Comparison of Corn and Fescue Rotations on Pathogenic Nematodes, Nematode Biocontrol Agents, and Soil Structure and Fertility on an Apple Replant Site

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ABSTRACT. Integrated whole farm management systems offer the potential to reduce impacts on the environment and human health by reducing inputs of petrochemicals while increasing net income to the

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fruit industry through reduced costs. This article reports on the rotation phase of orchard establishment focusing on integration of an alternative rotation crop system (tall fescue) with a conventional orchard establishment practice (corn + nematicide). A 5.6-ha (14-acre) orchard has been established at the West Virginia University Experiment Farm, Kearneysville, WV. The site has been divided into six 0.8-ha main plots with each plot randomly assigned one of two rotation treatments. Comparisons between rotation treatments included soil organic matter and fertility, populations of plant pathogenic nematodes, nematode biological control activity, and an economic analysis. When compared with the conventional corn rotation, plots rotated with fescue exhibited increased numbers of nematode biological control organisms, higher soil organic matter, and elevated soil fertility. Economic analysis of the two rotation systems showed that the increase in soil organic matter in the fescue plots was achieved at a lower expenditure than would have been required by compost application.

INTRODUCTION

West Virginia has approximately 6,120 hectares of apples currently in production (West Virginia Tree Fruit Survey, 1988). In the combined Mid-Atlantic region of Pennsylvania, Virginia, West Virginia, and Maryland, apples grown on 28,000 hectares command a market worth of about $124.3 million annually. Apples for the processing market account for 50-60% of the total production. Because most processing apples can be marketed with higher levels of insect and disease injury than would be acceptable for fresh market fruit, reductions in pesticide inputs can be a realistic management recommendation that may have substantial positive impacts on the environment. In addition, risks to human health are of greater concern on processed and concentrated food than on their parent raw commodities, and the Delaney Clause of section 409 of the Food, Drug, and Cosmetic Act applies a zero-risk standard to residue tolerances in processed food (National Research Council, 1987). Alternative agricultural systems must include an enhanced profitability component to producers (Ruttan, 1988). With orchards contiguous to urban centers, enhanced profitability will be required if the industry is to compete for the land resource and continue to provide the large quantities of fruit required by the processing industry.

Because of the perennial nature of fruit trees, soil management practices preceding and during establishment will have persistent effects on the soil characteristics for the life of the orchard. Soil management practices that influence soil physical and chemical factors such as soil pH, organic matter content, cation exchange capacity, and structure, can markedly affect the potential for pesticide and fertilizer movement to ground water. Currently, the predominant system of orchard floor management for deciduous tree fruit crops throughout the world involves grassed alleys between rows with a herbicide-treated strip of bare soil under the trees. The herbicide treated strip contains most of the tree's feeder roots and is the site of herbicide and fertilizer application. A portion of all pesticides applied to the tree canopy are washed to the soil surface by summer rains.

An organic mulch in the tree row provides a superior orchard soil management system; however, labor requirements, cost-effectiveness, and the potential for rodent damage to trees have limited the adoption of this practice. Welker and Glenn (Glenn and Welker, 1989a; Welker and Glenn, 1988) developed a soil management system, termed "killed sod," that attempts to combine these two systems by combining the beneficial soil effects of an organic mulch and a reduced risk of rodent damage. By planting trees into a killed grass sod, residues remain on the soil surface. The decaying sod root systems increase soil organic matter and provide intact root channels that enhance water infiltration (Bicki and Guo, 1989). Peach tree growth was increased 120% during the first three growing seasons and initial fruit yield by 160% when a killed sod system was compared with a herbicide-strip system (Welker and Glenn, 1988). These increases in productivity have been made in association with stable or increased soil organic matter levels and reduced rainfall runoff.

Glenn and Welker (1989b) have shown that maintaining a killed sod residue is as effective as a living sod in reducing rainfall runoff. The dead sod mulch prevents the raindrop impact on the soil surface that causes particle detachment, surface sealing, runoff, and erosion. The killed sod soil management system also has increased microbial activity over that of the conventional herbicide strip system (Welker and Glenn, 1988). Microbial decomposition is the most important means by which pesticides are degraded in the soil and increases in soil organic matter will enhance microbial activity (Kearney and Helling, 1969). Increased soil moisture interacts with microbial activity to influence nitrogen cycling rates (Sexstone et al., 1988) and may increase or decrease leaching of soil nitrate.

Microbial activity also is critical to the development of pathogen-suppressive soils. Suppressive soils are defined as soils in which a pathogen is present but does not increase or cause disease in the presence of a suitable host crop. Suppressiveness is usually associated with the presence of biological control agents or other physical factors that prevent the build-up of the pathogen. Host plants can contribute to the establishment of suppressiveness by secreting root exudates toxic to parasitic nematodes (e.g., marigolds) or by encouraging the proliferation of antagonistic microorganisms. Tall fescue infected with the endophytic fungus *Acremonium coenophialum* has been reported to be suppressive to several plant parasitic nematodes as well as a number of other plant pests (Dernoeden et al., 1990; Kimmons et al., 1990); however, the mechanism of suppressiveness has not been established.

Whereas substantial research effort has been dedicated to soil management systems in annual crops (e.g., USDA's MSEA sites), no comparable effort has been allocated to perennial crops, even though perennial crops provide unique soil management problems and opportunities. Because of the high agrichemical inputs associated with apple production, high priority should be given to management options that improve sustainability in orchard systems. This may be especially relevant to orchards in close proximity to urban and suburban areas (Hogmire et al., 1990).

Integrated orchard management systems offer the potential to reduce impacts on the environment and human health while increasing net income to growers. This research is being conducted to compare an advanced integrated orchard management program and conventional management practices on a whole-orchard scale. Two rotation crop systems are being evaluated for their impact on plant-parasitic nematode populations, nematode biocontrol agents, and soil structure and fertility. The goal is to identify crop rotation systems that will create a nematode-suppressive soil prior to planting the apple orchard. Ideally, this rotation system will also fit in well with alternative orchard production operations. This article describes the research site and the results of investigations on plant parasitic nematodes, nematode biological control organisms, soil structure and fertility, and an economic analysis of the two orchard rotation systems.

MATERIALS AND METHODS

Site History and Preparation

The study site had a history of apple production until 1989 when a large planting of 40-year-old "Rome" apple trees was removed. The entire block was planted to corn and soybeans during the summer of 1989, followed by application of 4.5 tonne/ha of lime in fall 1989. In spring 1990, the site was divided into six 0.8-ha main plots with each plot randomly assigned one of two treatments, e.g., conventional or alternative production practices. A Kentucky-31 (K-31) tall fescue (*Festuca arundinacea*) sod, seeded at 28.2 kg of seed/ha, was established in the alternative plots in May 1990. The sod was maintained for two growing seasons to increase soil organic matter and to favor development of nematode-suppressive soils. Conventional plots were disked and planted to corn in May 1990 and 1991, and received fertilizer, nematicide (Mocap EC, 9.5 L/ha, Rhône-Poulenc Ag Co.) and herbicide treatments. In April 1992, before planting the trees, the sod was killed in the tree rows of alternative plots with the herbicide glyphosate (Monsanto Corp, St. Louis, MO) at 2.3 kg a.i./ha. Alleys in the conventional plots were planted with K-31 and a herbicide-treated strip 2.4 m wide was maintained under the trees.

Each main plot was divided into four subplots that were planted in April 1992, with one of four apple cultivars, "York," "Golden Delicious," "Liberty" (resistant to apple scab), or "Fuji" on M. 26 rootstock. Trees were established at 2.5 × 5.5 meters with every tenth tree a pollinizing cultivar. Pollinizing cultivars included "Jonafree" (early, mid-season bloom), "Gala" (early, mid-season bloom), and "Braeburn" (mid-season, late bloom) on M.9 EMLA rootstock. Soil suction lysimeters have been installed in each subplot to collect soil water samples at three depths (0.3, 0.9, and 1.8 m) to determine the concentration of soil solution nitrogen. Soil type at the experimental site is Hagerstown silt loam (mixed mesic, Typic Hapludalf).

The experiment was arranged as a randomized block, split plot design with management systems as whole plot treatments and apple cultivars as subplot treatments. For nematode populations, nematode biological control organisms, soil organic matter, and fertility, data were analyzed with analysis of variance and means separated with Duncan's Multiple Range Test (SAS Institute, Cary, NC).

Soil Microbiology

Soil samples were collected from each subplot in May of each year and were assayed for plant-parasitic and beneficial predatory nematodes. Fungal parasites of nematodes were assayed by sprinkling 1 gram soil samples into Petri dishes containing water agar. Dishes were inoculated with nematodes and examined periodically for the presence of nematode trapping fungi. Biological control activity was determined, also. Replicate sterilized and nonsterilized soil samples were inoculated with approximately 200 root lesion nematodes (*Pratylenchus penetrans*) and incubated at 25°C for two weeks. Differences in percent survival between nonsterilized and sterilized soil provided an overall measure of biological control activity in that soil.

Soil Organic Matter and Fertility

Additional soil samples were collected in spring and fall 1991, and spring 1992, for determination of soil organic matter content and nutrient analysis. Soil organic matter was determined with either the potassium dichromate method or carbon loss on ignition. Soil nutritional analyses were conducted at the West Virginia University Soil Testing Laboratory with atomic absorption spectrophotometry.

RESULTS

Soil Microbiology

Population densities of root lesion (*Pratylenchus neglectus*) and dagger nematodes (*Xiphinema rivesi*) increased with time on corn even though a nematicide had been used (Figure 1). Dagger nematode populations were similar on fescue and corn, even though no nematicide was used on fescue. Root lesion nematode populations declined on fescue the first year, but increased significantly in the second year. It should be noted that *P. neglectus* is not known to be a pathogen of apple roots (Abawi and Mai, 1990), however, given the lack of information on this species, the possibility exists that *P. neglectus* may be an unrecognized pathogen of apple. A better understanding of *P. neglectus* is essential since recommendations to apply soil fumigants may be based on the presence of the genus *Pratylenchus* only, rather than on the species, which is more time-consuming and difficult to determine. Predatory nematode populations (mostly *Clarkus papillatus*) were lower in corn (Figure 1) than in the K-31 fescue plots.

The numbers of nematode destroying fungi were similar in fescue and corn, however, and perhaps more importantly, the diversity (number of different species present) was increased significantly in the fescue plots (Figure 2). Since different predators are active under different environmental conditions, the increased diversity of predators on fescue suggests that biological control of plant-parasitic nematodes is more likely. However, the assay of overall nematode biocontrol activity indicated that biologically-induced mortality was not significantly higher ($P < 0.05$) in soil from fescue plots (Table 1).

Soil Organic Matter and Fertility

Soil organic matter from fescue plots in spring 1991 was significantly greater ($P \leq 0.05$) than that in corn plots, averaging 5.3% compared with 4.3%, respectively. However, by fall of 1991, organic matter in corn plots had increased to levels similar to that in fescue plots, probably because of corn residue. In spring 1992, soil organic matter again was significantly greater ($P \leq 0.05$) in the fescue treatments when compared with the corn, averaging 3.8% and 3.1%, respectively. Thus, soil organic matter available for orchard establishment was significantly higher for the fescue plots. In soil samples collected in spring 1991, levels of calcium, magnesium ($P \leq 0.05$) and potassium ($P \leq 0.10$) were significantly higher in soil from fescue plots compared with corn plots; however, soil pH and phosphorus levels did not differ significantly (Table 2). Cation exchange capacity (CEC) was higher in fescue plots (30.5 vs. 22.4,

FIGURE 1. Population densities of dagger (*Xiphinema rivesi*) (top), root lesion (*Pratylenchus neglectus*) (middle), and predatory nematodes (mostly *Clarkus papillatus*) (bottom) (all as number of nematodes per 100 cc soil) in soil from two orchard rotation crops, corn (shaded bar) and Kentucky-31 tall fescue (K-31, solid bar), from May 1990, 1991, and 1992. Each bar represents the mean of 12 measurements. Asterisks denote significant differences ($P \leq 0.05$) between means at each sample date.

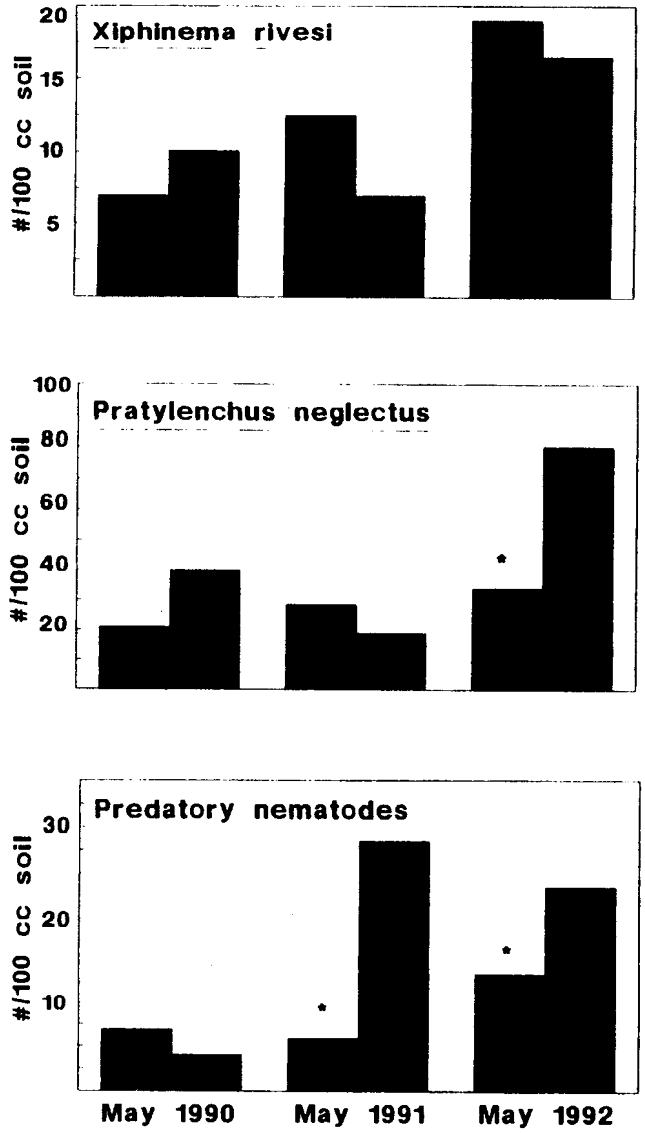
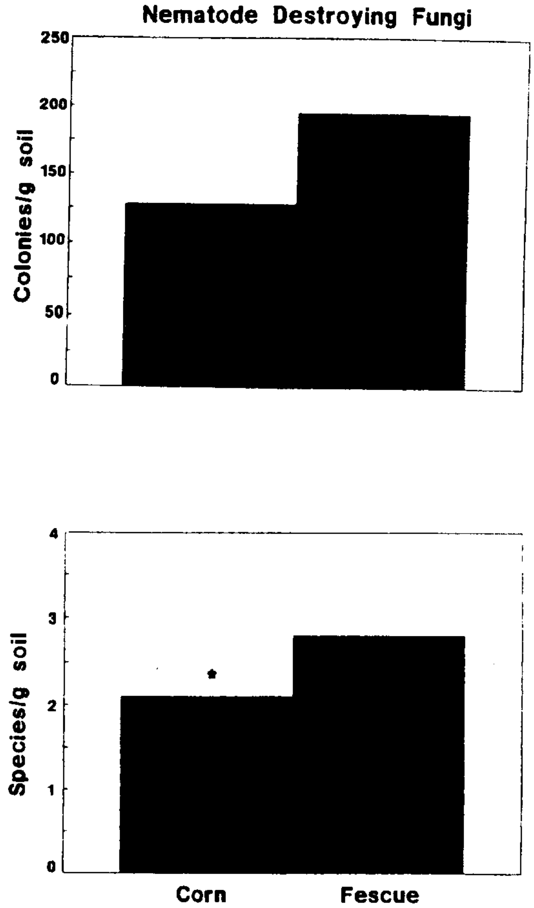


FIGURE 2. Nematode-destroying fungi as number of colonies/gram of soil (top) and number of species/gram of soil (bottom) from two orchard rotation treatments, corn (shaded bar) and Kentucky-31 (K-31, solid bar) tall fescue. Asterisks denote significant differences ($P \leq 0.05$) between means at each sample date.



$P \leq 0.05$), whereas K percent base saturation was higher in the corn system. In general, the fescue treatment had a higher base saturation and CEC, which probably was because of the increased soil organic matter compared with the corn system in spring 1991. In fall 1991, soil pH (7.1 vs. 6.9, $P \leq 0.10$) and magnesium ($P \leq 0.05$) were higher in the fescue plots, whereas hydrogen milliequi-

TABLE 1. Nematode biocontrol activity in soil from corn and Kentucky-31 tall fescue.

	Nematode survival (%)		
Rotation crop	Sterilized soil	Nonsterilized soil	Biocontrol activity[z]
Corn	18.2 (14)	10.4 (19)	7.8 a
Fescue	16.4 (8)	5.8 (6)	10.6 a

[z] Biocontrol activity is measured as difference in survival of *Pratylenchus penetrans* incubated at 25°C for 14 days in sterilized and nonsterilized soil. Data are mean (standard deviation in parentheses) of 12 samples.

valents were higher in corn plots. Levels of calcium, phosphorus, and potassium were not influenced by the rotation system at this time. Although CEC was not different between the two systems in fall 1991, percent base saturation for Mg and K was higher in fescue plots, and percent base saturation for hydrogen ion was lower in fescue plots compared with corn plots (Table 2). In spring 1992, at the time of planting, the fescue treatment exhibited significantly higher levels of Mg, Ca and K. Again, the fescue plots exhibited continued higher base saturation and CEC when compared with the corn system (Table 2).

Economic Analysis

The cost difference between corn and fescue management systems was $107 per hectare in 1990 dollars (Table 3). This cost difference covers two years of rotation crop management (1990 and 1991). The fescue system has higher costs primarily because of the planting and mowing expenses associated with the sod. In addition, return from corn production under the conventional system is foregone with the alternative system, although personal communications with orchardists have revealed that net returns from corn rotations are minimal. The foregone return is reflected in the contract between the University Experiment Farm and a local grower where corn was grown under orchard management specifications for herbicide and fertilizer applications (Table 3). It should be noted

TABLE 2. Nutrient analyses, cation exchange capacity (CEC), base saturation (%), and pH from alternative (fescue) and conventional (corn) rotations in Spring and Fall 1991, and Spring 1992.

System	Mg^{w}	Ca^{w}	K^{w}	H^{w}	P^{x}	CEC	$Mg(\%)^{y}$	$Ca(\%)^{y}$	$K(\%)^{y}$	$H(\%)^{y}$	pH
Spring 1991											
Ecosystem	2.3 a^{z}	27.7 a	0.7 a	0 a	74.0 a	30.5 a	7.7 a	90.0 a	2.2 b	0 a	7.4 a
Conventional	1.5 b	20.3 b	0.6 b	0 a	67.3 a	22.4 b	7.2 a	90.2 a	2.8 a	0 a	7.3 a
Fall 1991											
Ecosystem	1.7 a	18.1 a	0.6 a	0 b	60.4 a	20.2 a	9.1 a	88.2 a	3.0 a	0 b	7.1 a
Conventional	1.3 b	16.2 a	0.5 a	0.7 a	58.6 a	18.6 a	7.1 b	85.8 a	2.4 b	4.7 a	6.9 b
Spring 1992											
Ecosystem	1.7 a	17.3 a	0.5 a	0 a	60.4 a	19.6 a	8.8 a	90.1 a	2.8 a	0 a	7.3 a
Conventional	1.3 b	15.4 b	0.4 b	0 a	52.7 a	17.1 b	7.5 b	88.2 b	2.5 b	0 a	7.3 a

w meq/100 grams of soil.
x ppm.
y percent base saturation.
z Different letters between treatments in columns denote significant differences according to Duncan's Multiple Range Test ($P \leq 0.05$). Spring 1991 K (meq), Fall 1991 pH and K (%), and Spring 1992 Ca (meq) and K (%) are significant at $P \leq 0.10$.

TABLE 3. Cost differences (dollars per hectare) between conventional and alternative orchard management systems[y].

Year		Conventional corn rotation		Alternative fescue rotation
1990	$80	Plow and disc	$80	Plow and disc
	$107	Lime	$107	Lime
	$49	Contract[z]	$51	Plant fescue seed
	$139	Nematicide		
	$127	Fertilize potash and borax	$166	Fertilize sulpomag and borax
			$118	Mowing
1991	$25	Contract	$121	Mowing
Total discounted cost	$525		$632	
Total discounted cost difference between alternative and conventional rotations			$107	

[y] Labor cost assumed to be $6.15/hr, including benefits; seed cost = $0.55/kg; potash = $0.33/kg; sulpomag = $0.126/kg; labor and machinery costs for mowing and fertilization are from Kelsey and Schwaller (1989); labor and machinery costs for planting grass are from Taylor et al. (1990). All costs and prices were adjusted to 1990 or 1991 with the Agricultural Producer Price Index. A discount rate of 11.7% was used based on average loan rate for operating loans to farmers in 1990 (Agricultural Finance Databook, Board of Governors of the Federal Reserve System, Washington, D.C.).

[z] Contracts to grow corn were agreements between the University Experiment Farm and a local grower in 1990 and 1991. These contracts specified chemical application and corn production practices by the grower in exchage for the grower receiving a payment from the University Experiment Farm ($49 and $25 per hectare in 1990 and 1991, respectively) and being able to keep all revenue from corn grown on this land. Contract payments were viewed as returns to land from corn production in this analysis. These payments are costs of corn production due to the expenses incurred from orchard management specifications for chemical application.

that few fruit producers have the equipment needed to plant, maintain and harvest corn.

Whereas the costs of the alternative management system were $107 per hectare higher than the conventional system, gains from alternative management include increases in soil calcium and magnesium, increased groundcover protection to reduce soil erosion, increased biological control activity in the soil, and a 0.7% increase in soil organic matter. Since it is too soon in these experiments to determine the economic benefits from improved soil properties at this location, the putative benefits of a 0.7% increase in soil organic matter can be assessed in two ways. First, the costs of increasing soil organic matter by other methods can be determined. Second, tree growth benefits occurring in increased organic matter can be assessed.

For the first method, an alternative means of organic matter supplements for orchards is application of compost. By applying 182 tons of compost per hectare over two years, organic matter in agricultural land soils was increased by 1% (U.S. EPA, 1975). Even when orchard growers are given compost free of charge, the minimum cost to apply 182 tons of compost is about $500 per hectare (Collins, 1991). In the present study, approximately 127 tons of compost at an application cost of $350 per hectare would be required to increase soil organic matter by 0.7%. Thus, the $107 cost difference to achieve a 0.7% organic matter increase is much less than compost application.

Tree growth benefits are more difficult to project. For apple tree growth, significant differences in trunk diameter and tree height were noted for apple tree plantings in original soil (1.03% organic matter) versus non-orchard soil (2.4% organic matter) (Peryea and Covey, 1989). Welker and Glenn (1988) also demonstrated a linear response between trunk cross-sectional area and soil organic matter. Thus, in soils of low organic matter, early tree growth is stimulated by increased organic matter. Since the conventional system in this research has a moderate level of soil organic matter (3.1%), the benefits of early tree growth in this research probably will be less for a 0.7% increase than previous research results. Nevertheless, faster tree growth translates into earlier apple production. When orchard establishment costs range from $1,925 to $14,500 per hectare (Funt et al., 1992), earlier anticipated returns on this investment may warrant an extra cost of $107 per hectare with the alternative system.

DISCUSSION

Current recommended practices suggest a two-year rotation of corn or other agronomic crops prior to replanting apple orchards. This allows uniform soil fertility to be re-established, soil structure to be improved, and weeds and other pests to be controlled. Unfortunately, corn, even with a nematicide treatment, is an excellent host for both dagger and root lesion nematodes, the dominant nematode pests in apple orchards of the Northeastern U.S. Other on-going studies in West Virginia are finding suppression of nematode population densities with alternative rotation crops. One study has also shown suppression of dagger and root lesion nematodes in a peach orchard with a killed sod soil management system (J.B. Kotcon, unpublished). Thus rotation with an appropriate grass crop appears to suppress plant parasitic nematodes. Rotation with fescue also allows growers to immediately establish a killed sod soil management system in orchards, thereby obtaining the benefits of reduced soil erosion, improved rainfall infiltration and enhanced water use efficiency.

The mechanism of nematode suppression has not yet been established. Researchers in Kentucky and Maryland have found that fescue-infested with the endophytic fungus *Acremonium coenophialum* is associated with reduced nematode populations (Demoeden et al., 1990; Kimmons et al., 1990). Whether this is because of poor reproduction or a stimulation of nematode biological control agents in the soil has not been clearly established. Data reported herein indicate that fescue increases soil organic matter content and fertility, as well as populations of some nematode predators and parasites. Several years of data will be needed to determine if these preliminary trends are sustained, but if so, rotation with fescue and establishment of a killed sod system would provide a low cost alternative to annual nematicide applications.

In contrast to the above, Merwin et al. in New York observed decreases in soil organic matter in their study of orchard ground cover management and the development of crown and root rots of apple, caused by *Phytophthora* spp. (Merwin et al., 1992). Their study included killed sod-grass treatments composed of red fescue and perennial ryegrass compared to straw mulch and a conventional herbicide strip. Of the soil nutrients examined in their study, only K increased significantly in soils under a straw mulch ground cover. This treatment also was associated with prolonged soil saturation and higher disease incidence. Such differences among results of ground cover management studies may be related to site specific physical/chemical characteristics of soils, as well as the inherent availability of disease propagules, the presence of antagonistic microflora, the physical and chemical effects of the particular rotation crop, and particular environmental conditions.

Future direction. Budgets of fertilizer and pesticide inputs under the two systems will be maintained through the initial years of orchard establishment. Data on soil and leaf nitrogen concentrations will be used to reduce total nitrogen fertilizer inputs. Results from other studies suggest that the killed sod soil management system leads to more efficient use of nitrogen fertilizer (Glenn and Welker, 1989a). Analysis of soil water from beneath these plots will help determine how much excess nitrogen is leaching from the plots to ground water. Additional studies will assess vole populations (Byers, 1984) under these treatments, monitor growth responses of apple cultivars to these soil management systems, and continue monitoring populations of nematodes and nematode biological control agents.

Leaf nutritional analyses will be conducted to determine the status of macro- and micronutrients as influenced by the two treatments. If leaf N levels fall below a critical value (1.7 to 2.4%, depending on cultivar and time of season; Baugher and Singha, 1984) in any single plot, then additional nitrate fertilizer will be added to maintain plant productivity. Nitrogen fertilizer treatments will be adjusted on an individual plot basis to maintain optimum tree growth while avoiding over-fertilization. Thus, the amount of fertilizer applied becomes a parameter for evaluating the management systems. Tree growth will be determined by measuring trunk cross-sectional area at the end of each growing season. Tree efficiency will also be determined.

Suction lysimeter samples will be collected on five dates following rainfall events during the growing and dormant seasons. Soil cores will be collected for laboratory assays of nitrogen mineralization. Concentrations of soil insecticide/nematicide and herbicide in the soil solution will be monitored on a less intensive schedule. Field observations indicate that significant N immobilization occurs in the killed sod system during the first year. A budget of nitrogen inputs and losses will establish the fertilizer use efficiency of the two systems.

Arthropod pests and predators and fungal and bacterial diseases will be monitored and managed uniformly over the entire experimental site during 1992-1994 so as not to confound the primary objectives of the study during the establishment phase. Control will be achieved through the application of minimal insecticide, fungicide, or antibiotic sprays timed in accordance with outbreak periods by the organisms of concern. A six-strand high tensile fence has been constructed to control damage by white-tailed deer.

Farm level costs of orchard establishment will be collected under alternative and conventional systems. Monitored costs will include labor, machinery, fuel, pesticides, fertilizers, leaf analysis, crop rotation and tree establishment. Cost-effectiveness of orchard establishment will be compared between systems, initially on a per acre basis and later on a per bushel basis.

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