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Growth of apple trees, nitrate mobility and pest populations following a corn versus fescue crop rotation

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Abstract. *Conventional and alternative systems for the establishment of apple trees were compared on a replicated, whole-orchard scale. The alternative system consisted of a K-31 fescue sod rotation followed by planting of trees directly into sod that had been killed with herbicide. The conventional system consisted of a standard corn rotation, accompanied by application of fertilizer and nematicide. Orchard floor management in the three years following tree planting was based on the use of both pre- and post-emergence herbicides in the conventional system, and contact herbicide only in the alternative system. The study documented tree growth, pest incidence and nitrate-N mobility in the two systems. The alternative system compared favorably with the conventional system for the growth and establishment of four apple cultivars. Many advantages accompanied the killed sod system, including less subsurface leaching of nitrate-N and lower costs (largely due to decreased herbicide use). The alternative system provided an economical alternative to the problem of soil organic matter depletion in conventional orchard soils, without the increased use of commercial fertilizers. Grower concerns regarding increased potential for vole damage and poor initial tree growth were unsubstantiated.*

Key words: apples, orchard, rotation, economics, nitrate mobility, pest populations, nematodes, tree growth and development, voles

Introduction

In the Mid-Atlantic apple-growing region comprising Virginia, West Virginia, Maryland, and Pennsylvania, there are approximately 23,000 hectares of apples (*Malus domestica* Borkh.) currently planted, with fruit for the processing market accounting for approximately 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 would 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 (National Research Council, 1987).

Integrated orchard management systems can offer the potential to reduce impacts on the environment and human health with a potential for maintaining or 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. In a previously published paper, we evaluated two rotation crop systems, in replicated plots on a 5.6-ha site, for their impact on plant-parasitic nematode populations, nematode biocontrol agents, and soil structure and fertility (Biggs et al., 1994). The goal was to compare the conventional crop rotation system (corn + nematicide) with an alternative system (Kentucky-31 tall fescue) that would create a parasitic nematode-suppressive soil prior to planting the apple orchard. The alternative system exhibited increased numbers of nematode biocontrol organisms, higher soil organic matter, and elevated soil fertility (Biggs et al., 1994).

The objective of this paper is to describe the growth and establishment of four apple cultivars following the two crop rotation systems. Soil organic matter and fertility, nitrate mobility, tree nutritional status, and pest populations are documented and a cost analysis of the two orchard systems is conducted.

Methods

Site history and preparation. The study site and rotation treatments have been described previously (Biggs et al., 1994). Briefly, in spring, 1990, the 5.6-ha 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 (Glenn and Welker, 1989a,1989b). Conventional plots were disked and planted to corn in May, 1990 and 1991, and received fertilizer, nematicide, 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. Cultivars were chosen to represent current uses (‘York’ and ‘Golden Delicious’), to evaluate the potential for use of scab-resistant cultivars (‘Liberty’), and to evaluate the potential uses of a new cultivar (‘Fuji’). Trees were trained using the West Virginia slender spindle system (Baugher et al. 1992) and were established at 2.5 x 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. Trees were approximately 16 mm diameter at the time of planting. All trees were headed to 86 cm height with an average of four scaffold branches. Soil suction lysimeters (Model 1900 Soil Water Samplers, Soilmoisture Equipment Co., Santa Barbara, CA) were 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 (fine, mixed, mesic Typic Hapludalfs).

Soil organic matter and fertility, fertilizer use efficiency, and nitrate mobility. Soil samples were collected from each subplot in April of each year (1992 - 1994) for determination of soil organic matter content, pH, and nutrient analysis. Soil organic matter was determined by carbon loss on ignition. Soil nutritional analyses were conducted at the West Virginia University Soil Testing Laboratory with atomic absorption spectrophotometry. Decisions on fertilizer applications were based on soil, water and tissue sampling. In 1992, calcium nitrate was applied two weeks after planting at half the currently recommended rate (56 g (1/8 lb) per tree per year of tree age). Leaf nitrogen content was determined monthly from April to July of 1992 - 1994 and based on the results, calcium nitrate was applied (1/8 lb/tree) to all plots as needed. No nitrogen was applied to the trees in 1993 or 1994. Leaf samples for determination of the status of macro- and micronutrients were collected in July of each year. Leaf samples were washed with distilled water and then sent to the Pennsylvania State University Agricultural Analytical Services Laboratory (University Park, PA) for ICP analysis. Suction lysimeter samples were collected periodically (approximately monthly) during May through October of each year following rainfall events to assess nitrogen immobilization in the two systems.

Tree growth and pest incidence. During the first growing season, a 2.4-m wide weed-free strip was maintained in the tree rows in all plots through judicious use of contact herbicides. In 1993 and 1994, residual (Simazine 80% at 2.8 kg/ha, Surflan 2.8 kg/ha, applied in mid-May) and contact (Gramoxone 3.0 l/ha, applied in mid-July) herbicides were applied to the conventional system, and contact herbicides (Gramoxone 3.0 l/ha, applied in mid-May and mid-July) only were applied to the alternative system. Trees in both systems received uniform arthropod pest and disease control programs (Hogmire et al., 1992) during the study period. Nematode population densities were assayed from soil samples (Hogmire, 1995) collected from each plot in May, 1992; December, 1992; May, 1993; October, 1993; and May, 1994; and the results were compared to those from samples collected during the rotation phase of the study (Biggs et al., 1994). Nematicides were not applied to any plots during the orchard establishment phase of the study (1992 - 1994). Ten trees per subplot were selected randomly for routine monitoring of insect and mite populations, foliar disease incidence, weed populations, and tree growth. The same ten trees were used during the 3-year period. Tree growth was determined by measuring: 1) trunk cross-sectional area (TCA) at 20 cm above soil level, 2) tree height, 3) tree width, and 4) number of lateral branches. Voles were monitored in December of each year at bait stations established in the center three rows in each subplot.

Cost analysis. Farm level costs of orchard establishment were collected for alternative and conventional systems. Costs included trees, labor, machinery, fuel, pesticides, fertilizers, and training aides.

Data analysis. The experiment is arranged as a randomized block, split plot design with management systems as whole plot treatments and apple cultivars as subplot treatments. For nutrients, organic matter, nematodes, nitrates in soil pore water, insects, mites, diseases, weeds, tree growth and voles, data were analyzed with analysis of variance (SAS, Cary, NC). Means for systems were separated with Fisher's LSD and means for cultivars were separated with Duncan's multiple range test.

Results

Soil organic matter and fertility, fertilizer use efficiency, and nitrate mobility. Organic matter (%) and soil magnesium were higher in the alternative system in 1992 and 1993, but not in 1994 (Table 1). Soil potassium was higher in the alternative system in 1992 only (Table 1). Soil pH, phosphorus, and calcium were similar in both systems in all years of the study.

Leaf nitrogen (%) was higher in the alternative system in July, 1992; was similar in July, 1993; and higher in the conventional system in July, 1994 (Table 2). In 1993, leaf zinc was higher and leaf manganese was lower in the alternative system (Table 2). Leaf phosphorus, potassium, calcium, magnesium, boron, copper and iron levels did not differ between management systems (Table 2). Among cultivars, there were few differences that were consistent over the 3-year period. Fuji had higher leaf N than York in all three years, and York had consistently higher levels of leaf Fe than the other cultivars (data not shown).

Nitrate concentrations in soil pore water fluctuated during the season in each year, but were usually higher in the topsoil than in the subsoil and were higher in the conventional system than in the alternative system. Of the 14 sets of lysimeter samples that were collected over the 3-year period, depth was statistically significant in 1 of 3 1992 samples, 3 of 5 1993 samples, and 6 of 6 1994 samples. The depth x system interaction, which would test the hypothesis that the alternative system held nitrate in the higher soil layers whereas the conventional system would lose nitrate to the deeper soil layers, was significant on 3 occasions, 28 May 1992; 7 Sept. 1993; and 8 August 1994. On the first sampling date in 1992, which was one week following nitrate fertilizer application, the alternative system retained a higher level of nitrates in soil pore water in the top 0.3 m of soil and leached fewer nitrates to the 0.9 m and 1.8 m depths than did the conventional system (Fig. 1).

In 1993, nitrate concentrations tended to be lower in samples from the alternative system compared with the conventional treatment plots at all sample depths (Fig. 2), and were significantly lower at 0.9 m at 23 April, at 1.8 m at 18 August, and at 0.9 and 1.8 m at 7 September. In all plots, mean nitrate concentrations at the 0.9 and 1.8 m depths ranged from 54 to 218 ppm. At the 0.3 m depth, April samples obtained prior to fertilization averaged 9 ppm and increased steadily through the season, reaching an average of 295 ppm by 28 September. April through August nitrate concentrations obtained under Fuji and Liberty cultivars were consistently higher than those under Golden Delicious and York, a finding consistent with trends in leaf nitrogen levels.

In 1994, nitrate concentrations were higher initially at 1.8 m relative to 0.9 and 0.3 m on 20 April and 26 May (Fig. 3). For the remainder of the season, however, nitrate levels were generally higher at 0.3 m. System differences occurred on 20 April, 8 August, 18 August, and 26 September at 1.8 m, and at the latter three dates at 0.3 m (Fig. 3). Where system differences occurred, in all instances the conventional system exhibited increased nitrate leaching relative to the alternative system.

Lysimeter samples from 28 September 1993 also were analyzed (West Virginia Dept. Agriculture Pesticide Analysis Laboratory, Charleston, WV) for the presence of twenty-one pesticides that had been used on the plots since 1988, and none were detected.

Tree growth. Tree growth and development was excellent in all plots during this study because rainfall was adequate to above normal in all three seasons. No differences in growth (change in TCA) were found between trees in conventional and alternative systems (Table 3).

There were no significant differences between systems for total fruit weight (kg/ha) in 1994 and 1995 (Table 4), or for fruit weight (kg/tree) or mean fruit weight (kg/fruit) (data not shown). Total harvest in 1994 and 1995 showed that Golden Delicious provided higher early yields in years 3 and 4 relative to York, with no differences in mean fruit weight among the cultivars.

Pest Incidence. Incidence of arthropod pests did not differ between management systems in 1992 (Table 5). In 1993, spirea aphid (*Aphis spiraecola* Patch) was more abundant in the conventional system (Table 5). In 1994, levels of rose leafhopper (*Edwardsiana rosae* (L.)) and spotted tentiform leafminer (*Phyllonorycter blancardella* (F.)) were higher in the alternative system (Table 5). No differences between systems were observed for European red mite (*Panonychus ulmi* (Koch)) or Japanese beetle (*Popillia japonica* Newman). Incidence of Japanese beetle injury, white apple leafhopper (*Typhlocyba pomaria* McAtee), and rose leafhopper did not differ among the four cultivars in the subplots in 1993. However, in 1994, Liberty exhibited higher levels of Japanese beetle injury and higher numbers of rose leafhopper than the other cultivars. European red mite was most abundant on York, followed by Fuji, and least abundant on Golden Delicious and Liberty in 1992 and 1993.

Foliar incidences of scab (*Venturia inaequalis* (Cooke) G. Wint.), powdery mildew (*Podosphaera leucotricha* (Ellis and Everh.) E. S. Salmon)), cedar-apple rust (*Gymnosporangium juniperi-virginianae* Schwein.)and frogeye leaf spot (*Botryosphaeria obtusa* (Schwein.) Shoemaker)did not differ among management systems at any time during the study (Table 6). Apple scab foliar incidence was highest on Fuji and lowest on Liberty in 1992 and 1993, although York did not differ from Liberty in 1993. There were no differences in scab among the cultivars in 1994. Powdery mildew in all three years was lowest on Fuji (although not significantly different from York in 1992 or Liberty and York in 1994); cedar-apple rust was highest on Golden Delicious in 1992 and on York in 1993.

Number of active vole sites and number of meadow (*Microtus pennsylvanicus* Ord.) and pine *(Microtus Pitymyspinetorum* LeConte) voles caught were quite low in 1992, but the activity which was detected occurred in the alternative system (Table 7). In 1993 and 1994, there were no active vole sites in either treatment.

At the start of the 1993 season, higher populations of birdseye speedwell (*Veronica peregrina* L.) existed in the alternative system, whereas higher populations of common chickweed (*Stellaria media* (L.) Vill.) existed in the conventional system (Table 8). At the end of the 1993 season, higher populations of prostrate knotweed (*Polygonum aviculare* L.)existed in the conventional system. By August, 1994, the alternative system had higher levels of four weed species (prostrate knotweed, false buckwheat (*Polygonum convolvulus* L.), dandelion (*Taraxacum officinale* Wigg.), and smartweed (*Polygonum pensylanicum* L.)). Of these, only false buckwheat is known to compete significantly with apple trees.

Population densities of plant parasitic nematodes, which had increased on the corn and fescue rotation crops, declined rapidly after apple trees were planted in spring, 1992 (Table 9). Differences in population densities of dagger nematodes, *Xiphinema spp.*, between management systems were not significant at any sampling date. Population densities of root lesion nematodes, primarily *Pratylenchus neglectus*, were greater after the fescue rotation than after the conventional corn rotation when sampled in May, 1992. Subsequent samples after the sod in the tree rows was killed showed similar levels *P. neglectus (Table 9).* This nematode is a known pathogen of grasses, but its pathogenicity on apple is unknown. Population densities of predatory (beneficial) nematodes were higher in soil from killed sod plots than from conventional plots in May and December, 1992, and May, 1993. Later samples showed similar levels of predatory nematodes (Table 9).

Cost analysis. Over the three years considered in this study (1992-1994), the alternative management system costs were $245 per ha lower (a 2.7% cost reduction) than the conventional system (Table 10). This cost comparison utilized 1992 prices and 1992 as the base year for discounting. The bulk of the cost savings in the alternative system came from orchard establishment costs in 1992. These costs were $211 per ha lower (a 3.2% cost reduction) in the alternative management system compared to the conventional system (Table 10).

The cost difference in orchard establishment was primarily attributed to reduced machinery and chemical use in the alternative system. Machinery use was higher in the conventional plots during establishment because the corn plots had to be brush-hogged, disked and then seeded to fescue. Conventional system chemical costs were substantially higher due to the use of a residual herbicide versus contact herbicides only in the alternative system. Planting labor costs, however, were lower in the conventional system due to greater ease of planting trees in tilled soil versus killed sod.

In 1993, costs continued to be lower ($56 per ha) in the alternative system as lower chemical costs (mainly no use of residual herbicide) offset higher labor costs. In 1994, alternative system costs were only slightly higher ($18 per ha) due to higher labor and machinery costs. In addition, the difference in chemical costs between the two systems was lessened in 1994 due to increased weed competition in the alternative system. Revenues from fruit did not differ significantly between systems in 1994 and 1995.

Discussion

Soil organic matter continued to be higher in the alternative system, as was observed in 1990 and 1991, during the rotation phase of the experiment (Biggs et al., 1994). However, by 1994, soil organic matter in the two systems was similar. It is possible that, by the beginning of the third growing season, the residual organic material from the killed sod in the alternative system had been degraded by soil microbes and other natural processes. Higher soil organic matter levels may explain, in part, the higher leaf nitrogen levels detected in the alternative system in 1992. Increased weed competition (see below) probably contributed to the lower leaf N levels in the alternative system in 1994.

Leaf nutrient levels were within range that is considered normal for optimum growth of apple trees in West Virginia (Baugher and Singha, 1984). It is interesting to note that leaf phosphorus, potassium, calcium, magnesium, boron, copper and iron levels did not differ between management systems, even though no soil amendments were added to the alternative plots during the fescue rotation phase and heavy use of fertilizers accompanied two years of corn rotation (see Biggs et al. 1994). The system differences in foliar Zn, observed in 1993, and foliar Mn, observed in 1993 and 1994, did not appear to be related to soil pH, since pH was similar between systems in these years. One explanation could be related to levels of soil vesicular-arbuscular mycorhizzae (VAM) that contribute to the uptake of zinc. VAM fungi can be sensitive to the residual herbicides used in the conventional system, thus there may have been reduced Zn uptake in 1993. VAM have been found at higher levels in organically-managed apple orchards when compared with a conventional system (Swezy et al. 1994). The differences in Mn could be related to levels of soil organic matter. It is possible that the increased organic matter observed in the alternative system could have contributed toward making Mn less available for uptake by the tree root systems via the formation of organic Mn complexes (Stevenson and Ardakani, 1972). Some of the cultivar differences in leaf nutrient content were transient.

Subsoil nitrate levels were very high (exceeding U.S. EPA health advisory limits for potable water on each occasion) at all depths in 1992 because lysimeters were positioned within the area where localized treatments of fertilizer had been applied (20 to 60 cm from tree trunks, and over root zones, which is less than 5% area per ha). Assessment of nitrogen inputs and losses suggests that significant nitrate immobilization may have occurred in the alternative system due to increased organic matter levels and, that following fertilization, more nitrogen was held in the topsoil for uptake by the apple trees and weeds in this system relative to the conventional system, resulting in less nitrate leaching during the growing season. The increase in nitrate levels during the growing season could be due to the mineralization of organic matter. Our observations of generally higher nitrate-N levels in the conventional system of pre- + post-emergence herbicides, compared to the alternative system of post-emergence herbicides only, is in agreement with the findings of Merwin et al. (1996) where greater subsurface nitrate leaching was observed in apple orchard plots receiving residual herbicides compared to those receiving post-emergence herbicides.

No conclusions can be drawn from the yield data that were collected in 1994; however, yield in 1995 showed no differences in total fruit weight (kg/ha) between the two systems. The presence of harvestable fruit from Golden Delicious and Liberty in 1994, and Golden Delicious and Fuji in 1995, may make these cultivars more profitable in the short term, especially in comparison to York, but more data are needed to make this conclusion definitively.

Since arthoropod pest control programs were uniformly implemented across systems so that tree growth and establishment differences would be more clearly elucidated, few strong differences were noted in arthropod and disease incidence between systems. Spirea aphid populations were low in both management systems in 1993, but were significantly higher in the conventional system. One possible explanation for the difference could be related to differences in weed populations that may have influenced aphid predators. Although spirea aphid has a wide host range, including vegetables, it is not known whether common chickweed, which was more abundant in the conventional system, could have influenced spirea aphid populations. With the exception of moderate powdery mildew susceptibility, Liberty appears to be best suited to the reduced fungicide spray program which was initiated in the alternative system beginning in 1995.

Population densities of plant parasitic nematodes, which had increased on the corn and fescue rotation crops, declined after apple trees were planted in spring, 1992. The decline may have been due to the much reduced root biomass available for nematode feeding. Either the high root biomass and organic matter from the fescue rotation resulted in favorable environmental conditions for predatory nematodes, or their numbers were suppressed by nematicide treatment in the corn rotation, or both. While there is no direct evidence that predatory nematodes were suppressing plant parasitic nematode populations, the higher population densities of predatory nematodes indicate a more diverse and stable soil community was established in the killed sod, alternative system.

For weed suppression, it seems that the benefit of killed sod lasted approximately 2 years, and had less of an impact on weed density in 1994, relative to 1992 and 1993. The establishment of weeds in the alternative system could have contributed to depletion of soil N in this system.

Biggs et al. (1994) reported that preplant costs over the previous two years (1990 & 1991) were $107 per ha higher in the alternative system versus the conventional system. When the 1992-94 cost savings per ha are combined with the cost analysis results reported in Biggs et al. (1994), implementation of the alternative management system results in an overall cost savings. Discounted costs over this five year establishment period were 1.3% lower for the alternative management system. While a complete economic analysis of both these systems awaits additional years data on orchard returns, this cost analysis suggests that, under the terms of this experiment, the overall preplant and establishment costs for the alternative management system were slightly lower than the conventional management system. Based on these early results, the preplant fescue system appears to be a reasonable alternative to the conventional system.

In summary, we have demonstrated on a whole-orchard scale that an alternative system consisting of a sod rotation followed by establishment of trees into killed sod compares favorably with the conventional system for the growth and establishment of four apple cultivars. Many advantages accompanied the killed sod system, including less subsurface leaching of nitrate-N and lower costs (largely due to decreased herbicide use). The alternative system provided an economical alternative to the problem of soil organic matter depletion in conventional orchard soils, without the increased use of commercial fertilizers. Grower concerns regarding increased potential for vole damage and poor initial tree growth and yield were unsubstantiated.

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Table 1. Soil pH, organic matter, and nutrient analyses from alternative and conventional management systems.

Year/System	pH	OM (%)	P (ppm)	K (meq/100 g)	Ca (meq/100 g)	Mg (meq/100 g)
1992						
Conventional	7.3 a[1,2]	3.1 b	53.2 a	0.4 b	15.4 a	1.3 b
Alternative	7.3 a	3.9 a	60.5 a	0.5 a	17.3 a	1.7 a
1993						
Conventional	7.1 a	2.7 b	61.9 a	0.4 a	13.1 a	1.1 b
Alternative	7.0 a	3.1 a	59.6 a	0.4 a	13.5 a	1.3 a
1994						
Conventional	7.3 a	3.1 a	61.8 a	0.4 a	13.3 a	1.0 a
Alternative	7.3 a	3.5 a	58.8 a	0.4 a	14.8 a	1.3 a

[1] Values are the means of 12 observations from soil samples collected in April of each year.

[2] Different letters in columns within years denote significant differences according to Fisher's LSD ($P < 0.05$).

Table 2. Apple leaf nutrient analyses from trees grown under alternative and conventional management systems.

	Percent					ppm				
Year/System	N	P	K	Ca	Mg	B	Cu	Zn	Fe	Mn
1992										
Conventional	2.0 a[1,2]	0.19 a	2.1 a	1.2 a	0.32 a	34 a	6 a	38 a	77 a	101 a
Alternative	2.6 b	0.18 a	2.0 a	1.1 a	0.34 a	34 a	7 a	37 a	77 a	95 a
1993										
Conventional	3.0 a	0.26 a	1.9 a	1.1 a	0.29 a	47 a	9 a	40 b	73 a	110 a
Alternative	2.8 a	0.23 a	1.7 a	1.3 a	0.28 a	45 a	8 a	61 a	75 a	93 b
1994										
Conventional	2.5 a	0.18 a	1.5 a	1.0 a	0.27 a	32 a	29 a	36 a	68 a	81 a
Alternative	2.3 b	0.18 a	1.5 a	1.0 a	0.28 a	29 a	22 a	31 a	63 a	70 b

[1] Values are the means of 12 observations from samples collected in July of each year.

[2] Different letters in columns within years denote significant differences based on Fisher's LSD ($P < 0.05$).

Table 3. Change in trunk cross sectional area (ΔTCA), height, spread, and number of laterals for apple trees grown in alternative and conventional systems.

Year/System	Δ Trunk TCA (cm^2)[1]	Tree height (cm)	Tree spread (cm)	Laterals
1992				
Conventional	0.6 a[2]	155 a	88 a	6 a
Alternative	0.6 a	152 a	88 a	6 a
1993				
Conventional	6.1 a	198 a	159 a	11 a
Alternative	5.5 a	203 a	162 a	10 a
1994				
Conventional	7.4 a	222 a	215 a	12 a
Alternative	6.8 a	220 a	212 a	12 a
1995				
Conventional	11.9 a	276 a	245 a	12 a
Alternative	13.5 a	273 a	232 b	13 a

[1] Change in TCA from end of previous season to terminal bud set of the current season. Measurements taken 20 cm above ground level. Values are the means of 10 observations.

[2] Different letters in columns within years denote significant differences according to Fisher's LSD test ($P < 0.05$).

Table 4. Total fruit weight (kg/ha) and yield efficiency (g/TCA) from alternative and conventional systems and from four apple cultivars in 1994 and 1995.

	Total fruit weight (kg/ha)[1]		Yield efficiency(g/TCA)[2]	
System/Cultivar	1994	1995	1994	1995
Conventional	934.2 a[3]	4,169 a	108.4 a	222.8 a
Alternative	825.5 a	3,526 a	99.9 a	188.3 a
Fuji	251.0 b[3]	2,705 a	21.9 c	117.3 b
Golden Del.	1,411.5 a	2,827 a	142.8 b	160.1 a
Liberty	1,427.5 a	1,231 b	204.3 a	82.9 c
York	429.0 b	931 b	47.4 c	50.8 c

[1] Total fruit weight/ha is the mean total fruit weight from three replicate main plots (0.8 ha per main plot) per system and six replicate subplots (0.2 ha per subplot)per cultivar.

[2] Yield efficiency is calculated from yield (g) per TCA (cm^2) from 40 trees per main plot or 60 trees per cultivar.

[3] Different letters in columns for system denote significant differences according to Fisher's LSD ($P < 0.05$). Different letters in columns for cultivar denote significant differences according to Duncan's multiple range test ($P < 0.05$).

Table 5. Incidence of arthropod pests on apple in alternative and conventional management systems.[1]

Year/System	Spirea aphid	White apple leafhopper	European red mite	Rose leafhopper	Japanese beetle	Spotted tentiform leafminer
1992						
Conventional	---	---	10.2 *a*[2]	29.0 a	---	---
Alternative	---	---	19.4 a	21.8 a	---	---
1993						
Conventional	1.7 a	0.5 a	10.0 a	0.6 a	0.8 a	---
Alternative	1.0 b	0.9 a	10.4 a	0.5 a	0.4 a	---
1994						
Conventional	34.1 a	---	---	2.7 b	55.0 a	4.0 b
Alternative	43.8 a	---	---	5.5 a	38.4 a	8.2 a

[1] Insect management practices were not variable between systems. Data obtained from the following sampling protocol: Spirea aphid (no./most infested leaf, 5 terminals/tree), white apple leafhopper (nymphs/25 leaves/tree), European red mite (motile stages/10 leaves/tree), Japanese beetle (injured leaves/tree), rose leafhopper (nymphs/25 leaves/tree), and spotted tentiform leafminer (no. mines/5 min/tree).

[2] Different letters in columns and within years denote significant differences based on Fishers's LSD ($P < 0.05$).

Table 6. Foliar disease incidence on apple from alternative and conventional management systems.[1]

Year/system	Apple Scab	Powdery mildew	Cedar-apple rust	Frogeye leaf spot
1992				
Conventional	16.3 a[2]	8.9 a	13.8 a	17.3 a
Alternative	13.2 a	7.3 a	11.9 a	15.1 a
1993				
Conventional	5.1 a	16.9 a	0.7 a	-----
Alternative	5.9 a	16.1 a	0.7 a	-----
1994				
Conventional	0.4 a	0.8 a	6.4 a	-----
Alternative	0.3 a	0.2 a	7.3 a	-----

[1] Disease management practices were not variable between systems. Data are percent of infected leaves per terminal shoot from 3 terminal shoots/tree and 10 trees/cultivar (40 trees/system).

[2] Different letters in columns and within years denote the significance of differences based on Fisher's LSD test ($P \leq 0.05$). Mean separation based on arcsin-transformed percentages.

Table 7. Pine and meadow vole activity in alternative and conventional plots (Nov. - Dec. 1992-1994).

Year/system	No. active Vole sites	No. meadow voles caught	No. pine voles caught
1992			
Conventional	0/108[2]	0	0
Alternative	5/108	3	0
1993			
Conventional	0/108	0	0
Alternative	0/108	0	0
1994			
Conventional	0/108	0	0
Alternative	0/108	0	0

[1] Apples placed in runs and holes 5 to 15 cm below the soil surface were examined 24 hr after placement. Numbers of active sites refers to sites with vole tooth marks on the apples.

[2] No significant differences.

Table 8. Weed species and number of units per 1.5 square meters occurring in conventional and alternative systems in April and August, 1993 and 1994.

	1993				1994			
	April		August		April		August	
Weed	Conv	Alt	Conv	Alt	Conv	Alt	Conv	Alt
Allvi[1]	1.3 a[2]	2.0 a	--	--	1.5 a	1.3 a	--	--
Capbu	--	--	--	--	2.6 a	1.9 a	--	--
Carhi	1.4 a	3.8 a	--	--	--	--	--	--
Carpa	--	--	--	--	4.4 a	1.7 a	--	--
Conca	--	--	--	--	2.1 a	0.0 a	--	--
Fesar	--	--	0.7 a	0.0 a	--	--	--	--
Gerca	--	--	--	--	1.7 a	1.2 a	--	--
Lamam	--	--	--	--	0.6 a	0.4 a	--	--
Lampu	7.6 a	10.3 a	--	--	--	--	--	--
Lepvi	--	--	--	--	7.9 a	6.4 a	--	--
Polav	--	--	8.5 a	4.6 b	--	--	0.1 b	1.9 a
Polco	--	--	--	--	--	--	0.0 b	0.6 a
Polpe	--	--	--	--	--	--	0.1 b	1.1 a
Steme	8.3 a	0.9 b	--	--	0.9 a	0.9 a	--	--
Tarof	--	--	--	--	--	--	0.3 b	1.3 a
Thlar	2.7 a	4.1 a	--	--	0.0 a	0.2 a	--	--
Verpe	1.1 b	3.3 a	--	--	0.0 b	2.5 b	--	--

[1] Weed species as designated by the BAYER code as follows: Allvi = wild garlic; Capbu = shepherd's purse; Carhi = hairy bittercress; Carpa = cardamine; Conca = horseweed; Fesar = tall fescue; Gerca = Carolina geranium; Lamam = henbit; Lampu = purple dead nettle; Lepvi = pepperweed; Polav = prostrate knotweed; Polco = false buckwheat; Polpe = smartweed; Steme = common chickweed; Tarof = dandelion; Thlar = field pennycress; Verpe = birdseye speedwell. Only species with density greater than 0.5 units/1.5 sq meter are presented.

[2] Different letters in rows denote the significance of differences between treatments within year and month based on DMRT ($P \leq 0.05$).

Table 9. Soil population densities of plant parasitic and predatory nematodes on apple in alternative and conventional management systems.[1]

Date/System	*Pratylenchus*	*Xiphinema*	Predatory Nematodes[2]
May 1992			
Conventional	33 a[3]	19 a	13 a
Alternative	80 b	16 a	23 b
Dec. 1992			
Conventional	18 a	5 a	8 a
Alternative	33 a	3 a	15 b
May 1993			
Conventional	9 a	4 a	9 a
Alternative	12 a	6 a	20 b
Dec. 1993			
Conventional	3 a	7 a	4 a
Alternative	4 a	9 a	5 a
May 1994			
Conventional	33 a	25 a	36 a
Alternative	29 a	21 a	38 a

[1] Number of nematodes per 100 cm^3 soil. Soil samples were collected by compositing cores from the root zone of trees.

[2] Predatory nematodes were predominantly *Clarkus papillatus* with occasional specimens of *Mylonchulus obliquus, Iotonchus brachylaimus,* and *Discolaimus* spp.

[3] Different letters in columns and within year and month denote significant differences based on Fisher's LSD ($P \leq 0.05$).

Table 10. Orchard planting and establishment costs (nearest whole dollars per ha) for conventional and alternative systems.[1]

	Dollars/ha						Discounted dollars/ha[2]	
	1992		1993		1994		1992 - 1994	
Cost category	Conv	Alt	Conv	Alt	Conv	Alt	Conv	Alt
Trees	3,545	3,545	0	0	0	0	3,545	3,545
Labor	880	967	353	360	491	513	1,652	1,766
Machinery[3]	560	457	268	268	237	267	1,025	949
Chemicals	377	276	818	755	488	446	1,586	1,388
Conduit stakes	920	920	0	0	0	0	920	920
Fertilizer	130	130	27	27	0	0	155	156
Other	199	105	0	0	178	178	358	264
Total (net revenues)	6,611	6,400	1,466	1,410	1,394 -65	1,404 -57	9,243	8,788
Costs - revenues	6,611	6,400	1,466	1,410	1,329	1,347	9,185	8,937

[1] Data sources for the costs included: Funt et al. (1992), Hinman et al. (1991), Travis (1992), and material suppliers.

[2] A real discount rate of 5.78% was used. This rate was computed from the average interest rate for agricultural non-real estate debt minus the GNP deflator for inflation.

[3] Includes variable and fixed costs of tractors and equipment. Fixed cost based on machinery use for a 200-ha farm.

Figure legends:

Fig. 1. Nitrate-N from soil suction lysimeters at three depths from alternative and conventional apple production systems in 1992. Each value is the mean 12 observations. Different letters within date denote the significance of differences based on Duncan's multiple range test ($P \leq 0.05$).

Fig. 2. Nitrate-N from soil suction lysimeters at three depths from alternative and conventional apple production systems in 1993. Each value is the mean 12 observations. Different letters within date denote the significance of differences based on Duncan's multiple range test ($P \leq 0.05$).

Fig. 3. Nitrate-N from soil suction lysimeters at three depths from alternative and conventional apple production systems in 1994. Each value is the mean 12 observations. Different letters within date denote the significance of differences based on Duncan's multiple range test ($P \leq 0.05$).