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CROPPING SYSTEMS FOR THE MANAGEMENT OF PHYTONEMATODES

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Damage caused by nematodes is one of the limiting factors in crop production. Traditional nematode management is based on the use of crop rotations, resistant cultivars, nematicides, or combinations of these methods. For a crop like peanut (*Arachis hypogaea*), cultivars resistant to root-knot nematodes are not available. There are soybean (*Glycine max*) cultivars resistant to some of the species of root-knot nematodes (*Meloidogyne* spp.); however, most fields have nematode infestations composed of mixtures of species. Research at Auburn has shown that tropical crops can be used effectively in rotation to manage nematode problems. Rotations with American jointvetch (*Aeschynomene americana*), castor (*Ricinus communis*), hairy indigo (*Indigofera hirsuta*), partridge pea (*Cassia fasciculata*), sesame (*Sesamum indicum*), and velvetbean (*Mucuna deeringiana*) have resulted in good nematode control and increased yields of peanut and soybean. Some crops (castor, sesame) are considered 'active' in that they produce compounds that are nematicidal, whereas others (*e.g.* corn, sorghum) are simply non-host, that is, 'passive'.
KEY WORDS: Phytonematodes; antagonistic plant; cover crop; intercropping; monoculture; multicropping; nematicidal or nemostatic root exudate; non-host; rotation system.

INTRODUCTION

Problems caused by nematodes and other soilborne pathogens constitute one of the most important limiting factors in the maintenance of economic crop production. Traditional strategies for the management of these pathogens have been based on development of resistant varieties, pesticide applications, crop rotations and cultural

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practices that suppress pathogen inoculum in soil. This approach has been extraordinarily successful with many crops. With peanut (*Arachis hypogaea* L.) in Alabama, improvement in yield per hectare from 1940 to 1985 was so dramatic that it can be described in a quasi-exponential manner (Fig. 1). The data presented in the figure show that improvements in yields may be related to specific changes in peanut production ranging from the introduction of high-yielding cultivars to the use of fumigants and other nematicides. Marked improvements in the use of pesticides were also attained during this period. For example, the development of nematicides was marked not only by the introduction of new chemicals but also by a sharp decline in the amounts of material required per hectare to ensure an effective nematicide treatment (Fig. 2).

With peanut as with other crops, the production system in the United States and other industrialized nations has been based primarily on the use of high-yielding cultivars and of pesticides for disease management. Crop rotations and cultural practices for disease suppression were either ignored or ranked low in the choice of pest control strategies.

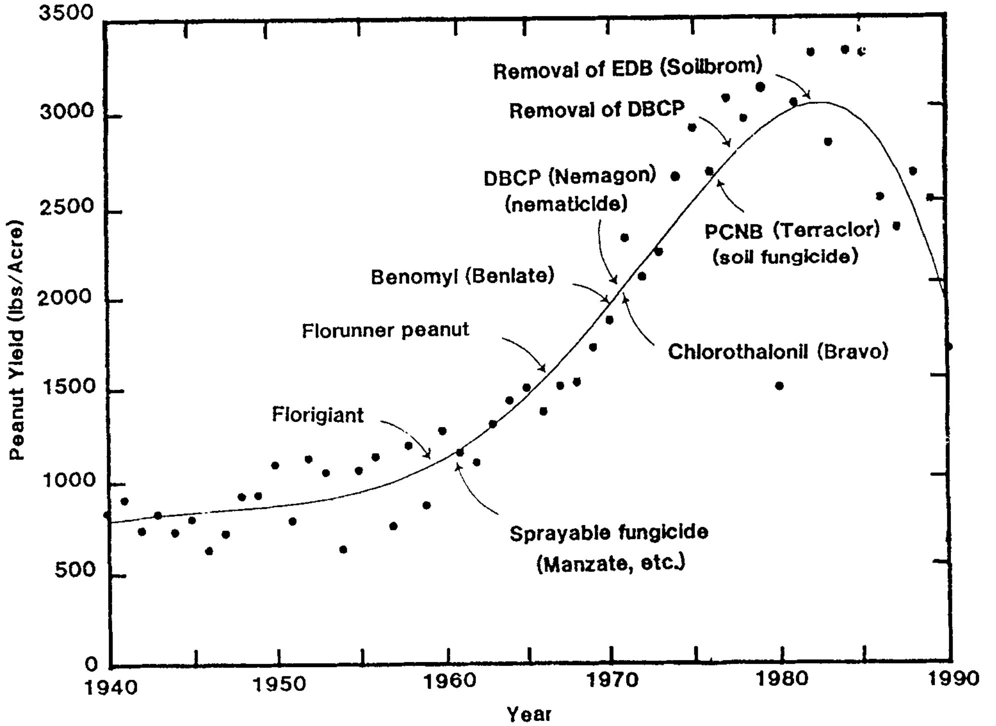

Fig. 1. Peanut (*Arachis hypogaea*) yields in Alabama relative to changes in production practices during the past 50 years.

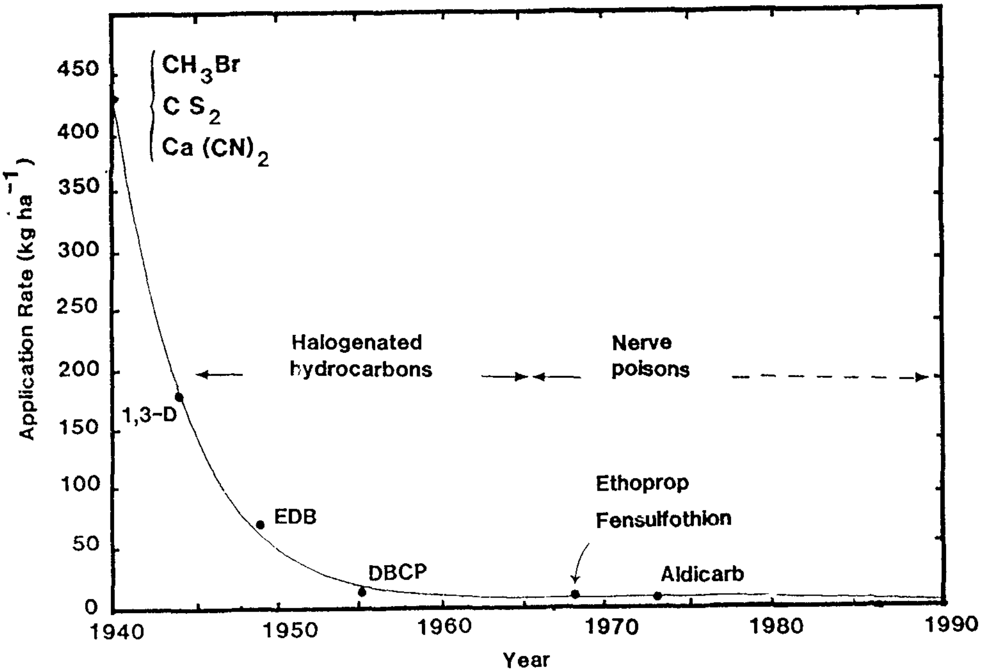

Fig. 2. Changes in the amounts of nematicide applied per hectare in response to the introduction of new nematicides from 1940 to the present.

This approach, dictated by economic considerations, was flawed in several respects and currently the management of nematode problems in peanut production in Alabama can be said to be in a state of crisis.

The use of nematicides in agriculture has been questioned in recent years because of problems caused by their toxicity to wildlife and humans. In addition, residues were detected in significant quantities in subterranean waters in agricultural areas where nematicides had been routinely applied at recommended application rates. These findings with nematicides and other pesticides have engendered a negative attitude by consumers regarding the application of pesticides in agriculture. Critical evaluations on the effects of pesticides on humans and the environment have led to the suspension of several highly effective nematicides. Comparisons show that only five nematicides (*viz.*, 1,3-D, aldicarb, phenamiphos, ethoprop, and formulations containing or generating methyl isothiocyanate) were permitted in 1990, half the number available in 1975. It is significant that two of the most effective nematicides, the fumigants DBCP and EDB, are no longer available. These fumigants were the cornerstone for nematode control in peanut (Fig. 1) and other crops during the last two decades. Meanwhile, the cost of effective nematicide treatments has risen substantially during the last decade. In the

United States it cost peanut producers on average U.S. \$12–15 ha^{-1} in 1975 to apply an effective nematicide treatment, but in 1990 the corresponding figure was \$50–80. In addition, the relative efficacy of currently available nematicides is markedly inferior to that of the suspended fumigants (21).

The development of cultivars resistant or tolerant to pathogens always has been one of the most successful methods for disease management. For some crops, such as peanut, sources of resistance to its many pathogens and in particular to the root-knot nematode, *Meloidogyne arenaria* (Neal) Chitwood, are either non-existent or are very few (15,16). There are today no commercially available peanut cultivars resistant (or tolerant) to *M. arenaria*. One problem in breeding for resistance is posed by pathogens with wide genetic variation. For example, it is necessary to develop cultivars resistant to races of pathogens such as the soybean cyst nematode (*Heterodera glycines* Ichinohe) and the potato cyst nematode (*Globodera rostochiensis* (Wollenweber) Behrens and *G. pallida* (Stone) Behrens). The appearance of 'new' races of a nematode in reaction to the use of cultivars resistant to a limited number of races of the pathogen, is a phenomenon that has been observed repeatedly (13,18,36). This has led to the thought that the utilization of cultivars with limited resistance can aggravate a nematode problem by shifting the nematode race profile in a given field, so that races for which there is no resistance become predominant with time. There is also the problem of fields with polyspecific nematode infestations. The planting of cultivars resistant to one or a limited number of nematode species often results in increased population densities of other species to which the cultivars are susceptible (39,40). These problems and considerations on plant breeding and on the use of nematicides led us to consideration of the subject of managing nematodes with strategies based on crop rotation.

CROP ROTATIONS AND MONOCULTURE

The use of rotations and cropping sequences is one of the oldest means of controlling or suppressing soilborne pathogens. Mentions of rotations to maintain production in agricultural fields are found in the Bible, in the literature of moorish Spain, in medieval and Renaissance works in Europe, and in ancient Chinese and Hindu writings. There is also evidence of rotation systems developed by the Inca and other pre-Colombian cultures of the American continent. These ancient rotation systems were developed from empirical observations and were considered to lead to sustained production. Typically no connection was made between the practice of those systems and reductions in the incidence of diseases. It was only in the 19th Century that the beneficial effects of such rotations were associated with reductions in the incidence of disease. Indeed, before the introduction of pesticides and the development of plant breeding in the early part of the present century, crop rotation was fundamental to the management of nematodes and other soilborne pathogens. The subject of crop rotations

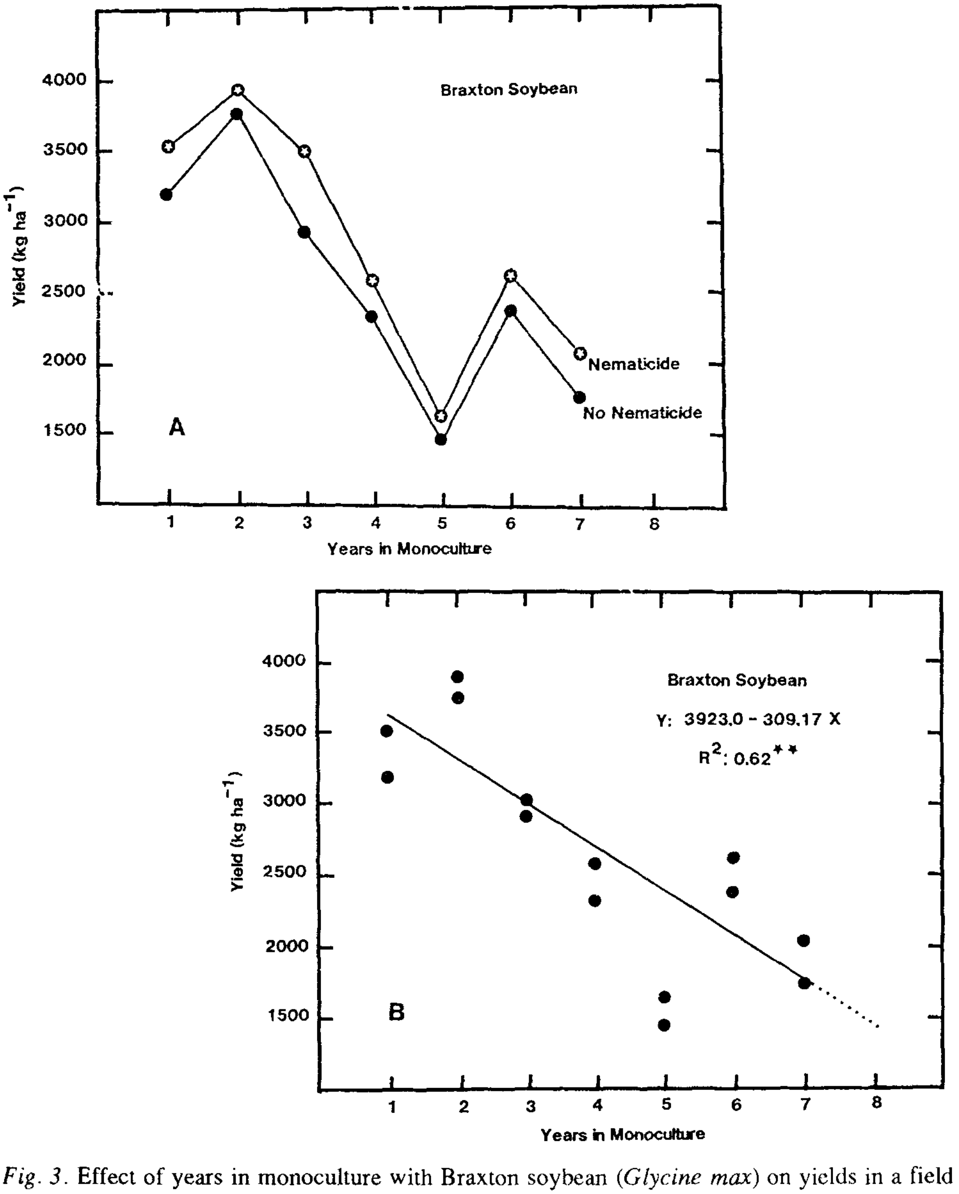

Fig. 3. Effect of years in monoculture with Braxton soybean (*Glycine max*) on yields in a field experiment in southern Alabama. A. Relation between yield, the number of years in monoculture and the effect of nematicide treatment. B. Linear equation describing yield (Y) as a function of the number of years in monoculture (X).

for disease management is thus old and has been reviewed repeatedly (2–4,8,10,14,35,37), and it is not our aim to add one more review to those already

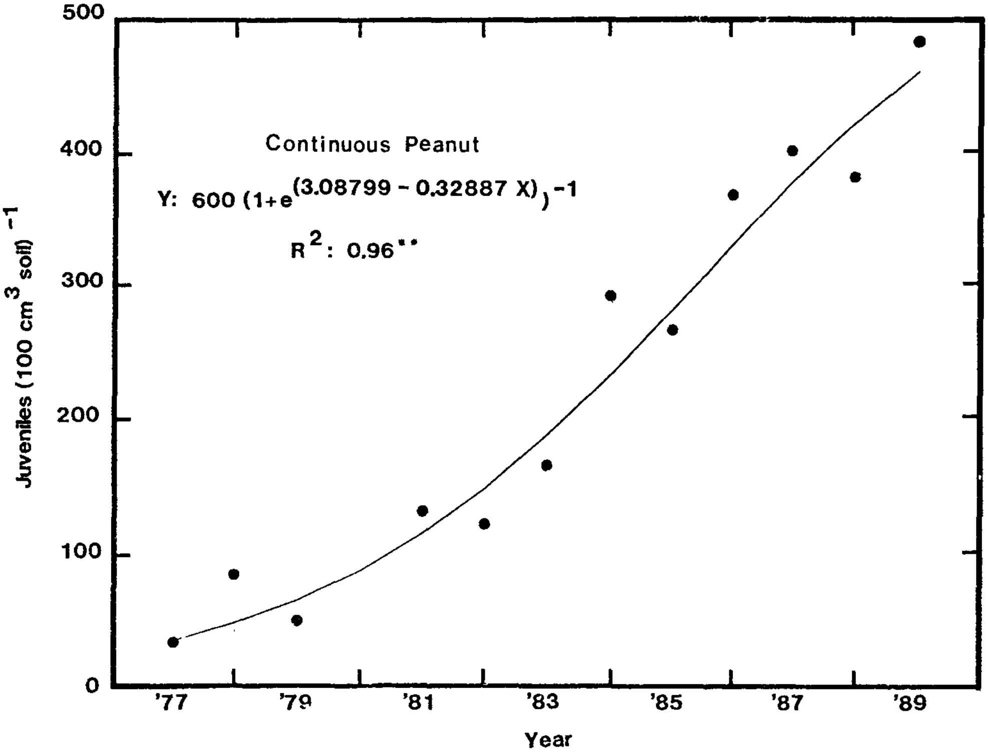

Fig. 4. End-of-season second-stage juvenile population densities of *Meloidogyne arenaria* in a field in monoculture with Florunner peanut from 1977 to 1989.

available. This paper presents new concepts and some old ideas that may be useful for the practice of agriculture with reduced pesticide application and integrated pest management.

From a pest-management point of view, the primary objective of crop rotation systems is to 'uncouple' or distance in time the population development curve of the pathogen(s) from the growth curve of the plant host. This can be achieved through the introduction into the production system of plants that are (*a*) non-hosts, (*b*) less suitable hosts than the main crop, or (*c*) in some manner inhibitory to the pathogen(s) within the production system (10,37).

The basic premise for the use of crop rotations for disease management is that monoculture of a host plant usually results in increased pathogen inoculum density and consequent yield losses. The monoculture of peanut and soybean (*Glycine max* L.) in the southeastern U.S.A. is one example. With soybean (Fig. 3), on most soils in the southeastern United States, there is a negative linear relationship between yield per hectare and the number of years in monoculture (27). A similar relationship exists for peanut, even though the quantitative description usually follows more closely an exponential model. In both these legumes there are increases in pathogen inoculum densities in response to the number of years in monoculture, as illustrated in Figure 4 for peanut and *M. arenaria* (19).

TRADITIONAL ROTATIONS

In contrast to the monoculture of peanut and soybean in the southeastern United States, there exist very effective production systems that help keep losses caused by nematodes and other pathogens at economically acceptable levels. A traditional crop rotation system for peanut in the region consists of one year of peanut followed by two

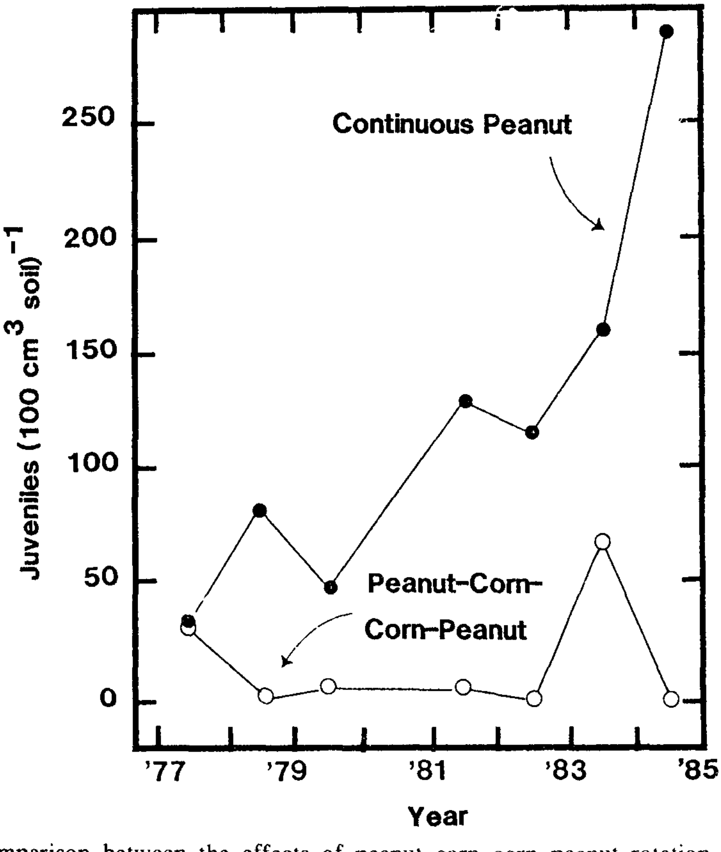

Fig. 5. Comparison between the effects of peanut–corn–corn–peanut rotation and peanut monoculture on end-of-season second-stage juvenile population densities of *Meloidogyne arenaria* in a field experiment at the Wiregrass Substation, near Headland, Alabama.

consecutive years of corn (*Zea mays* L.). This results (19) in the suppression of *M. arenaria* population densities in comparison with peanut monoculture (Fig. 5). There are other traditional cropping systems equally effective for suppression of nematodes in peanut and soybean (20,26,27,30).

THE DESIGN OF ROTATION: BENEFITS AND LIMITATIONS

The nature and sequence of crops, and the length of time (seasons) allotted to each crop in the rotation system, depend principally on the characteristics of the pathogen(s). The degree of susceptibility or resistance to the pathogen(s) of plant species that compose the system is also fundamental to the design of rotations. Thus, for nematode species with a wide host range, such as *Meloidogyne* spp., the number of rotation systems is limited (10,33,34,37). In contrast, for the potato cyst nematodes (*Globodera* spp.) and some *Heterodera* spp. with a relatively narrow host range, it is possible to devise a greater number of crop rotations than for *Meloidogyne* spp. (2,37). However, there are other considerations. The cysts of *Globodera* spp., for instance, serve to protect eggs from adverse conditions, *e.g.* lack of a suitable host. Thus, in the battle against *Globodera* spp. and similar types of pathogens, it is usually necessary to implement crop rotations that last 4 to 7 years or longer in order to reduce pathogen inoculum to levels that will permit economic production (2,37).

Economic evaluation of rotation systems must take into account all benefits accrued from the use of the systems. For example, some rotation systems can improve the soil physical properties. Bahiagrass (*Paspalum notatum* Flugge) can be used in rotation with peanut or soybean to suppress populations of *M. arenaria* and *H. glycines* (28,29). The roots of this pasture grass can penetrate through the compacted layers of the soil profile ('hardpans') resulting from routine operations with agricultural machinery. This hardpan situation is common to many fields in the southeastern United States. When bahiagrass is rotated with peanut or soybean, increases in yields of these crops are due in many cases as much to nematode suppression as to improvements in soil physical conditions. Peanut and soybean fields in many areas of the southeastern United States have soils that are typically of poor fertility, light textured, and underlain by clay subsoils, with low organic matter content and low water-holding capacity. In such soils it is important that the root system of crops will penetrate deeply to obtain moisture during the periods of little or no rainfall that occur in almost all growing seasons.

Some crop rotations effective in suppressing nematodes also serve to manage problems caused by other soilborne pathogens. In peanut production, rotation with cotton (*Gossypium hirsutum* L.) controls *M. arenaria* (Table 1) and reduces the incidence of southern blight caused by *Sclerotium rolfsii* Sacc. in peanut (20).

Rotation systems can be designed to suppress nematode population densities and add organic matter to the soil to improve fertility and tilth. This is particularly important in soils of the humid tropical and subtropical regions with characteristics similar to those of the southeastern United States. Velvetbean (*Mucuna deeringiana* (Bort.) Merr.) is used in Tabasco, Mexico, as a cover crop, and in combination with corn and other crops in order to improve soil fertility and to suppress damage caused by nematodes and other soilborne pathogens (7). Velvetbean produces root exudates that are nematicidal or nematostatic (38). There is also evidence that the rhizosphere bacteria of this tropical legume are significantly different from bacterial species found in the rhizosphere of root-knot nematode susceptible plants such as soybean; some of the velvetbean rhizobacteria may be antagonistic to *H. glycines* and *M. arenaria* (Rodríguez-Kábana, unpublished data).

TABLE 1: EFFECT OF CROP ROTATION AND ALDICARB (TEMIK 15G) TREATMENT ON *MELOIDOGYNE ARENARIA* POPULATION DENSITIES, THE INCIDENCE OF SOUTHERN BLIGHT (*SCLEROTIUM ROLFSII*) IN PEANUT, AND YIELDS OF DELTAPINE 90 COTTON AND FLORUNNER PEANUT IN A FIELD AT THE WIREGRASS SUBSTATION, NEAR HEADLAND, ALABAMA

Crop sequence and treatment[z]		*M. arenaria (juveniles per 100 cm^3 soil)*	*Yield (kg ha^{-1})*	*Southern blight (loci plot^{-1})*[y]
1985	*1986*			
Peanut (–)	Peanut (–)	72	2,929	10.0
Peanut (+)	Peanut (+)	15	3,200	9.4
Cotton (–)	Peanut (–)	41	3,499	8.3
Cotton (+)	Peanut (–)	23	3,499	8.6
Cotton (+)	Peanut (+)	15	3,363	6.9
Cotton (–)	Peanut (+)	10	3,689	6.1
Cotton (–)	Cotton (–)	16	1,844	
Cotton (+)	Cotton (+)	12	1,898	
LSD ($P = 0.05$)		22	409[x]	3.3

[z](–), no nematicide; (+), treated at-plant with aldicarb at 0.302 g a.i. m^{-1} of row in a 20-cm-wide band.
[y]One locus represents a ≤30 cm length of row with plants killed by *S. rolfsii*.
[x]LSD for peanut yields only; differences in cotton yields were not significant.

The use of cover crops for suppression of soilborne pathogens is a strategy that could be employed for the management of nematode problems in orchard crops (12) such as bananas (*Musa* spp.), avocado (*Persea* spp.), citrus, grapes (*Vitis* spp.), etc., in which damage caused by nematodes is an important factor in limiting yield. However, this approach has not been explored extensively.

Useful as crop rotation systems can be for the management of nematodes and other soilborne pathogens, they also have their disadvantages. Crop rotation systems, as mentioned already, require relatively long periods of time. The land typically has to be 'anchored' to a given system to obtain effective pathogen control. It is difficult to develop rotation systems that are profitable and effective for nematode control. Rotation systems must be acceptable to producers from both an economic and a logistic point of view. For example, in Alabama, a peanut–cotton rotation is highly effective in suppressing *M. arenaria* but this system is not always practiced because many producers in the peanut-growing regions of the state do not have the specialized and expensive equipment needed for cotton production.

NEW CROPS AND ANTAGONISTIC PLANTS

Several leguminous crops, in addition to velvetbean, have properties antagonistic to nematodes and other soilborne plant pathogens (6,7,9). Sesame (*Sesamum indicum* L.), castor (*Ricinus communis* L.), partridge pea (*Cassia fasciculata* Michx.), marigolds (*Tagetes* spp.), *Crotalaria spectabilis* Roth and other *Crotalaria* spp,. produce compounds that are antihelminthic or nemostatic (1,5,11,17,22–24).

The mode of action of plants 'antagonistic' to nematodes leads to a distinction between such plants and others which, although unsuitable for nematode development, *i.e.*, non-hosts, do not produce antihelminthic compounds. Crop rotation systems that include antagonistic plants may be thought of as 'active', whereas those with plants that are simply non-hosts to the nematodes are 'passive'. Examples of active rotation systems are those with peanut following castor or sesame for control of *M. arenaria* (23). Peanut followed by corn or by sorghum (*Sorghum bicolor* Moench) are examples

TABLE 2: YIELDS OF SELECTED CROPS AND THEIR EFFECTS ON POPULATION DENSITIES OF *MELOIDOGYNE ARENARIA* IN SOIL DETERMINED 3 WEEKS BEFORE PEANUT HARVEST IN A 2-YEAR FIELD STUDY AT THE WIREGRASS SUBSTATION, NEAR HEADLAND, ALABAMA

Crop sequence and treatment[z]		*M. arenaria (juveniles per 100 cm³ soil)*		*Yield (kg ha⁻¹)*	
1987	*1988*	*1987*	*1988*	*1987*	*1988*
Peanut (–)[z]	Peanut (–)	120	243	2,081	1,763
Peanut (+)	Peanut (+)	28	154	2,251	2,767
Castor	Peanut (–)	1	63	1,719	2,984
American jointvetch	Peanut (–)	1	263	6,173	2,685
Partridge pea	Peanut (–)	0	123	6,476	2,685
Sesame	Peanut (–)	2	124	263	2,821
Cotton	Peanut (–)	0	267	1,476	2,658
LSD ($P = 0.05$)		102	102	577[x]	414

z(–), no nematicide; (+), treated at-plant with aldicarb at 0.302 g a.i. m^{-1} of row in a 20-cm-wide band.
[y]Figures for castor and sesame are seed yields, those for jointvetch and partridge pea represent green shoot matter and those for cotton refer to seed cotton.
[x]LSD values for peanut yields only.

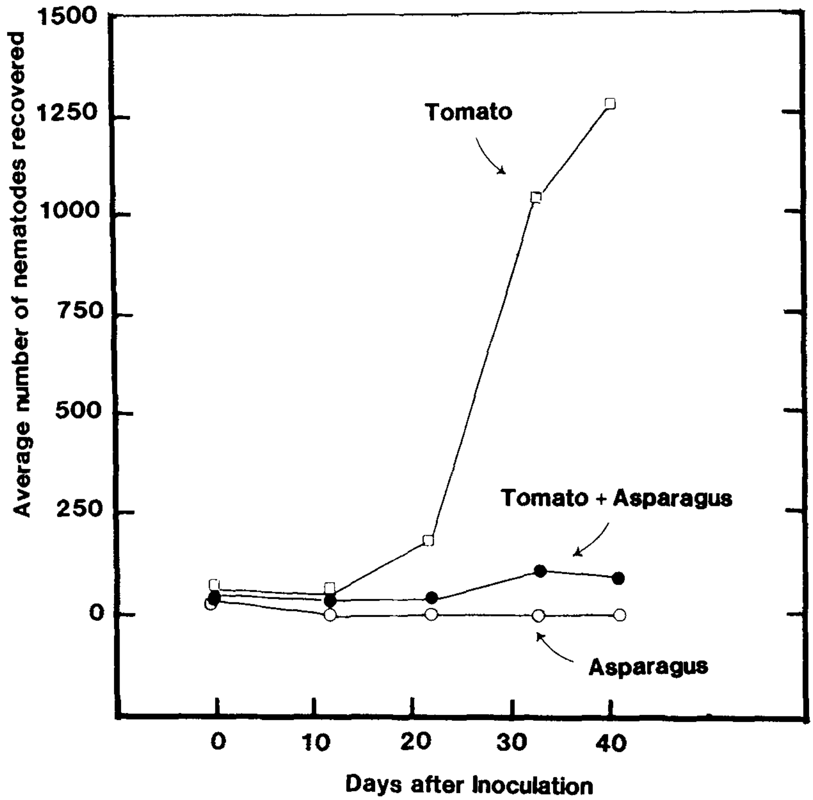

Fig. 6. Effect of intercropping tomato (*Lycopersicon esculentum*) with asparagus (*Asparagus officinalis*) on soil population densities of stubby-root nematode (*Paratrichodorus minor*).[From Rohde and Jenkins (32)]

of passive rotation systems (26). In active systems the nematode population density after growth of the main susceptible crop following a season with an antagonistic crop (Table 2) is typically lower than final population densities in monoculture fields with the main susceptible crop (24). In contrast, such differences in population levels do not exist when passive rotation systems are compared with monoculture.

Multicropping or intercropping with antagonistic plants could eliminate one of the main disadvantages of nematode management through crop rotation: the need to go through several years in a rotation to suppress nematode population densities. Rohde and Jenkins (32), in a study of intercropping of tomato (*Lycopersicon esculentum* L.) with asparagus (*Asparagus officinalis* L.), obtained suppression of *Paratrichodorus minor* (Colbran) Siddiqi (Fig. 6). More recently, velvetbean or castor grown for 2 months before peanut resulted in increments in peanut yield in a *M. arenaria*-infested field when compared with conventional monoculture peanut or with peanut after 2 months of fallow (Rodríguez-Kábana, unpublished data). The practice of preceding (or following) a susceptible crop with an active plant species permits an economy of time and allows management of nematode problems in situations where land cannot be assigned to multiyear rotation systems, *e.g.* rented land under short-term lease. There are several tropical legumes and other plants that are fast growing, may be antagonistic to nematodes (6,7,9,22,25,27,31), and would be worthwhile to explore and expand on the concept of multicropping for nematode management in temperate and subtropical regions of the world.

CONCLUSIONS

The examples and concepts presented show that crop rotation systems can be effective in managing or 'regulating' diseases caused by nematodes and/or other soilborne pathogens. It is also possible to develop crop rotation systems to maintain production at economically acceptable levels, but this means of nematode management is a long-term approach. There is an urgent need to explore multicropping with antagonistic plants to assess their value for controlling nematodes and to obviate the long-term requirements of conventional crop rotation systems.

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