Reviews

Biological Assessment of Herbicide Use in Apple Production I. Background and Current Use Estimates

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ADDITIONAL INDEX WORDS. weed control, tree fruit, pesticide impact, *Malus domestica*

SUMMARY. Weed management is an important concern for apple producers. Weeds compete with fruit trees for water, nutrients, light and pollination by insects. Weed competition can dramatically reduce apple tree (*Malus domestica* Borkh.) growth and yield. Weed control practices can impact rodent populations, and insect and disease management in orchards. Use of cultivation can increase soil erosion. Mulches are too expensive for use in orchards and can increase rodent problems. Weeds are generally controlled within the row using

herbicides while a grass sod is often used in row middles for erosion control. The most commonly used postemergence herbicides in apples are glyphosate, paraquat, and 2,4-D. Simazine is the most commonly used preemergence herbicide.

Apples are a valued horticultural crop in the United States, with over 350,000 bearing acres (141,645 ha) in production. One of the important challenges in fruit production is weed control. A variety of weed species infest apple orchards, including summer and winter annuals, and perennials (Derr, 1995; Derr and Chandran, 2000). Tree fruit growers therefore must maintain weed control for longer periods than one would use for an annual crop.

Weeds are managed in fruit production primarily through herbicide application. However, certain important herbicides may no longer be available to growers in the future. Estimated impacts from loss of such herbicides would be beneficial to apple growers and weed control specialists. An assessment of herbicide use in apple production, which was necessary to evaluate the benefits of pesticide use in fruit production and estimate herbicide loss impacts, was conducted using two methods. First, a literature review on the impacts of weed competition and herbicide use on apple growth and yield was completed. Second, a survey was sent to weed control specialists in the top 10 apple producing states. Included with the survey was a copy of the completed literature review and a copy of weed control effectiveness charts for herbicides used in apple production. The survey contained information on apple production and her-

bicide use estimates for their state. Respondents were asked to modify these numbers if they had more current information. Survey respondents were asked to assess the impact of loss for the seven most frequently used herbicides in apple production. This report summarizes results from the literature review and from the returned surveys.

Review of apple weed control

REASONS FOR THE NEED OF A WEED MANAGEMENT PROGRAM IN APPLE PRODUCTION. Common and scientific names for weed species that can infest apple orchards are listed in Table 1. Common summer annual grasses that infest apple orchards include large crabgrass, giant foxtail, and fall panicum (Derr and Chandran, 2000; Derr, 1995). Annual broadleaf weeds that infest tree fruit include common ragweed, ivyleaf morningglory, common lambsquarters and pigweed species. Winter weeds, such as horseweed, fleabane, and common chickweed can infest apple orchards. Perennial grasses are common in orchards, and include johnsongrass, quackgrass, purpletop, tall fescue, orchardgrass, and bermudagrass. Yellow nutsedge, a perennial sedge, can be troublesome in orchards. The hardest to control group are perennial broadleaf weeds such as poison ivy, virginia creeper, japanese honeysuckle, field bindweed, horsenettle, pokeweed, and bramble species including wild blackberry and dewberry. Dandelion and buckhorn plantain are examples of simple perennials that can infest apple orchards. Creeping perennials, such as poison ivy, tend to be harder to manage. Weedy trees, such as black locust and tree of heaven, can invade fruit growing areas.

Weed management is an important component for successful fruit production based on several factors (Derr, 1995). Weeds compete with fruit trees for water, light, nutrients, and space. Weeds will absorb part of the fertilizer destined for the crop and compete especially for nitrogen. Weeds compete with crops for water during drought conditions. If weeds are allowed to overtake fruit trees, their foliage will reduce the amount of sunlight reaching fruit leaves, reducing tree growth and production. Climbing vines also weaken and damage fruit branches.

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The author wishes to thank Jay Brunner, Rakesh Chandran, James Clark, Robert Craswell, Catherine Daniels, Jerry Hull, Clyde Elmore, Paul Vossen, Ian Merwin, Wayne Mitchem, Ann Morrell, Robert Parker, David Rosenberger, Jutta Roosen, Alan Schreiber, Charles Smith, Kent Smith, Tim Smith, Warren Stiles, Michael Willett, Ray William, and Roger Young for their assistance with this project. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.

Besides crop competition, weeds can also interfere with crop harvest. Poison ivy produces a toxin that causes a skin rash, which is thus an important health hazard to those harvesting fruit. Most people are sensitive to this toxin. In addition, weeds with thorns, such as

brambles or horsenettle, pose a hazard to those working in an orchard.

Certain weeds are allelopathic and can inhibit the growth of other plants. Certain weed species have been shown to produce inhibitory chemicals, although much more research is needed

to determine effects on fruit trees. Weeds with allelopathic potential that infest tree fruit include quackgrass, yellow nutsedge and common lambsquarters (Radosevich et al., 1997).

The presence of weed flowers

Table 1. Common and scientific names for species listed in the manuscript.

Classification	Common name	Scientific name
Summer annual grasses	Barnyardgrass	<i>Echinochloa crus-galli</i> L.
	Large crabgrass	<i>Digitaria sanguinalis</i> (L.) Scop.
	Giant foxtail	<i>Setaria faberi</i> Herrm.
	Fall panicum	<i>Panicum dichotomiflorum</i> Michx.
Summer annual broadleaf	Annual morningglories	<i>Ipomoea</i> L.
	Common groundsel	<i>Senecio vulgaris</i> L.
	Common lambsquarters	<i>Chenopodium album</i> L.
	Common ragweed	<i>Ambrosia artemisiifolia</i> L.
	Ivyleaf morningglory	<i>Ipomoea hederacea</i> (L.) Jacq.
	Knotweed	<i>Polygonum</i> L.
	Nightshade	<i>Solanum</i> L.
	Redroot pigweed	<i>Amaranthus retroflexus</i> L. Beauv.
	Smartweed	<i>Polygonum</i> L.
	Common chickweed	<i>Stellaria media</i> (L.) Vill.
Winter annual broadleaf	Fleabane	<i>Erigeron</i> L.
	Horseweed	<i>Conyza canadensis</i> (L.) Cronq.
	Mustard	<i>Brassica</i> L.
	Shepardspurse	<i>Capsella bursa-pastoris</i> (L.) Medicus
Perennial grasses	Bermudagrass	<i>Cynodon dactylon</i> (L.) Pers.
	Johnsongrass	<i>Sorghum halepense</i> (L.) Pers.
	Kentucky bluegrass	<i>Poa pratensis</i> L.
	Orchardgrass	<i>Dactylis glomerata</i> L.
	Purpletop	<i>Tridens flavus</i> (L.) A.S. Hitchc.
	Quackgrass	<i>Elytrigia repens</i> (L.) Nevski
	Tall fescue	<i>Festuca arundinacea</i> Schreb.
Sedges	Yellow nutsedge	<i>Cyperus esculentus</i> L.
Horsetail	Field horsetail	<i>Equisetum arvense</i> L.
Perennial broadleaf weeds	Black locust	<i>Robinia pseudoacacia</i> L.
	Brambles	<i>Rubus</i> L.
	Buckhorn plantain	<i>Plantago lanceolata</i> L.
	Canada thistle	<i>Cirsium arvense</i> (L.) Scop.
	Crownvetch	<i>Coronilla varia</i> L.
	Dandelion	<i>Taraxacum officinale</i> Weber in Wiggers
	Field bindweed	<i>Convolvulus arvensis</i> L.
	Hackberry	<i>Celtis</i> L.
	Horsenettle	<i>Solanum carolinense</i> L.
	Japanese honeysuckle	<i>Lonicera japonica</i> Thunb.
	Mallow	<i>Malva</i> L.
	Milkweed	<i>Asclepias</i> L.
	Poison ivy	<i>Toxicodendron radicans</i> (L.) Ktze
	Pokeweed	<i>Phytolacca americana</i> L.
	Sumac	<i>Rhus</i> L.
	Tree of heaven	<i>Ailanthus altissima</i> (Mill.) Swingle
	Virginia creeper	<i>Parthenocissus quinquefolia</i> (L.) Planch.
	White clover	<i>Trifolium repens</i> L.
Other species	Honey bees	<i>Apis mellifera</i> L.
	Meadow vole	<i>Microtus pennsylvanicus</i> Ord
	Oak	<i>Quercus</i> L.
	Pine vole	<i>Microtus pinetorum</i> LeConte
	Rosy apple aphid	<i>Dysaphis plantaginea</i> Passerini

Table 2. Labeled rates of the active ingredient for the major preemergence and postemergence herbicides used in apple production.

Common name	Rate (a.i.) ^z [lb/acre (kg·ha ⁻¹)]	Comments
Preemergence herbicides		
Diuron	0.8 to 3.2 (0.9–3.6)	Trees established at least 1 year
Napropamide	4.0 (4.5)	Newly planted and established trees
Norflurazon	2.0 to 4.0 (2.2–4.5)	Newly planted and established trees
Oryzalin	2.0 to 6.0 (2.2–6.7)	Newly planted and established trees
Oxyfluorfen	0.5 to 2.0 (0.6–2.2)	Newly planted and established trees
Pendimethalin	2.0 to 4.0 (2.2–4.5)	Nonbearing trees only
Pronamide	1.0 to 4.0 (1.1–4.5)	Trees established at least 1 year
Simazine	2.0 to 4.0 (2.2–4.5)	Trees established at least 1 year
Terbacil	0.8 to 3.2 (0.9–3.6)	Plantings 2 to 3 years and older depending on application
Postemergence herbicides		
2,4-D	1.5 (1.7)	Trees established at least one year
Fluazifop	0.25 to 0.37 (0.28–0.41)	Nonbearing trees only
Glufosinate	0.75 to 1.5 (0.84–1.7)	Trees established at least one year
Glyphosate	1.5 to 5.0 (1.7–5.6)	Newly planted and established trees
Paraquat	0.6 to 0.9 (0.7–1.0)	Newly planted and established trees
Sethoxydim	0.19 to 0.47 (0.21–0.53)	Newly planted and established trees

^zApplication rate is the amount applied per treated acre. For orchards maintained using strip culture, only about one third of the orchard floor receives this rate since row middles are untreated.

during apple bloom may interfere with pollination by honey bees. If bees are pollinating dandelion flowers, for example, they may not pollinate many apple blossoms (Mayer and Lunden, 1991). In some cases, bees may even prefer weed flowers over fruit tree blossoms (Hatjina, 1996). Of the bees found pollinating dandelion flowers at 9:00 AM, 35% to 63% were observed foraging on dandelion later in the morning. Pollen trapped from bees was 72% to 90% oak, and the percentage of dandelion pollen was numerically higher than that of apple pollen (Severson and Parry, 1981).

In another study, however, apple pollen accounted for over 90% of that collected by two colonies of bees during peak apple bloom, with 3% or less collected from dandelion (Lavery and Hiemstra, 1998). Flowering weeds in the orchard can attract bees during the growing season when insecticides are sprayed. Application of an insecticide when white clover flowers are present may result in bee kills or hive kills (W.E. Mitchem, N.C. State Univ., personal communication).

Weeds can harbor insect, disease, and rodent pests, which in turn can adversely affect fruit trees. Tomato ring-spot virus causes apple union necrosis. The virus is present in common orchard weeds, such as dandelion, and may be spread from weeds to apple trees by nematodes (Halbrendt, 1995). Buckhorn plantain harbors rosy apple

aphid (Elmore, 1996; Pfeiffer et al., 1995). Pine and meadow voles thrive in orchards that have dense vegetation under the trees and in the alleys (Sorensen, 1984). Voles caused greater damage in plots maintained with synthetic or hay mulches compared to herbicide application or cultivation (Merwin et al., 1995; Sullivan et al., 1998). Rodent populations are high when weeds such as field bindweed and dandelion are present in an orchard (Elmore, 1996). Weed control can be an important component of integrated management of other apple pests. Due to the indirect effects of weeds on fruit production, it can be difficult estimating the impact of weed management programs on successful fruit production.

Orchard ground cover management can affect frost protection and winter hardiness of apples (Parker, 1992). Systems where the vegetation is mowed short during the spring to increase the vegetation-free area under the tree may result in elevated air temperatures than that seen in a lush vegetative cover. Orchard floor management may provide some protection against frost damage during bloom. Wet, bare soil absorbs the most heat during the day and can release it at night, warming the air around trees. Actively growing grass during radiation frost can reduce air temperature (Skroch, 1992).

Growers often use high-density plantings in new orchards. High-den-

Table 3. National herbicide use in apples as reported in the 1997 Agricultural Chemical Usage Report, National Agricultural Statistics Service, 1997.

Herbicide	Proportion of acres treated (%)	Applications per year (no.)	Rate per application (lb/acre) ^z
2,4-D	14	1.8	0.8
Diuron	8	1.2	1.6
Glyphosate	35	1.5	1.1
Norflurazon	6	1.1	1.7
Oryzalin	7	1.2	2.0
Oxyfluorfen	4	1.1	1.2
Paraquat	26	1.5	0.7
Simazine	19	1.2	1.5
Terbacil	3	1.1	1.1

^z1.0 lb/acre = 1.12 kg·ha⁻¹.

Table 4. Apple acreage and value in the top ten apple producing states, utilizing NASS data (National Agricultural Statistics Service, 1996b) as amended by the survey respondents.

State	Bearing area (acres) ^z	Yield (lb/acre) ^y	Price (\$/lb) ^x
California	37,130	25,220	0.158
Washington	169,000	35,200	0.163
Oregon	8,467	19,720	0.118
Michigan	54,330	20,000	0.090
New York	51,100	18,300	0.130
Ohio	7,900	13,300	0.180
Pennsylvania	22,000	22,409	0.095
North Carolina	9,000	22,200	0.120
Virginia	19,800	18,100	0.088
West Virginia	11,000	15,700	0.094

^z1 acre = 0.4 ha.

^y1 lb/acre = 1.12 kg·ha⁻¹.

^x\$1.00/lb = \$2.20/kg.

sity plantings may be less competitive with weeds than traditionally larger trees and will therefore make weed control more important.

WEED MANAGEMENT IN ORCHARDS.

Since apples are often planted on hill-sides, some type of ground cover is generally necessary to minimize erosion and allow equipment to enter when the soil is wet (Ritchie et al., 1987; Skroch and Shribbs, 1986). Many growers, therefore, use a strip system, where the ground is kept bare in the tree row and mowed sod is grown between the rows. About one-third of the orchard floor is maintained weed-free, while the remaining two thirds (the row middles) is maintained in a grass sod. Therefore, herbicides are applied to only one third the orchard floor. Bare soil within the row is usually maintained through application of preemergence and postemergence herbicides, although cultivation is used in some orchards. Mulches, bare ground, and total orchard floor cover are alternative vegetation management systems used by some apple growers (Ritchie et al., 1987).

HERBICIDE USE IN APPLE PRODUCTION. A variety of preemergence and postemergence herbicides are used in fruit production (Derr and Chandran, 2000). Herbicide use in a given orchard is determined by tree age and the major weed species present. Weed control is probably most important during the first few years after planting, while trees are still in a nonbearing stage. As trees increase in size and provide increasing amounts of shade,

weeds should be less competitive with fruit trees. Certain herbicides are used primarily in young plantings since they pose less risk of crop injury than other herbicides. Growers utilize broader-spectrum herbicides after trees have become established. Since certain herbicides may only be used in the establishment phase, their importance may not be realized when utilizing data solely from bearing trees. This is important, since pesticide surveys are often directed exclusively towards bearing trees. Also, certain products are only registered for use on nonbearing fruit. These chemicals, therefore, could not serve as an alternative for a bearing orchard if use of another herbicide was discontinued.

Preemergence herbicides are used in tree fruit primarily for residual control of annual weeds, although certain preemergence herbicides suppress herbaceous perennial weeds (Table 2). Table 3 lists National Agricultural Statistics Service (NASS) estimates of national herbicide use in apples.

Preemergence herbicides are usually applied in spring. Certain growers will make a second preemergence application in midsummer to extend the period of weed control through the growing season. Fall applications of preemergence herbicides are made by a limited number of growers. Combinations of two or more preemergence herbicides are often used to broaden the spectrum of weed control.

The herbicides oryzalin, napropamide, pendimethalin, and norflurazon primarily control annual grasses and small-seeded broadleaf

weeds (Derr and Chandran, 2000). Oxyflourfen, simazine, diuron, and terbacil control a greater range of annual broadleaf weeds. Pronamide is used for preemergence and postemergence control of cool-season perennial grasses and selected winter weeds. Most preemergence herbicides do not control perennial weeds. One exception is terbacil, which suppresses certain herbaceous perennial weeds. None of the preemergence herbicides control troublesome perennial broadleaf weeds like wild blackberry, poison ivy, and honeysuckle. The most commonly applied preemergence herbicide is simazine (Table 3).

Postemergence herbicides are used to control existing vegetation. Since perennial weeds are generally not controlled by preemergence herbicides, postemergence chemicals are also used to control these weeds. Woody perennial weeds cannot be controlled through application of any preemergence herbicide. A postemergence herbicide is generally tank mixed with preemergence herbicides to control existing weeds as well as providing residual control. Glyphosate is the most frequently applied postemergence herbicide, followed by paraquat and 2,4-D (Table 3).

The contact herbicide paraquat is applied in spring for rapid control of existing weed foliage. A second application of paraquat is sometimes made in midsummer for weeds not controlled by the residual herbicide that was applied in spring. Contact herbicides such as paraquat will not affect the root system of perennial weeds so repeat applications are required for control. The remaining postemergence herbicides are systemic in plants. Sethoxydim and fluzifop are used strictly for annual and perennial grass control. The herbicide 2,4-D is used for controlling certain annual and perennial broadleaf weeds. Since 2,4-D selectively controls broadleaves and does not injure grasses, it is used for broadleaf weed control in row middles. It is essentially the only apple herbicide that can be used both in the row and in row middles where a grass sod is being maintained. Glyphosate is occasionally used in row middles for sod suppression, but the application rate is much lower than that used for weed control within the row. Glyphosate and glufosinate are used for annual

and perennial weed control. These two chemicals are nonselective, so careful application is needed to avoid tree damage.

IMPACT OF WEED CONTROL METHOD ON APPLE TREE GROWTH AND YIELD. Numerous studies have shown decreased apple tree growth and yield when weeds are not controlled. Yields for apples grown in grass sod maintained by mowing are considerably lower than in plots maintained free of vegetation using herbicides or cultivation. Crop yield in plots maintained with mulch are sometimes higher than in plots maintained by herbicides or cultivation, perhaps due to less soil compaction and greater water penetration (Jayant et al., 1999; Merwin et al., 1995). Mulches however are expensive and therefore generally not used in commercial orchards (Merwin, 1995). Also, rodents and root diseases may increase in mulched plots. Crop yields in cultivated plots are generally similar to plots maintained with herbicides, although some studies have shown lower yields in tilled plots, perhaps due to root damage. Cultivation may also contribute to soil erosion since apples are often grown on hill-

sides. Crop yields in plots treated with different preemergence or postemergence herbicides are often similar, although weed species shifts can occur with repeated application of a single herbicide.

Competition from grass weeds or annual weeds reduced apple yield by 16 to 49%, depending on year, when compared to herbicide-treated plots (Atkinson and White, 1981). Fruit were smaller in grass or annual weed plots than in herbicide-treated plots. Due to competition from grass or annual weeds, financial losses were 25% to 55% in these plots when compared to herbicide-treated plots. Maintaining weed free areas around newly planted apple trees in early summer appears to be more beneficial than areas maintained weed-free in late summer (Merwin and Ray, 1997). Yields increased as the duration of area maintained weed free increased.

Total cumulative yield decreased 27% and the number of large fruit decreased 57% when no weed control was practiced, compared to herbicide-treated plots (Schupp and McCue, 1996). Plots maintained with in-row rotary tilling had similar yields to plots

treated with herbicides. Weed control was better with in-row rotary tilling plus herbicide application than in-row tilling or herbicide alone treatments. Apple trunk cross-sectional diameter was similar in herbicide-treated and in-row tillage treatments, and was about twice that of untreated plots. In another study, apple trunk girth, shoot length, and fruit yield were higher in herbicide-treated plots than in plots maintained with clean cultivation (Jayant et al., 1999).

Tree growth increased with increasing levels of weed control (Mellenthin et al., 1965). Simazine and diuron-treated plots were similar in overall weed control and tree growth. However, shifts in the weed population occurred. Redroot pigweed and barnyardgrass increased in simazine-treated plots while plantains and smartweed increased in diuron-treated plots, indicating the need for chemical combinations and rotations to achieve maximum weed control. Maximum decrease in tree growth due to weed competition occurred in the first 2 years after planting, but significant decreases in growth in untreated plots extended to the third and fourth years,

Table 5. Respondents estimates of the most troublesome weeds infesting apple orchards.

Western states				
Annual broadleaves				
Pigweed sp.	Common lambsquarters	Nightshade sp.	Horseweed	
Shepardspurse	Mustard sp.	Fleabane species	Knotweed sp.	
Common groundsel				
Annual grasses				
Barnyardgrass	Foxtail sp.			
Perennial broadleaves				
Field bindweed	Mallow sp.	Canada thistle	Dandelion	
Plantain sp.	Milkweed sp.			
Perennial grasses				
Bermudagrass	Kentucky bluegrass	Johnsongrass	Quackgrass	
Other				
Yellow nutsedge	Horsetail			
Eastern states				
Annual broadleaves				
Pigweed sp.	Common lambsquarters	Mustard sp.	Morningglory sp.	
Shepardspurse				
Annual grasses				
Fall panicum	Foxtail sp.			
Perennial broadleaves				
Bindweed sp.	Bramble sp.	Canada thistle	Dandelion	Hackberry
Horsenettle	Plantain sp.	Poison ivy	Sumac	White clover
Virginia creeper				
Perennial grasses				
Tall fescue	Johnsongrass	Quackgrass		
Other				
Yellow nutsedge				

showing a need for continued weed control. In the second year of the study, plots treated in the spring with simazine or diuron had over twice the increase in trunk circumference compared to untreated plots at one location. The potential advantages of alternating herbicides include a possible decrease of residue buildup and decreased weed resistance (Langer et al., 1973).

Apples were more vigorous and established better under weed-free conditions using simazine than in overall clover, overall grass, or alleyway grass treatments (Stinchcombe and Stott, 1983). Apple trees grew best in a straw mulch when compared to cultivated or herbicide-treated plots (Baxter, 1970). Apple trees in herbicide-treated plots were similar in size to plots maintained with cultivation (Baxter, 1970; Schribbs and Skroch, 1986). Apples treated with herbicides had higher yield, greater trunk area increase, and greater increase in mean shoot length than grass sod plots (Baxter and Newman, 1971). Yields were 38 to 59% higher in herbicide-treated plots than in plots with mowed sod.

Similar yield was observed in terbacil, diuron, and simazine-treated plots, and yield in these herbicide-treated plots were twice the yield in full groundcover plots (Hogue and Neilsen, 1987). Yield was 46% higher in simazine-treated plots, 32% higher in diuron-treated plots, and 29% higher in terbacil-treated plots compared to mowed plots (Heeney et al., 1981). Vetch increased in simazine-treated plots. Apple yield was similar in paraquat and glyphosate-treated plots (Rupp and Anderson, 1985). Trees from herbicide-treated plots came into production sooner than trees where weeds were not controlled.

When different strip management systems were studied, mechanical weed control and grass alley treatments yielded less than herbicide-treated or wood mulch strips (Engel and Vedder, 1993). Soil moisture was lowest in the grass alleys plots, followed by mechanical cultivation, and was highest in wood mulch plots. Plots maintained using glyphosate or preemergence herbicides outyielded tilled, mowed sod, and crownvetch plots, and were equal to straw mulch plots in the first major crop harvest (Merwin and Stiles, 1994). However, straw mulch was the most expensive treatment to establish, and tree mortality caused by root disease and meadow voles were unacceptably

high in straw mulch. Apple yield was higher under herbicide use than in turf-grass or mulched plots (Merwin, 1993). Herbicide strips are the cheapest effective weed control program and thus the

one most widely used by fruit growers (Merwin, 1995). Mulches were much more expensive than herbicides or cultivation for weed control. There was no difference in total yield between culti-

Table 6. National Agricultural Statistics Service (NASS) estimates (National Agricultural Statistics Service, 1994, 1996a) of 2,4-D use as amended by survey respondents.

State	Acres treated (%)	Rate (a.i.) (lb/acre) ^z	Applications per year (no.)
California	4	0.8	1.4
Washington	16	0.9	1.7
Oregon	30	0.3	1.7
Michigan	12	0.9	1.1
New York	12	0.8	1.2
Ohio	13	0.8	1.4
Pennsylvania	45	1.2	1.2
West Virginia	42	1.5	1.0
North Carolina	50	1.0	1.2
Virginia	20	1.5	1.0

^z1.0 lb/acre = 1.12 kg·ha⁻¹.

Table 7. National Agricultural Statistics Service (National Agricultural Statistics Service, 1994, 1996a) estimates of diuron use, as amended by survey respondents.

State	Acres treated (%)	Rate (a.i.) (lb/acre) ^z	Applications per year (no.)
California	3	1.2	1.1
Washington	20	1.4	1.1
Oregon	27	0.7	1.2
Michigan	5	2.0	1.0
Ohio	10	1.2	1.1
New York	10	1.4	1.1
Pennsylvania	26	1.6	1.2
West Virginia	25	1.7	1.0
North Carolina	40	2.0	1.0
Virginia	20	1.8	1.0

^z1.0 lb/acre = 1.12 kg·ha⁻¹.

Table 8. National Agricultural Statistics Service (National Agricultural Statistics Service, 1994, 1996a) estimates of glyphosate use as amended by survey respondents.

State	Acres treated (%)	Rate (a.i.) (lb/acre) ^z	Applications per year (no.)
California	61	0.5	1.9
Washington	66	1.0	1.7
Oregon	58	0.7	1.6
Michigan	35	1.0	1.2
Ohio	31	0.9	1.5
New York	40	1.5	1.1
Pennsylvania	6	0.8	1.0
West Virginia	27	2.0	1.4
North Carolina	85	1.0	1.1
Virginia	25	2.0	1.0

^z1.0 lb/acre = 1.12 kg·ha⁻¹.

vated, preemergence plus post-emergence herbicides, or paraquat alone treated plots, and apples in all three

treatments had a higher yield efficiency than ones maintained in grass sod (Crabtree and Westwood, 1976).

Table 9. National Agricultural Statistics Service (National Agricultural Statistics Service, 1994, 1996a) estimates of norflurazon use, as amended by survey respondents.

State	Acres treated (%)	Rate (a.i.) (lb/acre) ^z	Applications per year (no.)
California	9	1.0	1.1
Washington	40	1.5	1.1
Oregon	9	0.9	1.0
Michigan	9	1.5	1.0
Ohio	5	1.3	1.1
New York	15	2.4	1.0
Pennsylvania	8	1.7	1.0
West Virginia	6	1.8	1.0
North Carolina	5	2.4	1.0
Virginia	10	1.8	1.0

^z1.0 lb/acre = 1.12 kg·ha⁻¹.

Table 10. National Agricultural Statistics Service (National Agricultural Statistics Service, 1994, 1996a) estimates of oryzalin use, as amended by survey respondents.

State	Acres treated (%)	Rate (a.i.) (lb/acre) ^z	Applications per year (no.)
California	12	3.0	1.0
Washington	20	2.1	1.1
Oregon	3	3.7	1.0
Michigan	9	2.0	1.0
Ohio	3	1.9	1.2
New York	5	5.0	1.0
Pennsylvania	0		
West Virginia	7	1.9	1.0
North Carolina	5	2.0	1.0
Virginia	3	2.0	1.0

^z1.0 lb/acre = 1.12 kg·ha⁻¹.

Table 11. National Agricultural Statistics Service (National Agricultural Statistics Service, 1994, 1996a) estimates of paraquat use, as amended by survey respondents.

State	Acres treated (%)	Rate (a.i.) (lb/acre) ^z	Applications per year (no.)
California	38	0.6	2.1
Washington	33	0.8	1.4
Oregon	33	0.3	1.8
Michigan	40	0.8	1.2
Ohio	20	0.6	1.4
New York	25	0.5	1.4
Pennsylvania	32	0.6	1.4
West Virginia	63	0.6	1.7
North Carolina	40	0.9	1.8
Virginia	60	0.6	1.5

^z1.0 lb/acre = 1.12 kg·ha⁻¹.

Assessment of impacts following herbicide loss using a survey

SURVEY METHODS. A project was undertaken through financial support of the National Pesticide Impact Assessment Program (NAPIAP) to estimate the impact of loss in herbicide registrations. The project utilized a survey mailed to weed control specialists in the top ten apple producing states to estimate potential impacts. Surveys were sent to university researchers, extension personnel, and private consultants in Washington, Oregon, California, Michigan, Ohio, New York, Pennsylvania, West Virginia, Virginia, and North Carolina.

Respondents were provided with average crop production estimates for their state based on 1993, 1994, and 1995 NASS data and estimates of current herbicide use using 1993 and 1995 NASS data (National Agricultural Statistics Service, 1996a, 1996b, 1994). A brief literature review of weed impacts on apple production, along with ratings of herbicide effectiveness against common orchard weeds was included with the survey. The survey asked for a listing of the most important weeds infesting apple production in their state. Respondents were asked for current estimates on apple acreage in production, yield per acre, and price per pound for their state. Respondents were asked to comment on estimated herbicide usage in their state. When multiple surveys were returned from a given state, the estimates were averaged.

Survey results

A total of 15 surveys were returned out of 21 mailed to university researchers, extension personnel, and crop consultants. Surveys were returned from all states except Ohio. For the nine states where surveys were received, Washington had the largest acreage, followed by Michigan, New York, California, Pennsylvania, Virginia, West Virginia, North Carolina, and Oregon (Table 4). Based on NASS estimates, Ohio ranked tenth in apple production. Production ranged from about 15,000 to 35,200 lb/acre (16,800 to 39,200 kg·ha⁻¹). Apple prices averaged \$0.09 to \$0.16/lb (\$0.2 to \$0.35/kg).

Major weeds infesting apple production

The respondents listed a variety of troublesome weed species in apple production (Table 5). Overall, the most

Table 12. National Agricultural Statistics Service (National Agricultural Statistics Service, 1994, 1996a) estimates of simazine use, as amended by survey respondents.

State	Acres treated (%)	Rate (a.i.) (lb/acre) ²	Applications per year (no.)
California	14	1.5	1.1
Washington	50	1.6	1.1
Oregon	13	1.5	1.0
Michigan	35	2.0	1.0
Ohio	18	1.6	1.1
New York	40	2.2	1.1
Pennsylvania	30	2.4	1.2
West Virginia	38	1.6	1.0
North Carolina	40	3.0	1.1
Virginia	40	2.0	1.0

²1.0 lb/acre = 1.12 kg·ha⁻¹.

troublesome weeds are perennial grasses and perennial broadleaves. Most of the annuals listed are summer weeds, although a few winter annual broadleaves are of importance in fruit production. There was considerable overlap in the lists of most troublesome weeds in the eastern and western U.S. For example, common lambsquarters, pigweed species, foxtail species, and mustard species are common annual weeds in eastern and western orchards. Dandelion, bindweed, canada thistle, and plantain species are troublesome perennial broadleaves in both the eastern and western U.S. Johnsongrass, quackgrass, and yellow nutsedge are important perennial monocot weeds in both regions.

Current herbicide use

2,4-D. Use of 2,4-D ranged from 4% to 50% of apple acreage, depending upon state (Table 6). Use for the western states (Washington, Oregon, and California) averaged 17% of total acreage at (a.i.) 0.7 lb/acre (0.8 kg·ha⁻¹) with 1.6 applications per year. Use for the eastern states (Michigan, Pennsylvania, New York, West Virginia, Virginia, and North Carolina) averaged 28% of total acreage at (a.i.) 1.1 lb/acre (1.2 kg·ha⁻¹) with 1.2 applications per year. In another survey, about 25% of the apple acreage was treated yearly with 2,4-D (Elmore, 1996), similar results to that seen with the returned surveys (Table 6).

DIURON. Use of diuron in the western states averaged 17% of total acreage at (a.i.) 1.1 lb/acre (1.2 kg·ha⁻¹) and 1.1 applications per year (Table 7). Use for the eastern states averaged

19% of total acreage at (a.i.) 1.7 lb/acre (1.9 kg·ha⁻¹) with 1.1 applications per year. Based on these estimates, diuron use appears to be similar in the eastern and western United States.

GLYPHOSATE. Glyphosate was used on 62% of the acreage at (a.i.) 0.7 lb/acre (0.8 kg·ha⁻¹) and 1.7 applications per year in the western states (Table 8). Use for the eastern states was 36% of the acreage treated at (a.i.) 1.3 lb/acre (1.5 kg·ha⁻¹) and 1.2 applications per year. Use patterns for glyphosate varied among states, perhaps due to grower preferences or localized weed problems.

NORFLURAZON. Use of norflurazon in the western states averaged 19% of total acreage at (a.i.) 1.1 lb/acre (1.2 kg·ha⁻¹) with 1.1 applications per year (Table 9). Use for the eastern states averaged 8% of total acreage at (a.i.) 1.8 lb/acre (2.0 kg·ha⁻¹) with 1.0 applications per year.

ORYZALIN. Use of oryzalin in the western states averaged 12% of total acreage at (a.i.) 2.9 lb/acre (3.2 kg·ha⁻¹) with 1.0 applications per year (Table 10). Use for the eastern states averaged 5% of total acreage treated at (a.i.) 2.5 lb/acre (2.8 kg·ha⁻¹) with 1.0 applications per year. Both oryzalin and norflurazon can be used on newly planted apple orchards (Derr and Chandran, 2000). Although estimates indicate low use of these compounds, estimates would probably be much higher if the survey was limited to applications made to nonbearing plantings. On older trees, growers can utilize additional chemicals that may be lower in cost or provide broader-spectrum weed control.

PARAQUAT. Use of paraquat in the western states averaged 35% of total acreage at (a.i.) 0.6 lb/acre (0.7 kg·ha⁻¹) with 1.8 applications per year (Table 11). Use for the eastern states averaged 40% of total acreage at (a.i.) 0.7 lb/acre (0.8 kg·ha⁻¹) with 1.5 applications per year. Paraquat use appears to be similar across the apple-producing states.

SIMAZINE. Use of simazine in the western states averaged 26% of total acreage at (a.i.) 1.5 lb/acre (1.7 kg·ha⁻¹) with 1.1 applications per year (Table 12). Use for the eastern states averaged 34% of the acreage treated at (a.i.) 2.1 lb/acre (2.4 kg·ha⁻¹) with 1.1 applications per year. Simazine use appears to be similar across the top apple production regions.

Summary and conclusions

The spectrum of weeds infesting apple orchards in the western and the eastern U.S. are similar. Annual grasses and broadleaves, perennial grasses and broadleaves, and yellow nutsedge infest fruit orchards in the United States. In general, the eastern and the western states have similar use patterns for 2,4-D, diuron, glyphosate, norflurazon, oryzalin, paraquat, and simazine. Simazine is the most commonly applied preemergence herbicide, while glyphosate is the most frequently applied postemergence herbicide in apple production.

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