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SUSTAINABLE AGRICULTURE RESEARCH AND EDUCATION PROGRAM AND AGRICULTURE IN CONCERT WITH THE ENVIRONMENT

1. FINAL REPORT:

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3. PROJECT TITLE: NOVEL ROTATION CROPS AS ALTERNATIVES TO FUMIGANT NEMATICIDE TREATMENT IN DECIDUOUS TREE FRUIT PRODUCTION

4. PROJECT STATUS: (for annual reports only)

___ **New:** receiving SARE or ACE funding for the first time.
___ **Continuation:** no major change in direction or objectives.
___ **Renewal:** project whose SARE or ACE funding was interrupted one or more funding cycles.
___ **Redirection:** major revision of an earlier SARE or ACE project.
___ **Change Funding Source:** from SARE to ACE or from ACE to SARE.

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11. ABSTRACT:

Dagger nematodes (Xiphinema spp.) are one of the most serious soil borne disease problems of the tree fruit industry. The nematodes are efficient vectors of tomato ringspot virus (TmRSV); causal agent of a lethal disease in many fruits including all peach and nectarine varieties and certain apple cultivars. In regions infested with TmRSV and its nematode vector, susceptible orchards frequently loose profitability and have a shortened productive life. In the most severe cases new orchard plantings have been lost before returning the cost of establishment. The yield loss resulting from tree mortality extends throughout the life of the orchard since TmRSV infested soil can not be replanted without first purging the site of virus and nematodes by fumigation. Widespread infestations result in tough economic decisions of keeping an orchard which is not highly profitable or reestablishing a new orchard at major expense and a loss of several years productivity.

Dagger nematodes and TmRSV are found throughout the northeastern United States. Common orchard weeds serve as natural virus reservoirs and also disperse the virus with their seed. However, the only natural means of fruit tree infection is by the feeding activities of the dagger nematode. The nematode acquires TmRSV when it feeds on infected weeds and transmits the virus when it feeds on tree roots. Current recommendations for control of TmRSV rely on preplant soil fumigation and postplant nematicides to keep nematode vectors in check. Many effective nematicides have recently been canceled or their use has been restricted because they are regarded as potential environmental hazards. The future availability of many nematicides is uncertain. As chemical control options for nematodes become more limited and expensive, the need for alternative control measures becomes more critical.

This research evaluated novel rotation crops as cost efficient and environmentally sound alternatives to soil fumigants and nematicides to suppress dagger nematode populations and control the spread of TmRSV. Additional benefits include reduced chemical input, safety, cost, weed suppression, erosion control, and improved soil structure. These features should make this approach attractive to growers and compatible with the philosophy of sustainable agriculture.

Two rotation crops (i.e. marigold and canola) effectively suppressed dagger nematodes. However, these crops were not equally beneficial when other characteristics were considered. Marigold was difficult to establish, did not compete well with weeds, and was susceptible to TmRSV. Virus susceptibility indicates a potential of spreading TmRSV in seed. Canola on the other hand, was relatively easy to establish and competed well against weeds. Winter and summer canola varieties provide flexibility in planting dates and winter cover crops minimize erosion from spring rains. Furthermore, canola was not susceptible to TmRSV. Research has since shown several Brassica species to be equal or superior in these characteristics. Canola was the only rotation crop tested where the biological basis for nematode suppression is thought to be understood.

Several rotation crops including wheat, oats, and fescue gave inconsistent results. These anomalies require further investigation but data from West Virginia suggested that such crops may differentially affect dagger nematode species. If this is true it would limit the usefulness of these crops for dagger nematode control. Fescue may present a special problem. Reportedly, endophytic fungi in fescue confers nematode resistance, however, we were unable to confirm a high level of infection by the fungus in the fescue tested.

No cover crop controlled dagger nematodes as well as soil fumigation but Brassica spp and marigold were as effective as postplant nematicides in most experiments. Our research has now focused primarily on Brassica spp because of traits which make it a desirable rotation crop. Research is needed to evaluate efficacy of different cultivars, rotation sequences, and various cultural practices before a standard orchard renovation practice can be recommended. Fruit growers have expressed great interest in this work even though nematode management with cover crops requires greater planning, preparation, and time commitment than with nematicides. It is anticipated that an effective crop rotation program for dagger nematode control will be readily accepted.

12. OBJECTIVES:

no change

13. PROJECT RESULTS:

Background Information:

Cultural practices for renovation of old orchard sites include removal of as much tree root debris as practical and one to two years of a rotation crop prior to planting new seedling trees. Rotation crops help ameliorate problems such as soil compaction and loss of organic matter resulting from years of tractor / sprayer traffic and herbicide use. Rotation crops also provide an opportunity to incorporate soil amendments to adjust pH and nutrient imbalances which may have developed. In the northeast, the most common rotation crop for this purpose is field corn. However, corn is a good host for the dagger nematode and population levels are typically higher at the end of a corn rotation. Corn cultivation further exasperates the dagger nematode problem by redistributing nematodes in the field. In regions where the dagger nematode posses a threat, growers have depended on soil fumigants and nematicides to control the problem. This research is a first attempt to develop a biorational approach using cover crop management to control the dagger nematode.

A. Findings:

Objective 1. Evaluate effectiveness of alternate crops for suppression of dagger nematodes in orchard replant sites.

Field Work:

Dagger nematode biology is not as well understood as many other nematode pests. These nematodes reportedly have a large host range but extensive host range studies have not been carried out. Field data have shown some plants to be excellent hosts but few if any plants have been identified as nonhosts or toxic. Therefore, rotation crops that will suppress dagger nematode populations must be identified through empirical means. In this study five rotation crops were initially chosen based on reports that the crops effectively reduced populations of other plant parasitic nematodes but the efficacy against dagger nematodes was not known. As the work progressed, greater attention was given to crops which yielded promising preliminary data. Several additional crops were also included so that a broader range of alternate crops was evaluated than originally proposed. Not all crops were evaluated in every test but results are based on crops that were tested in a minimum of two different field sites or two years in a single site.

First year field plots were located at Biglerville and Fairfield, Pennsylvania and Kearneysville, West Virginia. Additional plots were later established at Morgantown, West Virginia and Woodbine, Maryland. Plots at Biglerville and Woodbine were irrigated during the drought of 1991. Initial and final dagger nematode levels were determined each season. Detailed sampling determined population levels throughout the season in some plots. For most experiments corn was used as a positive check while soil fumigation or nematicide treatment was used as a negative check.

RESULTS: In virtually every experiment the nematode population increased substantially on the corn check. These data are consistent with previous reports and further support the need for research to identify a more appropriate rotation crop for renovation of orchard land. Several other rotation crops proved to be good hosts as well, these included sunflower, sudan grass, and alfalfa. Sudan grass and alfalfa are two crops which have also been used as orchard rotation crops in the northeast although not to the same extent as corn. Sunflower was included as a crop which grows well in temperate regions, is a novel commercial crop in the northeast, but very little is known about its host status for dagger nematodes.

Data from wheat, oats, and fescue did not show consistent trends regarding dagger nematode population dynamics. In some field plots populations declined while they increased in others, although not to the same extent as on corn, sunflower, sudan grass, or alfalfa. These data suggest that such crops may be relatively poor hosts but may serve to maintain nematode populations. On the other hand there is some indication that the nematode - host interaction may be more complex than these data indicate. Field experiments typically did not differentiate dagger nematode species but in one West Virginia experiment the data indicated that populations of Xiphinema rivesi survived better on fescue than did X. americanum. These preliminary data require verification but if fescue rotation differentially supports dagger nematode species, it would limit the value of such rotations for nematode control. Evaluation of fescue as a host was further complicated by the necessity of determining whether or not each plant was infected with the endophytic fungus Acremonium caenocephalium. Reportedly endophytic fungi confer nematode resistance to certain grasses but the level of infection can vary considerably in seed lots and also may decrease under storage. Research in West Virginia had difficulty in confirming a high level of endophyte infection in grass which reportedly harbored the fungus.

Dagger nematode populations decreased under rotations of marigold and canola. Although little information is known about the nematode parasites of canola, these data are consistent with reports of nematode control by Brassica spp and marigold. Rotations of white mustard, black mustard, and rapeseed gave similar results. In most field plots, suppression of dagger nematodes by these crops was as good as post plant nematicide treatments except that the benefit of nematicide was seen within weeks of application and rotation crops required a full season to achieve similar results. Soil fumigation was the most effective nematode control treatment and reduced dagger nematodes below detectable levels.

SIGNIFICANCE: Nematode management in tree fruit has not been studied as intensively as in field crops. To a large extent, the selection of a rotation crop for renovation of orchard land has in the past been made on the basis of convenience or cash value and without consideration of the impact the rotation crop may have on the nematode population. In part, nematodes have received little attention because on a high value crop they could readily be controlled by chemicals. This attitude must change. Recent attention given to the risks of nematicides on humans and the environment has resulted in elimination and/or restriction of many effective compounds. Furthermore, the high cost of product registration has dramatically reduced efforts by chemical companies to develop replacement chemicals.

Prime orchard land in the northeastern USA is limited and fruit growers must have methods available to suppress nematodes on infested sites to remain profitable. For this reason it is important to understand the effect of rotation crops on plant parasitic nematodes. This is true not only for the purpose of identifying nematode suppressive crops but also to recognize the detrimental affects of crops which foster population increases.

Corn, sunflower, sudan grass, and alfalfa were shown to be good hosts for the dagger nematode. Nevertheless, each of these rotation crops have certain advantages for the fruit grower which must be weighed against the negative aspect of exasperating nematode problems. For example: (i) Fruit growers typically do not have equipment to manage field crops and many prefer to have their land farmed during the renovation period. Since corn, alfalfa, and (potentially) sunflower have economic value such an arrangement can usually be made with local farmers. (ii) Corn, sunflower, and sudan grass have relatively shallow, fibrous root systems. This is an advantage if using conventional nematode control tactics, since nematodes deep in the soil must either starve or migrate closer to the surface where they are more susceptible to chemical control. (iii) Alfalfa and other legumes help replenish soil nitrogen. This benefit comes with a price, however, since their tap roots permit nematodes to remain deep in the soil where chemical control is less effective.

The benefit of a wheat, oat, or fescue rotation for nematode control is difficult to asses since data collected from these crops remain equivocal. In terms of land management, these rotation crops offer some of the same advantages previously mentioned for corn such as cash value (wheat and oats) and relatively shallow root systems for improved efficacy of chemical control.

Results showed that marigold and several species of Brassica effectively suppressed dagger nematode populations. However, as with any proposed rotation, this benefit must be put into perspective with other factors to determine whether or not the crops "fit" into an acceptable rotation program. Despite the benefit of nematode suppression, marigold was relatively difficult to establish and was initially a poor competitor with weeds until warm summer temperatures arrived. On this basis it appears that marigold rotations may be difficult to adopt on a commercial scale in the northeast. The level of nematode control with Brassica spp. was similar to marigold but they appeared to be more practical as a rotation crop. Canola, rapeseed, and mustard are cool season crops. They were relatively easy to establish and competed well with weeds in early spring. In addition, many types of grass seed spreaders can be adapted to handle rapeseed and therefore many growers already have the capacity to plant this crop. Although these crops are novel to the northeastern US, they potentially have economic value which may help foster acceptance as a rotation crop.

The advantage of soil fumigation is well known. Our results and also many other published reports show that fumigation is a very efficient and effective tactic for killing nematodes. But fumigation is a broad spectrum biocide and many beneficial organisms are also killed. In West Virginia no earthworms, nematode trapping fungi, predatory nematodes, or saprophytic nematodes were recovered from fumigated soil. Although plants may initially grow well in fumigated soil, natural pathways for nutrient recycling are suppressed because of the high mortality of saprophytic organisms. Natural antagonists of plant disease agents are also killed. New understanding and appreciation of the soil ecosystem indicates that broad spectrum soil sterilization by fumigants is incompatible with the philosophy of sustainable agriculture. Human health risks and potential for ground water contamination also contribute to the negative aspects of fumigant use. It would not be surprising if new standards of safety and environmental protection eventually banned the use of fumigants.

Greenhouse:

RESULTS: Greenhouse experiments were ancillary to field work. Three short term greenhouse experiments with selected rotation crops supplemented field plot studies.

Two experiments at Biglerville, PA monitored dagger nematode populations over three and a half months in pots. In one experiment dagger nematode levels declined slightly on sudan grass and grain amaranth but the number of nematodes recovered from canola was only one fourth as many as recovered from sudan grass. The second experiment was similar to the first except that alfalfa was used instead of grain amaranth and the initial population level was reduced by two thirds. The results were similar however, i.e. nematodes survived well on sudan grass and alfalfa but declined on canola. In Morgantown, WV five rotation crops were evaluated in greenhouse microplots over a period of eight and a half months. A population increase was recorded on all crops and in the fallow check plots but at very different orders of magnitude. Populations increased approximately 35X on corn, 20X on marigold, and 10X on canola and fawn fescue. Small population increases were observed on fescue 31 and in fallow microplots.

SIGNIFICANCE: One of the basic problems of interpreting the significance of greenhouse experiments is a lack of detailed information on the biology and reproductive potential of dagger nematodes. Dagger nematodes reportedly have a long life cycle and a low reproductive rate but no information is available concerning the egg laying capacity of females, the length of time eggs may remain dormant, or the life span of individuals. Reportedly it takes seven and a half months for the nematode to reach maturity under optimum conditions. Therefore, short term experiments of three to four months may only measure the ability of a plant to sustain nematodes as a population increase should not be expected. However, when using naturally infested field soil it is not possible to determine the occurrence of eggs which may hatch over varying periods of time or perhaps be stimulated to hatch by root exudates of different rotation crops. Neither is it possible to determine the length of time nematodes can go without feeding. Such factors could influence population levels in short term experiments that do not accurately depict the long term affect of using a particular rotation crop. In these experiments canola did not sustain dagger nematodes in the Pennsylvania experiments but did permit a limited population increase in the longer West Virginia microplot experiment. Such subtle differences in population growth / decline can not be reconciled in short term experiments without knowing more details of dagger nematode biology.

In general, rotation crops showed the same basic pattern of population development as field plots, i.e. corn, alfalfa, and sudan grass were good hosts for dagger nematodes but canola was not. Marigold appeared to be a better host in the microplot than in the field but possibly the experiment was not maintained long enough to evaluate the overall effect of this rotation crop on population development. The fact that dagger nematode populations did not decline in eight and a half months under fallow in the West Virginia experiment is an enigma. Apparently dagger nematodes are either able to survive eight and a half months without a host or dormant eggs continued to hatch over time, thus maintaining a detectable number of nematodes in the microplots.

Lab:

Most reports of nematode suppressive crops have been based on field or greenhouse experiments and generally very little research has been devoted to understanding the mechanism involved. Theories on how nematode suppressive crops affect nematodes include; starvation (i.e. the crop is a nonhost), inhibited reproduction (i.e. the crop is a "trap" crop), hostile environment (i.e. the crop fosters populations of nematode antagonists), and toxicity (i.e. the crop produces natural nematicides). Understanding the mechanism which brings about a decline in the nematode population has tremendous practical applications. For example such knowledge will allow screening of plant cultivars and closely related species to identify the most effective plants to use in rotation. It may also be possible to enhance nematode suppressive characteristics through breeding or genetic engineering.

A laboratory bioassay was developed to evaluate the toxicity of plant extracts. The bioassay evaluated development and mortality of the free-living nematode Caenorhabditis elegans in a dilution series of the extracts to determine lethal exposure levels. Caenorhabditis elegans was used as the test organism because it completes its life cycle in four days and subsequent work will confirm toxicity on dagger nematodes. The work has focused on Brassica spp. because (i) nematode populations were suppressed in field and greenhouse experiments; (ii) rapeseed and mustard have desirable characteristics for crop rotation; and (iii) the biochemistry of toxic compounds in Brassica spp. is well understood.

In essence, cruciferous plants are known to contain an assortment of related organic anions collectively referred to as glucosinolates. Glucosinolates may be hydrolyzed by the plant enzyme myrosinase. Upon hydrolysis, glucosinolates are converted to volatile compounds, some of which are toxic and known to have broad spectrum biocide activity. Hydrolysis of glucosinolate typically occurs as a result of plant injury or decomposition. The toxicity of compounds resulting from glucosinolate hydrolysis depends on the concentration and type of glucosinolates present.

RESULTS: Total glucosinolates were extracted from twenty different varieties of Brassica and from seed. Development and mortality of freshly hatched C. elegans were evaluated over a three day exposure to a dilution series of these extracts to which the enzyme myrosinase was added. Results of these bioassays showed a broad range of toxic activity. The six most toxic plants were critically evaluated by assaying glucosinolates separately from tops and roots at varying time intervals after planting. Results showed that nematicidal activity of these extracts varied with species, cultivar, plant age, and plant part. In general, toxic activity was greatest in extracts from seed and least in newly germinated seedlings. Toxic activity was greater in above ground portions of the plants compared to roots and increased with plant age. Senescent tissue lost toxic activity. Preliminary results have shown that dagger nematodes are more sensitive to these toxic compounds than C. elegans.

SIGNIFICANCE: Development of a toxicity bioassay using plant extracts has permitted rapid evaluation of putative nematicidal activity. This approach should be useful for a relatively quick determination of potentially effective nematode suppressive rotation crops. Results with various species of cruciferous plants has shown that nematicidal activity may vary with plant part and plant age. Such knowledge should help in the development of effective crop rotation strategies for nematode management. (More will be said on this topic under section #15 "areas needing additional study".)

Objective 2. Quantify the impact of alternate crops on tomato ringspot virus transmission, soil microflora associated with nematode biocontrol, and other nontarget soil organisms.

Development of a crop rotation program requires careful consideration. Nematode management was the main focus of this research and is a desirable outcome of crop rotation but it can not be the only criterion. Rotation crops will not be useful if growers do not have the proper equipment to manage the crop, if the crop can not "fit" into the growers rotation scheme, or if the crop has other special requirements which the fruit grower can not readily supply. Similarly, a philosophy of sustainable agriculture suggests that rotation programs should also consider less obvious but nevertheless important aspects such as the condition of the soil after crop rotation, including population levels of other soil borne disease and beneficial organisms. With this in mind, several indicators of biological activity in soil were evaluated for selected rotation crops.

RESULTS: A major objective of this research was to identify useful rotation crops which would effectively reduce dagger nematode populations in old orchard sites. This is important because dagger nematodes are efficient vectors of tomato ringspot virus.

Therefore, a second but significant objective was to determine whether or not these rotation crops would serve as reservoirs of TmRSV. Two experiments tested the ability of crops to become naturally infected with the virus. Experiment one was a greenhouse bioassay. Greenhouse pots were filled with naturally infested field soil containing viruliferous nematodes. Rotation crops were planted into these pots and maintained for one month. At the end of this period tissue samples of plant roots and tops were assayed separately for TmRSV by enzyme linked immunosorbent assay (ELISA) and a bioassay on the indicator plant Chenopodium quinoa. The second experiment was similar to the first except that the rotation crops were planted in an old orchard site known to have a high infestation of viruliferous nematodes. The results of both experiments were similar. None of the monocotyledon rotation crops including corn, wheat, oat, fescue, or sudan grass were infected with TmRSV. Of the dicotyledons, marigold showed the highest level of infection and sunflower and alfalfa were also infected but the virus was not recovered from any cruciferous plants.

In West Virginia several indicators of biological diversity were monitored in the rhizosphere of corn and fescue. Results showed a significant increase in the number of different species and the number of colony forming units of nematode destroying fungi under fescue as compared to corn. In the same study, the number of predatory nematodes also showed a significant increase under fescue as compared to corn.

Field experiments in West Virginia and Pennsylvania showed differential population development of nontarget parasitic nematodes under rotation crops. Populations of Helicotylenchus sp. increased under fescue, sudan grass, ryegrass, and sunflower; Hoplolaimus sp. increased under corn; and Pratylenchus sp. increased under sunflower, corn, wheat, ryegrass, and fescue. In field experiments, fumigation virtually sterilized the soil environment by killing pest and beneficial organisms alike. Biological activity in fumigated soil was negligible compared to untreated plots.

SIGNIFICANCE: Plants which may harbor latent infections of TmRSV should not be considered as crop rotations for orchards in the northeast even if they provide relatively good dagger nematode control. Such plants may produce seed which carry the infection and thus provide opportunities for the virus to overwinter and spread. These virus reservoirs may perpetuate TmRSV problems as residual nematode populations begin to increase.

Much of this project focused on aspects of dagger nematode control and reduction of TmRSV but these tactics attempted to adhere to the concepts of sustainable agriculture. A holistic approach such as this should evaluate the impact of nematode control on the health of the soil ecosystem and not view nematode control as an end in itself. A healthy soil environment is dynamic and control of pest nematodes should not dramatically disrupt natural systems of nutrient recycling and symbiosis in the rhizosphere. Ideally, nontarget organisms should not be adversely affected by nematode management tactics. In general, biological activity and diversity can be used as a crude indicator of soil health.

The diversity of organisms precluded detailed cataloging of soil communities, however, a few organisms were intensively sampled as indicators of biological diversity and activity. Differences were most evident in comparisons of chemical control with rotation crops. Most significant was the broad spectrum biocide activity of soil fumigation. Fumigation not only killed pest nematodes but also beneficial organisms such as predatory nematodes, saprophytic nematodes, earthworms, and nematode trapping fungi. Fruit trees initially grow well in fumigated soil but the benefits of fumigation wane with time. Possibly the lack of saprophytic organisms and nematode predators eventually becomes a liability for sustained healthy tree growth. Conventional knowledge in Pennsylvania says that the average productive life of peach orchards is now much shorter than in previous generations. If this is true, the disruption of the soil ecosystem by fumigants may help explain why. Long term studies on the recolonization of fumigated soil have not been done but such research would be useful.

The population dynamics of various nematode spp. under different cropping sequences raise additional questions on how to evaluate a healthy soil environment. For example, Helicotylenchus and Hoplolaimus spp. are frequently found in high numbers in healthy peach orchards and neither of these plant parasites have been reported to cause damage to fruit trees. Is it possible that benign parasites such as these compete with pest nematodes? If this is shown to occur then rotation crops which favor these nematodes may offer another alternative to dagger nematode control.

Objective 3. Assess the economic implications of integrating alternate crop production into existing orchard practices.

(see Economic Analysis below)

Objective 4. To disseminate research results via Extension and regional Experiment Farm Programs.

(see Dissemination of Findings below)

B. Case studies:

This project was designed to evaluate the feasibility of using selected crop rotations to reduce population levels of the dagger nematode and control TmRSV. This approach has not yet been promoted as a standard recommendation and a detailed rotation program has yet to be developed. Case studies were not part of the original proposal, however, it may be appropriate to relate the experience of one farm where the owners decided to plant a rapeseed rotation crop after seeing preliminary data from this project.

Larriland Farm (Woodbine, MD) is a large pick-your-own, family run business located about equidistant from Washington, DC and Frederick, MD. In recent years the farm developed severe decline problems on raspberries, blueberries, and strawberries. One of us (John Halbrendt) diagnosed these problems and determined that several causal agents were involved. Raspberries and blueberries were both infected with dagger nematode transmitted viruses. Raspberries were infected with TmRSV and blueberries were infected with tobacco ringspot virus (TbRSV). Strawberries were declining from black root rot caused by root-lesion nematodes and soil borne fungi. A review of the cropping history of these infested sites suggested that the nematode problems had developed over time by rotating fields with crops susceptible to dagger and/or lesion nematode, TmRSV and TbRSV. The owners allowed one infested site to be used as a research plot for this study.

The owners were aware of the preliminary nature of this research but decided to try rapeseed rotations on nine nematode infested fields totaling approximately 12 acres. The decision was based on discussions of nematode control alternatives, potential benefits of alternate crop rotations and the results of first year field trials. It should also be noted that the decision was made without the knowledge of scientists involved in this project. The nematode assays were sent to the University of Maryland and therefore, it was an unbiased test of this method. At the end of the growing season the owners sent us copies of the nematode assays for each field showing initial (preplant) and final nematode counts. Although the rapeseed treatments were not applied as replicated experiments with untreated controls the resulting nematode data were nevertheless very encouraging.

RESULTS: Four fields had populations of root-lesion, one field had dagger, and four fields had both nematodes in significant numbers. In all but two fields with root-lesion nematodes the populations declined. The two which did not decline did not change significantly. The greatest decline occurred in a field with an initial root-lesion count of 468 nematodes / 100 CC soil and a final count of 26 nematodes / 100 CC soil. In all cases dagger nematode counts were less at the end of the season than at the beginning. The greatest decline occurred in a field with an initial dagger count of 143 nematodes / 100 CC soil and a final count of 13 nematodes / 100 CC soil.

C. Economic Analysis:

To conduct an economic analysis of alternative rotation crops, the economic value of a reduction in nematode population must be determined. Such an analysis involves peach tree response data to nematode populations long after the rotation crop period. Prior research has shown no statistically significant impact of nematode populations on peach tree trunk cross-section or yield. Given these results, the emphasis of this analysis was to evaluate nematode population levels in conjunction with infestation levels of the tomato ringspot virus (TmRSV) - a lethal virus to peach trees which dagger nematodes serve as the only natural means of transmission.

In this analysis, the impact of nematode populations on peach tree production was evaluated using data collected in prior experiments conducted at The Pennsylvania State University Fruit Research Laboratory. In this experiment, nematode populations were varied by three control treatments: (1) no control; (2) an annual application of Nemacur 3 ®; and (3) preplant soil fumigation with Vorlex ® followed by yearly applications of Vydate ®. These treatments were applied at four levels of virus infestation: zero; low; medium; and high. The numbers of TmRSV infected dandelions per tree associated with these levels were 0, 1, 6, and 12 respectively. Peach trees were evaluated annually as healthy, declining, or dead.

To evaluate the combination nematode control and virus infestation, classification tables were used. First, a contingency table was used to categorize alive trees (both healthy and declining) in 1991 by nematode control treatment and TmRSV infestation level (Table 1). A Chi-square test did not reject the null hypothesis of independence between control treatment and virus infestation levels ($X_{(4)} = 2.44$). Thus, from a statistical standpoint, nematode control did not result in a greater number of alive trees than no control at a given infestation level. Given the small number of trees per treatment at each infestation level (six), statistical significance was difficult to achieve.

Table 1. Classification of healthy and declining peach trees by nematode control treatment and tomato ringspot virus infestation level, 1991 data.

Infestation Level	Treatment		
	Fumigation and Nematicide	Nematicide	No Control
	Number of Trees		
Zero	5	6	6
Low	6	6	4
Medium	6	3	2
High	4	2	2

Table 2. Classification of cumulative nematode exposure by peach tree health status and tomato ringspot virus infestation level, 19991 data.

Infestation Level	Tree Status		
	Healthy	Declining	Dead
Zero	64[a] (14)[b]	110 (3)	19 (1)
Low	51 (4)	79 (12)	116 (2)
Medium	61 (1)	62 (10)	135 (7)
High	- (0)	94 (8)	83 (10)

[a] Cumulative summation of average annual number of nematodes per peach tree, mean exposure per peach tree.
[b] Number of peach trees.

The second classification table compared infestation level and tree status with cumulative exposure to nematode populations over eight years of data (Table 2). Overall, lower tree health status was associated with increased cumulative exposure to nematode populations[1]. Again, due to small number of observations and wide variability of exposure, means of cumulative nematode population exposure were not statically significant.

[1]At high infestation, there was little difference between means because nematode population counts in declining trees continued for several years while dead trees were no longer exposed. Classification tables completed for 1988, 1989, and 1990 cumulative data show increasing means with lower tree health under high infestation.

To evaluate the economic impact of three treatments, cost data were obtained from peach orchard establishment and production budgets. Specific budget assumptions used in this analysis are shown in Table 3. With this budget data, the net present value of peach orchard returns and costs was computed for 14 years of cash flows beginning with a rotation crop of corn and orchard establishment. Yields for all alive trees (both healthy and declining) were assumed to be equal, and dead trees were assumed to be left out of production until the whole orchard block was replanted.

To compare treatments and infestation levels, potential loss figures were computed. Potential loss was computed by the difference in net present value of cash flows from each treatment and infestation level compared to the most favorable condition, i.e. where no nematode was conducted at a zero infestation level. Potential losses occur due to costs associated with: (a) the cost of fumigation and application of Nemacur 3®; and (b) lost peach production from trees which have died due to stem pitting from the virus. Thus, the treatment which has the least negative potential loss for each infestation level would be regarded as the most favorable.

The results of the potential loss computations show that nematode control was economically sound when the virus was present at low and medium infestations (Table 4). Large losses were associated with no control whenever the virus was present. At low virus infestation, the Nemacur 3® treatment saved about $660 per acre in potential losses ($338 vs. $1.004) compared to no control. At medium infestation, fumigation plus Vydate proved to be the least loss strategy with a savings of $971 compared to no control. When the virus had a high infestation level, neither treatment proved to have less losses than no control.

Table 3. Budget assumptions of the economic analysis.

Information	Assumption
Base year	1991
Inflation rate	GNP price deflator for 1991, 3.6%
Interest rate	Opportunity cost of return from apple production, 7.43% (Funt et al. 1992)
Peach prices	Sum-of-digit weighting for 1987 through 1991 prices in West Virginia the weighted average price was assumed to rise 1% annually
Cost of orchard establishment	Adjusted to 1991 from Hinman et al. (1989)
Cost of orchard production	Adjusted to 1991 from Kelsey et al. (1989)
Peach yields	Twelve years of data computed on a five year moving average (Funt 1984)
Corn production	Yields of Jefferson County, WV; WV prices; and budget data from USDA (1991)
Cost of control	Survey of WV peach growers

Table 4. Potential losses from nematode control and tomato ringspot virus infestation levels

	Treatment		
Infestation level	No control	Nematicide	Fumigation & Nematicide
	Present value (Dollars per acre)		
Zero	---[a]	-339	-1,500
Low	-1,004	-339	-1,014
Medium	-1,985	-1,882	-1,014
High	-2.000	-2.351	-2.034

[a] Zero infestation and no control was used to compute potential losses for each treatment and infestation level. The net present value of orchard costs and returns from this treatment was a minus $3,750 per acre. All other treatments and infestation levels had a lower net present value.

To protect the economic value of nematode population reductions from alternative crops, the following scenario was created: rapeseed would be planted for a two year rotation to reduce nematode populations by 50% and this rotation would be combined with annual applications of Nemacur 3® beginning in the second year of tree growth[2]. An alternative crop of rapeseed was chosen because of its effectiveness of reducing nematode populations. This scenario was evaluated with a low infestation level under the assumption that fumigation would be the least loss strategy when the virus is more prevalent. Increased costs of alternative rotation crops included delayed peach production from a longer rapeseed rotation and loss of corn production revenue.

The potential loss of an alternative rotation crop plus an annual Nemacur 3® application was $609 per acre. Addition of an alternative rotation crop added $270 per acre to the nematicide treatment, but the total loss remained below the $1,014 for fumigation plus nematicide treatment. Compared with no control and fumigation at low virus infestation, about $400 was saved by using alternative crops plus Nemacur 3®. Thus, when growers have orchards with relatively high nematode populations (over 10 per 100 cc of soil) and low virus infestation levels, the addition of an alternative crop with nematicide application would provide the least loss strategy compared to either no control or fumigation.

D. Dissemination of Findings:

Implementation: The results of this research have been integrated into the following extension program conducted by the Penn State University Regional Extension Agent - Fruit:

Tree Fruit Integrated Pest Management (IPM) Program - Information was shared with growers, consultants, and other industry related personnel through 6 county Fruit IPM meetings, 1 Multi-State Fruit School, and 4 issues of the Fruit Times newsletters. One educational news article was written for the local newspapers and the PA Fruit News. Two five minute radio programs devoted to explaining the recommendations to growers was produced for local radio stations. Two extension demonstration plots were established in commercial orchards in Adams and York counties. The information will be added to the Penn State University Tree Fruit Production guide within the next year. A slide set and video on the findings is in the process of being produced. It will be available for use by other extension agents and farm groups in surrounding States. Future plans are to integrate the findings into the Expert system as soon as they are fine tuned by the researchers.

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[2]Under this scenario, the nematicide treatment tree health status data was used. The 50% reduction in nematode population was assumed to be achieved by the alternative rotation crop in order to account for the initial population difference between no control and nematicide treatments.

E. Producer Involvement:

_____ Workshops	112 Field Days
_52__ Multi-State Fruit School	297 County IPM Meetings (6 meetings)

14. POTENTIAL CONTRIBUTIONS AND PRACTICAL APPLICATIONS:

A. Potential impact if findings of this study are widely adopted:

Results of this study show that selected crop rotations may provide economical and environmentally sound tactics for suppression of dagger nematode populations and control of TmRSV in old orchard soil. Fruit growers have expressed interest in this approach and it is anticipated that an efficacious crop rotation program will be well received provided the crop does not require specialized equipment.

- Nematode suppressive crops would reduce the need for chemical control of these pests. Soil fumigants and nematicides are considered potential environmental hazards.
- Fumigated orchards are prone to erosion problems because the chemicals prevent the growth of vegetation for weeks or months following treatment, this is particularly true of the mid-Atlantic region where the most productive orchards are on hillsides. Suppressive crops would minimize exposed soil and help control erosion.
- Fumigation is difficult or impossible in some orchards because of large rocks or the slope is too great. Suppressive crops would help control nematodes where fumigation cannot be applied.
- Nematode suppressive crops typically do not require specialized equipment, training, or certification to use thus making this approach attractive to growers.
- Good ground cover management has been shown to provide control of many noxious weeds and improve soil structure and fertility. Suppressive crops would help improve soil structure and promote nutrient recycling by maintaining a biologically active soil environment.
- Fruit growers need to be educated on nematode - host interactions in much the same way as when they utilize Integrated Pest Management (IPM) tactics for insect control.
- Rotation crops do not reduce nematode populations as quickly or as efficiently as chemicals. Fruit growers will need to plan much further ahead then they currently do when they intend to replant an orchard.

- Growers will need to pay greater attention to detail when utilizing rotation crops for nematode management. For example poor weed management can negate the beneficial effects of a good nematode suppressive crop.

B. New hypotheses or paradigms resulting from this research:

The idea that root diseases and parasitic nematodes can be controlled by crop rotation is not new. It is well known that continued planting of the same crop selects for organisms and disease that attack that crop ("monoculture effect"). Interrupting the cycle with a different and unrelated crop removes this selection pressure, reduces the pathogen population, and alters the soil environment to favor a different soil community structure. Frequent crop rotations have often been used to prevent soil borne disease problems from reaching damaging levels. However, these principles have been applied almost exclusively to field crops where crop rotation can readily be accomplished on a yearly basis. This project explored the benefits of crop rotation as a tool for renovation of old orchard land and is the first to identify effective rotation crops for the control of dagger nematode problems in tree fruit production.

Tree fruit have essentially the same effect on the soil community as monoculture. Years of perennial tree growth foster the selection and increase of specific plant parasitic nematodes that utilize the tree as a host. Mature trees generally tolerate high populations of parasitic nematodes because they are constantly producing new feeder roots and occupy a large volume of soil. The damage caused by the nematode population is usually of little consequence relative to the total volume of the tree. However, in replanted orchards young trees are vulnerable to high pathogen populations and are often stunted, devitalized, or killed. This problem is further complicated if the disease complex includes TmRSV and dagger nematodes. Nematode transmitted virus diseases perpetuate in common weeds and within the bodies of their nematode vectors.

Young trees planted on old orchard land benefit from renovation programs that purge the site of pest nematodes and virus diseases. Soil fumigation is a "quick fix" for these problems. In this regard soil fumigation has become a substitute for crop rotation on high value fruit crops where a primary objective has been to get the land back into production quickly. This practice must be carefully reconsidered. Fumigants are a burgeon threat to ground water contamination and excessive chemical use is incompatible with the philosophy of sustainable agriculture.

15. AREA NEEDING ADDITIONAL STUDY:

This project evaluated the ability of several novel rotation crops to suppress dagger nematode populations in old orchard soil. These crops were also evaluated for susceptibility to TmRSV, ease of establishment, and potential acceptance by fruit growers. Several cruciferous plants including canola, mustard, and rapeseed appeared to have the best combination of traits to be of practical value. This work set the stage for continued research to develop an effective crop rotation program for renovation of old orchard land in preparation for a new planting. Aspects of this work which require additional research include:

- Evaluation of cultivar differences: Results have already shown that different cultivars of the same crop vary in effectiveness of nematode control. A preliminary screening of twenty different cruciferous plants showed a broad range of nematicidal activity ranging from very little to highly toxic. Research is need to identify the most effective rotation crops for nematode control.
- Continue search for effective nematode suppressive crops: Only recently has agriculture begun to utilize the diversity and abundance of plant biochemical defences for control of pathogens. Other untested crops may be more highly effective at controlling nematodes but they need to be identified. Still other crops may have characteristics which would make them more desirable as rotation crops. There is a need to continue the evaluation of promising novel rotation crops as possible alternatives to soil fumigation.
- Development of crop rotation programs: Research is needed to develop crop rotation programs that will suppress nematodes and improve soil structure and fertility effectively in the shortest time frame. Data from this project indicate that two years of crop rotation may be necessary to get the same degree of dagger nematode control as soil fumigation. Two years is probably not an acceptable length of time for most fruit growers. It seems probable however, that a sequence of selected winter and summer rotation crops combined with a program to correct for nutrient imbalances and soil pH problems could prepare an orchard replant site within one year.