Groundcover Management Effects on Orchard Production, Nutrition, Soil and Water Quality

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The systems used to manage weed competition for nutrients and water in orchards influence not only the growth, physiology and yields of trees, but also soil and water quality in the surrounding ecosystem. With intensive use of mechanized tillage equipment and residual herbicides, it is possible to eliminate surface vegetation beneath fruit trees year-round, and this has become a common practice in many orchards. Because fruit-growing regions are often located on well-drained soils and upland slopes near lakes and rivers, there is a substantial risk of soil erosion and runoff or leaching of pesticides and fertilizers into water resources. A good fruit-growing site is also likely to be replanted to fruit crops many times over. This makes the long-term conservation of soil fertility and favorable soil physical conditions especially important from horticultural, economic and environmental perspectives.

For the last 15 years my research group at Cornell University has been studying the complex interactions of fruit trees, surface groundcovers such as weeds and mulches, soil physical conditions and fertility, the movement of fertilizers and pesticides, and soil-borne pathogens in orchard soils (Merwin, 2003). Our approach in these studies has been comparative and systems oriented. We establish different long-term groundcover management systems (GMSs), and then observe and compare how these systems affect above and below ground outputs and processes in orchards. In this article I will describe three of our studies and what we have learned about orchard nutrition and productivity, and soil and water quality through these experiments.

1986 Ground Cover Experiment

In 1986, Warren Stiles and I started an orchard GMS study at Cornell’s research farm in Ithaca, NY. We planted ‘Empire’ and ‘Jonagold’ trees on MM.111 rootstock, at 3 x 6-m spacing, into six replications of different GMSs established within 1.5 or 2.5-m wide strips in the tree rows. The GMS treatments were as follows: (1) Post-emergence applications of glyphosate (Roundup™) herbicide in May and July each year (Post-Herb); 2) Pre-emergence applications of norflurazon (Solicam™), diuron (Karmex™), and paraquat (Gramoxone™) herbicides in May each year (Pre-Herb); 3) A regularly mowed turfgrass of Lolium perenne and Festuca rubra; 4) Mechanical soil tillage each month throughout the growing season (Tilled); 5) A legume cover crop of Coronilla varia (Crown Vetch); and 6) A 10-cm deep layer of hay-straw mulch, renewed each May (Mulch). We continued this study from 1986 to 1994, publishing our results in a series of reports (Merwin et al., 1992, Merwin and Stiles, 1994; Merwin et al., 1994; Merwin et al., 1996, Merwin et al. 1999).

This study showed that GMSs have important effects on orchard soil quality, as well as on fruit yield and tree physiology. During six years of observations, soil organic matter degraded and bulk density increased in the Pre-Herb and Tilled GMSs compared with Grass or Post-Herb systems (Fig. 1). Water infiltration rates were greatly reduced in the continuously bare soil of the Pre-Herb treatment, and there was substantial soil erosion and herbicide runoff in that weed-free GMS. Soil was drier most summers and tree N supply was lower under the Grass and Vetch groundcovers. Cumulative yields were lowest on trees in GMSs with grass or vetch groundcovers; but we also noted that fruit color, firmness, and flavor were best in those treatments, especially for ‘Jonagold.’ Interestingly, cumulative yields were as good in a 1.5-m (5 ft) wide herbicide strip as in 2.5-m (8 ft) wide strips, and there were our long-term studies on orchard soil management show that season long bare soil treatments from either residual herbicides or tillage do not give the highest long term yield. The use of post emergent herbicides such as Roundup maintained better soil physical condition and resulted in less runoff and leaching of nitrogen. The most important time to control weeds is during May and June.

**Figure 1.** Change in orchard soil organic matter after six years under different GMSs.

**Figure 2.** Groundcover management impacts on cumulative fruit yield (kg/tree) after six years.
no significant differences in yields from completely weed-free Pre-Herb treatments compared with the two Post-Herb glyphosate treatments, that were quite weedy throughout the dormant season (Fig. 2). About 25% of the trees growing in the orchard were killed either from Phytophthora root infections and/or Phacelia orapholylla damage (Microtis sp.) during the 3rd and 4th years of the study. When we studied the effects of weed-free periods for orchard groundcovers and may encourage the use of herbicides and so-called “clean” cultivation (Fig. 3).

Our field experiment to determine weed damage thresholds involved factorial combinations of weed-control timing and space. We assumed that the main threshold factors would be the spatial area and temporal period in which weeds were suppressed within the tree rows. Other researchers such as Atkinson in the UK, or Glenn and Welker in the US had reported increased fruit yields, nitrogen uptake, and yield as the weed-free area underneath apple or peach trees increased, peaking at around 8 to 10 m² per tree. Since our planting was irrigated, we reduced the weed-free areas to a range of 0, 2, 4, and 6 m² per tree, assuming that trickle irrigation would compensate partially for weed proximity. In the absence of any previously published studies on critical weed-free periods for orchard weed competition, we decided to test 0, 1, 2, or 3-month periods of weed suppression, in monthly combinations from May to August during the growing season. In April 1991, we planted ‘Gala’ apple trees on M. 26 rootstocks at 3 x 6-m spacing with three trees per experimental plot. Paraquat herbicide was applied on the first day of each month to suppress weed growth for the designated 30-day periods and areas in each treatment combination.

During the next five years we measured tree growth, nutrient uptake, and fruit yields in this orchard. Contrary to previous studies done in non-irrigated orchards (Atkinson and White, 1976; Welker and Glenn, 1989), we observed no significant benefits to trees as the weed-free area increased from 2 to 6 m² per tree, although tree growth and yields in all three weed-free areas were much greater than in the mowed check treatment (Fig. 4). We attributed these results to the below-ground effects of trickle irrigation, which apparently concentrated the roots of our trees into a narrow volume not much wider than the 0.7-m width of the 2 m² per tree treatments.

The observed response to weed-control timing in this study was also remarkable. The trees responded best to early summer

Figure 3. Soil erosion sediment in irrigation tail water from a clean- cultivated California apricot orchard.

Figure 4. Yield vs weed control area in 1994.
(May and June) weed control, with decreasing tree growth and yields as weed suppression was delayed until August. This trend continued for five years, and was reflected in cumulative fruit yields as well (Merwin and Ray, 1997). When we plotted cumulative yield efficiency (kg fruit/cm² trunk cross-sectional area) vs. weed-control timing after five years, the typical curvilinear response of a pest damage threshold was evident. We concluded that weed-free strips could be narrowed substantially to 1 m or less in similar orchards with drip irrigation, and that the first 60 days of the growing season were the critical period for weed suppression, providing the most benefits per weed-control costs in New York orchards.

Other researchers have since repeated this experiment on tart cherry (Al Hinai and Roper, 2001) and strawberry (Pritts and Kelly, 2001) with similar results. Moreover, research with apples and grapes in Europe has confirmed that moderate weed competition with fruit crops during the latter part of the growing season can improve fruit quality. We need to learn more about the cost/benefit relationships for orchard groundcover vegetation in different climates and soil types, but it appears likely that complete eradication of orchard groundcover in the tree rows is neither necessary nor desirable. For similar reasons the use of non-residual post-emergence herbicides is recommended in European and New Zealand IFP (Integrated Fruit Production) protocols.

**1991 Nitrogen and Pesticide Leaching Experiment**

The third study I will describe is an ongoing experiment investigating the relationship between orchard GMSs, soil physical conditions, tree physiology and yield, agrichemicals leaching and runoff, and nitrogen uptake and retention. In 1991 we installed a field-scale (2 acre) replicated drainage lysimeter system beneath an experimental apple orchard to monitor agrichemical leaching and runoff, and nitrogen management practices are dynamic and variable from year to year.

Nitrogen and pesticide retention and losses from this orchard have also been influenced by GMSs. Using various sampling systems to extract soil water samples from the root zone, we have observed higher concentrations of nitrate-N and fungicide leaching and runoff from the two herbicide GMSs over successive years (e.g. Fig. 7). Although there are relatively few runoff events from this orchard because there is almost 1000 m of drainage installed beneath the 0.8-ha site, when runoff does occur during spring thaws and summer downpours, the greatest losses of nitrogen are usually in Pre-Herb plots where the soil surface structure has degraded so that infiltration is reduced and erosion increased, causing passive transport of suspended or adsorbed agrichemicals (N, P and benzimidazole fungicide) in runoff water.

During 12 years of observations, there has been a clear trend of greater agrichemical leaching and runoff from the two herbicide GMSs compared with the Bark Mulch and Mowed Sod treatments. However, in recent years as the trees ma-

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**Figure 5. Cumulative annual fruit yields (kg/tree) in each GMS treatment from 1992 to 2003.**

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**Figure 6. Annual fruit yields (kg/tree) for the three treatment groups for Tart cherry from 1994 to 2003.**

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**Annual Fruit Yields (kg/tree)**

- **Pre-Herb**
- **Post-Herb**
- **Mowed Sod**
- **Bark Mulch**
tured and nitrogen fertilizer applications were reduced or eliminated, the losses of Nitrate-N from this orchard to surface and groundwater have remained very low in all GMS treatments—well below the EPA drinking water health standard of 10 ppm.

The actual nitrogen content of the BarkMulch applied biennially in this orchard represents a very large annual input of 300 kg of N per ha. This N input was evident in the total soil-N values determined by combustion analysis, which averaged two-fold greater under the BarkMulch than other GMSs (Fig. 8). Why didn't we see greater leaching or runoff losses of N from this treatment, considering that it has more than doubled soil N content over ten years? One reason is that much of the N in this mulch is contained in lignins and humic substances that degrade and release N much more slowly than mineral-N fertilizers. Another probable factor is that the topsoil carbon content (organic matter) has doubled under the BarkMulch treatment during the past 12 years. This high carbon input fuels a greater microbial activity in the BarkMulch plots, which tends to stabilize much of the soil N in microbial biomass and organic forms. At some point when the mulch plots become fully saturated with N, they may begin to lose N through leaching and runoff; but this has not occurred yet after 12 years of treatments.

To study the dynamics of N uptake and partitioning within this orchard, from 1999 to 2001 we used small amounts of a non-radioactive $^{15}$N isotope to trace the movement of fertilizer N within soil and trees in each GMS. By comparing the ratio of $^{14}$N (the naturally abundant form of this element) vs. the rare isotope $^{15}$N, it is possible to trace the pathways and estimate the
amounts of N moving from soil N supply into water, weed groundcovers, and different parts of the apple trees. The naturally occurring ratio of $^{15}$N/$^{14}$N is 0.3667%, so any elevation above that ratio represents $^{15}$N derived from our potassium-nitrate fertilizer treatments that were enriched to 99%. Previous researchers using this technique in orchards have applied large amounts of N-labelled fertilizers to soil beneath trees in weed-free plots that had received large annual doses of N fertilizer, and then studied the uptake efficiency and recycling of nitrogen within those trees. Since our trees had not received any nitrogen fertilizers from 1995-1999 (based upon leaf analyses that indicated sufficient N supply), we chose to apply a very small amount of $^{15}$N (< 0.2 g per tree) to serve as a tracer for N uptake and allocations in trees adapted to low soil-N supply.

Unlike previous studies in California and Oregon, the N tracer applied in this orchard was quickly taken up and appeared throughout the trees (Fig. 9). Even the trace amounts of $^{15}$N applied around bloom-time quickly appeared in flowers and spur leaves of trees in our study, and remained detectable for the rest of the growing season. Among the GMS treatments, soil-applied N was more available to trees in the two herbicide treatments, because weeds and grass groundcovers had a greater affinity for soil N than the trees. When we sampled groundcover vegetation where the N fertilizer had been applied beneath trees, it contained about four times more $^{15}$N than the spurs or leaves of the trees (Fig. 9 vs. Fig. 10). This shows that surface vegetation has a greater affinity for soil N than fruit trees, an observation with several different implications for orchard management. On the one hand, trees obviously need effective weed suppression to obtain enough soil N during critical periods of the growing season. On the other hand, groundcover vegetation can provide an effective reservoir for N (known as N-relay cover crops in agronomic systems) in orchards during times when trees are not taking up soil N, such as late autumn or early spring when trees are dormant but cover crops are actively growing.

**Conclusions**

What practical conclusions can be drawn from these three experiments? First, they indicate that eradicating weeds in the tree rows throughout the growing season or year-round is probably not necessary in the short-term, and may not be desirable in the long-term. Second, they reveal some of the trade-offs between costs and benefits in various orchard groundcover and soil management systems, and these, results are helpful to understand these trade-offs in devising the best GMS for each grower’s situation.

**References**


Ian Merwin is an associate research and teaching professor in the Department of Horticulture who specializes in orchard groundcover management and environmental effects of orchard management.