VG501

Development of sustainable strategies for managing root-knot nematode in ginger

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INDUSTRY SUMMARY

This project aimed to minimise the need for nematicides in the Queensland ginger industry by developing integrated management strategies for root-knot nematode. Cleanliness of planting material was the first issue to be addressed, as surveys of the seed used by the ginger industry showed that more than 75% of samples were infested with nematodes. Data collected during this project confirmed that hot water treatment (48°C for 20 minutes) eradicated nematodes from seed and substantially reduced nematode damage in the following crop. An experiment in the field showed that nematode-free seed could be produced by growing ginger in a layer of sawdust mulch and discarding that portion of the rhizome that was in contact with soil.

Results of field trials in a clay loam soil showed that in both early and late harvest ginger, damage caused by root-knot nematode could be minimised through the use of appropriate crop rotations. Nematode populations remained relatively low in the first early harvest ginger crop following two years of green panic, while populations in late harvest ginger were lower following forage sorghum cv. Jumbo than following lablab. Soil amendments of poultry manure and sawdust also consistently reduced nematode populations and nematode damage to rhizomes in both early harvest and late harvest crops. In the last two of three successive early harvest crops, nematode damage in organically amended plots was reduced compared with unamended plots but control was not as good as EDB followed by two applications of fenamiphos. Nematode damage was never severe when late harvest ginger was grown in rotation with forage sorghum and several poultry manure and sawdust treatments reduced nematode populations to at least the same extent as a nematicide program. These results suggest that non-chemical control of root-knot nematode is achievable through the use of clean planting material, crop rotation and organic amendments. However, when two or more ginger crops are grown in succession, nematicides are needed to achieve satisfactory nematode control.

TECHNICAL SUMMARY

A survey of planting material used by the Queensland ginger industry showed that 13 out of 17 seed samples were infested with root-knot nematode. Generally, less than 20% of the seed pieces in a sample were infested, but in four samples, levels of infestation were 25%, 30%, 54% and 86%. Observations in a field where both nematode-free and nematode infested ginger was used suggested that nematodes multiplied more quickly and caused more damage where infested seed had been planted. Data collected during this project confirmed that hot water treatment (48°C for 20 minutes) eradicated nematodes from seed. Nematode-free seed was also produced by growing ginger in a layer of sawdust mulch and discarding the portion of the rhizome that was in contact with soil.

Field experiments were established on a well-structured clay loam soil to investigate the potential of crop rotation and organic amendments for controlling root-knot nematode. In an experiment in which early harvest ginger was grown for three successive years, root-knot nematode populations remained low and caused no damage in the first crop, which followed two years of green panic (*Panicum maximum*). Nematode damage was observed in the second and third crop, but the severity of symptoms on rhizomes was reduced by amendments containing poultry manure and/or sawdust. However, the best control was achieved with a nematicide program involving pre-plant fumigation with EDB and post-plant sprays of fenamiphos. When late harvest ginger was grown in rotation with a green manure crop, populations of root-knot nematode were lower following forage sorghum (*Sorghum bicolor* x *sudanense*) cv. Jumbo than following lablab (*Dolichos lablab*) cv. Highworth. Nematode damage was never severe in the ginger/forage sorghum rotation and several poultry manure and sawdust treatments reduced nematode populations and nematode damage to the same extent as nematicides.

These results suggest that non-chemical control of root-knot nematode can be achieved with clean planting material, crop rotation and the use of large quantities of organic matter (eg. at least 150 m^3/ha/annum of sawdust and poultry manure). However, nematode populations increase to high densities when successive ginger crops are grown and in this situation, nematicides are needed to achieve satisfactory control.

INTRODUCTION

Root-knot nematode (*Meloidogyne* spp.) is the most serious pest problem in the Queensland ginger industry. Good nematode control is essential for economically viable ginger production and all growers routinely use ethylene dibromide (EDB) as a pre-plant nematicide. This is often followed by post plant applications of fenamiphos. However, the future of both these chemicals is in doubt. EDB will be deregistered in Australia during 1997 because of its carcinogenicity and capacity to contaminate groundwater (Thomason, 1987), while the effectiveness of fenamiphos is declining due to enhanced microbial decomposition (Stirling *et al.* 1992).

Previous studies of non-chemical methods of nematode control in ginger have been directed towards the production of clean planting material by hot water treatment (Colbran and Davis 1969) or mulching with sawdust (Colbran 1974), and the use of organic soil amendments to suppress nematode damage in the growing crop (Stirling 1989). Although all these practices have shown promise, they are not used widely in the ginger industry, mainly because of concerns about their reliability and effectiveness. This project examined a number of non-chemical options for managing root-knot nematode, with the aim of developing an integrated management strategy for nematodes which would reduce the industry's dependence on nematicides.

MATERIALS AND METHODS

Population dynamics of nematodes on ginger

In July 1992, ten fields representative of the Queensland ginger industry were selected (Table 1). An area of 0.1-0.25 ha was identified in each field and 50 soil cores were collected with a 2 cm diameter probe at depths of 0-30 cm. After ginger was planted in each field, this same soil-sampling procedure was repeated every 6-10 weeks until rhizomes were harvested. All crops were grown according to the grower's standard management practice except that in one field, areas planted with heat-treated and untreated seed were compared.

Nematodes were extracted from a 200 ml sub-sample of soil using a Bearmann tray (Whitehead and Hemming 1965). Each sample was also bioassayed for root-knot nematode by mixing the soil 1:1 with coarse sand and adding 1500 ml of this mixture to a 15 cm pot. A tomato seedling (cv. Tiny Tim) was planted and galls on roots were counted after plants grew in a glasshouse for 4 weeks. When ginger was harvested from each sampling area, a sample of 50 rhizomes was rated for root-knot nematode damage as follows: 0 = no damage; 1 = occasional small lesions; 2 = moderate damage; 3 = numerous lesions covering most of the rhizomes. Root-knot nematodes were identified by determining esterase phenotype (Fargette, 1987a,b).

Clean planting material

Nematode infestation of seed

Seventeen samples of seed used within the ginger industry were collected from seven growers in August and September 1992. Between 30 and 50 seed pieces were potted individually in pasteurised sand and ginger was grown in a glasshouse for 5 months. Roots were then assessed for presence or absence of root knot nematodes.

Hot water/nematicide treatment

Ginger rhizomes heavily infested with root-knot nematodes were divided into seed pieces, treated with benomyl to control fungal rots and then air-dried. Seed was separated into three batches of 50 seed pieces and each batch was subjected to one of the following treatments.

Hot water: Hold in water for 48 °C for 20 minutes.

Fenamiphos: Dipped in 1 g/L fenamiphos (as Nemacur 400) for 10 minutes.

Untreated

After treatment, each batch was sub-divided into two groups of 25 seed pieces. Seed pieces in one group of each treatment were sliced individually into strips no more than 3 mm thick and these pieces were incorporated into pasteurised sand in pots. A tomato seedling was then planted in each pot. The second group of seed pieces were planted individually in pots containing pasteurised sand. After tomato seedlings had grown in a glasshouse for 1 month and ginger plants for 5 months, plants were harvested and roots were examined for the presence of root-knot nematode.

Clean seed production with sawdust

In August 1992, rhizomes were collected from a ginger field that was being used as a source of seed. Beds had previously been mulched with a layer of sawdust. A sample of 35 rhizomes were cut into seed pieces, with those that had grown in sawdust being separated from those that had grown in soil. Each seed piece was planted in a 15cm pot containing pasteurised sand and grown in the glasshouse for 5 months. Roots were then examined for root-knot nematodes.

In October 1993, an experiment was established in a field which had been planted to green panic (*Panicum maximum*) following a ginger crop four years previously. Trash was incorporated and allowed to decompose, beds 1.3 m wide were formed and they were then fumigated with EDB at 72 kg/ha. Sixteen plots each 10m long were marked out and sawdust (39 L per linear m of bed) was incorporated into eight plots to a depth of 10 cm with a rotary hoe. Four plots with and without incorporated sawdust were also mulched by applying sawdust to the bed surface at 130 L per linear m. Thus four treatments were established viz. Nil, incorporated sawdust, sawdust mulch and incorporated sawdust + sawdust mulch. Prior to applying the mulch, ginger seed was placed in two rows on the surface of the bed whereas in non-mulched plots it was planted at a depth of 10 cm.

Ginger was grown using management practices typical of the Queensland industry and seed was harvested in August 1994 from a 2.5 m length of bed in the middle of each plot. Rhizomes were weighed and a sample was collected for assessment of nematode infestation. In the two treatments where mulch had been applied, rhizomes were separated into two groups, those growing entirely in sawdust and those growing partly or completely in soil. These groups were weighed and sampled separately. Soil was collected from ten sampling points in each plot using a spade at depths of 10-15 cm. In plots covered with sawdust mulch, care was taken to avoid contaminating the sample with sawdust. Nematodes were extracted from 200 ml sub-samples. Rhizomes from each plot (two groups from mulched plots) were cut into seed and ten pieces were selected at random from each group. Each seed piece was planted in a 15 cm pot, grown in the glasshouse for 5 months and then each ginger root system was examined for the presence of root-knot nematode.

Susceptibility of rotation crops

Seedlings of nine crops reported to be resistant to root-knot nematode or potentially useful for rotation with ginger were transplanted into 15 cm pots containing pasteurised sandy soil. One week later, five replicate pots of each crop were inoculated with 1000 eggs of either *M. incognita*, *M. javanica* or *M. arenaria*, obtained from nematode infested tomato roots by soaking in sodium hypochlorite (0.5% available chlorine). Plants were harvested after 10 weeks in the glasshouse, roots were washed and eggs were extracted using the above hypochlorite procedure.

Field experiments

A number of crop rotation, organic and nematicide treatments were compared in two field experiments at the Australian Golden Ginger research farm, Kandanga, Queensland. The experiments were established in two adjacent areas in a field that had grown ginger for many years and where root-knot nematode was known to cause problems. In July 1992, when the site was selected, the field had not grown ginger for two years, but instead had been planted to green panic (*Panicum maximum* var. *trichoglume*). Bioassays of soil from the site indicated that root-knot nematodes were present at a population density of about 1 nematode/L soil.

Experiment with late harvest ginger

Green panic in the 80 m x 22 m experimental site was killed by spraying with herbicide and the site was cultivated and marked out into 32 plots each 10 m long and 5.5 m wide. Plots of this width were chosen so that eventually they could accommodate three beds of ginger on 1.83 bed centres. An experiment containing 8 treatments (Table 2) and 4 replicates was then set out in a randomised block design. Treatments were commenced during the period July-October 1992 and in both the 1993/94 and 1995/96 seasons, late harvest ginger was planted in September and harvested in July or August.

Organic amendments consisting of raw pine sawdust, poultry manure or urea were spread evenly over the surface of each plot and incorporated by rotary hoeing to a depth of approximately 10 cm. Analyses of these materials are set out in Table 3. Forage sorghum (cv. Jumbo) seed and *Rhizobium*-treated seed of *Dolichos lablab* (cv. Highworth) were planted by scattering the seeds at a rate of 3 g/m^2 and 1.5 g/m^2 respectively and then harrowing the plots. Prior to planting ginger, three beds 1.2m wide with furrows between them were prepared in each plot. Ethylene dibromide (EDB) was applied to appropriate plots by injecting the chemical using standard fumigation equipment at 108 kg/ha. Ginger seed taken from rhizomes growing in sawdust mulch was used to plant the experiment, and the level of nematode infestation was checked by planting seed pieces in sterilised soil in pots as described previously. Fenamiphos was applied to the growing crop by sprinkling granules of Nemacur 10G (100 g/kg fenamiphos) on the surface of the beds at a rate of 11 g/m^2.

Soil samples for nematodes were taken in June, prior to ploughing out the green manure crop. Approximately 25 cores were collected from each plot with a 2 cm diameter tube at depths of 0-25 cm and nematodes were extracted from 200 ml soil using a Whitehead tray. A further 750 ml soil was mixed with sterilised sand and added to a pot, a tomato seedling was planted and galls on roots were counted after plants grew for no more than 25 days in the glasshouse. Once ginger was planted, 25 cores were collected from each plot in February for nutrient and nematode analysis. Ginger was harvested in August by digging rhizomes from a 2 m length of the middle bed in each plot. A representative sample of 20 rhizome pieces were rated for nematode damage as described previously and the weight of nematode-damaged and marketable rhizomes was recorded. A soil sample was then collected from this disturbed area with a spade and analysed for nematodes as above.

Experiment with early harvest ginger

In this experiment, the methodology was similar to that used in the previous experiment with early harvest ginger. An area 100 m x 32 m containing 40 plots 10 m long x 5.5 m wide accommodated an experiment with 10 treatments (Table 4) replicated four times. The experiment commenced in March 1993 when the green panic was sprayed with herbicide and the soil was cultivated and planted to an oats-green manure crop. Ginger was planted in September every year (ie. 1993, 1994 and 1995), it was harvested in March of the following year and rhizomes were assessed as described previously. Soil samples for nematode and nutrient analyses were collected in February as described for the previous experiment and a further sample for nematodes was taken following harvest.

RESULTS

Population dynamics of nematodes on ginger

Comparison of nematode counts obtained using a Baermann tray with those obtained by bioassay showed that the bioassay method was more effective in detecting low populations of *Meloidogyne*. Populations capable of producing as many as 75 galls/750 g soil were frequently not detected using the tray method. Since one gall generally represents one nematode when bioassays contain less than 200 galls per root system, data for low populations of *Meloidogyne* was obtained by converting gall counts to nematodes/200 ml soil.

Results showed that *Meloidogyne* was generally detectable in the winter before ginger was planted, but populations were less than 5 nematodes/200 ml. Root-knot nematodes were not detectable during the first two months of the ginger crop but a rapid increase in populations generally occurred in the December-February period. In two fields where populations were greater than 100 nematodes/200 ml soil in December and early January, there was substantial damage to rhizomes in early harvested crops. However, in another field, nematode populations did not increase to significant levels and early harvested rhizomes were not damaged. In some late harvested ginger crops, root-knot nematode reached high population densities and caused significant damage, while in other crops, populations remained low and there was little damage. In the field where heat-treated and untreated seed was planted, nematode populations were higher and damage more severe with untreated seed.

Data for five of the fields are shown in Figure 1. Ginger at sites 1A - 1D was harvested in May or June and rhizomes were not damaged by nematodes in 1A and 1B but showed moderate damage in 1C and 1D. The early harvest crop (1E) showed severe nematode damage where untreated seed was planted, whereas only occasional damage was observed where the crop grew from heat-treated seed.

Esterase analysis of *Meloidogyne* from ginger fields showed that both *M. javanica* and *M. incognita* were present. Fields with a long history of ginger cultivation were infested with *M. incognita* whereas *M. javanica* occurred in fields rotated with pineapple and in fields in which ginger was a relatively new crop.

Clean planting material

Nematode infestation of seed

Assessment of root systems after 5 months showed that 13/17 samples were infested with root-knot nematode (Table 5). In most cases, less than 20% of seed pieces were infested, but in the most heavily infested samples, 21%, 25%, 30%, 54% and 86% of seed pieces were infested.

Hot water/nematicide treatment

Both methods of assessment confirmed that untreated seed was heavily infested with root-knot nematode. Seed dipped in fenamiphos showed a reduced level of nematode infestation, while hot water treatment eradicated the nematode (Table 6).

Clean seed production in sawdust

When levels of root-knot nematode infestation were compared in seed that had grown in sawdust or soil, seed from sawdust was much cleaner than that from soil. None of 36 seed pieces from sawdust were infested with nematodes whereas 17/43 of the seed pieces from soil were infested.

Sawdust had little effect on yield of ginger, whether incorporated into soil or used as a mulch (Table 7). In mulched plots, about 60% of the yield was produced in the mulch rather than soil. Root-knot nematode populations were lowest in plots into which sawdust had been incorporated. The level of seed infestation was too low to enable statistical analysis, but fewer seed pieces were infested in sawdust treatments than in the untreated area.

Susceptibility of rotation crops

Analysis of variance showed a significant ($P = 0.01$) effect of both nematode and plant species and a significant interaction. Data for each crop x nematode is presented in Table 8.

Field experiment with late harvest ginger

The root-knot nematode population was very low when the experiment commenced in July 1992 and these population densities were maintained for the next 12 months under forage sorghum. However, the nematode had increased to readily detectable levels in plots planted to *Dolichos lablab* (Table 9).

During the first ginger crop, some differences in soil nutrient status were detected between treatments but yields were similar in all treatment (Table 10). Root-knot nematode populations remained relatively low throughout the season and both nematode and *Fusarium* damage was insignificant at harvest. A few nematode-infested rhizomes were observed in two plots previously planted to *D. lablab* (treatment 5) and one control plot, but the level of the damage was insufficient to warrant rating a sample of rhizomes. Nevertheless, nematode populations in the control (treatment 8) and in plots where *D. lablab* had been grown were significantly higher than in all other plots (Table 11).

When the green manure crops that followed the first ginger crop were ploughed out in June 1995, root-knot nematode was not detectable in most treatments. Again plots which had grown *D. lablab* were the only ones where the nematode was consistently detected (Table 9).

The second late harvest ginger crop planted in September 1995 produced similar yields to the previous crops and there were no differences in yield between treatments (Table 13), despite differences in pH and many of the major and minor nutrients (Table 12). Populations of root-knot nematodes were higher in untreated and nematicide treated plots and this resulted in minor damage being observed in these treatments at harvest (Table 13). Nematode populations were relatively low in most organically-amended treatments and rhizome damage in these treatments was not observed (Table 13). Between 5 and 10% of the rhizomes were unmarketable due to *Fusarium*, but the level of rotting was not affected by treatment.

Field experiment with early harvest ginger

The data on soil nutrient status that was collected each January from three successive crops is presented in Tables 14, 16 and 18. Organic carbon levels varied from year to year but the organic treatments generally increased this parameter by 20-25%. Sawdust reduced soil pH, had a negative impact on NO_3-N, particularly in the second year and had little effect on most other nutrient levels, particularly P, K and some of the minor elements. Poultry manure increased most of the soil nutrients.

Populations of root-knot nematode remained relatively low during the first crop, so that nematode damage was insignificant and none of the treatments produced yields which differed significantly from the control (Table 15). During the second crop, nematodes increased in the untreated plots and there were significantly less nematodes in most other treatments (Table 17). This difference was reflected in the degree of nematode infestation of rhizomes as 67% of rhizomes in untreated plots were infested compared with less than 30% in several other treatments. Sawdust treatments generally yielded less than non-amended treatments and those involving poultry manure. Nematode populations were relatively high in the third crop and this was reflected in the rhizome damage that was observed at harvest. (Table 19). The nematicide treatment was the only treatment to give both high yields and good nematode control but some of the organic treatments produced high yields. (Table 19).

DISCUSSION

The level of nematode infestation in some samples of seed used in the ginger industry suggests that some growers have become careless about the quality of the seed they are using. Observations made in this project in a field where heat treated and nematode-infested seed was planted next to each other clearly showed the benefits of using clean seed and suggest that cleanliness of seed is one issue that requires continuing attention by the industry. Hot water treatment is available as a means of disinfesting planting material and its capacity to eradicate nematodes was confirmed in this project. However, the treatment is not widely used in the ginger industry because of the practical difficulties involved in treating large quantities of seed and concern by growers that the treatment is detrimental to germination. Since experimental evidence has shown that 48^0C for 20 minutes does not affect germination (Colbran and Davis 1969), this latter concern probably has arisen because of inadequate temperature control in some hot water facilities.

Although nematode infestation of ginger seed was widespread, it was not universal in the Queensland ginger industry. Four of 17 seed samples were free of nematodes, which shows that with careful attention to site selection and appropriate nematicide treatment, excellent quality seed can be produced. In situations where light infestations of nematodes occur, this project showed that the use of a thick layer of sawdust mulch and incorporation of sawdust into the topsoil could also be useful in improving seed quality. Thus with careful attention to seed production practices, there should rarely be any need to resort to hot water treatment.

The field experiments carried out in this project were established to determine whether practices such as crop rotation and organic amendments could be used in an integrated way to diminish the need for nematicides in the ginger industry. One important observation was that the use of a root-knot susceptible crop such as lablab in the summer before a ginger crop can lead to high root-knot nematode populations and the possibility of nematode damage in the following crop. This work and other unpublished data has shown that there are several alternative crops that will not increase populations of root-knot nematodes (eg. green panic, forage sorghum cv. Jumbo, buffel grass, rhodes grass cv. Nemkat, sudan grass cv. Superdan). Ideally a grass/legume forage crop could be useful but there are problems in finding a legume resistant to root-knot nematode. Of the range of material tested in Queensland, velvet bean *(Mucuna pruriens)* is one of the most useful legumes, but some nematode reproduction will still occur. However, regardless of the species used, it is important that the forage crop grows vigorously enough to smother weeds that may be an alternate host of the nematode.

The results of the experiment with late harvest ginger suggested that there was little nematode damage if ginger was grown after a nematode-resistant forage crop the previous year. When combined with the organic treatments tested in this study, the rhizomes produced were generally nematode free. All of the organic amendments were useful in controlling nematodes but some (eg. treatment 3 which received two applications per year of sawdust and urea) produced lower yields, probably due to nitrogen drawdown problems. Treatment 1 (two applications of poultry manure) and treatments 2 and 6 (sawdust/urea prior to planting forage sorghum followed by poultry manure prior to planting the next ginger crop) produced good yields and maintained low nematode populations in successive ginger crops, suggesting that they were the most appropriate organic treatments for ginger soils.

In the experiment with early harvest ginger, the results clearly showed the build-up in root-knot nematodes in successive ginger crops. Thus nematode populations remained relatively low in the first crop but were high enough to cause significant rhizome damage in the following two crops. Although organic treatments similar to those used in the late harvest experiment (particularly those containing poultry manure) reduced both nematode numbers and nematode damage and resulted in good yields, their effects were not sufficient to achieve the level of control obtained with nematicides.

One problem is interpreting the results of field experiments such as those described in this work is that crop nutrition is altered substantially by some organic treatments. Since the fertiliser program was not adjusted for these treatment effects as this would have compounded the results, many treatments would have received sub-optimal nutrition. Thus it must be recognised that the yield results achieved with some of the organic treatments could most likely be improved through better attention to nutrition.

One issue that requires some comment is the high quantities of urea applied with some of the organic treatments. As discussed previously (Stirling 1989), urea was used in an attempt to achieve nematicidal concentrations of NH^{+}-N in soil (Rodriguez-Kabana, 1986) and also to counteract the nitrogen drawdown problems that occur with materials such as sawdust, which have a high C:N ratio. However, it is now apparent that urea should not be used in this way. In addition to concerns about the possible environmental impacts of applying such high quantities of nitrogen, urea appeared to cause some crop damage when applied prior to planting ginger (see Table 17, eg. treatments 6 and 8 in the second early harvest crop). A single application of urea applied with sawdust also did not correct nitrogen drawdown problems and improved nitrogen nutrition is probably better achieved by regular application of nitrogen throughout the growing season.

In conclusion, the results of this project suggest that late harvest ginger can be grown every second year without nematicides, provided nematode-free planting material is used, a forage crop with nematode resistance is grown during the intervening summer and large quantities of organic matter are applied. The composition, timing and rate of application of the organic materials requires further experimentation, but 150m^3 of sawdust applied following ginger harvest and 150m^3 poultry manure at the time forage sorghum is ploughed in produced good results in our field trials.

Although the relatively short growing period for early harvest ginger restricts the level of nematode damage, results obtained in this project showed that damage can still occur in rhizomes harvested in March. Under the relatively benign soil temperature conditions that occur in Queensland from April to September, there is apparently insufficient time for nematodes that have increased on a previous ginger crop to decline to non-damaging levels. Nematicides may therefore be necessary whenever successive early harvest crops are grown.

Benefits of the project and future directions

This project was initiated in 1991 because of concern amongst ginger growers that EDB, a soil fumigant that is widely used within the industry, might be phased from use. That concern proved well-founded, as a decision was recently made to withdraw EDB from the market in 1997.

The results of this work suggest that good crops of ginger can be grown without nematicides, provided that clean seed is planted, that soil is amended with large amounts of organic matter and that successive ginger crops are not grown in the same field. This IPM strategy is already being used by some growers who have ample room for crop rotation. However, the choice of rotation crop is particularly important as the crop chosen must be resistant to root-knot nematode. A number of such crops have been identified in this and other projects, with forage sorghum cv. Jumbo being one of the most useful.

Because root-knot nematode has the capacity to multiply to high population densities on ginger, intensive ginger production (ie. cultivation of successive ginger crops in the same field) will continue to depend on the availability of nematicides. However, as soil fumigants are replaced by non-volatile materials that are generally less effective nematicides, the integrated management strategies developed in this project will be critically important in ensuring adequate nematode control.

In the foreseeable future, the availability of nematicides to the ginger industry is likely to decline, while limitations on land and economic pressures are likely to dictate that successive crops of ginger must be grown. To protect its future, the ginger industry may therefore have to consider investing in technologies that will lead to the development of nematode resistant ginger. Transgenic crops with resistance to certain diseases are now reaching the market place and there is no technical reason why transgenic ginger with resistance to root-knot nematode could not be developed. However, such technologies may prove prohibitively expensive for the relatively small ginger industry. An alternative approach would be to try and build on the substantial level of control that was obtained in this project with organic amendments. This antagonistic activity was almost certainly the result of microbiological action. If these biological processes were better understood, it might be possible to enhance biological activity to the point where successful biological control is achieved.

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Table 1 Details of ginger fields in which root-knot nematode populations were monitored during 1992/93.

Grower No.	Field No.	Soil texture	Cropping history (immediate past)	Type of ginger crop in 1992/93
1	1	Red clay loam	Early harvest ginger/oats	Early harvest ginger
2	2	Grey sandy loam	Early harvest ginger/oats	Early harvest ginger
	3	Grey sandy loam	Weedy fallow/oats	Market ginger (Harvested April 1993)
3	4	Red clay loam	Forage sorghum	Early harvest ginger
	5	Red clay loam	Early harvest ginger	Late harvest ginger
	6	Red clay loam	Early harvest ginger/oats	Late harvest ginger
4	7	Grey clay	Desmodium/forage sorghum	Late harvest ginger
	8	Brown sandy loam	Dolichos/forage sorghum	Early harvest ginger
5	9	Red sandy clay loam	Pineapple	Late harvest ginger
	10	Red sandy clay loam	Pineapple	Late harvest ginger

Table 2 Treatments* included in an experiment with late harvest ginger

1. Poultry manure (150 m^3/ha) + urea (600 kg/ha) incorporated in August 1992. Forage sorghum planted in October 1992 and ploughed out in July 1993. Poultry manure (150 m^3/ha) incorporated in July 1993 and ginger planted September 1993. Ginger harvested August 1994.

2. Sawdust (150 m^3/ha) + urea (1200 kg/ha) incorporated in August 1992. Forage sorghum planted in October 1992 and ploughed out in July 1993. Poultry manure (150 m^3/ha) incorporated in July 1993 and ginger planted in September 1993. Ginger harvested August 1994.

3. Sawdust (150 m^3/ha) + urea (1200 kg/ha) incorporated in August 1992. Forage sorghum planted in October 1992 and ploughed out in July 1993. Sawdust (150 m^3/ha) + urea (1200 kg/ha) incorporated in July 1993 and ginger planted in September 1993. Ginger harvested August 1994.

4. Sawdust (150 m^3/ha) + urea (1200 kg/ha) incorporated in August 1992. Forage sorghum planted in October 1992 and incorporated with sawdust (150 m^3/ha) in July 1993. Ginger planted in September 1993 and harvested in August 1994.

5. Sawdust (150 m^3/ha) + urea (1200 kg/ha) incorporated in August 1992. *Dolichos lablab* planted in October 1992 and incorporated in July 1993 with poultry manure (150 m^3/ha). Ginger planted September 1993 and harvested August 1994.

6. Sawdust (150 m^3/ha) + urea (1200 kg/ha) incorporated in August 1992. Forage sorghum + *Dolichos lablab* planted in October 1992 and incorporated in July 1993 with poultry manure (150 m^3/ha). Ginger planted in September 1993 and harvested August 1994.

7. No amendment in August 1992. Forage sorghum planted in October 1992 and ploughed out in July 1993. No amendment in July 1993. Fumigated with EDB and planted with ginger in September 1993. Ginger treated with fenamiphos in November 1993 and February 1994 and harvested in August 1994.

8. No amendment in August 1992. Forage sorghum planted in October 1992 and ploughed out in July 1993. No amendment in July 1993. Ginger planted in September 1993 without EDB fumigation, grown without fenamiphos and harvested in August 1994.

* In each treatment, the procedure described was repeated during the period August 1994-August 1996.

Table 3 **Analysis of sawdust and poultry manure used in field experiments with early and late harvest ginger.**

Amendment	Dry weight (kg/m^3)	%N
Sawdust	115	0.05
Poultry manure*		
(1992/93 batch)	270	2.53
Poultry manure*		
(1994 batch)	-	1.43
Poultry manure*		
(1995 batch)		1.90

* Poultry manure contained some sawdust, as it was obtained from broiler production sheds.

Table 4 **Treatments* included in an experiment with early harvest ginger.**

1. Oats planted in March 1993 and ploughed out in July 1993. Ginger planted in September 1993 without EDB fumigation, grown without fenamiphos and harvested in March 1994.
2. Oats planted in March 1993 and ploughed out in July 1993. Fumigated with EDB in September 1993 and planted to ginger. Fenamiphos applied in November 1993 and ginger harvested March 1994.
3. Poultry manure (150 m^3/ha) incorporated in March 1993. Oats planted in March 1993 and ploughed out in July 1993. Ginger planted in September 1993 and harvested in March 1994.
4. Poultry manure (150 m^3/ha) incorporated in March 1993. Oats planted in March 1993 and incorporated in July 1993 with urea (1200 kg/ha). Ginger planted in September 1993 and harvested in March 1994.
5. Sawdust (150 m^3/ha) + urea (200 kg/ha) incorporated in March 1993. Oats planted in March 1993 and ploughed out in July 1993. Ginger planted in September 1993 and harvested in March 1994.
6. Sawdust (150 m^3/ha) + urea (200 kg/ha) incorporated in March 1993. Oats planted in March 1993 and incorporated with urea in July 1993. Ginger planted in September 1993 and harvested in March 1994.
7. Oats planted in March 1993 and incorporated in July 1993 with urea (1200 kg/ha) and poultry manure (150 m^3/ha). Ginger planted in September 1993 and harvested in March 1994.
8. Oats planted in March 1993 and incorporated in July 1993 with urea (1200 kg/ha) and sawdust (150 m^3/ha). Ginger planted in September 1993 and harvested in March 1994.
9. Sawdust (150 m^3/ha) + urea (200 kg/ha) incorporated in March 1993. Oats planted March 1993 and incorporated in July 1993 with sawdust (150 m^3/ha) and urea (1200 kg/ha). Ginger planted in September 1993 and harvested in March 1994.
10. Sawdust (150 m^3/ha) + urea (200 kg/ha) incorporated in March 1993. Oats planted March 1993 and incorporated in July 1993 with poultry manure (150 m^3/ha) and urea (1200 kg/ha). Ginger planted in September 1993 and harvested in March 1994.

* In each treatment, the procedure described was repeated each season from August 1994 to August 1996.

Table 5 **Root-knot nematode infestation in 17 samples of seed from the Queensland ginger industry**

Degree of infestation (% infested seed)	No. of samples
0	4
1-10	4
10-20	4
> 20	5

Table 6 **Effect of hot water and nematicide treatment on nematode infestation of ginger seed when assessed by two methods.**

Treatment	% infested seed	
	Tomato method	Ginger method
Hot water	0	0
Fenamiphos	16.7	28.6
Untreated	83.3	64.9

Table 7 **Effects of sawdust incorporated into soil or used as a mulch on multiplication of root-knot nematode and yield of ginger and on the degree of nematode infestation in the seed.**

	Yield (kg/m bed)			Root-knot nematodes	% infested seed	
	Sawdust	Soil	Total	/200 ml soil*	Sawdust	Soil
Nil	-	10.3	10.3	134 (4.90)	-	11
Sawdust incorporated	-	11.9	11.9	33 (3.49)	-	0
Sawdust mulch	6.2	3.6	9.8	31 (3.44)	3	0
Sawdust (incorporated + mulch)	5.6	3.5	9.1	5 (1.52)	0	3
LSD (P = 0.05)			1.6	(-)	-	-

* Equivalent means with transformed means ($\ln x + 1$) in parentheses.

Table 8 Susceptibility of various crops to three species of root-knot nematode.

Crop	Nematodes/plant		
	M. incognita	*M. javanica*	*M. arenania*
Green panic (*Panicum maximum* var. *trichoglume*)	0	0	4
Forage sorghum cv. Jumbo	0	0	14
Buffel grass (*Cenchus ciliaris*)	0	0	0
Bahia grass (*Paspalum notatum*)	36	16	29
Castor bean (*Ricinus communis*)	244	17	383
Joint vetch (*Aeschynomene americana*)	31	3	12
Soybean (*Glycine max*)	126	0	21
Lablab (*Dolichos lablab*)	950	398	658
Cowpea (*Vigna unguiculata*)	496	134	1127
LSD (P = 0.05)		151	

Table 9 Root-knot nematode populations in soil in June 1993 and June 1995, prior to ploughing out green manure crops. Late harvest ginger was planted the following September.

Treatment	Nematodes /200 ml soil	
	June 1993 *	June 1995†
1. PU/J/P	0 (0)	0 (0.00)
2. SU/J/P	0 (0)	0 (0.00)
3. SU/J/SU	0 (0)	0 (0.00)
4. SU/J/S	0.1 (0.06)	0 (0.00)
5. SU/D/P	16.8 (2.88)	92.7 (4.54)
6. SU/JD/P	0.6 (0.50)	7.9 (2.19)
7. -/J/EDB	0.1 (0.10)	1.9 (1.07)
8. -/J/-	0 (0)	1.1 (0.76)
LSD (P=0.05)	(0.56)	(2.05)

* Nematode populations were obtained by bioassay and converted to numbers/200 ml.

\+ Data presented as equivalent means, with transformed means (l_n (nematodes + 1)) in parentheses.

† Nematode populations determined by extraction of Whitehead tray.

Table 10 Nutrient status of soils from the first late harvest ginger crop. February 1994.

Treatment	pH	Org. C %	EC mS/cm	Cl mg/kg	NO_3-N mg/kg	P mg/kg	K meq %	Ca meq %	Zn mg/kg	Cu mg/kg
1. PU/J/P	6.1	2.7	0.129	16	38	362	1.35	9.0	10.4	2.7
2. SU/J/P	6.1	2.7	0.114	8	26	243	1.15	8.9	8.4	2.7
3. SU/J/SU	5.9	2.4	0.094	13	24	68	0.82	7.1	3.1	2.2
4. SU/J/S	6.1	2.6	0.100	29	23	58	0.75	7.7	2.7	2.1
5. SU/D/P	5.9	2.6	0.107	7	32	202	0.99	8.0	6.3	2.5
6. SU/JD/P	6.2	2.6	0.124	7	31	241	1.30	9.6	7.7	2.6
7. -/J/EDB	6.2	2.1	0.089	0	26	76	0.91	7.9	3.2	2.0
8. -/J/-	6.6	2.1	0.084	0	23	80	1.10	10.1	3.6	2.0
LSD (P=0.05)	0.4	0.38	0.029	12	4.1	40	0.40	2.1	0.8	0.25

Table 11 Root-knot nematode populations on ginger in February and July 1994 and yield of the first late harvest ginger crop. (July 1994).

Treatment	Nematodes/200 ml soil * February 1994	Nematodes/200 ml soil * July 1994	Rhizome damage rating +	Marketable yield (kg/m row)
1. PU/J/P	0 (0)	0 (0)	-	11.4
2. SU/J/P	0 (0)	0 (0)	-	10.8
3. SU/J/SU	0.9 (0.60)	1.6 (0.95)	-	10.6
4. SU/J/S	0 (0)	22.8 (3.17)	-	12.0
5. SU/D/P	16.5 (2.86)	134.6 (4.91)	-	12.7
6. SU/JD/P	0 (0)	1.6 (0.94)	-	11.7
7. -/J/EDB	1.4 (0.86)	6.5 (2.02)	-	11.3
8. -/J/-	1.3 (0.84)	113.4 (4.74)	-	12.5
LSD (P=0.05)	(1.14)	(2.64)	-	n.s.

* Data presented as equivalent means, with transformed means (1_n(nematodes +1)) in parentheses
+ Since nematode damage to rhizomes was insignificant, data were not collected

Table 12 **Nutrient status of soils from the second late harvest ginger crop. February 1996.**

Treatment	pH	Org. C %	EC mS/cm	Cl mg/kg	NO_3-N mg/kg	P mg/kg	K meq %	Ca meq %	Zn mg/kg	Cu mg/kg
1. PU/J/P	6.1	2.9	0.190	22	37	447	1.55	11.0	21.0	3.7
2. SU/J/P	5.8	3.0	0.135	24	41	264	1.55	9.1	12.5	3.4
3. SU/J/SU	5.9	2.8	0.085	14	18	100	0.7	7.8	3.7	2.4
4. SU/J/S	6.2	2.8	0.085	12	18	87	0.56	9.1	3.3	2.2
5. SU/D/P	5.6	2.9	0.140	16	36	290	1.10	8.3	13.0	3.6
6. SU/JD/P	6.0	2.8	0.135	12	56	259	1.25	9.9	11.5	3.3
7. -/J/EDB	6.6	2.3	0.080	11	18	104	0.99	9.8	3.2	1.9
8. -/J/-	6.7	2.2	1.075	12	16	99	0.93	10.0	3.2	1.9
LSD (P=0.05)	0.4	0.27	0.014	13	19	34	0.19	2.1	2.4	0.3

Table 13 **Root-knot nematode populations on ginger in February and July 1996 and yield of the second late harvest ginger crop (July 1994).**

Treatment	Nematodes/200 ml soil*			Marketable
	February 1996	July 1996	Rhizome damage rating	(kg/m row)
1. PU/J/P	0.1 (0.17)	19 (2.99)	0.00	10.6
2. SU/J/P	1 (0.52)	1 (0.77)	0.00	11.3
3. SU/J/SU	5 (1.77)	10 (2.37)	0.00	9.4
4. SU/J/S	1 (0.62)	122 (4.81)	0.02	11.2
5. SU/D/P	17 (2.91)	214 (5.37)	0.00	10.6
6. SU/JD/P	2 (1.25)	9 (2.26)	0.00	11.3
7. -/J/EDB	15 (2.80)	307 (5.73)	0.30	10.7
8. -/J/-	70 (4.26)	1001 (6.91)	0.71	9.8
LSD (P = 0.05)	(1.41)	(2.25)	0.34	n.s.

* Data presented as equivalent means, with transformed means (l_n(nematodes + 1)) in parentheses

Table 14 **Nutrient status of soil from the first early harvest ginger crop. January 1994.**

Treatment	pH	Org. C %	ED mS/cm	Cl mg/kg	NO_3-N mg/kg	P mg/kg	K meq %	Ca meq %	Zn mg/kg	Cu mg/kg
1. -/O/-	6.3	2.3	0.138	23	36	58	0.66	8.6	2.4	1.55
2. -/O/EDB	6.3	2.4	0.149	34	37	68	0.70	8.6	3.1	1.70
3. P/O/-	6.3	2.5	0.186	60	37	164	1.05	9.3	5.8	1.70
4. P/O/U	6.1	2.7	0.176	30	42	186	1.08	8.6	6.2	2.05
5. SU/U/-	6.2	2.5	0.133	18	30	60	0.61	8.9	2.6	1.75
6. SU/O/U	5.8	2.5	0.139	29	36	57	0.62	7.8	2.7	1.70
7. -/O/PU	6.1	2.6	0.174	39	43	166	1.03	8.7	6.6	2.10
8. -/O/SU	6.0	2.3	0.127	19	36	59	0.65	7.6	2.8	1.75
9. SU/O/SU	6.0	2.6	0.152	43	34	56	0.70	8.3	2.8	1.80
10. SU/O/PU	6.0	2.6	0.188	44	49	146	1.00	8.7	6.3	2.00
LSD (P=0.05)	0.17	0.30	0.050	61	8.7	24	0.19	0.84	0.55	0.28

Table 15 **Root-knot nematode populations in January and March 1994 and yield of the first early harvest ginger crop(March 1994).**

Treatment	Nematodes/200 ml soil * January 1994	Nematodes/200 ml soil * March 1994	Rhizome damage rating+	Marketable yield (kg/m row)
1. -/O/-	4.5 (1.70)	54.7 (4.02)	-	8.4
2. -/O/EDB	1.4 (0.89)	9.6 (2.36)	-	6.8
3. P/O/-	1.6 (0.94)	3.9 (1.58)	-	8.2
4. P/O/U	6.8 (2.05)	6.0 (1.95)	-	8.0
5. SU/O/-	3.6 (1.52)	21.6 (3.12)	-	8.6
6. SU/O/U	9.4 (2.35)	10.4 (2.43)	-	8.2
7. -/O/PU	1.3 (0.85)	5.4 (1.85)	-	9.6
8. -/O/SU	0.7 (0.55)	1.0 (0.69)	-	7.7
9. SU/O/SU	0.6 (0.45)	12.7 (2.62)	-	8.1
10. SU/O/PU	0.6 (0.49)	2.6 (1.29)	-	9.8
LSD (P=0.05)	(2.34)	(2.60)	-	2.16

* Nematode populations were obtained with Whitehead trays in March, but a bioassay was used in January and gall counts were converted to nematodes/200ml soil. Data presented as equivalent means with transformed means (l_n (nematodes +1)) in parentheses.

+ Since no nematode damaged rhizomes were observed, data were not collected.

Table 16. Nutrient status of soil from the second early harvest ginger crop. January 1995.

Treatment	pH	Org. C %	Ec mS/cm	Cl mg/kg	NO_3-N mg/kg	P mg/kg	K meq %	Ca meq %	Zn mg/kg	Cu mg/kg
1. -/O/-	7.0	2.1	0.135	31	7	75	0.54	9	3.3	1.35
2. -/O/EDB	6.9	2.1	0.130	33	7	92	0.51	9	3.7	1.50
3. P/0/-	6.9	2.5	0.175	37	16	250	0.96	10	6.9	1.60
4. P/O/U	6.5	2.6	0.195	40	23	275	1.46	9	7.7	1.85
5. SU/O/-	6.3	2.5	0.135	33	8	65	0.49	10	3.0	1.50
6. SU/O/U	6.5	2.4	0.150	43	9	61	0.48	9	3.0	1.55
7. -/O/PU	6.6	2.5	0.200	44	20	265	1.65	11	8.7	1.95
8. -/O/SU	6.6	2.4	0.150	34	6	73	0.54	8	3.1	1.60
9. SU/O/SU	6.5	3.0	0.160	38	6	78	0.62	9	3.3	1.65
10. SU/O/PU	6.7	2.8	0.220	43	23	295	1.70	11	10.4	2.00
LSD (P=0.05)	0.21	0.26	0.018	10	5.6	44	1.03	0.8	1.37	0.16

Table 17. Root-knot nematode populations in January and March 1995 and yield of the second early harvest ginger crop (March 1995).

Treatment	Nematodes/200ml soil* February 1995	March 1995	Rhizome damage rating	Marketable Yield (kg/m row)
1. -/O/-	191 (5.25)	1212 (7.10)	1.12	9.3
2. -/O/EDB	2 (0.84)	2 (0.66)	0.05	9.1
3. P/O/-	2 (0.89)	49 (3.89)	0.37	9.5
4. P/O/U	20 (3.01)	79 (4.37)	0.59	9.7
5. SU/O/-	8 (2.06)	286 (5.66)	0.42	8.3
6. SU/O/U	10 (2.30)	121 (4.80)	0.76	5.7
7. -/O/PU	3 (1.20)	34 (3.84)	0.39	9.8
8. -/O/SU	11 (2.41)	47 (3.84)	0.29	5.9
9. SU/O/SU	5 (1.58)	39 (3.68)	0.33	7.1
10. SU/O/PU	1 (0.17)	69 (4.24)	0.36	7.5
LSD (P=0.05)	(1.64)	(2.34)	0.55	3.2

* Data presented as equivalent means with transformed means (l_n (nematodes + 1)) in parentheses.

Table 18 **Nutrient status of soil from the third early harvest ginger crop. January 1996.**

Treatment	pH	Org. C %	EC mS/cm	Cl mg/kg	NO_3-N mg/kg	P mg/kg	K meq %	Ca meq %	Zn mg/kg	Cu mg/kg
1. -/O/-	6.8	2.0	0.115	-	25	89	0.69	11	2.55	1.60
2. -/O/EDB	6.8	2.0	0.115	-	24	101	0.68	11	2.95	1.65
3. P/O/-	6.8	2.15	0.140	-	34	226	1.02	11	6.15	1.75
4. P/O/U	6.5	2.35	0.140	-	39	287	1.02	11	7.05	2.10
5. SU/U/-	6.7	2.25	0.125	-	29	71	0.72	11	2.45	0.94
6. SU/O/U	6.5	2.20	0.090	-	20	75	0.57	10	2.30	1.70
7. -/O/PU	6.7	2.25	0.140	-	33	268	1.10	12	8.00	2.15
8. -/O/SU	6.4	2.18	0.130	-	28	79	0.78	9	2.80	1.85
9. SU/O/SU	6.4	2.50	0.140	-	40	86	3.90	10	2.95	1.85
10. SU/O/PU	6.7	2.45	0.155	-	42	313	1.15	12	9.10	2.15
LSD (P=0.05)	0.2	0.17	0.016	-	13	61	3.0	0.7	1.06	0.80

Table 19 **Root-knot nematode populations in January and March 1996 and yield of the third early harvest ginger crop. March 1996.**

Treatment	Nematodes/200 ml soil * January 1996	Nematodes/200 ml soil * March 1996	Rhizome damage rating	Marketable yield (kg/m row)
1. -/O/-	47 (3.88)	1199 (7.09)	0.45	5.6
2. -/O/EDB	0 (0.00)	3 (1.34)	0.01	8.7
3. P/O/-	20 (3.03)	613 (6.42)	0.72	9.0
4. P/O/U	70 (4.26)	961 (6.87)	0.31	8.5
5. SU/O/-	118 (4.78)	1421 (7.26)	0.24	7.7
6. SU/O/U	122 (4.81)	2120 (7.66)	0.74	7.9
7. -/O/PU	26 (3.29)	827 (6.72)	0.40	9.8
8. -/O/SU	84 (4.44)	2017 (7.61)	0.31	9.7
9. SU/O/SU	44 (3.81)	538 (6.29)	0.26	8.5
10. SU/O/PU	14 (2.68)	598 (6.39)	0.34	10.5
LSD (P=0.05)	(1.03)	(1.93)	0.35	4.2

* Nematode populations were obtained with Whitehead trays in March, but a bioassay was used in January and gall counts were converted to nematodes/200ml soil. Data presented as equivalent means with transformed means (l_n (nematodes +1)) in parentheses.

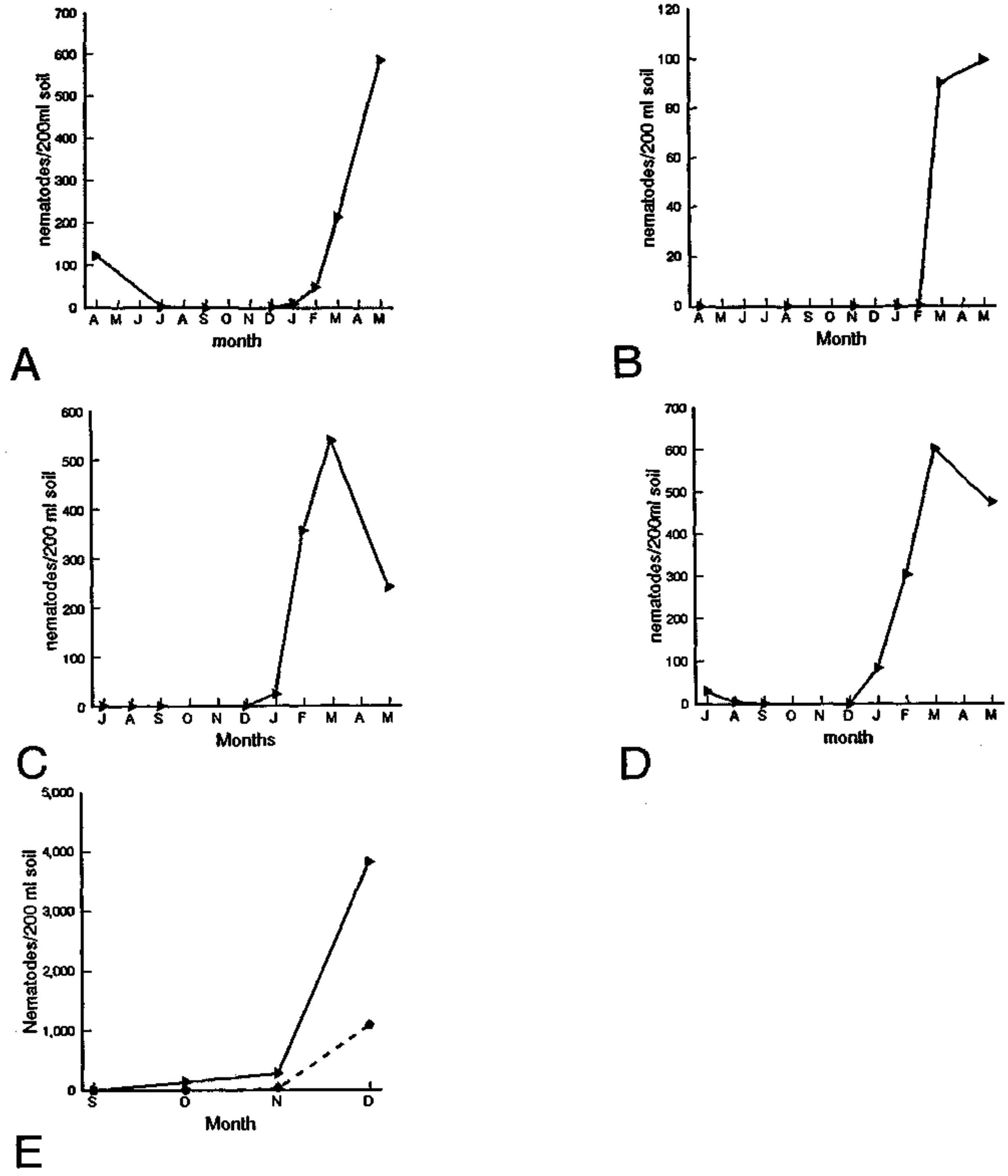

FIGURE 1. Population dynamics of root-knot nematode in five Queensland ginger fields. **A.** Weedy fallow planted to market ginger in September following EDB fumigation. **B.** A long-term green manure crop of *Desmodium* forage sorghum ploughed out in April and late harvest ginger planted in September without nematicide. **C, D.** Fenamiphos applied and late harvest ginger planted in September following pineapple. **E.** A field fumigated with EDB and planted in September with heat-treated seed (dotted line) and untreated seed (solid line).