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Impacts of groundcover management systems on yield, leaf nutrients, weeds, and arthropods of tart cherry in Michigan, USA

JR. Sirrine [a,*], D.K. Letourneau [b], C. Shennan [b], D. Sirrine [b], R. Fouch [c], L. Jackson [b], A. Mages [b]

[a] *Michigan State University Extension, Suite 107, 8527 E. Government Center Drive, Suttons Bay, MI 49682, United States*
[b] *Department of Environmental Studies, University of California, Santa Cruz, CA 95064, United States*
[c] *Fouch Orchards, Traverse City, MI 49686, United States*

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Abstract

Three different assemblages of cover crops were planted, fertilizer and herbicide input reduced, and mulch side-delivered in a northern Michigan tart cherry orchard to evaluate effects on tree leaf nutrients, arthropod communities, weed control, and tart cherry yield. The three treatments were compared against the conventional management system, which consisted of sod alleys and herbicide-maintained tree rows. Although fertilizer was reduced by 1/2 and herbicides eliminated in the ground cover management systems (GMSs), there was no evidence of reduced cherry yields. All GMSs provided more plant cover than the unmanipulated sod control. Biomass samples suggested that there was not enough side-delivery mulch to significantly reduce understory weed growth in the tree rows when compared to the non-mulched plots. The GMSs increased species richness, abundance, and diversity (H') of arthropods, despite frequent pesticide applications in all treatments. The results of the economic analysis suggest that cover cropping, half N fertilizer, and herbicide elimination may be a viable alternative to conventional groundcover management in northern Michigan.

Keywords: Groundcover management system; Cover crop; Mulch; Natural enemy; *Prunus cerasus*; Orchard

1. Introduction

Ground cover management to promote tree growth and crop yield is a key component of orchard crop production. In most cases, ground cover is managed to reduce nutrient and moisture competition with the trees, damage from pests and disease, and improve the ease of machinery movement and aesthetics. The standard groundcover management system (GMS) in North American orchards is mowed grass alleys and herbicide-maintained tree rows (Merwin, 2003). This system has gained acceptance because it dramatically reduces erosion compared to clean cultivation and moisture competition between vegetation and trees in a relatively inexpensive manner.

However, GMSs do not always provide benefits, and in some cases can have negative effects on orchard bio-physical conditions. For instance, groundcover can compete with tree crops for nutrients and water (Anderson et al., 1992), decrease tree growth (Parker and Meyer, 1996) and fruit yield (Pedersen, 1997), host crop pests (Meagher and Meyer, 1990), and increase frost damage (Proebsting, 1970). Mulches have been found to increase *Phytophthora* root disease in apple orchards (Merwin et al., 1992), vole populations and rodent tree damage (Prokopy, 2003), and costs for growers, making mulch systems less profitable than conventional orchard management (Edson et al., 2003).

While GMSs may be useful components of alternative orchard production systems, in order to be adopted by growers, the benefits of GMSs must outweigh the potential negative effects. The purpose of this research was to investigate the effects of three multi-species GMS treat-

* Corresponding author.
E-mail address: sirrine@msu.edu (J. Sirrine).

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ments, all containing nitrogen fixing forbs, but with differing plant composition and species richness compared to the conventional production system on an operating tart cherry farm in northern Michigan. Here tart cherry yield, leaf nutrients, arthropod richness and abundance, side-delivery mulch for weed control, half N fertilizer, and herbicide elimination are evaluated. We hypothesize that under the three alternative GMSs there will be no reductions in tart cherry yield or leaf nutrients, that alternative groundcover will provide substantial biomass for weed control, and will increase arthropod richness and abundance.

2. Methods

On-farm manipulations were carried out on Old Mission Peninsula, 35 km north of Traverse City in Grand Traverse County, MI, latitude 45°N, longitude 85°35′W. Average annual precipitation in the region is 762 mm, with cold, snowy winters (December–February average low −8 °C) and warm, humid summers (average June–August high 25 °C). Encompassing 6 ha, the study site was part of a functioning 15 ha tart cherry orchard that has been under a conventional, chemical-intensive management regime since its planting in 1980 (7–10 fungicide, 3–5 insecticide, 1–2 post-emergent herbicide applications annually). Pre-emergent herbicides were infrequently used on this site only prior to 1980. The slope was minimal, and soils represented a mixture of Emmet sandy loams (0–2% slope) and Leelanau–Kalkaska loamy sands (2–6% slope). These soils were deep, well to moderately-well drained, with low to moderate available water holding capacity and organic matter content, rapid to moderate permeability, and were slightly acidic–neutral. The experimental orchard was 24 trees (east-west) × 52 trees (north-south), with 6 m between trees.

2.1. Experimental design

Experimental plots were established in early June of 2000 on a conventionally managed 20-year-old tart cherry orchard, using a randomized block design with four main treatments (conventional sod control, five species mix, clovers/mustard, and rye/vetch), and two split-plot sub-treatment levels (mow/mulch and mow) replicated four times each.

Each plot consisted of four rows of four trees separated by 6 m × 24 m alleys planted to the same cover crop treatment. Manipulated alleys were treated with an initial glyphosate application (280 l/ha) to kill all vegetation before seeding with cover crop assemblages with a 2 m no-till drill (Great Plains Mfg. Inc.). The five species mix understory treatment was sown with *Trifolium pratense* (9 kg/ha), *Trifolium repens* (9 kg/ha), *Brassica juncea* (13 kg/ha), *Secale cereale* (11 kg/ha), and *Vicia villosa* (22 kg/ha). Clovers/mustard understory was sown to *T. pratense* (11 kg/ha), *T. repens* (11 kg/ha), *B. juncea* (17 kg/ha), and rye/vetch understory was sown with *S. cereale* (22 kg/ha) and *V. villosa* (34 kg/ha). Groundcover plants were sampled seven times and arthropods four times over 2 years in the main experimental plots. Experimental plots were not re-seeded. Tree rows were unmanipulated in the experimental plots. In unmanipulated groundcover plots, the farmer managed tree rows with a 3-m wide herbicide-treated strip (glyphosate; 187 l/ha), and tree alleys were left as sod that was originally seeded with Kentucky bluegrass at the time of orchard establishment, but has since become a grass mixture composed mainly of (*Elytrigia repens*). One spring fertilizer application of tree-row banded granular N (NH_4NO_3 299 kg/ha, 98 kg actual N/ha) and potash (K_2O) 149 kg/ha) was applied in late-April of each year in the conventional check plots. Tree-row herbicide was eliminated and fertilizer rate was reduced by half for the three alternative groundcover treatments. In the mow + mulch sub-treatment, alley groundcover was cut in late August of each year and the biomass (1000–1500 kg/ha/year (dry weight)) was delivered to the tree rows with a side-delivery mower. The mowed sub-treatment consisted of mowed sub-plots with clippings left in the alley. Drip irrigation, and insecticide and fungicide applications were held constant across all treatments.

Because this research was on a functioning cherry orchard, it was impossible to compare the three GMS treatments against an actual ''control'' plot for fear of yield reductions or tree death from pest and disease pressure. Therefore, pests and diseases in the three GMS treatments and the conventionally managed treatment were all intensively managed with multiple applications of pesticides at manufacturer recommended levels: three pre-harvest applications of insecticides (esfenvalerate (one @ 0.31 l/ha)), azinphosmethyl (two @ 1.12 kg/ha)), seven pre-harvest applications of fungicides (chlorothalonil (three @ 2.34 l/ha)), liquid and powder sulfur (four @ 4.68 l/ha and 5.60 kg/ha, respectively) and one post harvest fungicide application (liquid and powder sulfur and chlorothalonil; same rates as above).

2.2. Leaf nutrients

Leaf samples were collected annually in August of 2000–2002 using procedures modified from Hanson and Hull (1994). Twenty-five fully expanded leaves were collected from the middle of the current season's growth from each of the four data trees per replicate (100 leaves/replicate × four replicates for each treatment). Leaves were removed by pulling toward the shoot base to ensure that petioles remained attached to the leaves. The leaves were then washed in soapy liquid and rinsed, before being dried and sent to the Michigan State University Soil and Plant Nutrient Laboratory for nutrient analyses.

2.3. Yield

In 2000 and 2001, yield (kg/ha) of the four center trees per plot was measured during harvest in July, using a custom catching-frame mounted scale, and calculated as the mean of the 16 trees per treatment (four center trees × four replicates). Abnormally warm conditions in mid-April, followed by unseasonably cold temperatures recorded on Old Mission Peninsula (average minimum temperature −2.8 °C, 27 °F; MAWN, 2002) and throughout the region on April 21–23, caused substantial damage to Michigan's tart cherry crop in 2002. As a result, total Michigan tart cherry production in 2002 was only 6.8 million kg, the lowest yield since 1925 and down from 134.7 million kg the previous year (USDA NASS, 2005). Our experiment trees produced minimal cherry yield in 2002, and were not harvested. In 2003, yields from each of the four treatments were estimated (#tanks/treatment) during harvest by the grower, with particular attention to trees remaining after removal of several treatment trees due to cherry block replacement.

Beginning in October 2000, compositional cover, species richness, and functional group richness were estimated in 0.25 m^2 quadrats (0.5 m × 0.5 m) in alleys (nine samples/replicate × four replicates; 36 samples) and tree rows (12 samples/replicate × four replicates; 48 samples). Compositional cover was calculated as the summed percent cover of all plant species per quadrat. The percent cover of each species was visually determined within a quadrat and each species appropriately assigned a number (1 = 1–10%, 2 = 10–25%, 3 = 25–50%, 4 = 50–75%, 5 = 75–100%). Thus, compositional cover was an additive measure of total percent cover per quadrat, and values could exceed 100%. In 2001 and 2002, compositional cover, species richness, and functional group richness were sampled within 1 week of arthropod samples in June and August. In August 2000, 12 understory plant biomass samples per treatment were collected from 0.25 m^2 quadrats in alleys, separated by species, dried and weighed for later estimates of mulch dry-weight.

2.4. Arthropod species richness, abundance, and H'

In both June and August 2001 and 2002, arthropod samples were collected from the center alley of each plot using a modified leaf blower (Osborne and Allen, 1999), for 30 s. Sixteen samples (four/treatment) were collected per sampling date. Arthropods were removed from the mesh collection bag, placed into Ziploc® bags on ice, and then frozen for identification. Arthropods were later identified to morpho-species and placed in two dram vials of 70% ethyl alcohol. Morpho-species were identified to family and assigned to trophic groups: herbivores, primary parasitoids, predators, and others to determine abundance and species richness of potential pest and beneficial arthropods. The "other" group included consumers of litter or decaying vegetation, water and soil borne scavengers, pollen and nectar feeders, and hyperparasitoids. Additionally, arthropod diversity (H') (Shannon's diversity index) was calculated. Because there was significantly greater arthropod diversity (H'), richness (S), and abundance (A) in August ($H' = 2.61 \pm 0.07$ S.E.; $S = 38.9 \pm 2.0$ S.E.; $A = 333 \pm 24.3$ S.E.) than June ($H' = 2.07 \pm 0.08$ S.E.; $S = 18.5 \pm 1.0$ S.E.; $A = 100 \pm 9.3$ S.E.) sampling dates in both years (H': $p < 0.001$; S: $p < 0.001$, A: $p < 0.001$), data from June 2001 and 2002, and from August 2001 and 2002 were combined.

2.5. Economic viability

To determine cost-effectiveness of alternative groundcover treatments, an economic analysis comparing the costs of the alternative GMSs with the conventional management regime was performed. Conventional costs included herbicide and full fertilizer costs, and fuel costs for six orchard trips per year. Alternative cover crop treatments included seed costs, fuel for four orchard trips in year 1, and two orchard trips in subsequent years. Costs did not include fungicide, insecticide, and other chemical inputs that did not differ between the alternative groundcover treatments and the conventional management regime. Yields were not factored into the analysis because they were not significantly different between treatments in 2000 and 2001, and the farmer reported no obvious differences in yield between treatments in the following years.

2.6. Statistical analyses

All statistical analyses were performed using SPSS (SPSS Version 13.0). Because tree size can contribute to yield differences (Sanchez et al., 2003), initial baseline tree size (tree circumference at 0.3 m) was measured in 2000 for comparison among treatments (3-way ANOVA; tree cm × treatment × sub-treatment). Yield data were analyzed using a split-plot repeated measures analysis of variance (RM ANOVA) test with treatment as the main factor, mulch as the sub-treatment factor, year as the repeated measure, and tart cherry yield (kg/ha) as the response variable. Repeated measures were used to account for potential effects of sampling the same trees over time. Leaf nutrient data were collected annually from 2000–2002, and were analyzed in 2002 using an analysis of variance (ANOVA) test with treatment as the main factor, mulch as the sub-treatment factor, and leaf nutrients as the response variable. Compositional cover means were calculated from the midpoints of the categories (see Dethier et al., 1993). For example, if the compositional cover for a quadrat was between 1% and 10%, 5% was used for statistical analysis. Compositional cover, plant species richness, and plant functional group richness data were compared between treatments using a RM ANOVA test with treatment as the main factor, sample date as the repeated measure, and vegetation factor as the response variable. Arthropod dynamics were analyzed using a 2-way ANOVA and richness, abundance, and diversity as response variables to assess changes over time. Dunnet's post-hoc tests were used to compare treatments to the unmanipulated conventional system for vegetation and arthropod factors. All data were tested for normality using Kolmogorov–Smirnov tests. For all statistical analyses we used the Levene test for equality of variances, and Kolmogorov–Smirnov, residual calculations, and standard error of skewness and kurtosis to check that assumptions were met. We also used Mauchly's test of sphericity and Box's test of equality of covariance matrices to check assumptions for the multivariate approach within the repeated measures analyses. Data were (ln) transformed when necessary to meet normality assumptions.

3. Results

Initial tree circumference averaged 64 cm ± 1.38 (S.E.), and did not vary significantly among treatments and the conventional sod treatment. Baseline yields of tart cherries in 2000 averaged 5653 kg/ha ± 437.5 (S.E.), and in 2001 averaged ca. 2.5× greater than the initial year ($p < 0.001$). However, there were no significant yield (kg/ha) differences among the three alternative groundcover treatments and the conventional sod treatment (control = 13738 ± 809 S.E., five species mix = 14490 ± 1368 S.E., clovers/mustard = 14127 ± 1018 S.E., rye/vetch = 17129 ± 995 S.E.). There were also no differences in yield (kg/ha) between mulched and conventionally managed plots (no mulch) in 2001 (mulched 14562 ± 665 S.E., conventional managed 15227 ± 892 S.E.). After three years of treatments, there were no significant differences in leaf nitrogen (%) (control = 2.23 ± 0.06 S.E., five species mix = 2.25 ± 0.07 S.E., clovers/mustard = 2.16 ± 0.04 S.E., rye/vetch = 2.12 ± 0.03 S.E.) or other leaf nutrient levels between treatments and the conventional system. In both 2003 and 2004, the farmer reported that treatment trees remaining yielded above average compared to other tart cherry blocks owned by the grower. Thus according to the farmer, yield was not reduced as a result of the alternative cover crop treatments (data not presented).

GMS treatments had an effect on compositional cover, plant species richness, and functional group richness. Cover crops established well in the first year and persisted through at least three seasons without re-seeding for the five species mix and clovers/mustard GMSs. However, in the second year, the rye/vetch treatment was out-competed by other vegetation. Proportionally, legume species accounted for the majority of total cover for both the five species mix and clovers/mustard treatments from May 2001–August 2002. Both *T. pratense* and *T. repens* dominated the understory vegetation producing vigorous stands each year. Species composition and percent cover of the conventional sod treatment did not vary noticeably over time and was primarily comprised of *E. repens* and *Poa trivialis*. *S. cereale* and *B. juncea* did not establish well, and were both virtually absent by August 2002. *V. villosa* established well by fall 2000, but declined each subsequent year.

While there were significant differences among treatments for all vegetation factors (compositional cover: $p < 0.001$; plant species richness: $p < 0.001$; functional group richness: $p < 0.001$), there was also a significant interaction between time and treatment in each case. Therefore, we compared treatments for each date separately. The five species mix and clovers/mustard treatments provided more cover than the conventional system on all dates, and in general all three alternative groundcover treatments had significantly higher levels of plant species richness and functional group richness than the conventional system.

Not surprisingly, elimination of mid–late summer herbicide treatment led to greater vegetative growth in the tree rows of all three treatments compared to the herbicide-treated control ($p < 0.001$). However, like alley compositional cover, there was also an interaction between date and treatment. Separate analyses for 2002 data revealed that spring weed cover tended to be more prominent in conventional system tree rows and vegetation-free area more prominent in tree rows in the five species mix and rye/vetch treatments (Fig. 1).

The addition of litter to tree rows using side-delivery mulch from the alleys did not reduce weed growth when compared to the non-mulched plots. There was no significant difference between the mulched and non-mulched sub-treatments in compositional cover. The result of biomass samples suggests there was not enough side-delivery mulch to significantly reduce understory weed growth in the tree rows. Although it had the lowest alley compositional cover, the control yielded the highest mean alley vegetation biomass (1500 kg/ha dry weight), followed by the clovers/mustard treatment (1400 kg/ha), the mix (1300 kg/ha) and the rye/vetch treatment (1100 kg/ha).

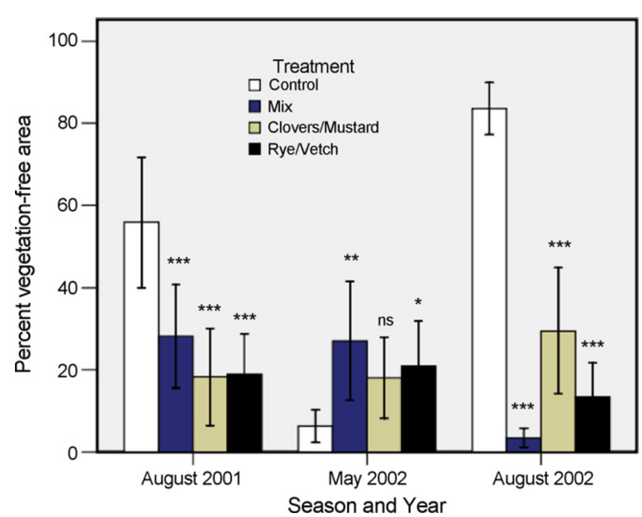

Fig. 1. Mean percent vegetation-free area within tree rows over time: *0.05 > p > 0.01, **0.01 > p > 0.001, ***$p < 0.001$ for Dunnet's post-hoc tests comparing each treatment to the control only. Three dates analyzed separately. Error bars represent 95% confident intervals.

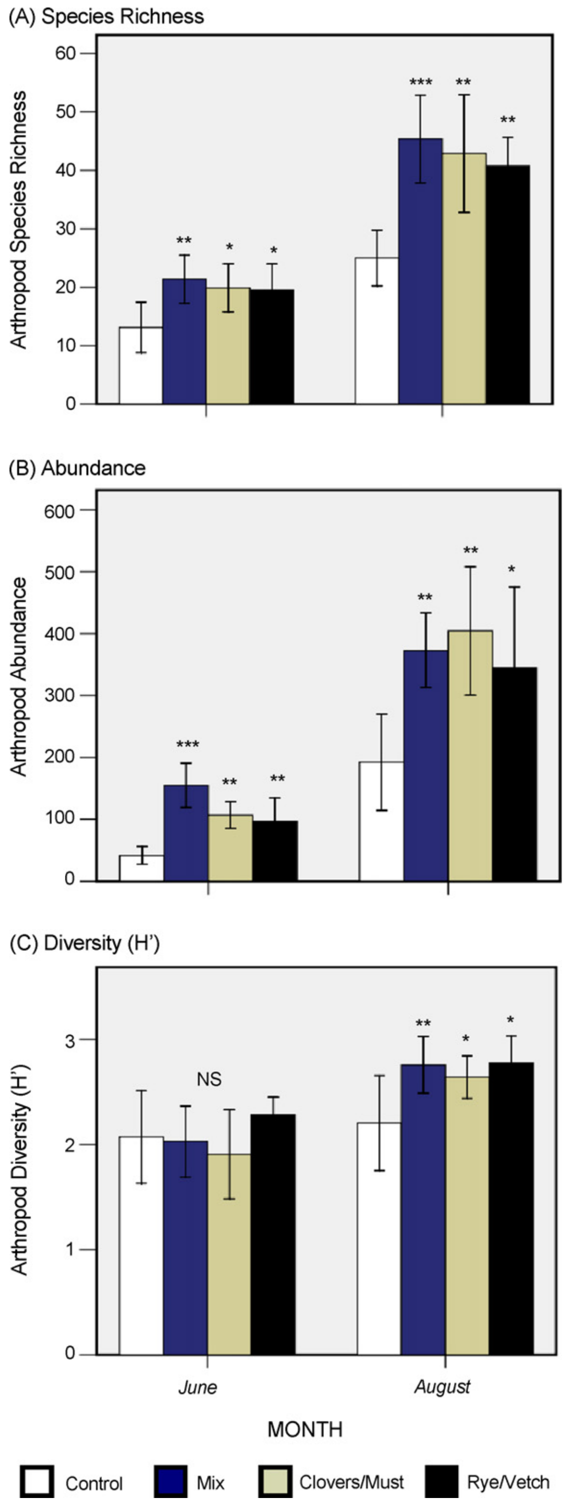

Fig. 2. The effects of treatment on arthropod species richness, abundance, and diversity (H'). $*0.05 > p > 0.01$, $**0.01 > p > 0.001$, $***p < 0.001$ for Dunnet's post-hoc tests comparing each treatment to the control only. *Note*: error bars = 95% confidence intervals.

The results suggest that GMSs had significant positive effects on arthropod species richness (S), abundance (A), and diversity (H') (S: $p < 0.001$; A: $p < 0.001$; H': $p < 0.05$). Because there was a significant seasonal effect, arthropod data were separated into spring (June) and summer (August) for comparison. Species richness, abundance, and diversity all increased as the community developed over time (Fig. 2). The GMSs resulted in changes among trophic groups, as well. In terms of trophic group richness and H', in general there were no significant differences between the GMSs and the control in the spring. However, in the summer all three GMSs resulted in significant species richness and H' increases for all trophic groups except "other species richness" (not shown). The analyses for trophic group abundance, however, yielded somewhat different results. In June, ln(herbivore abundance) was higher in all three GMSs when compared to the control, but not in August. On the contrary, ln(predator abundance) was higher in all three GMSs in August but not in June, and parasitoid abundance was not significantly different in either June or August.

The first year cost of each of the three cover crop treatments averaged \$259/ha, which was greater than the conventional management cost of \$192/ha. The cost of cover crop seed accounted for 63% (five species mix), 55% (clovers/mustard) and 53% (rye/vetch) of the first year treatment cost[1]. However, because cover crops were not re-seeded, the cover crop treatment costs dropped substantially in subsequent years to \$61/ha. This cost reduction made all of the GMS treatments more cost-effective than the conventional system by the second year. Farmer reports of no yield differences between treatments in subsequent years, provided evidence that GMSs may be a potentially cost-effective management option for growers.

4. Discussion

Although the results suggest that mowed, side-delivered mulch at 1000–1500 kg/ha/year had negligible effects on weed suppression and yield, in spring 2002 there was greater weed growth in the conventional system tree rows compared to the five species mix, and rye/vetch GMSs. Further benefits at higher mulch levels are expected, whether through the application of off-farm mulch or high biomass on farm mulch species. Edson et al. (2003) found that supplemental straw mulch (10,000 kg/ha/year (dry weight)) significantly reduced weed growth and increased tart cherry yield. Additionally, the potential for long-term soil quality benefits in orchards should be higher in mulch systems through enhancement of soil fertility.

Though measured yield results were limited to one post-baseline year, eliminating herbicide use and halving the rate of fertilizer caused no significant reduction in tart cherry yields as perceived by the grower in the following years. Similarly, in a long-term experiment, Landis et al. (2002) demonstrated that alternative orchard floor and nitrogen

[1] he economic analysis does not include costs that were the same for both the conventional and cover crop treatments (e.g. insecticide and fungicide applications, harvest costs). Thus, the overall cost (\$/ha) for both the conventional and cover crop treatments were higher than the costs shown.

management in Michigan did not reduce tart cherry yield. There are several potential reasons why yields did not decline.

First, the treatment trees were nearing 25 years old, presumably have well-established, relatively deep root structures, and perhaps exploit a different resource niche (in space or time) than understory vegetation (Hall, 1995). While yields were not reduced for these older, well-established trees, understory vegetation has been shown to compete for nutrients with newly planted tart cherry trees (Anderson et al., 1992) that extract nutrients and water from similar soil zones. Second, the timing of weed control may also play a role in maintaining tree vigor and productivity. In apple orchards, the potential for weed competition declines through the growing season and with tree age (Merwin and Ray, 1997). Third, conventional management may be inefficient in terms of nutrient cycling (N over-application, inefficient application, or inefficient uptake by tart cherry trees). After three years of alternative management, the results of our tree leaf nutrient analyses suggested no evidence of alley cover crops or tree-row weeds competing with trees for nitrogen. Fourth, in addition to scavenging for excess nutrients, tree-row vegetation can act as a winter and spring mulch layer and maintain higher soil moisture levels than bare ground tree rows (Walsh et al., 1996).

Though a majority of Michigan cherry growers use some form of integrated pest management (IPM), 99% of all U.S. tart cherry acreage receives both insecticide and fungicide sprays (USDA, 2002). In spite of intensive pesticide application, we found higher levels of predator abundance, species richness, and diversity (H'), and higher levels of parasitoid species richness, and diversity (H') in the GMSs. Researchers have demonstrated natural enemy increases with crop diversification, either with cover crops (Bugg and Waddington, 1994) or intercropping (Letourneau, 1997). And, in some cases, increased abundance of natural enemies in diversified systems has lowered levels of vineyard insect pests (Altieri and Schmidt, 1985), though not always to economically viable levels (Daane et al., 1998).

Alternative GMSs are potentially an economically viable alternative to conventional tart cherry management regimes. Although the initial cost ($/ha) of seeding the cover crops made the overall first year treatment cost greater than the conventional management system, by the second year the cost was recuperated for the three cover crop mixtures we measured. For each alternative cover crop treatment, after the first year, fertilizer costs were reduced by half, the cost of herbicide eliminated, and the number of orchard trips reduced by two-thirds ($100/ha/year savings).

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