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Regulation of Population Densities of *Heterodera cajani* and Other Plant-Parasitic Nematodes by Crop Rotations on Vertisols in Semi-Arid Tropical Production Systems in India[1]

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Abstract: The significance of double crop (intercrop and sequential crop), single crop (rainy season crop fallow from June to September), and rotations on densities of *Heterodera cajani, Helicotylenchus retusus,* and *Rotylenchulus reniformis* was studied on Vertisol (Typic Pellusterts) between 1987 and 1993. Cowpea (*Vigna sinensis*), mungbean (*Phaseolus aureus*), and pigeonpea (*Cajanus cajan*) greatly increased the population densities of *H. cajani* and suppressed the population densities of other plant-parasitic nematodes. Mean population densities of *H. cajani* were about 8 times lower in single crop systems than in double crop systems, with pigeonpea as a component intercrop. Plots planted to sorghum, safflower, and chickpea in the preceding year contained fewer *H. cajani* eggs and juveniles than did plots previously planted to pigeonpea, cowpea, or mungbean. Continuous cropping of sorghum in the rainy season and safflower in the post-rainy season markedly reduced the population density of *H. cajani.* Sorghum, safflower, and chickpea favored increased population densities of *H. retusus.* Adding cowpea to the system resulted in a significant increase in the densities of *R. reniformis.* Mean densities of total plant-parasitic nematodes were three times greater in double crop systems, with pigeonpea as a component intercrop than in single crop systems with rainy season fallow component. Cropping systems had a regulatory effect on the nematode populations and could be an effective nematode management tactic. Intercropping of sorghum with *H. cajani* tolerant pigeonpea could be effective in increasing the productivity of traditional production systems in *H. cajani* infested regions.

Key words: cropping system, cyst nematode, *Helicotylenchus retusus, Heterodera cajani,* nematode management, production system, *Rotylenchulus reniformis*

Farmers regard rotations of crops as a pragmatic way to sustain soil fertility and control soil-borne diseases, but cropping decisions in the semi-arid tropics are dynamic mixtures of conscious efforts to rotate crops and of adjustments compelled by weather and other environmental variables (1). The Vertisols (Typic Pellusterts) represent a vastly underutilized soil resource. These soils are traditionally kept fallow in the rainy season due to poor drainage and soil management constraints. However, with the advent of watershed-based technologies, which allow for improved drainage, the ability to grow crops in the rainy as well as post-rainy season has increased. In semi-arid tropical peninsular India, farmers cultivate sorghum (*Sorghum bicolor* (L.) Moench), pigeonpea (*Cajanus cajan* (L.) Millsp.), mungbean (*Phaseolus aureus* Roxb.), and cowpea (*Vigna sinensis* (L.) Savi ex Hassk.) in the rainy season and chickpea (*Cicer arietinum* L.), safflower (*Carthamus tinctorius* L.), and sorghum in the post-rainy season. These crops host a large range of plant-parasitic nematode species, some of which are pathogens of agricultural crops (6,7). Little is known about the influence of cropping systems comprising these crop species on plant-parasitic nematodes on Vertisols (12).

The rationale of this field study was to investigate how these crops as components of production systems influence the population densities of plant-parasitic nematodes, particularly of the pigeonpea cyst nematode (*Heterodera cajani* Koshy), which is prevalent in the region (9,11), and to identify useful cropping systems for reducing the adverse effects of nematode populations on the productivity of component crops of the traditional production systems of peninsular India.

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Materials and Methods

This study was part of a long-term project to determine the effects of different cropping systems and their rotations on soil fertility and crop production. The field trials were initiated in 1983 on a Vertisol (Typic Pellusterts, 23.5% sand, 22.8% silt, 53.7% clay) at the research farm (18°N, 78°E) of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Asia Center, Patancheru, Andhra Pradesh, India. Fifteen cropping systems consisting of sequential crops, intercrops, and crop fallows were used to compare the productivity of traditional single crop (rainy-season crop fallow between June and September) and newer double crop systems (intercropping and sequential cropping). Cowpea cv. EC 6216, mungbean cv. S 8, pigeonpea cv. ICP 1-6, and sorghum cv. CSH 6 were planted in June. Chickpea cv. Annegiri, safflower cv. Manjira, and sorghum cv. CSH 8R were planted in September or October. The crops were planted on 100-cm broad beds interspaced with 50-cm furrows using bullock-drawn wheeled tool carrier. Dry planting of crops was completed before the onset of monsoon rains, generally in the first 2 weeks of June. Furrows between beds facilitated surface drainage of rain water. Sorghum and cowpea were intercropped with pigeonpea (Table 1). Row-to-row distance for pigeonpea was 150 cm, and two rows of sorghum or cowpea were sown on either side of pigeonpea rows at a 45-cm distance. Three rows of chickpea in post-rainy season were sown in rows spaced 45 cm apart. Sorghum rows were spaced at 75 cm in rainy, and post-rainy seasons. Spacing between safflower rows was 75 cm. The cropping systems in Table 1 were rotated in a 2-year cycle and arranged in a randomized complete block design with three replications. The plot size was 6 m × 6 m. The trial plots received 48 kg P_2O_5/ha as basal dose band placed 5-cm away from seed rows. Zinc sulphate (50 kg/ha) was applied once in 3 years. The plots were not irrigated. All crops were harvested at physiological maturity. Rainy-season crops were harvested in September and October. Pigeonpea and the post-rainy season crops were harvested in January or February of the next year. Crops were harvested from 9-m^2 sample areas from the center of all plots.

TABLE 1. Effect of cropping systems on population densities (per 100 cm^3 soil) of *Heterodera cajani*, *Helicotylenchus retusus*, *Rotylenchulus reniformis*, and total plant-parasitic nematodes.

Cropping systems and rotation	*H. cajani* egg + J2	*H. retusus*	R. reniformis	Total plant-parasitic nematodes
		Year 1–Year 2		
S/PP-S + SF	277	221	166	782
S + CP-S + SF	73	413	77	704
C/PP-S + SF	272	88	326	776
S + SF-S + SF	93	368	116	720
S + SF-S/PP	1,695	179	159	2,126
S + CP-S/PP	1,102	193	223	1,647
S/PP-S/PP	762	274	185	1,327
S + CP-S + CP	96	421	50	688
S/PP-S + CP	370	238	99	834
S + SF-S + CP	115	394	60	712
S + SF-C/PP	1,462	40	502	2,043
F + S-F + S	17	168	108	379
F + S-F + CP	62	158	66	366
F + CP-F + S	107	171	76	435
M + S-M + S	479	211	136	933
LSD (P = 0.05)	424	123	144	427

Underlined cropping systems are preceding year crops in 1990.
C = cowpea, CP = chickpea, F = fallow, M = mungbean, PP = pigeonpea, S = sorghum, SF = safflower. / = intercrop, + = succeeding crop, - = rotation.

Effects of these systems on population densities of plant-parasitic nematodes were followed from 1987 to 1993. Soil nematode populations were estimated in June 1987, January and June 1988, January 1989, June 1991, and January 1993. The plots were sampled for plant-parasitic nematodes by taking four to six 5-cm-diam. cores 20 cm deep with a sampling tube. At each sampling, between 540 and 810 soil cores in total were collected. Nematode populations were extracted from 100-cm^3 samples by suspending them in water, pouring them through nested sieves (850-, 180-, and 38-μm pore), and placing the residue from the 38-μm-pore sieve on modified Baermann funnels to collect the vermiform stages of the nematodes (5). Nematode cysts were collected on a 180-μm-pore sieve (8). Eggs were extracted by crushing the cysts on a glass plate. Eggs and second-stage juveniles (J2) were counted to estimate *H. cajani* densities. Nematode population density data were analyzed with the randomized complete block design model. Least significant differences ($P = 0.05$) were calculated and mean differences in nematode population densities in different treatments and between treatments were examined. Mean nematode densities in all the cropping systems at planting and at harvest time, in single-crop and double-crop systems with or without pigeonpea component, and in plots with same cropping systems in the preceding year, were compared. Data in Table 1 were further subjected to analysis using the SAS general linear model procedure, and orthogonal contrasts were used to test for differences between cropping systems (Table 2). Data on overall mean (averaged across all sampling dates) population densities of different plant-parasitic nematodes are given only in text to avoid repetition.

In June 1987, the remaining soil samples after taking 100-cm^3 aliquot were bulked, thoroughly mixed, and filled in 12 15-cm-diam. pots, and seeds of cowpea, pigeonpea, mungbean, sorghum, safflower, and chickpea were sown into two pots each. The tops of all the plants were cut after every 10 weeks, and seeds of respective plant species were sown again. After 1 year, nematode populations in these pots were examined by processing a 100-cm^3 soil sample (4,5,7,8) for the most prominent nematode species associated with a crop.

Results and Discussion

Heterodera cajani, Helicotylenchus retusus, and *Rotylenchulus reniformis* populations constituted 84 to 94% of total population of plant-parasitic nematodes. *Heterodera cajani* was the most common plant-parasitic nematode and constituted 33 to 69% of the total density of plant-parasitic nematodes. *Hoplolaimus seinhorsti, Tylenchorhynchus vulgaris, Pratylenchus* spp., *Paratrophurus* sp., *Tylenchus* sp., and *Xiphinema* sp. were occasionally present in the soil but their densi-

TABLE 2. Effects of cropping systems on population densities (nematodes per 100 cm^3 soil) of *Heterodera cajani, Helicotylenchus retusus, Rotylenchulus reniformis*, and total plant-parasitic nematodes.

Cropping systems	*H. cajani* egg + J2	*H. retusus*	*R. reniformis*	Total plant-parasitic nematodes
Single-crop systems	62	166	83	393
Double-crop systems without pigeonpea	171	361	88	751
Double-crop systems with pigeonpea	849	176	237	1,362
All cropping systems without pigeonpea	130	172	86	617
Contrasts				
Single crop vs. double crop without pigeonpea	NS	***	NS	*
Single crop vs. double crop with pigeonpea	***	NS	***	***
Systems without pigeonpea vs. systems with pigeonpea	***	***	***	***

*, *** = Significant at $P \leq 0.05$ and 0.0001, respectively; NS = Non-significant.

ties were low (range 0–0.5/cm^3 soil). After 1 year of culturing in pots, *H. retusus* on sorghum (376/100 cm^3 soil), safflower (332/100 cm^3 soil), and chickpea (280/100 cm^3 soil), *R. reniformis* on cowpea (540/100 cm^3 soil), and *H. cajani* on pigeonpea (815/100 cm^3 soil) were the most prominent nematode populations.

Heterodera cajani: Population densities of *H. cajani* were significantly influenced by the cropping systems. Effects varied among years but some trends were evident: after 8 years in 1991, the nematode densities were extremely low in plots continuously planted to sorghum + safflower, sorghum + chickpea, fallow + sorghum, and fallow + chickpea systems (Fig. 1). Overall mean egg and J2 density (averaged across all sampling dates) of *H. cajani* ranged between 2.7 and 14.6 per cm^3 soil in cropping systems with pigeonpea, cowpea, and mungbean at least once in 2 years (Table 1). Mean *H. cajani* density ranged between 0.2 and 1.0 eggs and J2 per cm^3 soil in cropping systems without pigeonpea, cowpea, or mungbean, which are good hosts of the nematode. Double-crop systems with pigeonpea as a component crop once in a 2-year rotation contained significantly greater number of *H. cajani* egg and J2 than did single-crop systems and double-crop systems without pigeonpea (Table 2). Plots continuously under a fallow + sorghum system had the least number of *H. cajani* eggs and J2. The preceding year's cropping system had a significant influence on the at-planting time nematode population (Table 3). Plots previously planted to sorghum-pigeonpea intercrop, cowpea-pigeonpea intercrop, and mungbean + sorghum sequential cropping contained greater numbers of *H. cajani* than did plots previously planted to sorghum + safflower, sorghum + chickpea, and rainy season fallow + sorghum. Mean densities of *H. cajani* were low in continuous-fallow or rainy-season sorghum and post-rainy season safflower or chickpea sequences. Continuous cropping of sorghum in the rainy season and safflower in the post-rainy season suppressed the nematode densities. *Heterodera cajani* populations in the beginning did not reproduce as well on mungbean as on pigeonpea and cowpea, and the reproduction level increased gradually. Steady increase in the level of parasitism of mungbean was a likely indicator of genetic diversity in the parasitic capabilities of *H. cajani* genome. Continuous cultivation of resistant varieties and poor hosts can result in the selection of virulent populations, with a greater frequency of genes for parasitism on hosts that were previously known to suffer slight damage (13).

The densities of *H. cajani* at planting in 1987, 1988, and 1991 were greater than threshold levels; thus, losses in pigeonpea yield were expected in all years (4,10). Crop growth was stunted and a gradual reduction in plant vigor was observed. In sorghum-pigeonpea intercrop, sorghum, a nonhost of *H. cajani*, presumably suffered lesser damage because of the suppressive effect of *H. cajani* on population development of other nematodes that can parasitize sorghum. Due to high fecundity and shorter life cycle, *H. cajani* may have moderated the population increase of other nematode species in the community (2). Mean grain yield of sorghum was greater in cropping systems with good hosts (cowpea and pigeonpea) of *H. cajani* than in other systems (Fig. 2). Sorghum following a cowpea-pigeonpea intercrop system or a sorghum-pigeonpea system consistently showed higher grain yield and dry matter production when compared to sorghum yield in sorghum + chickpea and sorghum + safflower sequential cropping systems. Greater yields of sorghum after a legume crop are typically attributed to the increase in soil fertility by the legumes. However, reduced densities of nematodes pathogenic to sorghum could contribute to increased yields of sorghum. Productivity in a sorghum-pigeonpea intercrop system could be enhanced by intercropping of sorghum with *H. cajani* tolerant pigeonpea. The tolerant pigeonpea would not suffer in yield loss due to the nematode parasitism, and sorghum yield would not

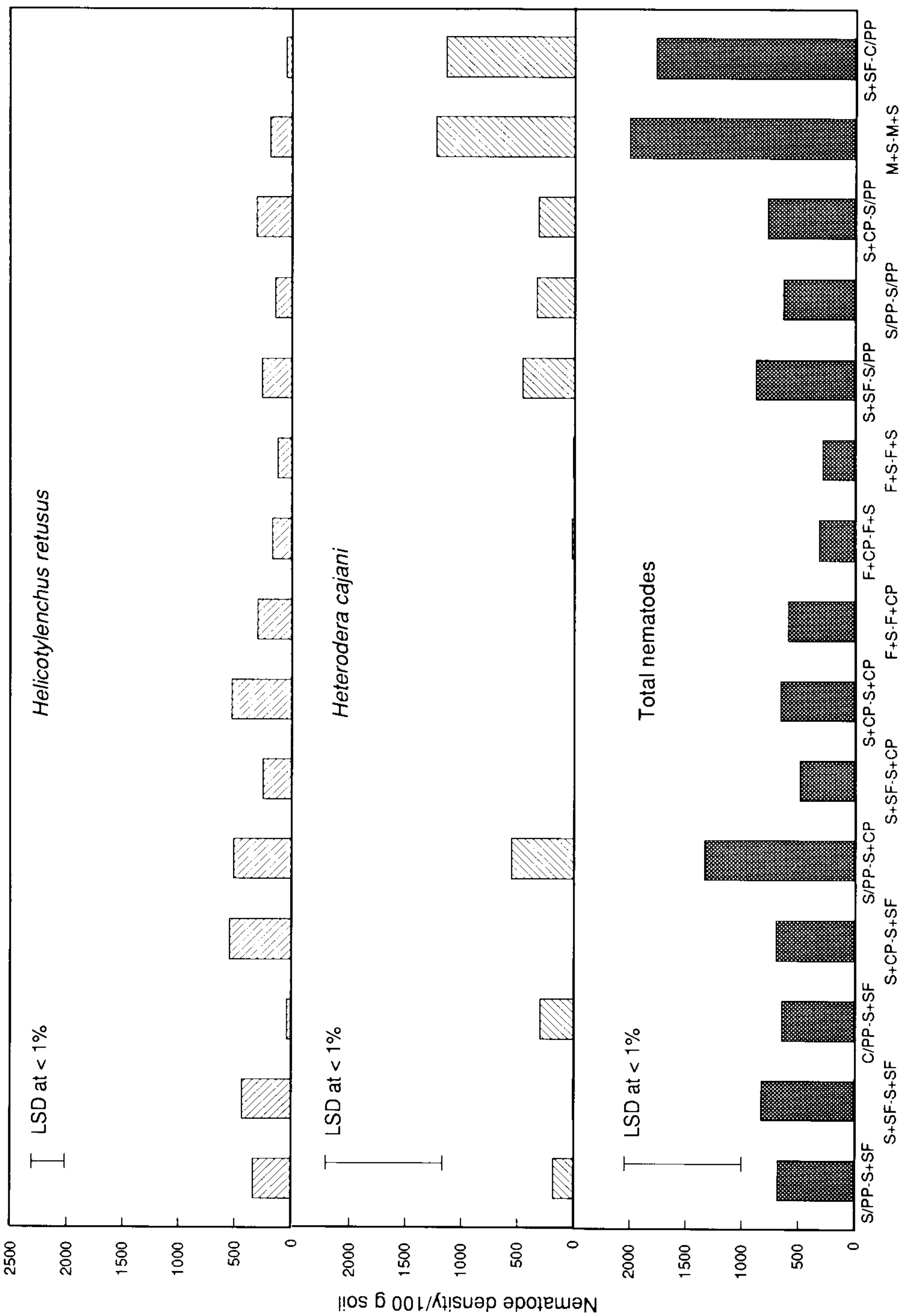

FIG. 1. Effect of cropping systems on population densities of *Heterodera cajani*, *Helicotylenchus retusus*, and total parasitic nematode population after 8 years, 1983–90. C = cowpea, CP = chickpea, F = fallow, M = mungbean, PP = pigeonpea, S = sorghum, SF = safflower. / = intercrop. + = succeeding crop. - = rotation.

TABLE 3. Mean at-planting time densities (per 100 cm^3 soil) of plant-parasitic nematodes in single- and double-crop systems.

	Single crop[a]	Double crop with pigeonpea[b]	Double crop without pigeonpea[c]	LSD (P = 0.05)
H. cajani eggs + J2	77	619	151	242.9
R. reniformis	89	241	94	119.6
H. retusus	124	188	352	80.7
Total plant-parasitic nematodes	366	1,151	726	257.6

[a] Mean of nematode densities at-planting time in 1987, 1988, and 1991 in cropping systems with fallow component.
[b] Mean of nematode densities at-planting time in 1987, 1988, and 1991 in cropping systems with pigeonpea component at least once in 2 years.
[c] Mean of nematode densities at planting time in 1987, 1988, and 1991 in cropping systems without pigeonpea and fallow components.

be influenced by the low population densities of other nematodes.

Helicotylenchus retusus: Large variations in *H. retusus* densities were observed between crop treatments (Fig. 1). The lowest mean density of *H. retusus* was on a cowpea-pigeonpea intercrop followed by a sorghum + safflower sequential crop. The nematode densities were greater than 3.6/

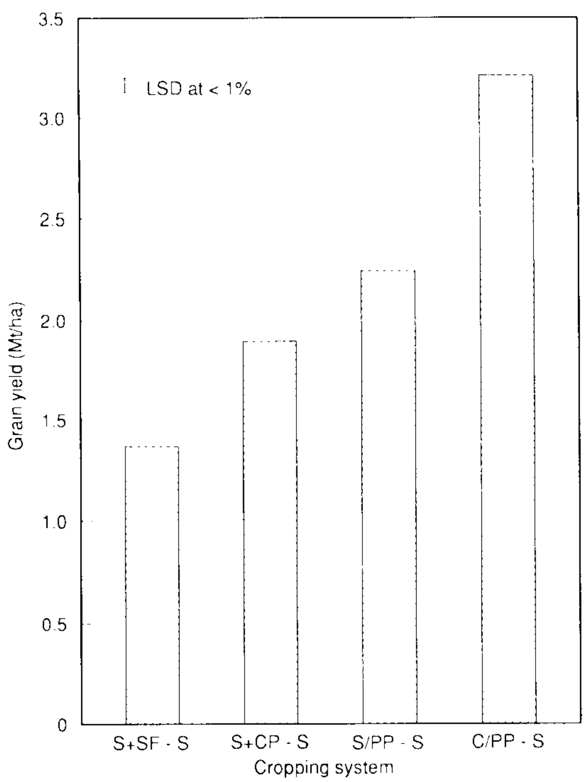

FIG. 2. Mean grain yield of rainy-season sorghum (Mt/ha) following different legume and non-legume based cropping systems without application of nitrogen, 1984–92. C = cowpea, CP = chickpea, PP = pigeonpea, S = sorghum, SF = safflower. / = intercrop, + = succeeding crop, − = rotation.

cm^3 of soil in cropping systems with sorghum, safflower, and chickpea as component crops without rainy-season fallow, cowpea, or pigeonpea in the system. Densities of *H. retusus* were affected by the preceding cropping system (Table 1). Plots previously planted to mungbean, cowpea, or pigeonpea contained fewer numbers of *H. retusus* than did plots planted to sorghum + safflower, and sorghum + chickpea. A rainy-season fallow system had about 2.4 times lower population density than did double-crop system without pigeonpea (Table 2). Damage thresholds of *H. retusus* on sorghum, safflower, and chickpea have not been investigated; however, the nematode is obviously an important parasite of these crops. Continuous cultivation of sorghum in the rainy season followed by chickpea or safflower in the post-rainy season in *H. retusus* infested areas would augment the nematode densities to damaging levels at planting time of the post-rainy season crops. *Helicotylenchus* spp. are important parasites of sorghum in Australia and Thailand (7). Association of *H. retusus* and of *R. reniformis* with stunted and wilted safflower plants, observed during this study, deserves detailed investigations.

Rotylenchulus reniformis: The overall mean population density of *R. reniformis* was lowest in rainy-season fallow + sorghum or chickpea systems and greatest in the sorghum + safflower followed by cowpea-pigeonpea intercrop system. The nematode densities were greatest in all cropping systems with cowpea as a component crop once in the 2-year rotation. The nematode density was significantly greater in plots previously planted to cowpea, pigeonpea intercrop than to other crops (Table 1). In the cowpea and pigeonpea intercrop followed by sorghum + safflower system, the overall nematode density ($3.2/cm^3$ soil) was 2 times greater than in sorghum and pigeonpea intercrop followed by sorghum + safflower ($1.6/cm^3$ soil). *Rotylenchulus reniformis* is an important nematode parasite of pigeonpea that thrives better on Alfisols than on Vertisols (9). The nematode densities on pigeonpea were lower when compared to *H. cajani,* which also is an important parasite of pigeonpea and thrives well on Vertisols (9).

Total plant-parasitic nematodes: Nematode population densities were generally higher in plots with pigeonpea, cowpea, and mungbean as component crops in the system (Table 1). Overall mean densities of total plant-parasitic nematodes ranged between $3.6/cm^3$ in cropping systems with a fallow component and $21.2/cm^3$ in cropping systems with pigeonpea as component of intercrops once in 2 years. In a sequential crop system, the carry-over nematode densities could affect the performance of the succeeding crop because planting-time nematode populations greatly influence crop growth and yield. At planting time, nematode population densities were lowest in plots previously under the fallow + sorghum system.

Summer fallow (February–May), which is an important component of cropping systems in semi-arid India, significantly reduced the mean population densities of *H. retusus* and *R. reniformis* by about 60%. As reported by Sharma and Nene (9), populations of *H. cajani* were not as susceptible to summer fallowing as were *H. retusus* and *R. reniformis.*

Crop rotations have wide-spectrum effects on the rhizosphere chemical and biological environment, including other soil-borne pests and diseases that were not part of this study; regulation of nematode population densities, directly or indirectly through the rhizosphere, is only one of such consequence. Holistic appraisal of these regulatory repercussions could greatly assist in identification of crop rotations that would permit the populations of damaging nematode species to subsist but not in harmful levels (10). A crop rotation could be an effective tactic to manage damage caused by plant-parasitic nematodes in the cereal- and legume-based production systems in the semi-arid tropics. For example, sorghum-pigeonpea intercrop is a widely adapted cropping system in the semi-arid tropics; incidence of Fusarium-wilt in pigeonpea is reduced in sorghum-intercropped pigeonpea (3). Productivity of this traditional production system could be enhanced by intercropping with *H. cajani* tolerant pigeonpea. The development of nematode-tolerant pigeonpea cultivars as one of the priorities of breeding and nematology programs would be helpful. It is clear that productivity of production systems technologies can be enhanced by inclusion of a nematode-management component (11,12).

Literature Cited

1. Jodha, N. S., and R. P. Singh. 1989. Crop rotations in traditional farming systems in selected areas of India. Resource Management Program, Economics Group Progress Report-91, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics, Patancheru.

2. Koshy, P. K., and G. Swarup. 1971. On the number of generations of *Heterodera cajani,* the pigeonpea cyst nematode, in a year. Indian Journal of Nematology 2:1–6.

3. Natarajan, M., J. Kannaiyan, R. W. Willey, and Y. L. Nene. 1985. Studies on the effects of cropping systems on Fusarium wilt of pigeonpea. Field Crop Research 10:333–346.

4. Saxena, R., and D. D. R. Reddy. 1987. Crop losses in pigeonpea and mungbean by mungbean cyst nematode, *Heterodera cajani.* Indian Journal of Nematology 17:91–94.

5. Schindler, A. F. 1961. A simple substitute for a Baermann funnel. Plant Disease Reporter 45:747–748.

6. Sharma, S. B. 1985. A world list of nematode pathogens associated with chickpea, groundnut, pearl millet, pigeonpea, and sorghum. Pulse Pathology Progress Report-42. Patancheru, India: International Crops Research Institute for the Semi-Arid Tropics.

7. Sharma, S. B., and D. McDonald. 1990. Global status of nematode problems of groundnut, pigeon-

pea, chickpea, sorghum, and pearl millet and suggestions for future work. Crop Protection 9:453–458.

8. Sharma, S. B., and Y. L. Nene. 1986. Extraction of *Heterodera cajani* cysts using modified sieving technique. Indian Journal of Nematology 16:123–124.

9. Sharma, S. B., and Y. L. Nene. 1992. Spatial and temporal distribution of plant-parasitic nematodes on pigeonpea in Alfisols and Vertisols. Nematropica 22: 13–20.

10. Sharma, S. B., Y. L. Nene, M. V. Reddy, and D. McDonald. 1993. Effects of *Heterodera cajani* on biomass and grain yield of pigeonpea on Vertisol. Plant Pathology 42:163–167.

11. Sharma, S. B., D. H. Smith, and D. McDonald. 1992. Nematode constraints of chickpea and pigeonpea production in the semi-arid tropics. Plant Disease 76:868–874.

12. Singh, M., S. B. Sharma, and M. M. Anders. 1994. Plant-parasitic nematode densities in cereals and legumes based cropping systems in Vertisols. Afro-Asian Journal of Nematology 4:44–50.

13. Triantaphyllou, A. C. 1975. Genetic structure of races of *Heterodera glycines* and inheritance of ability to reproduce on resistant soybeans. Journal of Nematology 7:356–364.