Spatial and Temporal Factors in Weed Interference with Newly Planted Apple Trees

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Abstract. Temporal and spatial combinations of tree-row weed suppression treatments were evaluated during 5 years in a New York apple (*Malus domestica* Borkh. cv. Imperial Gala on Malling 26 rootstocks) orchard planted in Apr. 1991, and provided with trickle irrigation. Twenty-eight factorial treatment combinations [0, 2, 4, and 6 m² weed-free areas (WFAs); and May, June, July, August, May + June, June + July, May + June + July, and June + July + August weed-free times (WFTs)] were maintained from 1991 to 1995 by postemergence paraquat herbicide applications in tree-row strips. Trunk cross-sectional area (TCA) growth and yield were monitored annually, and few differences were observed as WFA increased from 2 to 4 to 6 m² per tree. However, WFT substantially influenced TCA, fruit production, and yield efficiency. Early summer WFTs increased TCA during the first two growing seasons, compared with late summer treatments. When trees came into production in 1993-94, yields increased as the duration of WFT increased, but where similar periods of WFT had been established later during the growing season, annual yield, cumulative yield efficiency, and the ratio of crop value to weed-control costs were all reduced. Groundcover species distribution was evaluated each year in September, and graminaceous weeds were more prevalent in the early and midsummer WFTs, while herbaceous broadleaf weeds dominated in the August treatments. A quadratic model regressing cumulative yield efficiency on WFTs grouped into 30-, 60-, and 90-day categories showed that efficiency peaked between 60 and 90 days of WFT. It appeared that timing of weed suppression may be as important as the area of suppression beneath trees in comparable apple orchards, that early summer weed control was especially important for newly planted trees, and that drip irrigation allowed reductions in the area and amount of tree-row herbicide applications, without significant losses in apple tree growth or crop value.

Practical experience and research have established the climatic conditions, phenologic stages, and "damage thresholds" or "economic injury levels" beyond which many pest arthropods and fungi cause sufficient damage to justify control treatments on apple and other horticultural crops (Agnello et al., 1993). In recent decades, the development of damage-threshold decision rules and Integrated Pest Management (IPM) programs has substantially reduced insecticide and fungicide usage in fruit production (Klonsky et al., 1990; Kovach et al., 1989), but herbicide usage has actually increased during this same era (National Research Council, 1989; U.S. Dept. of Agriculture, 1992). Without reliable weed-

control decision rules, most fruit growers now schedule mechanical or chemical weed controls by calendar date, just as insecticides and fungicides were usually applied before the advent of IPM (Gholson, 1987).

Most research in herbicide methodology has been conducted in annual crop systems where crop seedlings are vulnerable to weed competition and require virtually "weed-free" conditions during stand establishment (Burnside, 1993; Oliver, 1988). In the absence of other proven criteria, a weed-free standard has also been adopted by many commercial fruit growers, and groundcover vegetation is often eradicated beneath trees or over the entire orchard floor, throughout the growing season (Atkinson and White, 1976; Hogue and Neilsen, 1987). Unlike most herbaceous crops, fruit trees usually overshadow surface vegetation, so weed/tree competition for sunlight is minimal. Also, there is substantial retention and recycling of mineral nutrients and carbohydrates in the perennial biomass of fruit trees, which may reduce weed interference with crop nutrient supply. These aspects of woody perennial crop systems suggest that trees or vines might tolerate higher weed populations than agronomic crops. Quantitative studies of spatial and temporal factors in weed interference with fruit trees could provide information

about weed-tree interactions, enabling development of more efficient and sustainable weed-control strategies. Previous experiments have demonstrated spatial threshold responses to weed-free area (WFA), weed densities, and distribution patterns around young peach (*Prunus persica* L.) trees (Welker and Glenn, 1985, 1989, 1991) and apple trees (Hipps et al., 1990; Merwin and Stiles, 1994). However, to our knowledge, there are no published reports describing damage thresholds for weed-free time (WFT) or duration in orchards, nor have the potential interactions between WFA and WFT been investigated previously in fruit plantings.

There are cogent economic and environmental reasons to reduce herbicide usage by deferring control measures until weed populations or distributions exceed predetermined damage thresholds (Coble and Mortensen, 1992; Fryer, 1981; Gholson, 1987). Eliminating groundcover vegetation beneath fruit trees or over the entire orchard floor obviously minimizes short-term weed interference with the crop (Atkinson and White, 1976). However, long-term soil structural integrity, nutrient availability, water infiltration and retention, and beneficial soil macrofauna also may decrease in herbicide-treated or cultivated orchards (Haynes, 1981; Haynes and Goh, 1980; Hipps and Samuelson, 1991; Hogue and Neilsen, 1987). Groundcover vegetation can provide important benefits, such as soil organic matter input, protection of soil from erosion and traffic compaction, reduced splash dispersal of disease inoculum, and habitat for beneficial arthropod predators (Bugg and Waddington, 1994; Harris, 1981; Merwin and Stiles, 1994; Merwin et al., 1994; Moore et al., 1989). Leaching and runoff of nitrate-N and pesticides also may be reduced in orchards where tree-row groundcover vegetation is managed with nonresidual postemergence herbicides or regular mowing, rather than eliminated with residual herbicides (Merwin et al., 1996). Weeds or groundcovers therefore require careful management, but year-round elimination of groundcover vegetation would be unnecessary and undesirable in perennial crop systems if we could determine with adequate certainty the threshold WFAs and WFTs at which the negative impacts of various groundcover species mixtures or densities outweigh their positive impacts in the soil/crop system (Hipps and Samuelson, 1991; Skroch and Shribbs, 1986). In this report we describe a 5-year field study of temporal and spatial aspects of weed interference with newly planted apple trees. Our primary objective was to provide information useful for determining economic damage thresholds for weeds in apple orchards of the northeastern United States.

Materials and Methods

The experiment was located on a silty-clay loam soil (mixed, mesic, Aeric Ochraqualf) with pH ranging from 6.2 to 6.8, and soil organic matter content of 4.5 (in previous tree rows) to 6.2% (in previous drive lanes), at a

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Table 1. Analysis of variance for yearly and cumulative effects of weed-free time (WFT) and weed-free area (WFA) on trunk cross-sectional area growth of apple trees from 1991 to 1995.

Source of variation	df	1991	1992	1993	1994	1995	1991-95
WFT	8	***	***	***	***	NS	**
WFA	2	NS	NS	NS	NS	NS	NS
WFT × WFA	16	NS	**	NS	NS	NS	NS
Mean square error	84	0.08	0.70	1.69	2.87	2.97	21.78

NS, **, ***Nonsignificant at $P > 0.05$ or significant at $P < 0.01$ or 0.001 , respectively.

Table 2. Analysis of variance for yearly and cumulative effects of WFT and WFA on fruit yields of apple trees from 1993 to 1995.

Source of variation	df	1993	1994	1995	1993-95
WFT	8	***	***	***	***
WFA	2	NS	NS	NS	NS
WFT × WFA	16	NS	NS	NS	NS
Mean square error	84	2.68	19.56	46.80	116.22

NS, **, ***Nonsignificant at $P > 0.05$ or significant at $P < 0.01$ or 0.001 , respectively.

Cornell Univ. research farm in Lansing, N.Y. A 20-year-old apple orchard at the site was removed in 1990, and in Apr. 1991 we planted a 0.7-ha orchard of 'Imperial Gala' apple trees on Malling 26 rootstocks, in augured holes at 3 × 6-m spacing. The new tree rows were realigned in midcenter of well-established sod (a mixture of perennial grasses and clovers) drive lanes from the previous orchard at this site. A red fescue (*Festuca rubra* L.) turf was seeded in the previous tree rows, then subsequently maintained by monthly mowing. Trees were trained to a modified vertical axe system, supported on metal poles and trellis wires at 2.5-m height. A single trickle irrigation line with pressure-compensating 3 L·h⁻¹ emitters at 40-cm intervals was installed adjacent to trees along each row, and irrigation was applied throughout the orchard when the four tensiometers located in the mowed control plots indicated that soil water potential was < -75 kPa at 20-cm depth under the irrigation lines.

The design involved fully randomized factorial combinations of nine WFTs (May, June, July, Aug., May + June, June + July, July + August, May + June + July, June + July + August); three WFAs (2, 4, and 6 m² per tree, consisting of continuous strips 0.7, 1.3, and 2 m wide, respectively); and a control where the sod groundcover was mowed at the beginning of each month. Paraquat herbicide (1,1'-dimethyl-4,4'-bipyridinium ion; active ingredient) was applied at 0.5 kg·ha⁻¹, with a backpack sprayer on the first day of each designated month, to kill or suppress groundcover vegetation. The paraquat treatments generally provided a weed-free plot surface for the specified times and areas, although sparse weed regrowth occurred toward the end of some months, especially in single-month treatments during summers with abundant rainfall (1992 and 1993). After the first year, we mowed all plots not receiving herbicide treatments each month, to prevent rodent infestations and damage to trees. Each of the 28 WFT × WFA treatment combinations and the mowed-sod control were randomly assigned without blocking, and replicated four times in plots containing three trees, comprising a total of 336 trees. Annual increase in above-ground tree biomass was estimated by measuring trunk cross-sectional area (TCA) 20 cm above the graft union

of each tree, and the relative projective cover of the ground surface by various weed species was estimated in early September each year, using a diagonal beaded-string transect method (Southwood, 1978).

All fruit from every tree were counted and weighed at harvest, and a chemical thinning treatment (naphthaleneacetic acid at 10 mg·L⁻¹) was applied uniformly throughout the orchard in 1994 and 1995 to minimize biennial bearing. Trees were fertilized annually in late March, by sidedress applications of NH₄NO₃ (providing N at 25, 50, 70, and 80 kg·ha⁻¹ in 1992, 1993, 1994, and 1995, respectively), and K₂SO₄·2MgSO₄ (providing, kg·ha⁻¹, 80, 95, 110, and 120 K and 40, 48, 55, and 60 Mg in 1992, 1993, 1994, and 1995, respectively), broadcast on plot surfaces within the dripline of each tree. Foliar nutrient applications supplied annual totals (kg·ha⁻¹) of 10 Ca, 0.5 B,

and 3.0 Zn in four postbloom cover sprays. All other cultural practices in the orchard were typical of commercial apple production in New York State. Weed-control treatment expenses were estimated as materials plus labor and machinery costs, with fruit valued at \$US 1.00 per kg to estimate the cost/benefit ratios of weed-controls and yields. Trends within and across the 5 years were tested by two-way factorial and repeated-measures analysis of variance (ANOVA), respectively; treatment means within years were separated by least significant differences (LSDs), and grouped treatment effects were compared with single-degree-of-freedom contrasts, using the StatView 4.0 statistical program (Abacus Concepts, Berkeley, Calif.).

Results and Discussion

Repeated-measures ANOVA for the 5 years indicated that WFT, years, years × WFT, and years × WFT × WFA were all significant sources of variation ($P < 0.01$) in tree growth and yield. Therefore, we used ANOVA and treatment mean comparisons within individual years, and cumulative trends after 5 years to interpret the data. The timing and duration of WFT influenced TCA in every year except

Fig. 1. Cumulative apple tree trunk cross-sectional area (A) and fruit yield (B) from 1991 to 1995 in weed-free areas of 0, 2, 4, and 6 m² per tree. Values are means with standard error bars and LSDs ($P < 0.05$) for at least four observations in each treatment combination.

Fig. 2. Increase in trunk cross-sectional area (annual increase per tree) of trees in plots where weeds were suppressed during various months of 1991 (left bars) and 1992 (right bars) (A); and 1993 (left bars), 1994 (middle bars), and 1995 (right bars) (B). Standard error bars and LSDs ($P < 0.05$) are for yearly means of at least four observations in each treatment combination.

1995, and yield per tree in every cropping year, but the amount of WFA had no significant impact on TCA or yield in any year of our study (Tables 1 and 2). Trees in the mowed control plots were smaller and less productive cumulatively in comparison with trees in any of the three WFAs, but neither cumulative TCA nor fruit yields increased as WFA expanded from 2 to 4 or 6 m² per tree (Figs. 1 A and B). Cumulative yield was suppressed relatively more than cumulative TCA growth in the mowed control compared with all three levels of WFA, indicating that trees were not only larger but also more productive when at least a 2-m² area beneath each tree was treated with herbicide.

In the first two growing seasons, weed control during early summer usually resulted in larger TCA increases than equal durations of WFT later in the growing season (Fig. 2A). Pairwise contrasts of grouped treatment means confirmed ($P < 0.05$) that WFT in May 1991 resulted in more tree growth than any later single-month treatment, and was equivalent to 90 d of WFT in June + July + August; furthermore, the TCA increase was largest in 60- or 90-d WFTs that included May. During 1992, there was still some decline in tree growth as 30-d WFTs were imposed later in the growing season (until August), but contrasts of grouped means indicated a significant ($P < 0.05$) gain in TCA as WFT increased from 30 to 60 to 90 d, regardless of the monthly combinations involved. Early summer was the most critical time for weed interference with apple tree growth, possibly because shoot and root growth are relatively vigorous at that time and uptake of soil, water, and nutrients would favor weed

or tree roots that are first to occupy and exploit the rhizosphere early in the growing season (Atkinson, 1980; Chalmers, 1989).

Fruit production began in 1993, and reflected the tree-size effects of WFT observed during prior years (Fig. 3). More fruit was produced by the relatively larger trees that had received early summer WFT in previous years, and fruiting in the mowed control was delayed by 1 year. The larger crop load associated with early summer WFTs appeared to complicate subsequent tree growth trends (e.g., Figs. 2B and 3). Higher fruit demand for photoassimilate and other essential nutrients probably superseded shoot and root growth assimilation of these resources, thereby reducing TCA

growth on the more heavily cropped trees in early summer WFTs (Faust, 1989; Forshey and Elfving, 1989). Crop load in 1994 was substantial, and the previous trend of larger TCA with increased cumulative WFT was sustained. However, when WFTs were grouped and compared in linear contrasts, the impact of monthly WFT sequence on tree growth was actually reversed from previous years, and the rankings for TCA in 1994 were: May < June < July < August; May + June = June + July < July + August; and May + June + July < June + July + August.

With subsequent yearly harvests, the early summer WFT effects on yield diminished. Yields in 1994 and 1995 were similar for all 30-d WFTs, and increased in 60- and 90-d WFTs, with no apparent differences between early or later WFT sequences. The apples were quite small in all treatments at the 1993 harvest (averaging 106 g per fruit, ranging from 38 g in the mowed control to 129 g in 90-d WFTs), but were significantly heavier in treatments including May and August WFTs. In 1994, average fruit weight was higher (153 g per fruit), but there were no differences in fruit weight among the various WFTs or WFAs. In 1995, fruits averaged 159 g, and were heavier in the single month and mowed control WFTs, but there were fewer fruits per tree in these treatments (data not shown).

Cumulative yield efficiency (kg fruit per cm² TCA) after 5 years revealed long-lasting effects of the early summer WFT impacts observed in the first 2 years (Fig. 4A), contrasting sharply with the negligible yield impacts of increased WFA, except in comparison with the mowed control plots (Fig. 1B). Within single-, double-, and triple-month WFTs there was a trend of decreasing cumulative yield efficiency as weed suppression was delayed beyond May. Moreover, when WFTs were grouped by duration (0, 30, 60, and 90 d) ignoring monthly sequences, and tested in a polynomial regression model as predictors of cumulative yield efficiency, a WFT yield threshold response was evident (Fig. 4B). The yield efficiency curve peaked between 60 and 90 d of WFT. Despite the differences among

Fig. 3. Kilograms of fruit harvested per tree in plots where weeds were suppressed for various monthly periods during 1993 (left bars), 1994 (middle bars), and 1995 (right bars). Standard error bars and LSDs ($P < 0.05$) are for yearly means of at least four observations in each treatment combination.

Fig. 4. Cumulative yield efficiency (kg fruit per cm² TCA) of trees after 5 years in different monthly WFTs (A), and second-order polynomial regression model for cumulative yield efficiency as a function of grouped 30-, 60-, and 90-d WFTs (B). Regression equation is: yield efficiency = 0.77 + 0.28 WFT - 0.00018 WFT²; $r^2 = 0.29$, and $P < 0.001$ for regression model, intercept, linear, and quadratic terms. WFT monthly symbol designations: (V) May + June + July; (boxed x) June + July + August; (□) May + June; (diamond with a plus sign) June + July; (x) July + August; (x) May; (○) June; (○) July; (+) August; (Δ) mowed control. Values and LSDs ($P < 0.05$) are for means of at least four observations in each WFT treatment.

Fig. 5. Ratio of crop value to yearly weed control costs for various (A) weed-free times (months) and (B) weed-free areas (m² per tree) during 1993 (left bars), 1994 (middle bars), and 1995 (right bars). Standard error bars and LSDs ($P < 0.05$) are for yearly means of at least four observations in each treatment combination.

individual monthly WFTs in the early years of this study, the cumulative yield regression model predicted 29% of total variation in tree efficiency, with significant quadratic and linear trends ($P < 0.001$).

Weed-control costs increased proportionally with the treated area and number of herbicide applications each year. Packout values per fruit were similar in all WFTs and WFAs, so yields and crop value increased less than weed-control costs as the area and frequency of herbicide treatments were increased. In the first harvest the ratios of crop value to weed-control costs were higher for May and August WFTs; in the 1994 and 1995 harvests, they were higher in all single-month WFTs, and decreased as WFTs doubled or tripled or were established later in the growing season (Fig. 5A). When the WFAs were compared, benefit : cost ratios were consistently lowest in the mowed control, and highest in the 2-m² WFA (Fig. 5B).

Reviewing these observations, it appears that postemergence herbicide weed control in a narrow (0.7-m-wide) strip for 60 to 90 d early in the growing season was sufficient to optimize yields over the initial 5 years at this orchard. The equivalent tree growth and yield in 2, 4, and 6 m² WFAs observed in our study differed considerably from trends reported by Atkinson and White (1976) for apple, and Welker and Glenn (1985, 1989, 1991) for peach orchards. Such results may indicate greater vulnerability of peach than apple trees to weed interference, and may also be attributed to drip irrigation that was provided in our orchard but not in the earlier studies. The evidence about concentration of fruit tree roots beneath trickle irrigation emitters in humid and arid regions is somewhat contradictory (Atkinson, 1980; Swietlik, 1992). We did not sample root distribution to evaluate this phenomenon in our study, but visible wetting patterns on the soil surface beneath driplines were about the same width as the 2-m² WFA treatment. Our sidedress fertilizer applications during the first 2 years of this experiment were also concentrated in an area of 2 to 4 m² beneath trees. We monitored leaf nutrient content each year, and observed that tree nutritional status was also affected by WFT much more than by WFA (data not shown). Concentration of tree roots beneath trickle irrigation lines could explain the lack of substantial tree growth, yield, or nutritional responses to increased WFA in our study. Although we could not confirm this, it seems likely that irrigation may reduce the need for "bare soil" or "weed free" orchard floor management.

To estimate how weed control timing affected relative groundcover species dominance, we evaluated plot surface coverage by grass and broadleaf weeds during the first week of September each year in the 4-m² plots that had received single-month WFT treatments (Figs. 6A and B). Grasses were more prevalent in the May, June, and July WFTs—predominantly crabgrass (*Digitaria sanguinalis* L. Scop.), yellow foxtail (*Setaria lutescens* L.), witchgrass (*Panicum capillare* L.), orchard grass (*Dactylis glomerata* L.), and quackgrass (*Agro-*

pyron repens L.) (Fig. 6A). In the August WFTs, broadleaf weeds were relatively more prevalent—especially broad and narrow leaf plantains (*Plantago* spp.), knotweed (*Polygonum aviculare* L.), healall (*Prunella vulgaris* L.), dandelion (*Taraxacum officinale* Weber), white clover (*Trifolium repens* L.), and an unidentified bryophyte moss (Fig. 6B). The observed impacts of early vs. late summer WFTs, therefore, may have involved several intensities or levels of interference specific to grass or broadleaf groundcovers, but, we can not confirm this hypothesis, because we did not measure the relative dominance by various groundcover species at monthly intervals in all treatments throughout each growing season.

Relatively little information has been published about the effects of weed-control timing in orchards. Most previous studies have involved preemergence applications of residual herbicides that suppressed weeds for the entire growing season or year, and compared residual herbicides with other weed control systems such as mulches, cultivation, or mowed sods (Hogue and Neilsen, 1987). There was no yearlong WFT in our experiment, and it is certainly possible that tree growth and yield in such a treatment would have surpassed that observed in our 3-month treatments. However, in another orchard experiment comparing early and midsummer postemergence glyphosate treatments with a year-round bare soil preemergence residual herbicide treatment, we observed no significant differences in long-term apple tree growth or productivity, despite considerable weed regrowth by late summer in the postemergence herbicide treat-

ments (Merwin and Stiles, 1994). Considering the edaphic and environmental benefits of properly managed groundcovers in orchards, and fruit trees' apparent tolerance of coexisting groundcover vegetation at certain times of the growing or dormant seasons without significant losses, it seems worthwhile to reexamine the prevailing "weed-free" standards, and to develop damage-action thresholds that will facilitate IPM systems for orchard groundcover vegetation.

Literature Cited

- Agnello, A., J. Kovach, J. Nyrop, H. Reissig, and W. Wilcox. 1993. Apple IPM: A guide for sampling and managing major apple pests in New York State. NYS-IPM Program Publ. No. 207. Cornell Coop. Ext., Ithaca, N.Y.
- Atkinson, D. 1980. The distribution and effectiveness of the roots of tree crops. Hort. Rev. 2:424-481.
- Atkinson, D. and G.C. White. 1976. Soil management with herbicides—The response of soil and plants. Proc. 1976 Brit. Crops Prot. Conf., p. 873-883.
- Bugg, R.L. and C. Waddington. 1994. Using cover crops to manage arthropod pests of orchards: A review. Agr. Ecosys. and Environ. 50:11-28.
- Burnside, O.C. 1993. Weed science—The step child. Weed Technol. 7:515-518.
- Chalmers, D.J. 1989. A physiological examination of regulated deficit irrigation. N.Z. J. Agr. Sci. 23:44-48.
- Coble, H.D. and D.A. Mortensen. 1992. The threshold concept and its application to weed science. Weed Technol. 6:191-195.
- Faust, M. 1989. Physiology of temperate zone fruit trees. Wiley, New York.
- Forshey, C.G. and D.C. Elfving. 1989. The relationship between vegetative growth and fruiting in apple trees. Hort. Rev. 11:229-287.
- Fryer, J.D. 1981. Weed control practices and changing

- weed problems, p. 403-414. In: J.M. Thresh (ed.). Pests, pathogens and vegetation: The role of weeds and wild plants in the ecology of crop pests and diseases. Pittman, London.
- Gholson, L.E. 1987. Adaptation of current threshold techniques for different farm operations. Plant Dis. 71:462-465.
- Harris, D.C. 1981. Herbicide management in apple orchards and the fruit rot caused by *Phytophthora syringae*, p. 429-436. In: J.M. Thresh (ed.). Pests, pathogens and vegetation: The role of weeds and wild plants in the ecology of crop pests and diseases. Pittman, London.
- Haynes, R.J. 1981. Effects of soil management practices on soil physical properties, earthworm population, and tree root distribution in a commercial orchard. Soil & Tillage Res. 1:269-280.
- Haynes, R.J. and K.M. Goh. 1980. Seasonal levels of available nutrients under grassed-down, cultivated and zero-tilled orchard soil management practices. Austral. J. Soil Res. 18:363-373.
- Hipps, N.A., M.S. Ridout, and D. Atkinson. 1990. Effects of alley sward width, irrigation and nitrogen fertiliser on growth and yield of Cox's Orange Pippin apple trees. J. Sci. Food Agr. 53:159-168.
- Hipps, N.A. and T.J. Samuelson. 1991. Effects of long-term herbicide use, irrigation and nitrogen fertiliser on soil fertility in an apple orchard. J. Sci. Food Agr. 55:377-387.
- Hogue, E.J. and G.H. Neilsen. 1987. Orchard floor vegetation management. Hort. Rev. 9:377-430.
- Klonsky, K., F. G. Zalom, and W. Barnett. 1990. California's almond IPM program. Calif. Agr. 44:21-24.
- Kovach, J. and J.P. Tette. 1988. A survey of the use of IPM by New York USA apple producers. Agr. Ecosys. and Environ. 20:101-108.
- Merwin, I.A., J.A. Ray, T.S. Steenhuis, and J. Boll. 1996. Groundcover management systems influence fungicide and nitrate-N concentrations in leachate and runoff from a New York apple orchard. J. Amer. Soc. Hort. Sci. 121:249-257.
- Merwin, I.A. and W.C. Stiles. 1994. Orchard groundcover management impacts on apple tree growth and productivity, and soil nutrient availability and uptake. J. Amer. Soc. Hort. Sci. 119:209-215.
- Merwin, I.A., W.C. Stiles, and H.M. van Es. 1994. Orchard groundcover management impacts on soil physical properties. J. Amer. Soc. Hort. Sci. 119:216-222.
- Moore, D.C., M.J. Singer, and W.H. Olson. 1989. Improving orchard soil structure and water penetration. Calif. Agr. 43:7-9.
- National Research Council. 1989. Alternative agriculture. Natl. Academy Press, Washington, D.C.
- Oliver, L.R. 1988. Principles of weed threshold research. Weed Technol. 2:398-403.
- Robinson, D.W. and N.D. O'Kennedy. 1978. The effect of overall herbicide systems of soil management on the growth and yield of apple trees 'Golden Delicious'. Scientia Hort. 9:127-136.
- Skroch, W.A. and J.M. Shribbs. 1986. Orchard floor management: An overview. HortScience 21:390-394.
- Southwood, T.R.E. 1978. Ecological methods. Chapman and Hall, London.
- Swietlik, D. 1992. Yield, growth, and mineral nutrition of young 'Ray Ruby' grapefruit trees under trickle or flood irrigation and various nitrogen rates. J. Amer. Soc. Hort. Sci. 119:22-27.
- U.S. Dept. of Agriculture. 1992. Agricultural chemical usage: 1991 fruits and nuts summary. U.S. Dept. Agr., Natl. Agr. Stat. Serv. AgCh 1(92). Washington, D.C.
- Welker, W.V. and D.M. Glenn. 1985. The relationship of sod proximity to the growth and nutrient composition of newly planted peach trees. HortScience 20:417-418.
- Welker, W.V. and D.M. Glenn. 1989. Sod proximity influences the growth and yield of young peach trees. J. Amer. Soc. Hort. Sci. 114:856-859.
- Welker, W.V. and D.M. Glenn. 1991. Growth response of young peach trees to distribution pattern of vegetation-free area. HortScience 26:1141-1142.

fig. 6. Percent of ground surface covered by grass (A) and broadleaf (B) weeds, estimated by beaded-string transect analysis at beginning of Sept. 1992 (left bars), 1993 (middle bars), and 1994 (right bars), in 4-m² tree-row plots treated with postemergence herbicide at beginning of designated months. Values are means and standard error bars for four observations in each single-month WFT.