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

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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.

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

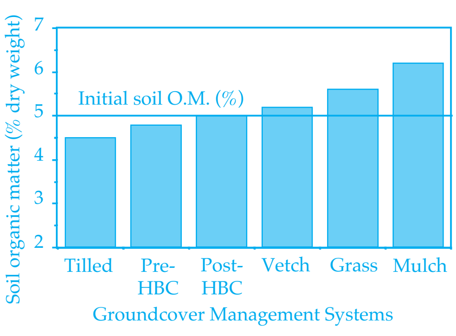

Figure 1. Change in orchard soil organic matter after six years under different GMSs.

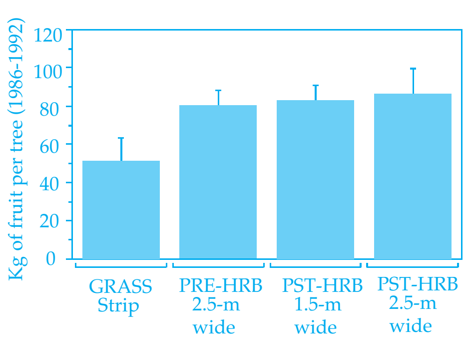

Figure 2. Groundcover management impacts on cumulative fruit yield (kg/tree) after six years.

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 Mulch plots died either from Phytophthora root infections and/or meadow vole damage (*Microtus* sp.) during the 3rd and 4th years of the study. When we studied the below-ground movement of nitrate-N and pesticide analogs under different GMSs at this orchard, we observed different patterns of runoff and leaching of these agrichemicals, indicating a greater potential for off-site movement of fertilizers and pesticides in the herbicide treatments (Merwin et al, 1996).

This first study demonstrated both the negative aspects, and the long-term benefits of maintaining groundcover vegetation to protect the soil beneath trees. Groundcovers help to conserve soil and water quality. They can increase or maintain soil organic matter, which improves soil structure and fertility. They protect soils from compaction and damage by foot and machinery traffic. There is also evidence that groundcover vegetation can improve biological control of some pests. So the surface vegetation that we often view as competitive or nuisance weeds can actually be beneficial for soil fertility conservation. If "weeds" have both positive and negative impacts on the orchard agro-ecosystem, then we need to determine the optimal balance between groundcover benefits for soil and fruit quality, and groundcover interference with soil water and nutrient availability. To do this, we need to understand the damage thresholds for weed competition in apple orchards. For this purpose, in 1992 we began another study to evaluate spatial and temporal thresholds for groundcover competition with apple trees.

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

1992 Weed Damage Threshold Experiment

Damage thresholds are defined as the level of pest infestation or population where yield loss or damage will probably occur to the crop if that pest is not controlled. The economic damage threshold is a somewhat higher pest level where the costs of control measures will be offset by the expected economic benefits of controls. This is a fundamental concept for Integrated Pest Management (IPM) that is essential for biological control of arthropod pests such as mites and other foliar pests, and for preventing or delaying the development of pesticide resistance. At present, not much is known about damage thresholds for weeds in orchards. With a powerful arsenal of machinery and herbicides to control weeds, most researchers and growers have assumed that effective weed control means complete year-round eradication of weeds in the tree rows. This Wild-West "shoot first and ask questions later" approach, is apparent in the trade names—for example Ambush, Lasso, Roundup, Ramrod, Spike, or Fusillade—used to market herbicides in the USA. Such an approach ignores the potential benefits of orchard groundcovers and may encourage the overuse 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 yields as the weed-free area beneath apple or peach trees increased, peaking at around 8 to 10 m^2 per tree. Since our planting was irrigated, we reduced the weed-free areas to a range of 0, 2, 4, and $6m^2$ 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 m^2 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 m^2 per tree treatments.

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

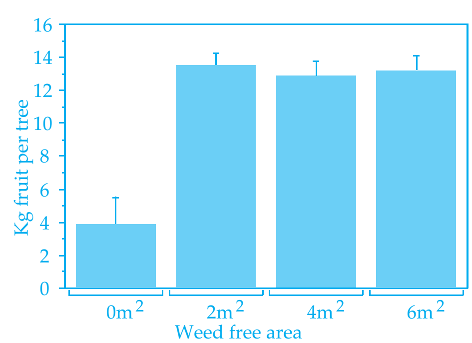

Figure 4. Yield vs weed control area in 1994.

(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/cm^2 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 agrichemicals movement and other important impacts of four different tree-row GMSs: 1) Pre-emergence herbicides (norflurazon, diuron and glyphosate); 2) Post-emergence herbicides (glyphosate); 3) Mowed Sodgrass (red fescue); and 4) A shredded hardwood (mixed *Quercus*, *Fraxinus*, *Acer*, *Fagus*, and *Juglans spp.*) bark mulch. In 1992, we planted 20 trees per replicate (four rows of five trees), with a buried drainage line beneath trees in each plot to intercept water that infiltrated through the GMS treatments, enabling us to sample the outflows of nutrients and pesticides. Two surface weirs in each plot enabled us to sample and analyze runoff water. The trees were 'Empire' on M.9/MM.111 rootstocks, planted at 3 x 6 m spacing, with microsprinkler irrigation. The entire site was datalogged to provide continuous records of soil moisture and temperature. Suction lysimeters were used to extract retained water samples from the tree root zone. The site sloped gently toward nearby Cayuga Lake, and the soil was a silty clay loam that averaged about 4.5% organic matter concentrations when GMS treatments were first established in 1992 (Merwin et al, 1996).

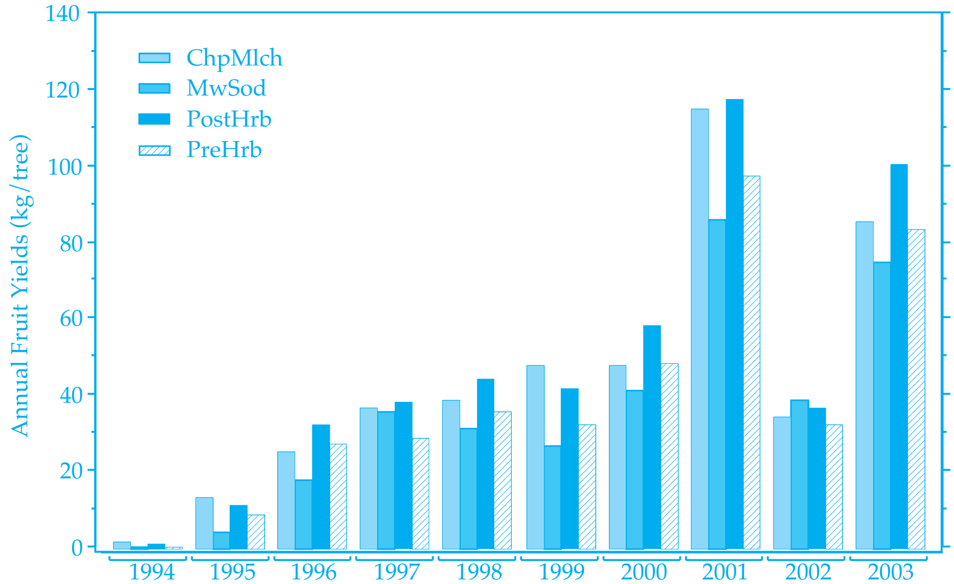

Figure 5. Cumulative annual fruit yields (kg/tree) in each GMS treatment from 1992 to 2003.

The following trends have been observed in this study during the past decade. From 1992 to 1997, and cumulatively through 2003, trees in the Post-Herb (glyphosate) treatment have produced the most fruit (Fig. 5). The best tree growth and second highest cumulative yields have been in the BarkMulch GMS. Trees in the MowedSod plots have been the smallest and least productive, while trees in the bare-soil Pre-Herb treatment ranked third—similar in growth with slightly more yield than the MowedSod treatment. Considering that the ground surface beneath trees in the Pre-Herb treatment is almost completely weed-free year-round, while the tree rows of Post-Herb and BarkMulch treatments have sparse weed coverage (a low biomass of weeds covering about 40% of the soil surface) during the dormant season (Fig. 6), it appears that total weed eradication in the Pre-Herb GMS has been detrimental not only to soil quality, but also to tree growth and yields after 12 years. It is worth noting in this regard that most orchard weed-control studies have involved time-spans of only 2 to 4 years—the establishment period in typical orchard production cycles. Looking over the cumulative trends in our study, one could draw different and contradictory conclusions about which GMSs treatments were best from years 1 to 4 vs. years 5 to 9 (Fig. 5). Orchards are a perennial crop system with production cycles of 10 to 50 years. Over such time-spans fruit trees can adapt to varying soil conditions and nutrient supply, with the result that short- and long-term responses to groundcover and nutrition 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 matured 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

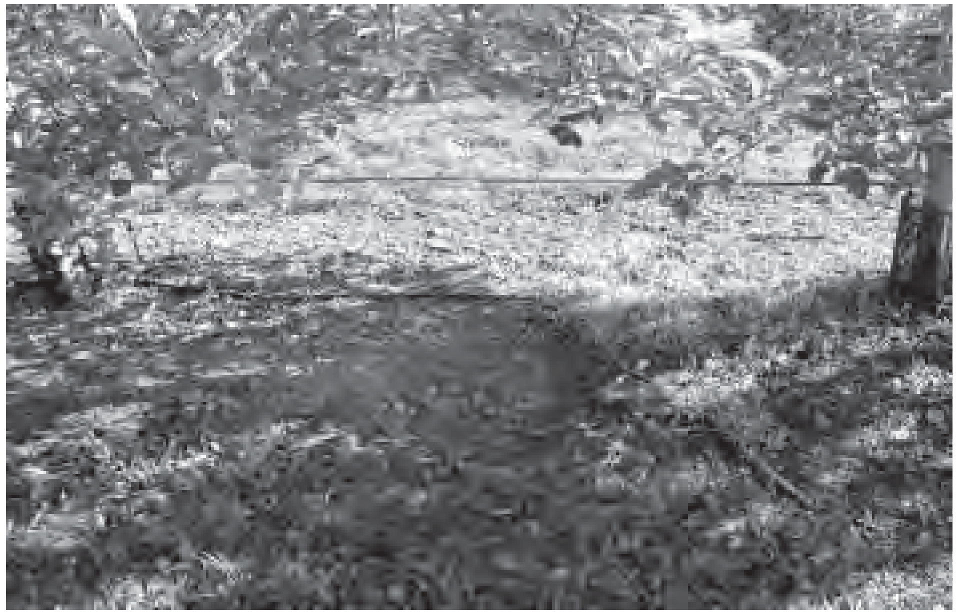

Figure 6. Tree-row surface conditions in weed-free Pre-Herb (left) vs. the sparsely weedy Post-Herb (right) treatments in late autumn.

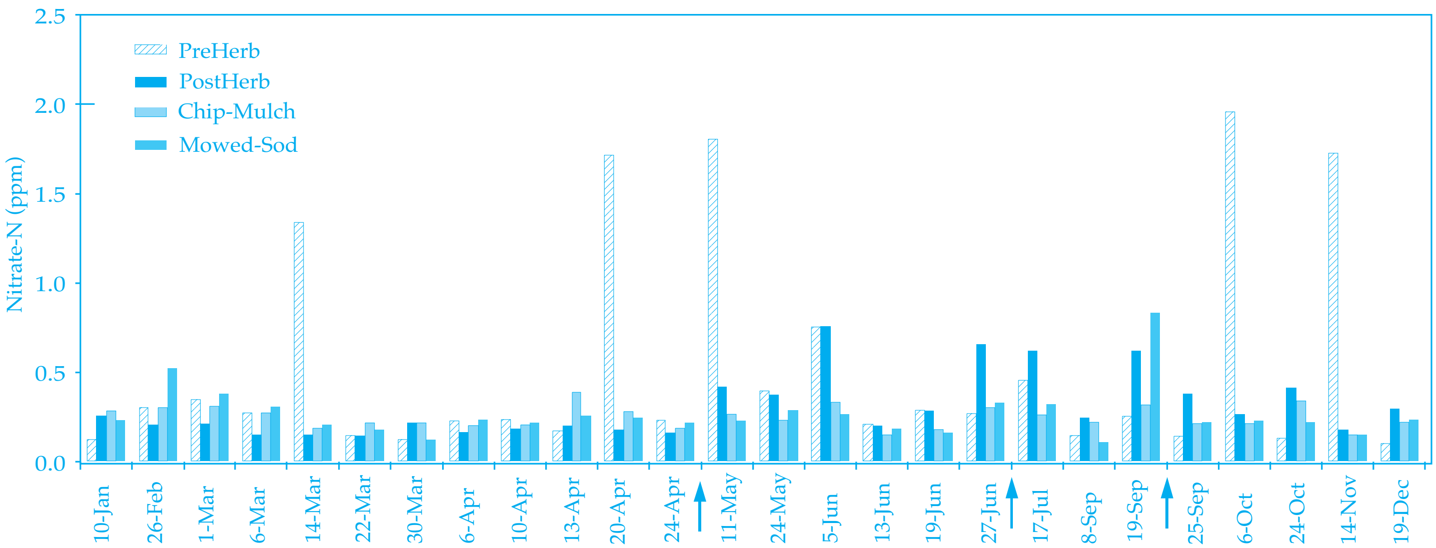

Figure 7. Mean nitrate-N concentrations (ppm) in drainage water outflows from four GMS treatments during 2000. Black arrows indicate dates of three N tracer applications.

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

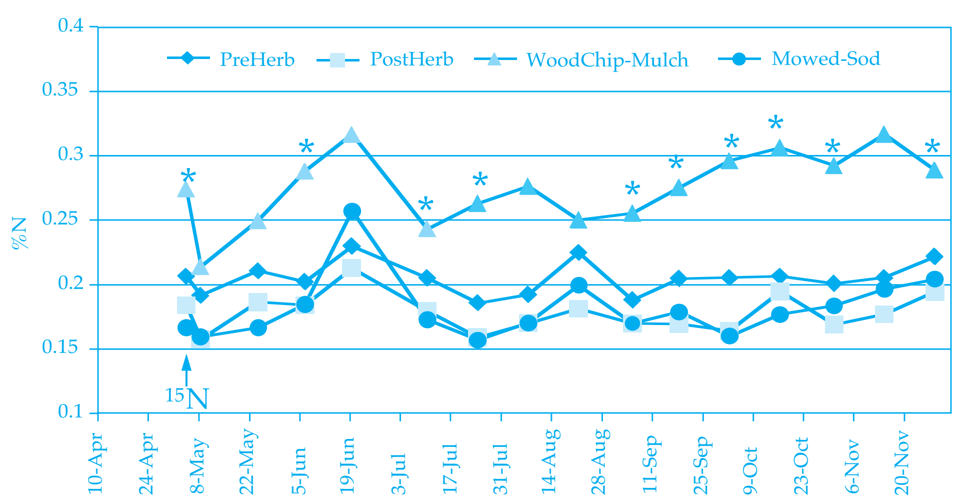

Figure 8. Soil N content (% drt wt basis) in several GMS treatments. Asterisks denote significant (P=0.05) differences on sampling dates during 2000. the N tracer was applied May 15.

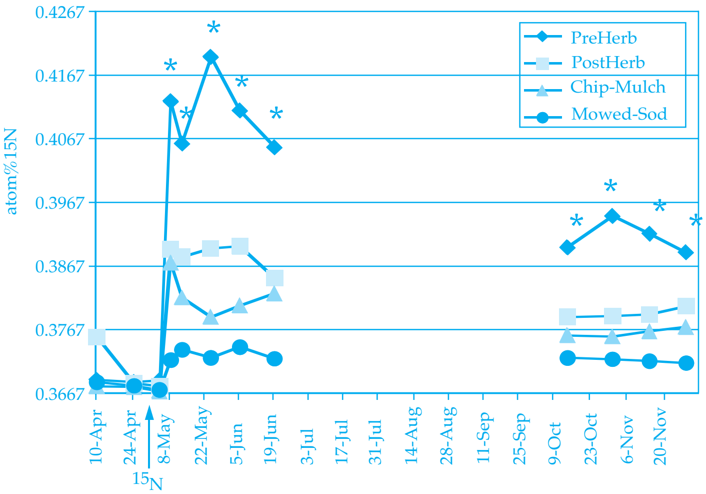

Figure 9. Fruit spur cluster atom % ^{15}N by treatment during 2000. Asterisks denote signifincat differences. N tracer was applied May 5, 2000.

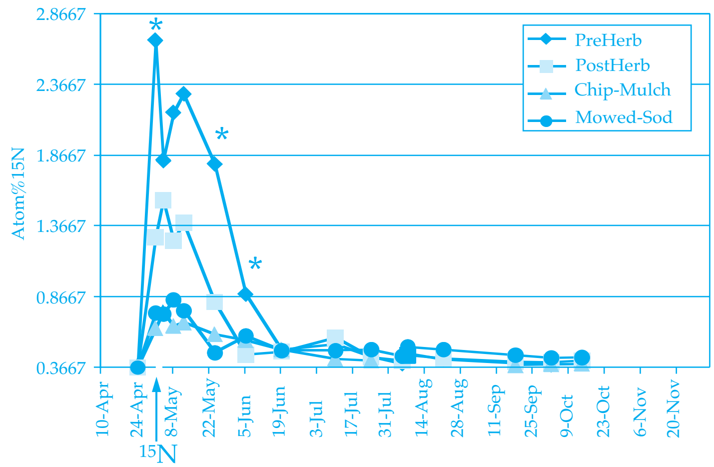

Figure 10. Ggroundcover vegetation atom % ^{15}N by GMS treatments in 2000. Asterisks denote significant differences. The N tracer was applied May 5, 2000.

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% ^{15}N. 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 third, these results are helpful to understand these trade-offs in devising the best GMS for each grower's situation.

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