen for inclusion in the high-risk and low-risk treatments based on a preliminary study of production, pest problems, and market conditions in the area (Larson Vasquez, 1998). The principal objective was to determine if adding certain crops to corn and beans would increase the need for actively managing nematodes.

## MATERIALS AND METHODS

Field plots were maintained from May 1996 to April 1997 at the Escuela de Formación Agrícola in Sololá, Guatemala, at an altitude of 2095 m. The soil was a sandy loam alfisol (66% sand, 22% silt, and 12% clay), with a pH of 5.6 and an organic matter content of 3.6%. Total precipitation was 1273 mm during the corn cycle and 38 mm during the bean cycle. Mean daily temperatures ranged from a minimum of 12.2°C to a maximum of 21.1°C, with the mean of daily median temperatures being 16.6°C.

Plots were planted to corn monoculture and intercrops from May to December and to bean monoculture and intercrops from December to April. Cropping system treatments were as follows: 1) corn monoculture followed by black bean monoculture; 2) a high-risk intercrop treatment consisting of corn, black beans, broccoli (*Brassica oleracea* L.), and faba beans (*Vicia faba* L.), followed by black beans and tomatoes (*Lycopersicon esculentum*); 3) a low-risk intercrop treatment consisting of corn, black beans, cilantro (*Coriandrum sativum* L.), and amaranth (*Amaranthus cruentus* L.), followed by black beans and husk tomato (*Physalis pruinosa* L.). Plant arrangements for the intercrop treatments are shown in Figure 1.

The experimental design was a randomized complete block with six replicates. Plots measuring 15 × 8 m were laid out along the contour within each block and separated by at least 7 m. The land comprising one block had been in pasture for the preceding ten years, while the other two blocks were previously planted with a variety of vegetable crops, primarily potato (*Solanum tuberosum* L.), tomato, and broccoli. Plots were terraced, with two to three hoe-constructed terraces per plot, and rows were planted along the contour. Monthly cutting with a machete minimized vegetation in areas between plots. Local farmers carried out all land preparation, planting, and weeding with hoes and machetes, and agronomic practices followed those of the region. Fertilizer applications followed nutrient requirements of crops rather than standard practices in the region but were within the economic possibility of most local farmers. Locally grown seed was used for all crops except broccoli and amaranth, and no pesticides were applied.

On 18 May 1996, four seeds of local yellow corn per 8-cm-diameter-machete-made hole were planted in all plots at a distance of 0.6 m between plants and 1.0 m between rows (16 667/ha.), following application of diammonium phosphate (18-46-0 N-$P_2O_5$-$K_2O$) at 100 kg/ha to holes. In plots of intercrop treatments, three black bean seeds were added to each planting hole. Soil was mounded around each planting hole, and processed chicken manure (3-2-3 N-$P_2O_5$-$K_2O$) was applied in a furrow beside each mound at 841 kg/ha. Each intercrop received 75 kg/ha of diammonium phosphate applied to holes at planting. At three weeks after planting, muriate of potash (0-0-60 N-$P_2O_5$-$K_2O$) and urea (46-0-0 N-$P_2O_5$-$K_2O$) were broadcast at 100 kg/ha in monoculture plots and at 150 kg/ha (divided into two applications) in intercrop plots. All plots received two more applications of urea (100 and 150 kg/ha at each application for monoculture and intercrops, respectively) at 9 and 13 weeks after planting. Amount and placement of fertilizers was based on pre-plant soil analysis and recommended optimum fertilization for the crops under study. Differences in fertilizer applications among treatments were necessary due to the different types of crops in each treatment.

In the high-risk intercrop treatment, at three weeks after corn planting, two local faba bean seeds were planted per hole within the corn row at a distance of 0.6 m between plants (16 000/ha). Two weeks later, five-week-old broccoli seedlings produced in a nearby seedbed were transplanted between corn rows at a distance of 0.6 m between plants (14 000/ha). In the low-risk intercrop treatment, local cilantro seed was planted three weeks after corn, between corn rows at a distance of 10 cm between plants (100 000/ha). Due to poor germination over all plots, cilantro was replanted five weeks later in two rows between every other row of corn (10 cm between plants and 20 cm between rows), with amaranth planted in two rows between the remaining rows of corn (15 cm between plants, 20 cm between rows, 80 000/ha). Poor germination resulted in replanting of amaranth three and six weeks later. In the other treatments, reseeding was also done as needed for corn, bean, and faba beans after germina-

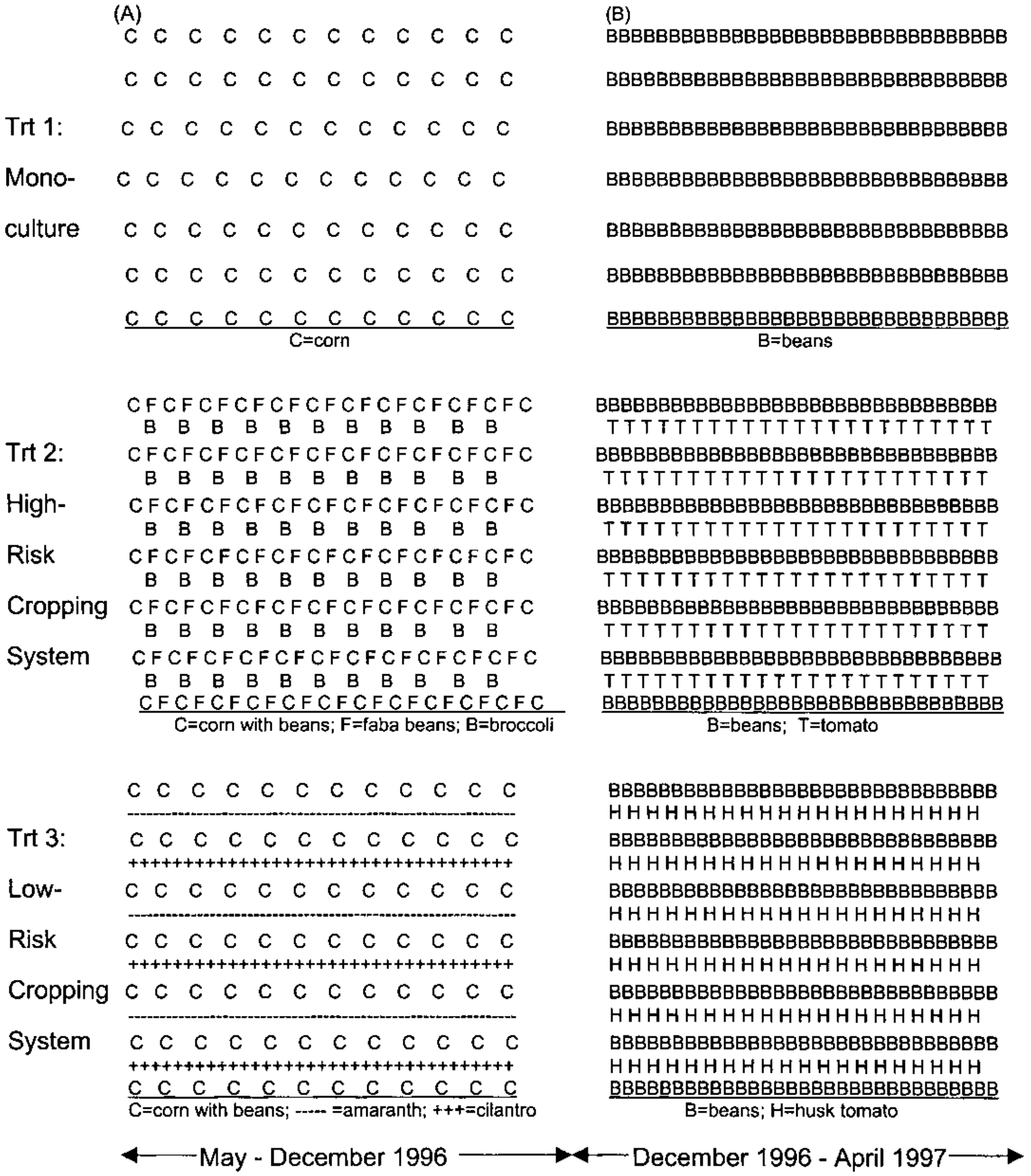

Fig. 1. Plant arrangements in experimental plots of corn-based (A) and bean-based (B) cropping systems, with treatments consisting of: 1) corn monoculture followed by bean monoculture, 2) corn and beans with faba beans and broccoli, followed by beans with tomato; and 3) corn and beans with cilantro and amaranth, followed by beans with husk tomato.

tion, and missing broccoli seedlings were replaced. Replanting intensity for corn was similar across treatments.

Black beans were harvested on 3 September 1996 and sun dried. Faba beans were harvested on 16 October, 9 November, and 2 December. Broccoli was harvested on 4 September, 18 September, and 16 October. Cilantro was harvested on 16 October and 25 November, and amaranth was harvested on 6 December. Due to strong winds in August, lodged corn plants with no potential for ear development were removed on 29 August, and on 23 October remaining lodged plants were removed and harvested for fresh ears. Remaining corn for grain was harvested by hand on 25 November.

During the second half of the experiment, plots were cleared of roots and debris from the previous corn cycle and cultivated with hoes. Local black bean seed was treated with captan at 2.54 g/kg and planted in all plots on 13 December, at a spacing of 1.0 m between rows and 20 cm between plants (50 000/ha), with two seeds per 10-cm-diameter hole, into which diammonium phosphate (18-46-0 N-$P_2O_5$-$K_2O$) at 100 kg/ha had been incorporated. The following week, six-week-old tomato seedlings produced in a nearby seedbed were transplanted between bean rows at a spacing of 40 cm between plants, in all plots that had been planted previously with broccoli and faba beans. Diammonium phosphate at 100 kg/ha was applied to approximately 15-cm diameter holes (23 333 per ha) at transplanting. Two weeks after planting beans, seven-week-old husk tomato seedlings produced in a nearby seedbed were transplanted to remaining plots in the same manner as tomato plants. Tomato plants, but not husk tomato plants, were staked. Missing tomato and husk tomato seedlings were replaced one week after transplanting, and non-germinating bean was reseeded four weeks after planting. Reseeding intensity of bean plants was similar for all treatments.

At four weeks after planting bean, muriate of potash (0-0-60 N-$P_2O_5$-$K_2O$) and urea (46-0-0 N-$P_2O_5$-$K_2O$) were broadcast to all plots at 100 kg/ha for monoculture plots and 150 kg/ha for biculture (treatments 2 and 3) plots. At seven weeks after planting, plots received another equal urea application. All plots were watered three times weekly, receiving approximately 900 liters of water per irrigation session with either a hose or the traditional method of manually throwing water onto the field with a shallow plastic dish from an irrigation furrow above each terrace. As in the corn cycle, all work was performed by hand, and land preparation, planting, weeding, and harvesting followed local management practices.

Nematodes were sampled four times during the experiment: (1) initial population densities ($P_i$) after plots were prepared but before planting (10 May 1996); (2) at mid-season of the corn crop (9 September 1996); (3) after the corn was harvested and before beans were planted (6 December 1996); and (4) final population densities ($P_f$) after the bean harvest (21 April 1997). Soil samples, allocated systematically within each plot, were taken within the root zone of the corn and later the bean crops. Each sample consisted of 12 cores per plot (2.5 cm-diameter and 15-20 cm depth), removed with a soil corer.

For each plot, cores were combined and a subsample of 100 $cm^3$ was taken for nematode extraction by a combined sieving and Baermann technique (Christie and Perry, 1951). The subsample was suspended in water and passed through a coarse sieve, and caught on a 400-mesh sieve. The concentrated sample was placed on a tissue paper (Kimwipes®, Kimberley-Clark Corporation, Roswell, GA, U.S.A.) in a modified Baermann setup consisting of a plastic electrical gang cover with wire screening set in a plastic sandwich dish filled with water to the level of the screening. After 48 hours at a temperature of 17-22°C, nematodes were removed, killed by heating in a 60°C waterbath for 15 minutes, and preserved in 10% formalin for later identification.

Nematodes were counted by genus and assigned to trophic groups according to Yeates *et al.* (1993). For the most prevalent genera and for trophic groups, initial and final population densities among the three treatments were compared for both the corn and bean cycles of the experiment, as were the ratios of final to initial population densities for the corn cycle, bean cycle, and entire year. $P_f/P_i$ ratios are based on values to which 1 was added to avoid division by zero, because in some cases initial population densities were too low to be detected. Therefore in all cases, reported $P_f/P_i$ ratios are actually $(P_f + 1)/(P_i + 1)$. Analysis of variance was performed on nematode count data transformed by $\log_{10}(x + 1)$, using the PROC GLM procedure of SAS (SAS Institute, 1990). The Student-Newman-Keuls test was used to separate means when significant treatment differences were detected at $\alpha = 0.05$. Although transformed counts were used when determining treatment differences to meet the assumptions of analysis of variance, tables report treatment means for untransformed data.

## RESULTS

The principal genera of plant-parasitic nematodes found in the cropping systems studied are given in Table 1. In addition, plant-parasitic genera found occasionally included *Criconemoides, Paratylenchus,* and *Scutellonema.* The genus *Psilenchus,* for which food habits are unclear, was also found occasionally and included with the plant parasites to which it is closely related.

While the population densities of some genera of plant-parasitic nematodes declined over the corn cycle in some cropping systems, population densities of all principal plant parasites increased during the bean cycle. This contributed to an increase over the year ($P_f/P_i > 1$) in all but *Meloidogyne* spp. in the low-risk treatment (Table 1). This genus constituted 54% of the plant-parasitic nematodes in all treatments at the start of the experiment ($P_i$) and only 17% at the end of the corn cycle, increasing again during the bean cycle to 29% of the total. In contrast, 23% of plant parasites were *Helicotylenchus* spp. at $P_i$, increasing to 58% after the corn cycle and decreasing to 32% by the end of bean cycle. The relative composition of the plant-parasitic nematode community remained fairly constant for the remaining genera (Fig. 2). During the corn cycle, there were no significant differences among cropping systems for either $P_i$ or $P_f$ of any of the principal plant-parasitic genera, and densities of all plant parasitic nematodes in soil remained below 25 per 100 $cm^3$ soil. The reproductive factor ($P_f/P_i$) also did not differ by cropping system for any of the principal genera during the corn cycle (Table 1).

During the bean cycle, the only difference in plant-parasitic nematodes observed among treatments was in the final density ($P_f$) of *Tylenchorhynchus* spp. (12.0 ± 4.1 nematodes per 100 $cm^3$ soil), which was significantly higher in the beans with husk tomato treatment (low-risk treatment) than in the bean monoculture (7.33 ± 4.62 nematodes per 100 $cm^3$ soil). Subsequently, *Tylenchorhynchus* spp. showed a higher reproductive factor in both intercrop treatments than in the monoculture. The great increase in *Tylenchorhynchus* spp. over the bean cycle resulted from its near absence (very low $P_i$) prior to this crop. During the bean cycle, most genera had high reproductive factors across treatments, but final population densities did not exceed 35 nematodes per 100 $cm^3$ soil for any genus.

*Tylenchus* (root associate), *Aphelenchus* (fungivore), and *Eucephalobus* (bacterivore) were among the most common genera of

Table 1. Ratio of final to initial nematode population densities ($P_f/P_i$) by genus from 100-cm$^3$ soil samples taken from monocultures (corn followed by beans) and two alternative intercrops (high-risk intercrop of corn with black beans, faba beans, and broccoli, followed by black beans with tomato; and low-risk intercrop of corn with black beans, cilantro and amaranth, followed by black beans with husk tomato).

| | Corn cycle Mean $P_f/P_i$ ± SEM | Bean Cycle Mean $P_f/P_i$ ± SEM | Total for year Mean $P_f/P_i$ ± SEM |
|---|---|---|---|
| | | *Meloidogyne* | |
| Monoculture | 0.70 ± 0.19 a | 8.08 ± 6.54 a | 2.37 ± 1.42 a |
| High-risk intercrop | 0.40 ± 0.14 a | 5.24 ± 1.70 a | 2.86 ± 1.50 a |
| Low-risk intercrop | 0.45 ± 0.31 a | 5.22 ± 2.59 a | 0.96 ± 0.37 a |
| | | *Helicotylenchus* | |
| Monoculture | 3.91 ± 1.48 a | 2.66 ± 1.68 a | 4.75 ± 1.37 a |
| High-risk intercrop | 2.13 ± 0.70 a | 3.47 ± 1.17 a | 8.86 ± 4.86 a |
| Low-risk intercrop | 1.63 ± 0.59 a | 2.53 ± 0.85 a | 2.69 ± 0.66 a |
| | | *Pratylenchus* | |
| Monoculture | 1.51 ± 0.92 a | 1.78 ± 0.72 a | 1.63 ± 0.63 a |
| High-risk intercrop | 0.89 ± 0.34 a | 5.80 ± 1.78 a | 6.81 ± 4.57 a |
| Low-risk intercrop | 1.40 ± 0.57 a | 5.11 ± 2.74 a | 5.75 ± 4.36 a |
| | | *Trichodorus* | |
| Monoculture | 1.83 ± 0.31 a | 4.73 ± 1.70 a | 4.78 ± 1.51 a |
| High-risk intercrop | 1.38 ± 0.58 a | 3.90 ± 2.64 a | 2.83 ± 1.20 a |
| Low-risk intercrop | 2.21 ± 0.89 a | 3.39 ± 1.41 a | 6.86 ± 4.24 a |
| | | *Hemicycliophora* | |
| Monoculture | 0.86 ± 0.09 a | 1.77 ± 0.35 a | 1.49 ± 0.42 a |
| High-risk intercrop | 1.72 ± 0.59 a | 1.51 ± 0.55 a | 1.89 ± 0.57 a |
| Low-risk intercrop | 1.42 ± 0.33 a | 1.28 ± 0.34 a | 1.31 ± 0.32 a |
| | | *Tylenchorhynchus* | |
| Monoculture | 1.08 ± 0.20 a | 3.54 ± 1.23 b | 4.25 ± 2.27 a |
| High-risk intercrop | 0.67 ± 0.30 a | 10.08 ± 4.19 a | 3.64 ± 1.91 a |
| Low-risk intercrop | 0.53 ± 0.11 a | 11.67 ± 4.11 a | 8.01 ± 4.67 a |

Samples taken in May 1996 (corn $P_i$ and total $P_i$), December 1996 (corn $P_f$ and bean $P_i$) and April 1997 (bean $P_f$ and total $P_f$). For all mean values, n = 6. Treatment means within cropping cycle and genus followed by the same letter are not significantly different (a = 0.05, ANOVA and Student-Newman-Keuls test performed on data transformed by $\log_{10}(x + 1)$ after adding 1 to avoid division by zero).

non-plant-parasitic nematodes encountered. Additional fungivores included *Aphelenchoides* and *Nothotylenchus,* while the bacterivores *Monhystera, Plectus,* and *Wilsonema* were seen occasionally. The omnivores *Mesodorylaimus* and *Eudorylaimus*

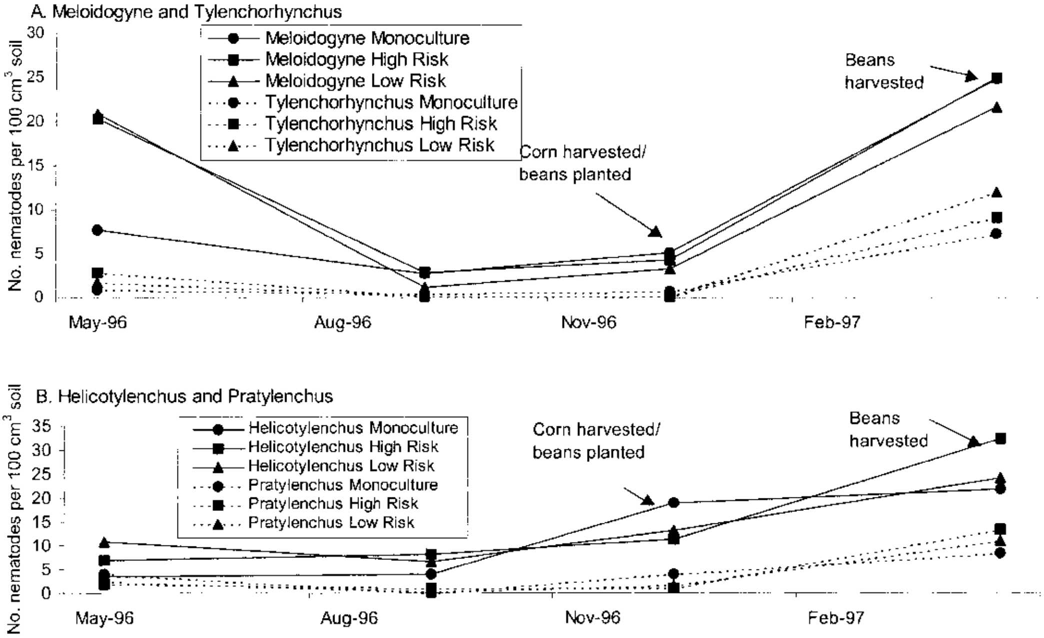

Fig. 2. Mean densities (no. per 100-cm³ soil) of plant parasitic nematodes from samples taken from monocultures (corn followed by beans) and two alternative intercrops (high-risk intercrop of corn with black beans, faba beans, and broccoli, followed by black beans with tomato, and low-risk intercrop of corn with black beans, cilantro and amaranth, followed by black beans with husk tomato), May 1996 to April 1997.

and the predators *Mononchus* and *Seinura* constituted the rest of the nematode genera in the cropping systems examined.

The initial nematode community was dominated by plant parasites (mean of 45%), with 31% fungivores and 14% bacterivores. At the end of the corn cycle, plant parasites had decreased to 35%, with fungivores constituting 36% and bacterivores 17%. After the bean cycle, bacterivores were dominant (39%), and plant parasites accounted for only 29%. Fungivores comprised 24% of total nematodes at $P_f$. Relative densities of omnivores and predators were low throughout the year. These groups constituted 7-16% and 0.4-1.2% of total nematodes, respectively, during the year. The reduction in plant parasites and fungivores and increase in bacterivores over the year was consistent for all treatments. Even with overall increases in densities of plant-parasitic genera during the bean cycle, plant parasites never constituted a majority of the total nematode community (Fig. 3).

During the corn cycle, initial density of plant parasites in the treatment consisting of corn with black beans, cilantro, and amaranth (low-risk intercrop) was higher than in the monoculture (Table 2). Densities of fungivores and of total nematodes were initially lower in the corn monoculture, and by the end of the corn cycle, densities of bacterivores and omnivores in the monoculture were greater than in the other two treatments. No other significant differences in densities were observed for any sampling date.

The reproductive factor for total nematodes was greater for the corn monoculture than for the other two treatments. There were no other significant differences in reproductive factor among treat-

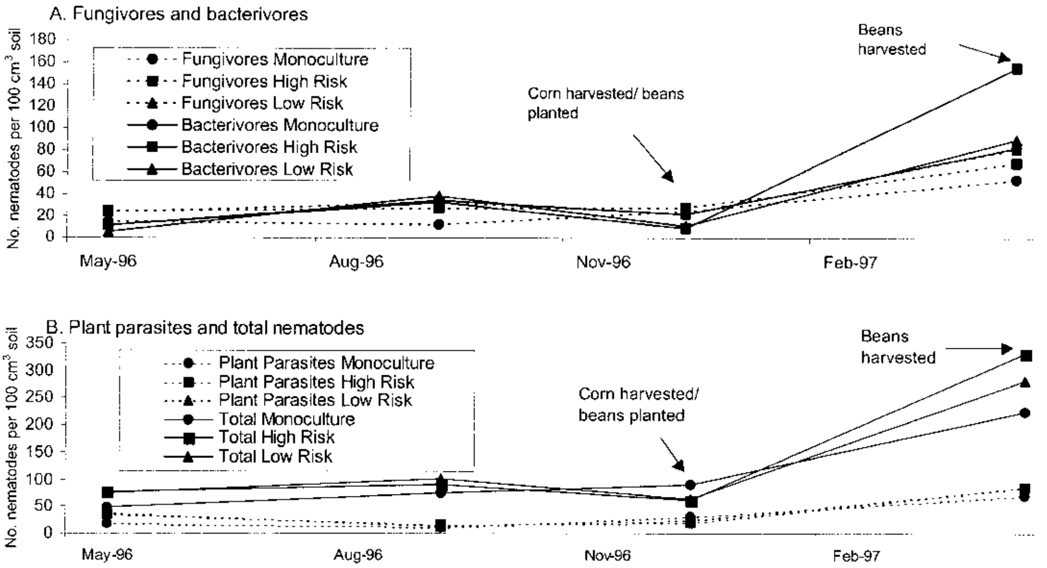

Fig. 3. Mean densities (no. per 100-cm$^3$ soil) by trophic group of nematodes from samples taken from monocultures (corn followed by beans) and two alternative intercrops (high-risk intercrop of corn with black beans, faba beans, and broccoli, followed by black beans with tomato, and low-risk intercrop of corn with black beans, cilantro and amaranth, followed by black beans with husk tomato), May 1996 to April 1997.

ments for any trophic group in the corn cycle (Table 3). In a few cases, high standard errors indicate that some reproductive factors were highly variable across replicates.

Although initial densities of bacterivores and omnivores in the bean monoculture were higher than in the other two treatments, there were no differences in final densities for any trophic group. Furthermore, reproductive factor was not different among treatments for any trophic group in either the bean cycle or the total year. Although very low initial densities for most genera and trophic groups contributed to some high $P_f/P_i$ values, the greatest population increase observed was 13-fold, an increase in bacterivore density in the high-risk intercrop (beans with tomato) during the bean cycle. However, the reproductive factor of bacterivores was not significantly different among treatments.

## DISCUSSION

Among the nematode genera able to reproduce on corn, the most commonly encountered include *Meloidogyne* and *Pratylenchus*, while *Trichodorus* spp. (including *Paratrichodorus* spp.) are among the most potentially destructive (Shurtleff, 1980). In this experiment, during the corn cycle, the population density of *Meloidogyne* spp. remained below damage thresholds established in the United States for several species, the lower range of which starts at 50 nematodes/100 cm$^3$ soil (Barker, *et al.*, 1985). In fact, *Meloidogyne* spp. populations did not increase on corn in any cropping system studied ($P_f/P_i < 1$ for all treatments). While in some cases densities of *Meloidogyne* spp. do not increase significantly on corn (Hutton *et al.*, 1983; Kinloch, 1983), in many instances corn has been found to be a suitable host (Gallaher *et al.*, 1991; Heffes *et al.*,

Table 2. Nematode densities (mean no. per 100 cm$^3$ soil ± SEM) by trophic group for sampling dates with differences among cropping system treatments, taken from monocultures (corn followed by beans) and two alternative intercrops (high-risk intercrop of corn with black beans, faba beans and broccoli, followed by black beans with tomato; and low-risk intercrop of corn with black beans, cilantro and amaranth, followed by black beans with husk tomato).

| | |
|---|---|
| | Plant parasites, May 1996 ($P_i$) |
| Monoculture | 18.67 ± 5.91 b |
| High-risk intercrop | 34.17 ± 11.03 ab |
| Low-risk intercrop | 38.17 ± 5.72 a |
| | Fungivores, May 1996 ($P_i$) |
| Monoculture | 15.00 ± 4.31 b |
| High-risk intercrop | 24.50 ± 7.42 a |
| Low-risk intercrop | 23.83 ± 4.03 a |
| | Total nematodes, May 1996 ($P_i$) |
| Monoculture | 48.33 ± 16.57 b |
| High-risk intercrop | 78.00 ± 27.86 a |
| Low-risk intercrop | 74.50 ± 8.90 a |
| | Bacterovpres, Dec. 1996 (corn $P_f$, bean $P_i$) |
| Monoculture | 21.83 ± 4.72 a |
| High-risk intercrop | 8.92 ± 5.25 b |
| Low-risk intercrop | 10.92 ± 3.26 b |
| | Omnivores, Dec. 1996 (corn $P_f$, bean $P_i$) |
| Monoculture | 11.08 ± 4.85 a |
| High-risk intercrop | 5.25 ± 2.26 b |
| Low-risk intercrop | 4.75 ± 1.08 b |

For all mean values, n = 6. Treatment means within cropping cycle and trophic group followed by the same letter are not significantly different (a = 0.05, ANOVA and Student-Newman-Keuls test performed on data transformed by $\log_{10}(x + 1)$).

1992; Sumner *et al.*, 1985). Local corn used in the current study was a poor host, and the crops added to the system did not affect *Meloidogyne* spp. densities around the corn roots. Further investigation of the resistance of the local corn to *Meloidogyne* spp. nematodes is needed in order to better interpret the results of this experiment.

*Pratylenchus* spp. also are common in soils in which corn has been grown, and *P. neglectus* has been shown to compete with *M. chitwoodi* on barley (*Hordeum vulgare* L.) and potatoes (Tanda and Atwal, 1988). In the present study, however, mean densities of *Pratylenchus* spp. remained below 6 nematodes/100 cm$^3$ during the corn cycle and constituted no more than 9% of the plant parasitic nematodes extracted. Finally, populations of *Trichodorus* spp. (including *Paratrichodorus* spp.) can change rapidly and can be highly destructive to corn, but were not observed to rise beyond 4 nematodes/100 cm$^3$ during the corn cycle. The other plant-parasitic nematodes recovered

Table 3. Ratio of final to initial nematode population densities ($P_f/P_i$) by trophic group from 100-cm$^3$ soil samples taken from monocultures (corn followed by beans) and two alternative intercrops (high-risk intercrop of corn with black beans, faba beans and broccoli, followed by black beans with tomato; and low-risk intercrop of corn with black beans, cilantro and amaranth, followed by black beans with husk tomato).

| | Corn cycle Mean $P_f/P_i$ ± SEM | Bean Cycle Mean $P_f/P_i$ ± SEM | Total for year Mean $P_f/P_i$ ± SEM |
|---|---|---|---|
| | | Plant Parasites | |
| Monoculture | 1.77 ± 0.88 a | 6.80 ± 3.84 a | 4.52 ± 1.27 a |
| High-risk intercrop | 0.73 ± 0.26 a | 4.99 ± 1.29 a | 3.19 ± 0.57 a |
| Low-risk intercrop | 0.73 ± 0.24 a | 4.66 ± 2.04 a | 2.54 ± 1.15 a |
| | | Fungivores | |
| Monoculture | 2.05 ± 0.64 a | 5.16 ± 2.56 a | 4.86 ± 1.51 a |
| High-risk intercrop | 1.44 ± 0.72 a | 6.00 ± 2.54 a | 3.89 ± 1.12 a |
| Low-risk intercrop | 0.85 ± 0.28 a | 6.57 ± 1.98 a | 3.96 ± 1.26 a |
| | | Bacterivores | |
| Monoculture | 5.14 ± 2.19 a | 4.05 ± 1.36 a | 21.53 ± 13.24 a |
| High-risk intercrop | 1.72 ± 0.59 a | 26.88 ± 16.06 a | 21.42 ± 6.02 a |
| Low-risk intercrop | 2.05 ± 0.61 a | 10.30 ± 3.78 a | 18.07 ± 5.30 a |
| | | Omnivores | |
| Monoculture | 6.74 ± 4.86 a | 2.08 ± 0.70 a | 8.69 ± 6.27 a |
| High-risk intercrop | 1.76 ± 0.89 a | 5.83 ± 2.30 a | 11.14 ± 7.70 a |
| Low-risk intercrop | 1.00 ± 0.28 a | 6.31 ± 2.98 a | 5.14 ± 2.74 a |
| | | Predators | |
| Monoculture | 1.72 ± 0.46 a | 1.44 ± 0.56 a | 1.94 ± 0.48 a |
| High-risk intercrop | 0.92 ± 0.08 a | 2.17 ± 0.48 a | 2.00 ± 0.52 a |
| Low-risk intercrop | 1.89 ± 0.76 a | 1.59 ± 0.89 a | 1.47 ± 0.42 a |
| | | Total Nematodes | |
| Monoculture | 2.59 ± 0.88 a | 3.39 ± 1.10 a | 6.54 ± 1.76 a |
| High-risk intercrop | 1.03 ± 0.40 b | 8.64 ± 3.03 a | 5.92 ± 1.54 a |
| Low-risk intercrop | 0.83 ± 0.23 b | 6.90 ± 2.60 a | 4.07 ± 1.42 a |

Samples taken in May 1996 (corn $P_i$ and total $P_i$), December 1996 (corn $P_f$ and bean $P_i$), and April 1997 (bean $P_f$ and total $P_f$). For all mean values, n = 6. Treatment means within cropping cycle and trophic group followed by the same letter are not significantly different (a = 0.05, ANOVA and Student-Newman-Keuls test performed on data transformed by $\log_{10}(x + 1)$ after adding 1 to avoid division by zero).

would require much higher population densities to exert economic effects on corn (Shurtleff, 1980).

While *Tylenchorhynchus* spp. were found in association with the soil around bean roots, they are not considered to cause damage to the bean plant. In fact, among the nematodes at this site, *Meloidogyne* and *Pratylenchus* are the only two nematode genera with the potential to inflict substantial damage to bean (Hall, 1991). Mean soil densities of these nematodes in the cropping systems examined were never greater than 30 per 100 cm$^3$, despite the presence in the high-risk cropping system of tomato, generally an excellent host that can build up population levels of *Meloidogyne* spp. (Jones *et al.*, 1991).

For all treatments, bacterivores increased in density more rapidly than any other trophic group during the bean cycle. Bacterivorous nematodes are important components of the soil biota, with a major role in decomposition and nutrient cycling, and as such are beneficial to crop plants present, particularly by increasing availability of nutrients (Freckman, 1988).

In the cropping systems tested, nematode densities either decreased or increased only slightly during the corn cycle, with consistent increases during the bean cycle ($P_f/P_i > 1$ in all cases). The decline in relative abundance of plant parasites and augmentation of bacterivorous nematodes in the study plots over the year illustrate the favorable nature of the cropping systems tested in terms of effects on the nematode community.

Densities of all plant-parasitic nematode populations remained low throughout the study, indicating the lack of need for nematode management. Furthermore, neither of the alternative cropping systems tested resulted in significant increases over the monoculture in terms of population densities of nematodes considered to be economically damaging in corn or beans. The results allow us to consider these cropping systems within the local communities for their economic and nutritional merits, without concern of contributing to the difficulty farmers may encounter in managing nematode pests as a result of their already limited information and capital. The low-risk intercrop treatment was found to provide greater nutritional benefit and higher economic return over the year than the monoculture, despite having higher input costs (Larson Vasquez 1998).

By assuring that the addition of particular crops to corn and beans did not result in nematode problems for the farmers of the study area, we can recommend further experimentation to improve returns from the low-risk cropping system treatment evaluated here. In addition, further testing should be carried out in the study area to encounter other crops that when added to corn and beans may improve economic and nutritional returns without increasing nematode populations to economically damaging levels. While the general principles employed in this study may be applied to other small-scale farming communities in the tropics, local conditions were very specific and therefore particular results are directly applicable only to the immediate study area.

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