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INTEGRATED ORCHARD WEED AND SOIL MANAGEMENT

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Growing fruit is a complex and high-stakes enterprise. Crop values can exceed $25,000.00 per acre, and damage caused by weeds, insects and diseases can easily render that crop unmarketable or unprofitable. Pest control accounts for a substantial portion of fruit production costs, and weed control is one of the factors that determine the short-term success and long-term sustainability of fruit growing.

A variety of methods can provide effective weed control. Growers need to decide which methods are best suited to their farming conditions, intended market, and personal preferences. Public concerns and governmental regulation of soil and water quality and pesticide residues on foods raise additional questions about potential health and environmental impacts of weed control practices. Choosing the best weed and soil management systems is, thus, an important and complex decision.

This report provides information about how weed management systems affect fruit crops, soils and groundwater, and other beneficial or detrimental organisms in fruit plantings. The advantages and disadvantages of various methods for managing weed competition will be described, and the importance of integrating weed control practices into comprehensive systems for sustainable fruit production are emphasized.

Interactions Of Weeds, Crops, Soils And Water

The traditional definition of a weed is "any plant growing where it is not wanted," but this simple definition is not really adequate because growers may want to control weeds that do not really need to be controlled. To avoid unnecessary and wasteful weed control expenditures, we need to distinguish between "ground covers" (meaning naturally occurring weeds, mulches, cover crops or turfgrasses that can be managed as a useful part of the crop system), and "weeds" (meaning undesirable surface vegetation that must be controlled or eliminated). From this perspective, it becomes clear that some plants may be weeds during the growing season, but a useful ground cover during the dormant season.

Growers need to know when control measures are really justified by economic returns. For this purpose, a more practical definition for weeds is "non-harvested plants that significantly reduce crop yield or quality by competing for essential resources such as nutrients, water or sunlight, without providing compensatory benefits." This broader definition reflects an important concept of integrated pest management (IPM), recognizing that weeds and other pests require control only if they are likely to cause economic damage to the crop.

The level of pest infestation where anticipated crop damage justifies the cost of control measures is known as the "damage action threshold" or "economic injury level" for that pest. Advances in herbicide and cultivation technology have made it easier and cheaper than ever to control weeds

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and manage ground covers, but the potential environmental impacts of any particular technology must be considered in the pest control decision-making process. For example, the potential soil conservation benefits of ground covers could be factored into economic damage thresholds for weed control. It is not easy to assign dollar values to natural resources like soil and water quality, but the importance of soil fertility and safe drinking water is recognized by everyone.

Though it is possible to eliminate surface vegetation in fruit plantings during the entire growing season, this may not be necessary or advantageous. Fruit crops require ample nutrients and water for good production, but an exposed soil without ground cover is vulnerable to wind and water erosion. The loss of vital topsoil and organic matter eventually reduces availability of soil moisture and nutrients, and can threaten the quality of ground water, local streams and lakes. For example, our tests in a New York orchard demonstrated that soil organic matter content increased after six years under mowed sod grass and mulches, but decreased when residual herbicides and cultivation were used for weed control (Figure 1). In the same orchard, available N, P, K, Ca and Mg increased under grass, mulch or residual weed ground covers compared with weed-free herbicide plots or cultivation. Rainfall infiltration and retention were also better under grass, mulch or killed weed residues in post-emergence herbicide strips, compared with weed-free herbicide or cultivated plots.

Access with equipment during wet weather and visual appeal of plantings for pick-your-own customers can also be enhanced when turf grass is maintained in drivelanes between the crop rows. Considering these benefits of ground covers, it is important to develop weed control systems that optimize trade-offs between weed competition with the crop and ground cover contributions to the stability and sustainability of the total fruit planting environment.

IPM Systems For Weed Control

Researchers have established damage action thresholds for fruit pests such as spider mites, leafrollers and leafminers, apple maggots and codling moths, and for diseases such as powdery mildew, Botrytis grey mold, apple scab and fireblight. However, reliable action thresholds have not been determined for weeds in fruit plantings or other crops, and the usefulness of this concept is still controversial in weed control.

Fundamental differences between weeds and other pests make action thresholds more difficult to use in weed IPM. Unlike other pests, natural biological control of weeds is rarely enhanced by delaying or deferring chemical or mechanical controls. In contrast to other pests that are sporadic and often do not appear in sufficient numbers to cause damage in fruit plantings, the weed "seed bank" in every agricultural soil makes it a sure bet there will be plenty of weeds to compete with the crop in every growing season. Strategies for integrated weed management, therefore, differ in some respects from other IPM programs, but taking an integrated approach to weed and soil management is still worthwhile.

Integrated weed management provides many of the same advantages as IPM for other pests. Preventing pesticide resistance is important for weed control, just as with insect or disease pests. Repeated use of the same herbicide eventually creates genetic or ecological resistance in weed populations, leading to control failures and crop loss. Repeated mechanical weed control can have similar consequences because it favours deep-rooted persistent weeds (such as milkweed, dock or

thistles) and weeds that sprout from tubers or rhizomes (such as nutsedge or quackgrass). Some of these weeds are also difficult to control chemically, and can become serious problems when encouraged by repeated mechanical tillage.

Preplant eradication and exclusion are other standard IPM practices that are useful for weed control. Applications of systemic herbicides or broad-spectrum soil fumigants before new plantings will minimize subsequent weed problems, especially in crops like strawberries for which only a few effective herbicides are available once the crop is established. Growing preplant cover crops or establishing a dense turfgrass before the fruit is planted also helps to exclude problem weeds afterwards, and can increase organic matter content and water-holding capacity of the soil. Finally, crop tolerance for weed competition can be maximized by careful selection of varieties and rootstocks that are best adapted to the soil, climate and production system at each site.

Certain ground covers can help to suppress pests. Preplant cover crops of marigold or Sudan grass have provided substantial control of parasitic nematodes in some orchards. It has also been shown that flowering ground covers provide pollen and nectar for insect predators and sometimes help reduce aphid and mite populations in fruit or nut trees. Survival of fruit fly larva in the soil may also be reduced in orchards where ground covers provide habitat for carabid beetles and other predators that may consume overwintering larvae and emergent fruit flies.

Some ground covers can aggravate other pest problems. Legumes often increase tarnished plant bug (Lygus) damage to fruit, and aphids or leafhoppers are more likely to infest fruit crops if certain weeds are present. When surface vegetation or mulches create sheltering habitat, meadow or pine vole (Microtus species) populations can increase rapidly and severely damage the roots and lower trunks of fruit trees. Many broadleaf weeds are favourable hosts for parasitic nematodes, viruses, and other pathogens that cause disease problems such as graft-union necrosis, orchard replant stunting, X-disease of stone fruits, and Pierce's disease of grape vines. Selective weed control (such as broadleaf herbicides that help suppress those weeds in turf) is essential to remove these alternate host weeds where such pests are a major problem.

Another concern in orchards is the effect of flowering ground covers on honeybees and other pollinators. As parasitic mites and brood diseases weaken and kill feral honeybee colonies throughout the country, insufficient pollination is becoming a real threat to fruit growers. When dandelions, yellow rocket, or other spring flowers are present in orchards at bloom time, bees and other pollinators may be distracted from visiting blossoms in the trees. This can substantially reduce fruit set and cropping. Applying selective herbicides and mowing the orchard floor during bloom will encourage bees to pollinate fruit trees instead of weeds. Managing the tree rows and drivelanes to maintain turfgrasses or other non-flowering ground covers is also important later during the growing season to prevent unintentional harm to bees that are foraging in the orchard when insecticides are applied to control economic pests.

In summary, many basic IPM concepts are useful in fruit crop weed management:

- Weed control can be deferred when crop damage is unlikely.
- Herbicide ingredients or mechanical controls can be combined or alternated to postpone development of pesticide resistant weeds.
- Health and vigor of the crop can be managed to enhance tolerance to weed competition.

- Environmental impacts and effects on beneficial insects and wildlife can be considered to select the safest effective ground cover management system.
- Different IPM strategies can be combined as appropriate for each farm, recognizing the complex interactions between weeds or ground covers, the fruit crop and pest complex, and local climate, soil and water resources.

Weed Control Decisions

Practical research and experience indicate that a year-round weed-free soil surface is not necessary for optimal fruit crop yields, and that long-term soil fertility is enhanced under well managed ground covers. Even so, there are no simple rules for deciding when and how to control weeds. Growers must consider present and past crop vigor, seasonal weather conditions and soil or wind erosion potential. Also, the weed species that are known to be present and potential difficulties in controlling them, the need to harvest or access plantings during wet weather, and the signs of weed interference with crop production must be recognized.

Crop vulnerability to weed competition depends upon soil type, seasonal variation in climate and rainfall, and other site specific conditions. Newly planted trees or vines, non-irrigated plantings on shallow or droughty soils of low fertility, and shallow rooted berry crops like strawberries or brambles are especially vulnerable to weed competition and require consistent and effective ground cover management.

On the other hand, mature fruit trees on a fertile soil, or during a wet summer, might benefit from a competing sod ground cover that limits mud and soil compaction, curtails late season shoot growth in the trees, and improves fruit colour and firmness at harvest. Just as insecticides and fungicides are no longer applied at fixed calendar intervals, weed controls can also be selected and applied on a flexible basis, depending upon local circumstances in each fruit planting.

The essential resources that are most often deficient in crop systems are sunlight, soil nitrogen, and water. Weed competition for sunlight is usually a negligible problem in established orchards or vineyards because the crop canopy overshadows all but the most vigorous or shade-tolerant weeds. However, newly planted trees or vines and low growing crops like strawberries that are shaded by weeds will be severely stunted, and may take years to recover if weed control is neglected during the first growing season. Plantings of all crops and ages are vulnerable to ground cover competition for soil nitrogen and water, because most weeds utilize nitrogen and water more quickly and efficiently than fruit crops. For example, studies have demonstrated that when nitrogen fertilizer is applied to turfgrass beneath fruit trees, most of the nitrogen gets taken up by the grass instead of tree roots.

Supplying additional fertilizers or irrigation to compensate for weed competition is not effective, because without other controls these weeds merely become more vigorous and problematic for the crop. Consequently, little or no benefit for the crop may be seen from this approach. Low-stature, slow growing, shade tolerant ground covers that become semi-dormant during mid-summer probably cause the least crop competition, but the perfect ground cover that never behaves like a weed remains to be developed or discovered!

Weed Control Area

The roots of trees and vines can extend considerable distances into soil wherever nutrients, water, oxygen, and pore space are adequate for root growth and metabolism. Nonetheless, root proliferation decreases with depth in the soil and distance from the lower trunk or crown region, and the root density of most fruit crops is less than that of common weeds. Therefore, resource competition between weeds and the crop is most intense in the topsoil within the crop canopy dripline or row.

How extensive or complete of a weed control area must be maintained to optimize crop growth and production? This will depend on crop characteristics, including plant age and pattern of root development, plus characteristics of the soil, such s soil texture and effective rooting depth, that influence root development and water availability. For example, competition from annual weeds and grasses can severely limit the growth of newly planted, non-irrigated apple trees in a coarse textured soil (Table 1).

On the other hand, in a New York orchard with trickle irrigation on a fertile fine textured soil apple tree growth, fruit production and the cost/benefit ratio for weed control were optimal in a 2.5 foot wide tree row strip treated with post-emergence herbicides (Figure 2). Other research by Mike Glenn in West Virginia has suggested that mature peach trees grown in narrow weed-free herbicide strips are smaller but equally efficient in yield as more vigorous trees in wider herbicide strips, although peach production was considerably lower for younger trees in the narrower herbicide strips. Dick Layne also reported that in Ontario, Canada, long-term survival of peach trees was better in grassed drivelanes with a tree row herbicide strip, compared with clean cultivation throughout the orchard. This was attributed to reduced perennial canker and cold injury in the trees with moderate levels of water and nutrient competition from the sod ground cover.

Based on our research in New York, it appears that mature or trickle irrigated apple trees can adapt to partially restricted rooting in a rather narrow area of weed control. However, young trees and non-irrigated orchards will probably establish and come into production more quickly if weeds are controlled for most of the growing season within a 6 – 8 foot wide strip along the tree row.

The extent of weed/crop competition also depends upon the density or biomass of weeds within the crop row. Weed density can be visually estimated as number of weeds or percentage weed coverage per square foot of soil surface. When weeds are small and sparsely concentrated they are less likely to pose a problem for the crop. Long-term tests at Cornell have shown no real differences in tree growth or yield in completely weed-free residual herbicide treatments compared with post-emergence herbicide treatments that left killed weed residues on the soil surface and allowed sparse regrowth of weeds during later summer and autumn. A sparse ground cover can still provide some protection for the soil surface in dormant season rains and runoff, without causing problems for the crop.

Weed Control Timing

How important is timing for effective weed control? Research during the early years of mechanical cultivation demonstrated that tillage early in the growing season was essential to conserve soil water reserves and provide nutrients for fruit crops. Usually this involved turning under a winter

cover crop of legumes or annual grasses that was seeded late in the previous growing season. Nutrients are released from cover crop biomass and soil organic matter that decomposes after each tillage, and this is still a common practice in orchards and vineyards of the southwestern United States.

With the advent of long-lasting residual herbicides, year-round eradication of weeds became a possibility. Applying tank mixes of post-emergence and residual pre-emergence herbicides in the fall, late spring or early summer can eliminate ground cover vegetation from the crop row for most, if not all, of the growing season. However, with increasing concern about soil erosion and agrichemicals, growers should consider alternatives to total weed control that leaves soil bare and exposed to weathering and erosion. Research in newly planted orchards and strawberries at Cornell University indicates that weed control with non-residual post-emergence herbicides is more effective early in the growing season. Crop benefits diminish as the initial weed treatment is delayed until mid-summer (Figure 3). A recent experiment with tart cherries in Wisconsin revealed similar results.

What about late summer weed control? Studies with established bearing apples, grapes, peaches, and other fruit crops suggest that moderate weed competition for water and nutrients during certain periods of fruit development or after harvest can be beneficial. Wine grape quality and apple fruit colour and storage quality may be improved when weeds are allowed to regrow or ground covers are seeded during the final stages of fruit ripening. Peach fruit size in California tests has been unaffected, but pruning costs were reduced when ground cover management or deficit irrigation were carefully utilized to create moderate nutrient or water stress during pit hardening and after harvest. Winter cold tolerance and perennial canker resistance of peach wood and buds may actually improve when late summer shoot growth is restrained by judicious ground cover and irrigation management. There is good evidence that more precise timing of weed control and ground cover management can benefit fruit crops.

Control Of Problem Weeds

Certain weeds pose serious threats to human health and make harvest and maintenance operations difficult. Poison ivy, brambles and horsenettle can scratch or cause dermatitis in workers. Seeds, pollen or chaff from pigweed or ragweed can pose a problem for workers or clients in pick-your-own farms. Others weeds such as yellow nutsedge are especially difficult to control and can proliferate aggressively. For these weeds, prompt treatment with systemic herbicides or mechanical removal is usually necessary.

GROUND COVER MANAGEMENT SYSTEMS

Weed Control Strips With Ground Covers Between Rows

Variations of this system offer many advantages and have become popular among fruit growers. Weed control within the crop row may consist of using herbicides, mulches, cultivation or periodic mowing. The width of the crop row strips can be adjusted periodically in response to crop vigor, soil differences, and climatic conditions. Permanent turfgrasses or other ground covers are usually maintained between the rows to facilitate access during inclement weather or harvest, and to minimize soil erosion and compaction from traffic.

Permanent Ground Covers

Turfgrasses are probably the most manageable ground cover for fruit plantings. Fineleaf fescues such as red fescue (Festuca rubra) or hard fescue (Festuca duriuscula) are tolerant of heavy traffic, relatively low growing and tend to go dormant during hot, dry weather. Unfortunately, they are also slow to establish, and seed is expensive. Perennial ryegrass (Lolium perenne) is less expensive and easier to establish, but also requires more moisture and nitrogen to hold its own against invasive weeds. Other grasses such as tall fescue (F. arundinacea) and annual ryegrass (Lolium multiflorum) are cheaper, but more competitive for water and nitrogen, and they require more frequent mowing. Periodic applications of selective herbicides to control broadleaf weeds may be needed to maintain these grasses.

Preplant Cover Crops

The "killed sod" system developed by Mike Glenn is probably one of the best ground cover systems for new fruit plantings. In this system, a grass is established and strips are killed with glyphosate or other non-residual herbicides shortly before establishing the fruit crop, which is then planted directly into the killed sod with minimal disturbance of the soil. The persistent killed sod residues reduce weed seed germination, protect the soil surface, provide additional organic matter and retain soil moisture during the first years of the planting.

Vetches, clovers and other legumes are often recommended as preplant or seasonal cover crops. As "green manures" and to improve soil physical conditions, these are excellent ground covers. However, there are many disadvantages to these cover crops in fruit plantings. Legumes are more deep rooted and consume more water than most grasses. In our experience over many years in various plantings, the N fixed by root nodules in legumes has usually remained unavailable to fruit crops unless the legumes were killed and incorporated into the soil – which is often not practical or possible in perennial fruit plantings. Legumes can also increase parasitic nematode populations in the soil and serve as alternate hosts for various insects and diseases that affect fruit crops. Finally, most legumes flower during the summer months, and attract honeybees that may be killed by pesticides used to protect fruit crops. White clover (Trifolium repens) is common in the soil seed-bank in northeastern soils, and often appears naturally in fruit plantings. It is perhaps the least problematic legume ground cover – low growing, durable, a good companion for many grasses, tolerant to a wide pH range – but it is quite competitive for soil water.

Natural Ground Cover Mixtures

If no ground cover is seeded, the natural soil seed-bank and wind-blown seeds at each site will determine which weeds predominate during subsequent years. Most fruit plantings have a mixture of 15 to 50 weed species already present in the topsoil, and every tillage brings up more seeds of some of these while also burying others. With so many different species present, it is difficult to avoid problems with alternate hosts for pests and diseases such as rust fungi and viruses. This is another rationale for establishing and maintaining more desirable ground covers.

Mulches

Mulches were a popular method for controlling weeds and conserving soil prior to the advent of herbicides. The current concern for reduced agrichemical inputs in fruit growing has renewed the interest in mulches. Potential choices for mulch materials have also increased greatly in recent years. We can now choose among a variety of synthetic mulch materials such as polypropylene plastics and bonded polyesters, recycled biomass mulches such as wood chips or paper pulp, and traditional mulches such as hay and straw. The costs and availability of various mulch materials are changing as fuel prices fluctuate and recycling waste materials becomes a priority. For example, wood chips and tanbark have long been used to mulch trees and shrubs in urban landscapes, but these natural mulch materials were very expensive in the past. However, as many landfills have begun to prohibit dumping of brush or wood, some public utility and tree maintenance companies will now deliver wood chips free to backyard gardeners or commercial fruit growers by prior arrangement. Similar changes are likely to occur as communities and corporations around the country seek new ways to recycle paper and other waste products.

Mulches are usually more expensive than conventional weed management systems such as herbicides or cultivation (Table 2). Polyethylene plastics and ground cover fabrics, hay-straw, and wood chips are the practical alternatives. Plastic films are widely used as mulches in vegetable and strawberry growing. These thin films are relatively inexpensive, and equipment is available for mechanical placement. Moisture conservation is excellent under plastic mulches. They also increase soil temperatures early in the spring, which can be an important advantage with some fruit crops. Plastic mulches add nothing in the way of nutrients or organic matter, but do influence nutrient availability through their effects on soil moisture and temperature. They also protect the soil surface against weathering and erosion. The primary drawback with these mulches is their lack of durability. Most require annual replacement. This creates problems with disposal of the used plastic. Many growers simply cultivate used mulches into the soil, which leaves unsightly and annoying shreds throughout the fruit planting for many years. Even the so-called biodegradable plastic films will not break down rapidly in the soil, though they may disintegrate enough to make removal more difficult.

The ultraviolet-resistant synthetic "landscape cloth" or fabric mulches are more durable, and may for several years substantially reduce their annual costs. Most of these are woven or spinbonded fabrics rather than films so they permit penetration of rainfall and may be sturdy enough to remove intact and reuse. The major problem with these fabrics is their high initial purchase and placement cost.

Hay or straw mulches provide partial control of annual weeds and are very beneficial as a soil amendment, but in recent years the costs of straw for mulch have increased greatly. In areas where waste hay or straw is available at a reasonable cost, there are many good reasons to consider this mulch. As with plastic mulches, availability of soil K, P, Ca and water is often increased under straw mulch, and in low fertility or droughty soils these benefits can be very beneficial. Natural biomass mulches will also gradually increase soil organic matter and improve pore structure and aeration of the soil.

On the downside, meadow voles (Microtus spp.) can become a serious problem under straw as well as plastic mulches. Mulch removal and rodenticide baiting during the winter months when these rodents feed on roots and bark can provide partial control of this problem. Another serious potential problem with mulches is excessive soil moisture in poorly-drained soils. In such sites, the use of straw mulches can greatly increase Phytophthora root and crown rots and mortality of fruit trees and brambles. Planting on mounds or raised beds so that water does not flood the crown and upper root zone will reduce these problems somewhat, but in poorly drained soils the likelihood of root and crown rots is still substantial under mulches.

Wood chips or shredded bark offer several advantages relative to hay or straw mulches. Hardwood chips contain more lignins and other compounds that make them decompose more slowly than hay or straw. This reduces the need for annual renewal of wood chip mulches and minimizes potential problems of excess late summer release of nitrogen or nitrogen immobilization by decomposing mulch material. If an inexpensive source (utility tree crews or saw mills) is available, this is an excellent mulch system. One note of caution: If wood chips are hot and fermenting or composting at the time of application, they may release ammonia or volatile organic acids which can injure the lower foliage on canes or vines.

Mechanical Cultivation

Tillage has been popular in fruit plantings for centuries, and is often done in conjunction with winter-grown cover drops, especially in irrigated sites. This management system increases soil nutrient and water availability for about a month after each cultivation. However, even when cover crops are turned under, repeated cultivation of the soil depletes organic matter, causes compaction and collapse of soil structure, and increases the likelihood of erosion. In sites with restricted rooting depth, particularly with shallow-rooted plants like brambles, the injury of crop roots with each cultivation is also a serious drawback.

Chemical Mowing

A few post-emergence herbicides are labeled at sub-lethal rates as "chemical mowers" for vegetation between the tree or vine rows. Low rates of glyphosate (about 10% of standard recommended rates) can be applied several times per season, depending upon the weed spectrum and type of crop. Chemical mowing has not been tested extensively, but appears to suppress ground cover competition with fruit trees somewhat more effectively than conventional mowing.

Herbicides

This is the cheapest effective system of weed control and consequently the most widely used by fruit growers. The short-term benefits of herbicide weed control include soil nutrient and moisture conservation, optimal growth, and early cropping of young fruit plantings. However, prolonged use of pre-emergence herbicides depletes soil organic matter and may leave chemical residues in the soil which can cause problems when it's time to replant the orchard. Some of our studies also indicate that there may also be more subsoil leaching and surface runoff of agrichemicals from fruit plantings where residual pre-emergence herbicides are applied, compared with mulches or mowed ground covers. This is another factor to be considered in comparing herbicides with other ground cover management systems. Herbicides are most effectively used as one part of an integrated weed management program to optimize crop production. Combinations of herbicides or sequential applications may be necessary due to variable weed populations and the need for residual control of weeds in some fruit plantings.

Conclusion

There are some good reasons for adopting an IPM approach to orchard weed control. Total year-round suppression of weeds is rarely necessary for optimal fruit production and quality, and it can seriously degrade soil and water quality on and off the farm. Overuse or misuse of herbicides and mechanical cultivation is also a waste of money and time, and can lead to problems with herbicide or tillage resistant weeds. Weed control decisions are best made on a cost/benefit basis, and it is important to consider all of the long-term costs and benefits of different weed or ground cover management systems to make the best decision for your farm and family.

TABLE 1. Total shoot growth of newly planted apple trees in relation to percent of weed control within a six-foot wide row strip, in a non-irrigated sandy loam (data from Stiles, 1984).

Weed-free Area (%)	Shoot Growth Per Tree (ft)	Tree Growth Reduction (%)
100	9.3	0
75	8.4	10
50	7.5	20
25	6.6	29
0	5.8	38

TABLE 2. Estimated costs per acre of orchard to establish and maintain natural and synthetic mulches, herbicides, grasses, or cultivation in 6-foot wide strips with 16 feet between tree row centers, in a New York apple orchard (Merwin et al., 1995).

System	Materials ($/ac)	Labour ($/ac)	Total $/ac (year)
Hay-straw mulch	150-400	145	300-550
Wood chip mulch	70	295	130-315 (1-3 yrs)
Weed collar™	9,800	200	10,000
1.2 mil polyethylene	150	35	185
Belton-Sarlon™ plastic	735	35	190-770 (1-4 yrs)
Agritex™ plastic	980	35	238-1015 (1-4 yrs)
Typar™ plastic	1,420	35	1455
Warren's Weed-Arrest™	1,800	35	395-1835 (1-4 yrs)
Herbicide strip	10-50	5	15-55
Mowed sodgrass	30	40	70-100
Clean cultivation	15	35	50

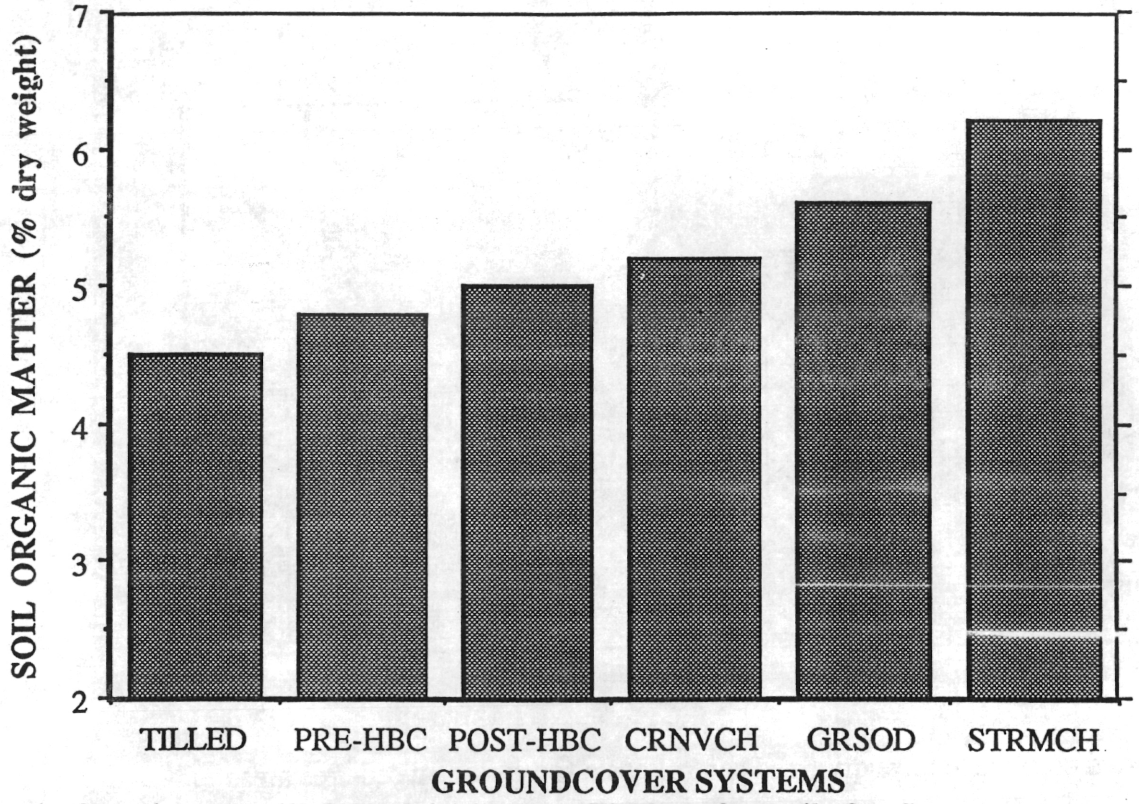

Fig. 1. Organic matter (% dry weight) in upper 8 inches of topsoil after five years under different groundcover management systems. Treatment abbreviations: TILLED = monthly rototilling during growing season; PRE-HBC = pre-emergence applications of paraquat, norflurazon and diuron herbicides in April each year; POST-HBC = two post-emergence applications of glyphosate herbicide in May and July each year; CRNVCH = "living mulch" of crownvetch; GRSOD = mowed sodgrass of red fescue and perennial ryegrass; STRMCH = applications of 4-inch deep hay-straw mulch each May.

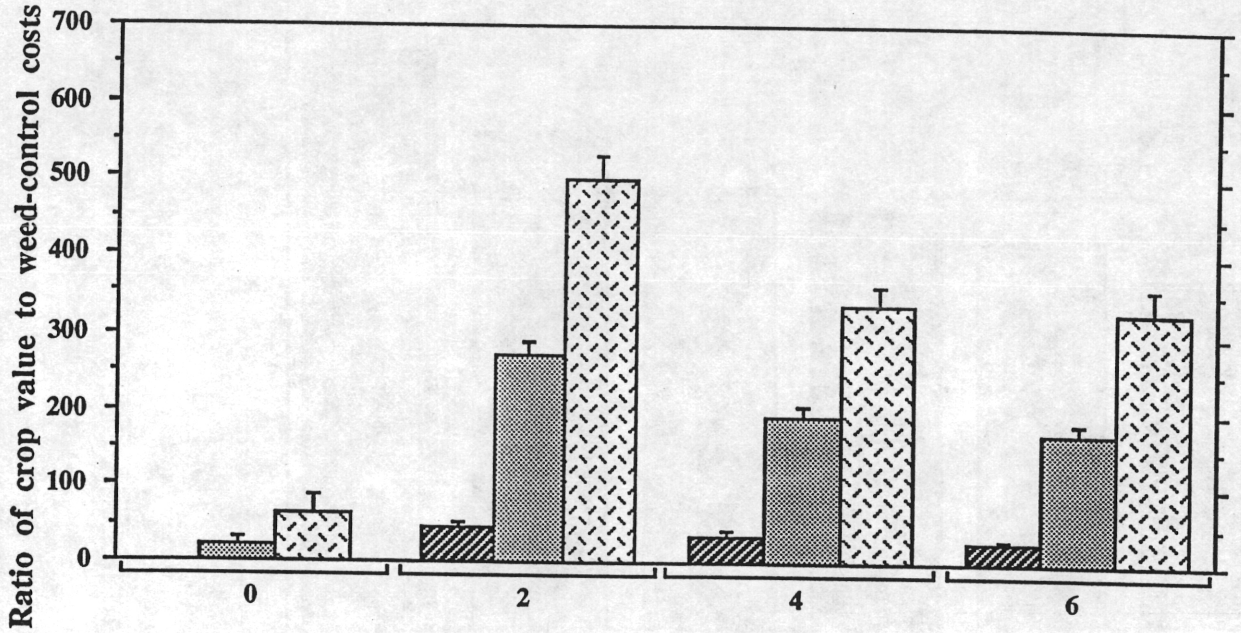

Fig. 2 . Ratio of harvested crop value to yearly weed control costs for various weed-free areas (m^2 per tree) in a newly planted orchard during 1993 ( ), 1994 ( ), and 1995 ( ). Standard error bars are for yearly means in each treatment.

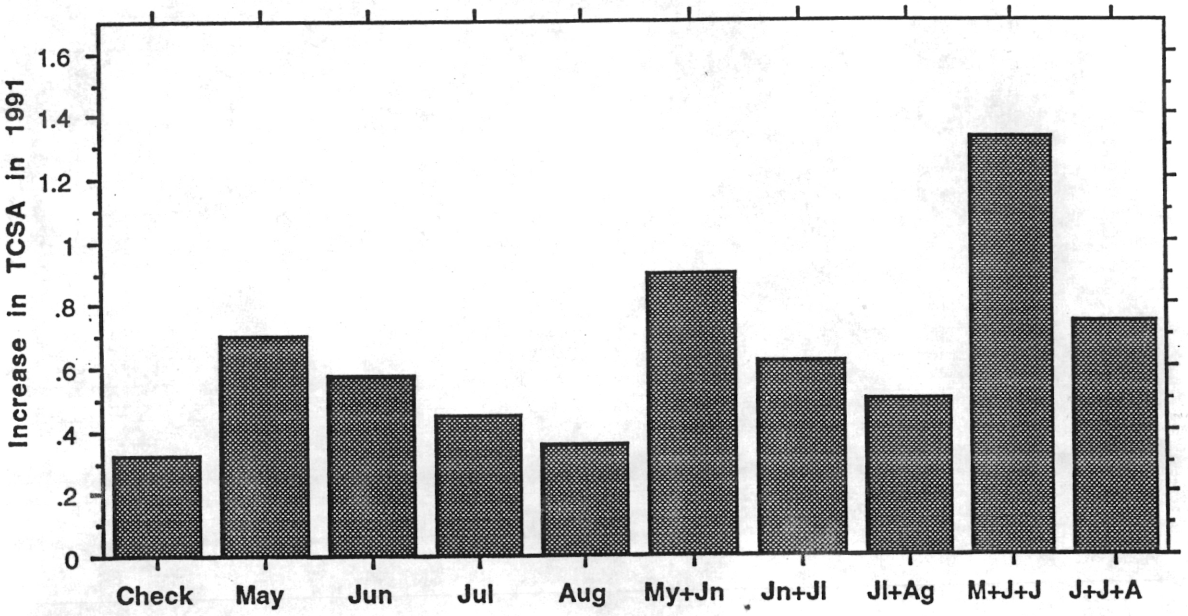

Fig.3. Effect of different timing and duration of weed control trunk cross sectional area (TCSA, in cm^2) of drip-irrigated apple trees during the first year after planting (1991).