Use of 2,4-D and Other Phenoxy Herbicides in Orchard,Vineyard, Hops, and Soft Fruit Production in the United States

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- The loss of 2,4-D could cause significant economic and production challenges in some tree, vine, and fruit crops.
- 2,4-D has a unique fit in production systems that use grass cover crops between or within the rows of perennial fruit and nut plants. No other available post-emergence herbicide can provide the same level of broadleaf weed control without causing significant damage to grass cover crops.
- 2,4-D isopropyl ester can be used at very low rates as a growth regulator on some citrus crops.

Introduction

The orchard, vineyard, and berry crop group has undergone many changes since the last review of the importance of phenoxy herbicides in U.S. crops. Most notable among these is the increasing production intensity of tree crops in the western U.S. as well as the expanding acreage and increasing value of fruit and nut crops in general.

2,4-D is the only phenoxy herbicide widely registered in the diverse group of orchard, vineyard, and berry crops. The registration status and importance of 2,4-D for control of weeds varies greatly regionally and among crops. Many of the crops in this group are relatively sensitive to injury from 2,4-D which limits both registration and use; however, it remains critical in some crops that have few other options. As in other crop groups, the primary use of 2,4-D in orchards, vineyards, and fruiting fields is for control of broadleaf weeds. Its most important niches in this crop group are for control of perennial weed species and for control of broadleaf weeds in grass alleyways between tree or vine rows. While of only modest importance to these crops in the aggregate, 2,4-D is an important crop management tool for specific crops and situations. The impact of a loss of 2,4-D registration in tree, vine, and berry crops could range from virtually unnoticed in some tree, vine, and fruit crops to great economic and production challenges in others.

The importance of phenoxy herbicides

Compared to some other crop groups, the phenoxy herbicides and other synthetic auxin herbicides (WSSA Group 4) are not widely used in orchard, vineyard, and berry systems as a whole. However, in some specific crop and weed scenarios these herbicides are quite important.

The only phenoxy herbicide widely registered in tree, vine, or berry crops in the US currently is 2,4-D. Although there a few registered uses of other synthetic auxins, including picolinic acid (e.g. clopyralid) and pyridine herbicides (e.g. fluroxpyr), these are typically local registrations and not within the scope of this review.

As in other crops, the principal use of 2,4-D in orchard, vineyard, and berry production systems is for selective post-emergence control of annual and perennial broadleaf weeds. Many of these crops are produced with grass cover between the crop rows to reduce erosion and maintain orchard access during the winter; 2,4-D can be an important tool for selective control of broadleaf weeds in these situations (Ingels et al. 1998; McCurdy et al. 2013).

In recent years, for some regions and crops, 2,4-D has become a somewhat more important weed control tool due to the evolution of glyphosate-resistant broadleaf weeds (e.g. hairy fleabane and horseweed or marestail), or shifts to tolerant species (e.g. panicle willowherb, sharppoint fluevellin, and cutleaf evening primrose) in orchards and vineyards (Hanson et al. 2014). 2,4-D is also used for weed control in summer renovation of matted-row strawberry as well as being used, often mixed with glyphosate, to remove strawberry and raspberry plantations prior to planting a rotational crop.

Currently, the 2,4-D amine (dimethylamine salt) formulation is registered in many crop sectors including apple, pear, stone fruit, and nuts. However, it is not registered in some tree crops (e.g. fig, olive, persimmon, pomegranate, and quince), some berries (e.g. caneberry), or in other minor crops (e.g. kiwifruit or guava) and is not registered in California for any crops in this group.

Another 2,4-D formulation (triethylamine salt) is registered for use in almond, apple, apricot, grape, nectarine, peach, pear, pecan, pistachio, plum, prune, and walnut crops in California, Washington, and Oregon, as well as for control of rootstock suckers for Oregon's hazelnut crop. Most of these products are registered for use on trees and vines that are more than three years of age for control of susceptible annual and perennial weeds. Other formulations and special local need labels may be available for state registrations in some crops. One example is the isopropyl ester of 2,4-D which is registered as a plant growth regulator in navel orange and grapefruit crops. It is used on young fruit to reduce fruit drop. This has allowed longer harvest periods of high quality navel orange and grapefruit crops in Arizona and California. This is the only registration where 2,4-D is applied directly to the tree. Registration (and re-registration) of 2,4-D has been difficult in orchard and vineyard crops due to their relatively small acreage, lack of patent protection for the product, cost of registration, lack of support for re-registration, and the risk of significant crop injury on high-value crops in the event of drift, volatilization, or should other crop exposure occur.

Crop Specific Information

Apple: There were approximately 328,000 acres of apples produced in the US in 2013, down slightly from 350,000 acres in the late 2000s (NASS 2014). Washington produces about 48% of the national total; other states with large apple acreages include California, Michigan, New York, Pennsylvania, and Virginia.

The primary use of 2,4-D in apple crops is to selectively remove perennial broadleaf weeds in perennial grass cover on the orchard floor. These include field bindweed, dandelion, common catsear, and hawksbeards. In orchards where bare ground is chemically maintained in the tree row, 2,4-D is also sometimes used. Tall weeds in this strip, such as horseweed, Canada thistle, annual sow thistle, curly dock, and common cocklebur interfere with workers at harvest and are typically removed using herbicides or by mowing. 2,4-D may be applied at up to 1.4 lbs ae/acre in apple, with a pre-harvest interval of 14 days. Some apple cultivars (Gala, Fuji, and Golden Delicious, in particular) are more sensitive to 2,4-D than other apple cultivars, so growers are usually careful to apply to orchards with less sensitive cultivars. Approximately 20% of the apple acreage in Washington is treated with 2,4-D annually.

The primary use of 2,4-D in apple crops is to selectively remove perennial broadleaf weeds in perennial grass cover on the orchard floor.

Loss of 2,4-D as a selective material would limit cover crop options for apple orchards. There are few alternatives to 2,4-D in the grass cover crop between tree rows, particularly for perennial broadleaf weed species. Clopyralid may replace 2,4-D for weed species primarily in Asteraceae (such as Canada thistle or dandelion), but it provides little control of problem weeds from other plant families such as Polygonaceae (curly dock) or Convolvulaceae (field bindweed). Reduced rates of sethoxydim are sometimes used for growth suppression of grass, but this herbicide does not control broadleaf weeds. Glyphosate may also be applied to established grass cover crops at reduced rates, but such rates will not control established perennial weeds and may cause them to develop an herbicide resistance.

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The primary post-emergence herbicide used to control perennial weeds in the bare ground strip under a tree row is glyphosate. Apple growers who currently apply 2,4-D for this use would likely use glyphosate, or one or several of the other foliar-applied, translocated herbicides registered for use in apple crops. Halosulfuron and rimsulfuron will control many broadleaf annual weeds, but only suppress most perennial species. Use of dormant-season herbicides, such as dichlobenil, norflurazon, indaziflam, and pronamide, might result in an increased suppression of certain perennial weeds, but control is not as reliable as with 2,4-D, and potential for tree injury is greater. Loss of 2,4-D will not appreciably reduce a grower's ability to control annual broadleaf weeds, as there are many pre-emergence and post-emergence herbicides available for control of those species in apple crops. However, the cost of most of these herbicides is much higher than for similar applications of 2,4-D.

Increased use of mowing for weed control in apple crops will likely occur if 2,4-D was no longer registered. This would increase fuel cost and potentially increase the hazards of working with farm equipment if multiple mowing operations are used in place of a single 2,4-D application. There is also increased potential for physical damage to trees when equipment is operated close to the trees. Finally, reliance on mowing alone will result in a shift of weed species to those capable of withstanding mowing, such as low-growing weeds and perennial species.

Avocado: California produces in excess of 90% of all avocados produced in the US and Florida produces most of the remainder. There is a registration of 2,4-D in non-bearing avocado in California but very little is actually used (only 4 acres treated in 2012 [CADPR 2012]). By far, the two most important herbicides used in California avocado groves are glyphosate and simazine. Avocado producers would not face significant losses if 2,4-D were unavailable.

Blueberry: Blueberry acreage has been rapidly expanding in the US and worldwide in recent years. Blueberries were produced on about 79,000 acres in the US in 2013 - a 23% increase from 60,500 acres in 2008. Major blueberry producing states are California, Georgia, Michigan, New Jersey, North Carolina, Oregon, and Washington. Approximately 515 million pounds of cultivated blueberries were produced in the US in 2013. Wild blueberry, primarily produced in Maine, accounted for an additional 87 million pounds of fruit from 60,000 acres of production.

2,4-D is not registered for use in blueberry crops in California. In other blueberry producing states, the primary use of 2,4-D is in the grass cover crop grown between cultivated blueberry rows, but 2,4-D is not used at all in wild blueberry production. When used, 2,4-D can control difficult perennial broadleaf weeds such as Canada thistle, dandelion, curly dock, field bindweed, and wild blackberry. 2,4-D may be applied at rates up to 1.43 lbs ae/acre directed to the weeds or grass strips between rows using a shielded sprayer. If this 2,4-D registration is lost, clopyralid will likely be the primary replacement herbicide, particularly in blueberry plantings with grass cover crops. Clopyralid is more expensive than 2,4-D for this use, however, and the spectrum of weed control is limited primarily to weeds in the Asteraceae (such as Canada thistle and dandelion) and Fabaceae (such as clover) families. Clopyralid is not registered for blueberry crops in California.

Mowing will likely be used more frequently if this 2,4-D registration is lost, resulting in additional operating expenses and increased greenhouse gas emissions. Application of a selective herbicide such as 2,4-D often is preferable to mowing for management of perennial weeds in the alleyways because control usually is more complete and longer lasting. A single use application of 2,4-D is equivalent in cost to a single mowing cost of $13/acre, however, multiple mowings are required in a season (Jimenz et al. 2009). Additional mowing operations would have a significant impact on grower economics. Furthermore, mowing is not an option from approximately one month prior to harvest until harvest completion, as equipment brushing against blueberry bushes results in an unacceptable level of fruit loss as berries ripen.

Caneberry (blackberry, raspberry): Fruiting caneberries, also known as brambles, consist of blackberries, raspberries, and their various hybrids. Raspberries (predominantly red raspberry) are produced on about 18,000 acres; blackberries are grown on 6,000 acres, while 500 acres of marionberries and 50 acres of loganberries are also produced in the US. Caneberries as a whole are not tolerant to 2,4-D and therefore this herbicide is not registered for use in these crops.

Citrus (orange, grapefruit, lemon): There is little or no use of 2,4-D for weed control in citrus groves. However, in California and Arizona, 2,4-D isopropyl ester can be used at very low rates as a growth regulator on some citrus crops. Typically, in this use pattern, 2,4-D is applied on navel orange and grapefruit crops from October or November at about 0.06 lb/A, or at 0.03 lb/A in December to January. This application prevents formation of the abscission layer in January so the fruit will not fall from the tree. In the fresh citrus industry, this use allows fruit to be harvested into June rather than only March or April and can reduce cold storage costs and increase product quality for the consumer.

Cranberry: Cranberries are grown on about 42,000 acres in the US, with about 50% of the production in Wisconsin. Other cranberry-producing states include Massachusetts, Michigan, New Jersey, and Washington. Cranberries are a low-growing perennial vine and very susceptible to weed competition, particularly when bogs are being established. Weeds also foul harvesting equipment thereby contaminating fruit and reducing harvest efficiency.

2,4-D is registered for application to dormant, established cranberry crops at rates of 2 to 4 lb ae/acre. The higher rates are used as spot treatments on certain perennial weeds, while lower rates typically are used in combination with other herbicides. Moderate rates (3 lb ae/acre) are often used in combination with dichlobenil, used in split treatments (half in February, half in March) to improve control of some of the more persistent perennial weeds. This application timing is difficult for cranberry producers who maintain ice or apply water on their fields through the winter and early spring, or for sites with saturated soil during dormancy. In some areas, 2,4-D may be applied using a wiper applicator to broadleaf weeds that are tall enough to extend beyond the cranberry leaf canopy. Glyphosate is often mixed with 2,4-D for these applications to broaden the spectrum of activity. Wiper treatments aid in the management of perennial weeds that are not well controlled by dormant season applications and are otherwise poorly controlled in cranberry bogs. Herbicides such as norflurazon and clopyralid may also be applied to dormant cranberry for control of broadleaf weeds, while chlorimuron, mesotrione, or quinclorac can be used during the non-dormant period.

Although not widely used due to concerns about crop safety, loss of 2,4-D in cranberry production would result in poorer control of weeds such as yellow loosestrife, dewberry, greenbrier, asters, goldenrods, sedges, and cinquefoil. Wiper applications with glyphosate or clopyralid would likely continue to be used, but with reduced efficacy. Clipping or removal of individual weeds by hand would increase, although hand weeding is more expensive in terms of labor costs (e.g., up to $150 hour/acre/year; Schaeffer et al. 1995), is less effective for control of perennial species, and is usually accompanied by disruption to cranberry uprights and roots.

Grape: Grape cultivars are of several types, depending on how the fruit is ultimately to be used. These cultivars include wine grapes, juice grapes, table grapes, and grapes grown for dried fruit (raisins). Taken together, grapevines are grown on just over 1 million acres in the US. The top ten grape-growing states in 2014 included California, Michigan, Missouri, New York, Ohio, Oregon, Pennsylvania, Texas, Virginia, and Washington (NASS 2014).

2,4-D has minimal use in vineyards because of the potential for crop injury (Bettiga 2013). Grapes are very sensitive to 2,4-D; even low rates can extensively damage grapevines if drifted onto foliage or fresh pruning wounds. Grapes are most easily injured if 2,4-D drift occurs during or immediately after flowering. However, some growers use 2,4-D to control broadleaf weeds between vine rows during the dormant period or during the growing season using shielded sprayers and low-pressure flooding nozzles, or as a spot-treatment with directed sprays. In some regions, 2,4-D applied to grass cover crops between grape rows prior to budbreak is a particularly important use and one that does not have an easy replacement. Field bindweed, common St. Johnswort, dandelion, and Russian knapweed are perennial broadleaf weeds in vineyards that would be particularly difficult to control without 2,4-D.

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There are several alternative herbicides for broadleaf weed control in grape vineyards. Diuron, indaziflam, napropamide, norflurazon, oryzalin, pendimethalin, pronamide, and simazine applied pre-emergence will control many annual broadleaf weeds. Dichlobenil applied to dormant vines will control most annual broadleaf weeds and will suppress field bindweed but has marginal crop safety on young vines. Trifluralin will also control field bindweed, but it requires special equipment and application methods due to its volatility. Herbicides with pre-emergence and post-emergence activity include flazasulfuron, flumioxazin, oxyfluorfen, and rimsulfuron. None of these herbicides can be used without damage to grass cover crops in alleyways.

Cultivation equipment can be used to control most weeds in vineyards but is not very effective on weeds like field bindweed. Cultivation is incompatible with no-till grape culture, which is the desired method of managing vineyards by many farmers and is especially important in vineyards with moderate or steeply sloping topography due to concerns about erosion and runoff. Mowing can be used effectively in vineyard alleyways, especially when combined with chemical control. Reliance on mowing alone, however, will likely give the competitive advantage to low-growing weeds and perennial species. Mowing is also more expensive, potentially more hazardous to workers, less effective on perennial broadleaf weeds, and can cause injury to vines from contact with mowing equipment. Depending on the rockiness of site, mowing may not be a viable option at all for weed control in some vineyards.

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Kiwifruit: California is responsible for 98% of the kiwifruit produced in the US, on about 4,200 acres. There is no current (2014) registration of 2,4-D in kiwifruit although there was a small usage reported in 2012 (CADPR 2012). Glyphosate is the most important herbicide used in California kiwifruit production. Kiwifruit producers would not face significant losses if 2,4-D were unavailable.

Pear: Pears are grown on about 50,000 acres in the US, with greater than 90% of the production in Washington, California, and Oregon. While pears are widely known to be susceptible to 2,4-D drift injury, this herbicide is very important for control of established perennial weeds in pear orchards, with an estimated 15% of the pear acreage treated annually in the Northwest, but less than 10% in California. Troublesome broadleaf perennial weed species in pear orchards include Canada thistle, curly dock, dandelion, and field bindweed.

The grass cover crop planted between pear rows is where the majority of 2,4-D applications are made. The registered use rate is 0.95 to 1.4 lb ae/acre, preferably applied in the fall following fruit harvest. Applications are recommended after irrigation or rainfall to improve foliar uptake and translocation in treated weeds, and to reduce the amount of root uptake that would occur if irrigation is applied within 10 days of a 2,4-D application. 2,4-D may also be applied as a directed spray to perennial weeds in the bud stage of growth, with care taken to prevent herbicide contact with pear foliage, flowers, fruit, bark, or root suckers.

If 2,4-D registrations were lost, there would be no selective herbicides available for control of perennial broadleaf weeds in the grass strips in pear orchard alleyways. Other auxinic herbicides are not registered, and reduced rate applications of glyphosate or sethoxydim to suppress grass cover crop growth will not provide broadleaf weed control between the pear rows and could lead to selection of herbicide-resistant biotypes. Mowing for weed control would be used more, with concurrent increase in labor costs, potential injury to workers, fuel use, and damage to lower tree trunks from mowing equipment. A weed shift to low-growing species and more particularly to perennial weeds would also likely occur.

Pomegranate: The total US pomegranate acreage data is not available, but a reasonable estimate is about 40,000 acres. Most of this is in California which has around 32,000 acres owned by a few large producers in the San Joaquin Valley (for juicing and fresh market) plus a number of small fresh market producers in other parts of the state. Pomegranates are also grown for the fresh market in Oregon, Washington, and several southeastern and northeastern states but acreage of individual farms tends to be relatively small in those regions.

Pomegranates, whether for juice or fresh market, are typically harvested by hand crews. As a minor crop with few related higher acreage crops, pomegranates do not have many herbicides registered for bearing orchards. Growers typically rely heavily on tillage, mowing, and on the relatively few available herbicide options for weed control. In the eastern US, University extension personnel indicated that 2,4-D is very important to the pomegranate industries due to the lack of broadleaf herbicide options. However, in California, 2,4-D is not registered on pomegranate and those growers largely use glyphosate and oxyfluorfen. There is some likelihood that additional herbicides including saflufenacil and rimsulfuron will eventually be registered in pomegranate through work being done by the USDA-IR4 Program.

Stonefruit: Stonefruit crops (apricot, cherry, nectarine, peach, plum, prune, etc.) are produced in many states, totaling approximately 332,000 acres in 2014 (NASS 2014). Slightly more than half the total stonefruit acreage is in California, including most of the commercial plum, prune, apricot, and nectarine acreage. Washington, Michigan, California, and Oregon produce most of the cherries. The greatest acreage of peach production is in California but the crop is also widely grown in many eastern and south eastern states.

Stonefruit production systems vary considerably among regions. Because most of these crops are harvested by hand from ladders, orchard access is important for efficiency and worker safety. Many stonefruit orchards have either complete weed control across the orchard floor or clean tree rows and mowed cover crops between rows (Elmore et al. 1999).

In California, herbicidal weed control in stonefruit orchards is dominated by glyphosate and oxyfluorfen (CDPR 2014). However, 2,4-D is also relatively common and is used on approximately 10% of the California stonefruit acreage each year for control of broadleaf weeds, especially field bindweed. In other states, particularly the northeast, rainfall patterns allow more grass covercrops and 2,4-D is a very important tool for weed management in stonefruit orchards.

Strawberry: Strawberries are grown on about 54,000 acres in the US, with about 70% of the production in California. Most of this acreage consists as day-neutral plants grown as annuals in California, Florida, North Carolina, and other southern states. June-bearing cultivars are grown as perennials in matted-row culture primarily in New York, Oregon, Washington, and other northern states.

2,4-D is not widely used in day-neutral cultivars, but may be applied at post-harvest renovation or in late dormancy in matted-row strawberry (Stevens et al. 2011). The labelled rate is 0.9 to 1.4 lb ae/acre. Even at these low rates, 2,4-D may cause crop injury if applied when strawberry leaves are present and plants are actively growing. Consequently, dormant-season applications are most often used in regions where strawberry plants fully defoliate during winter and before new leaves are produced, or following fruit harvest in fields where plants are stripped of leaves, are slightly drought-stressed, or have been flamed.

Tree nuts: The tree nut (almond, hazelnut, pecan, pistachio, walnut) production system has significantly expanded and intensified since the last review, particularly in California, and now totals over 1.4 million acres (NASS 2014). In 2014, there were approximately 860,000 bearing acres of almonds, 215,000 acres of pistachio, and 290,000 acres of walnut mostly in the Central Valley of California. Arizona and New Mexico also have significant acreage of pecan and pistachio under intense production systems. Other states, particularly in the Great Plains, also produce pecan and walnut but usually in much less intense production systems. Oregon is the primary producers of hazelnuts, with about 30,000 bearing acres.

Almonds, walnuts, and pecans are usually shaken from the tree and mechanically swept up from the orchard floor, while hazelnuts and pistachios are more commonly shaken onto mechanized catch frames. In recent decades, most of these production systems have become much more intense and economically valuable due to high prices for the nuts as well as increasing costs for land and input costs, especially water. Tree nut growers typically have a low threshold for weeds and expend considerable effort during the growing season to achieve a high level of weed control.

Tree nut weed control in the highest production regions is usually obtained with relatively intense herbicide usage (pre-emergence and post-emergence) in strips making up the 25-50% of the orchard floor within the tree rows and less intense programs in the remaining “middles” (Bugg et al. 2003). Vegetation between tree rows is typically managed with cultivation or mowing several times per year. In some cases, broadleaf management materials including 2,4-D are used in the middles if a grass cover is to be maintained. Most growers also use a broadcast application of a broad spectrum herbicide to burn down any remaining vegetation in early summer to facilitate the efficiency of the harvest operations which includes shaking the nuts from the tree and mechanically sweeping and picking the nuts up from the orchard floor.

2,4-D, mostly as the dimethylamine salt, is of modest importance in the tree nut system. In California in 2012, 2,4-D was applied to approximately 110,000 acres of almond, walnut, pistachio, and pecan crops - less than 20% of the total bearing acreage in that year (CDPR 2014). In contrast, glyphosate and oxyfluorfen were applied to 1.5 million and 750,000 acres, respectively, in almond alone.

In the absence of 2,4-D, there would likely be some increase in the use of pre-emergence herbicides in these crops as well as increasing control costs for those growers who rely on relatively inexpensive 2,4-D post-emergence herbicide programs (Grey et al. 2014).

If 2,4-D were not available to tree nut growers in California and the other intense production systems, they would likely use additional applications of glyphosate and protox inhibiting herbicides such as saflufenacil for post-emergence control of broadleaf weeds. This would not greatly impact producers in the San Joaquin Valley, who typically do not utilize grass cover crops because of inadequate winter rainfall. However, it would be of some concern in areas of the Sacramento Valley where annual grass cover in the winter is more common. In recent years, glyphosate- resistant or tolerant broadleaf weeds such as Palmer amaranth hairy fleabane, horseweed, and panicle willowherb have led to an increased interest in 2,4-D for resistance management in tree nut crops. In the absence of 2,4-D, there would likely be some increase in the use of pre-emergence herbicides in these crops as well as increasing control costs for those growers who rely on relatively inexpensive 2,4-D post-emergence herbicide programs (Grey et al. 2014).

Weed Control Alternatives If 2,4-D Were Unavailable

Other available herbicides: The primary utility of 2,4-D is for post-emergence control of broadleaf weeds; either by selectively controlling broadleaves and sparing grasses, or by providing additional control of broadleaves as part of an herbicide tankmix. Importantly,

2,4-D is translocated and can provide good control of perennial broadleaf weeds such as field bindweed. Since the last review of the importance of 2,4-D in tree, vine, and berry crops, several major herbicide registration changes occurred that have changed the relative importance of 2,4-D in this diverse crop sector. It should be noted that herbicide registrations, both for 2,4-D and for alternatives, differ significantly among crops and among states.

Glyphosate has become the most widely used herbicide in most tree and vine crops in recent decades. In California, which has detailed herbicide use reporting, glyphosate is used on 10-20 times more acres than 2,4-D even in those crops in which 2-4-D is fairly important. This shift is partially due to the loss of registration or reduced interest in some other herbicides. However, the biggest driving factor for this shift was the end of patent protection for Roundup branded products and the subsequent market entry of many glyphosate herbicides. The market competition drove deep price reductions and glyphosate herbicides now provide very economical control of a broad spectrum of weeds, including perennial broadleaf weeds. However, glyphosate is not very selective and cannot be effectively used in situations where a grass cover crop is desired; a practice for which 2,4-D is commonly used. Additionally, in some orchard crops, evolution of glyphosate-resistant weeds or shifts to glyphosate-tolerant species have complicated glyphosate-based weed management programs (Hanson et al. 2014; Heap 2014).

Glufosinate-ammonium has been registered for post-emergence weed control in some orchard and vineyard crops in the past decade. In particular, it has been relatively widely adopted in the tree nut and grape production systems of the western US. Glufosinate-ammonium can provide non-selective control of many grass and broadleaf weeds but does not control larger weeds or perennial species well because it is not translocated extensively. Although it is a relatively expensive product, the active ingredient is now off-patent and several new products are entering the market and may lead to downward price pressure.

Paraquat and, to a lesser extent diquat, are used for non-selective burndown control of grass and broadleaf weeds in some of these crops. These herbicides are relatively economical, however, they have only contact activity and often only suppress grasses, larger broadleaf, and perennial weeds. Additionally, most paraquat formulations have a "Danger/Poison" labelwhich limits to some degree their adoption, either due specifically to safety concerns or toadditional regulatory, handling, or record-keeping requirements. Paraquat resistance has been reported in some orchard weeds and could become a more widespread issue if selection pressure is increased (Moretti et al. 2013).

As a group, the protox inhibitors (WSSA Group 14 herbicides) have become important in this crop group since the last review of 2,4-D. Some of these products, such as oxyfluorfen, flumioxazin and sulfentrazone, have both pre-emergence and post-emergence activity on broadleaf weeds and suppression of some grasses. Others, such as carfentrazone, pyraflufen-ethyl, and saflufenacil primarily are used for post-emergence burndown of broadleaf weeds. Several of these post-emergence herbicides can be used to selectively control broadleaf weeds in grass cover crop situations but are usually not as effective as 2,4-D on larger weeds or on perennial species due to the fact that they do not translocate in the plant.

While 2,4-D is used as a post-emergence herbicide, there have also been changes in pre-emergence herbicide use in orchard and vineyard crops which has impacted the relative importance of 2,4-D in these crops. For the most part, these changes have had the greatest impact in the tree or vine rows where weed-free strips are maintained in many crops. First, dinitroaniline herbicides (WSSA Group 3 herbicides), primarily oryzalin and pendimethalin, have had some label expansions and competition from generic manufactures. These herbicides are primarily used for control of seedling grasses and small-seeded broadleaf weeds. Second, introduction or label changes to cellulose synthesis inhibiting herbicides (WSSA Groups 20, 21, and 29) have resulted in some weed managers including more pre-emergence herbicides rather than relying as heavily on post-emergence materials. The most important of these herbicides in the past several years has been indaziflam, which has been fairly widely adopted in orchard systems and is either registered or being evaluated in a number of other tree, vine, and berry crops. Finally, several sulfonylurea herbicides (WSSA Group 2) with both pre-emergence and post-emergence activity have been registered in many of these crops. The mostly widely used herbicide of this group is probably rimsulfuron, but others including penoxsulam, flazasulfuron, halosulfuron, and others are used in some situations.

Non chemical alternatives: There is always an alternate method of weed control, but each method or integrated program has its own set of benefits and drawbacks in terms of economics, management, and environmental impact (Fennimore et al. 2013). Hand hoeing is effective on annual weeds, but it is labor intensive and costly and not feasible in most of the commercial-scale production systems. The mechanical methods and hand weeding are not effective for perennial weed control in the orchard, and mechanical methods can sometimes make weed problems more severe by spreading weed propagules.

Increasing cultivation will come at the cost of additional fuel and equipment, and frequent tillage can further contribute to dust and soil erosion in some environments. Another factor is the increase in greenhouse gas emissions from more extensive use of heavy equipment.

Cultivation with disks, hoes, harrows, and in-row cultivators (of many types) all have a place for annual weed control in orchards and vineyards. Soil conditions, such as texture and amount of rocks, orchard or vineyard topography, and weed species will determine which one of these implements will be most effective. Cultivation equipment will continue to improve at controlling weeds around trees or vines without damaging them. Increasing cultivation will come at the cost of additional equipment and fuel costs (e.g. $17/acre for disking vs. $6/acre for spray equipment; Connell et al. 2012) and frequent tillage can contribute to dust and soil erosion in some environments (Southard 2010). Cultivation is also very slow, especially in closely planted rows of tree, vine, and berry crops.

Use of fabrics for weed control has become more common in many fruit and nut crops, often for organic production but also more and more commonly for use in conventional systems. Loss of 2,4-D alone would not likely drive producers toward this alternative, although use of fabrics may reduce the need for 2,4-D applications, particularly in the crop row.

Some farmers have shown a renewed interest in flaming for the control of weeds. Flaming is an organic practice that has been available for many years but may not be economically viable when fuel, usually propone, costs are high. Flaming is effective only on young weeds, with better control of annual broadleaf weeds than grasses. Care is required so that the crop is not damaged by fire in dry vegetation, particularly around the base of trees and vines. Flaming is slow, fuel-intensive, has a high carbon footprint, and usually is only partially effective.

Importance of 2,4-D for Tree, Vine, and Berry Production Systems

Many of the crops in this group are relatively sensitive to injury from 2,4-D which has limited the number of registrations. Even in tree, vine, and berry crops in which 2,4-D is registered, use is often relatively limited. However, 2,4-D has some attributes that make it very important for some specific sectors of this diverse crop group.

There are three primary benefits to maintaining the availability of 2,4-D for growers of tree, vine, and berry crops. First, 2,4-D provides very economical control of broadleaf weeds compared to some alternative products. Importantly, it can provide much better control of perennial broadleaf weeds such as field bindweed compared to the protox inhibiting herbicides also used in these systems. Second, 2,4-D has a unique fit in production systems that use grass cover crops between or within the rows of perennial fruit and nut plants. No other available post-emergence herbicide can provide the same level of broadleaf weed control without causing significant damage to grass cover crops. This use is particularly important in high rainfall regions and in production regions with sloping fields; adding annual or perennial grass sod to orchard floors can greatly reduce soil erosion and the associated environmental damage.

The three primary benefits to maintaining the availability of 2,4-D for growers of tree, vine, and berry crops:

1. *2,4-D provides very economical control of broadleaf weeds compared to some alternative products*
2. *2,4-D has a unique fit in production systems that utilize grass cover crops between or within the rows of perennial fruit and nut plants*
3. *The unique mode-of-action of 2,4-D makes it valuable in a weed-resistance management program*

Third, the unique mode-of-action of 2,4-D makes it valuable in a weed-resistance management program. In recent years, glyphosate-resistant weeds have become an important management concern in the western US tree and vine crops (Hanson et al. 2014). Several weed surveys in California have indicated that glyphosate-resistant grasses and broadleaf weeds are relatively common throughout the Central Valley where most of the state's orchard and vineyard crops are produced (Hanson et al. 2009; Okada et al. 2014; Hanson unpublished research). Because of these issues, 2,4-D has seen something of a resurgence for management of glyphosate-resistant broadleaf weeds in rotation or as a tankmix partner with glyphosate in some regions.

Most tree fruit and nut crops are currently produced much differently than at the time of the last re-registration for 2,4-D. The majority of apples, pears, and stone fruit are now produced on dwarfing or semi-dwarfing rootstocks and at much higher densities than in the past. Similarly, tree nuts are also being grown at higher densities and, while competition with weeds is more acute in these systems, the negative consequences of poor weed control is greater.

The more intensive production systems have decreased the tolerance of producers for the presence of weeds in orchards and vineyards, while higher returns per acre have removed some of the incentive for use of lower-cost herbicide programs.

Use of drip and micro-irrigation systems is also far more common than in the past, particularly in the semi-arid West, resulting in less moisture at the soil surface within crop rows and throughout the soil between crop rows. Annual weed seed germination is typically less under these conditions than when soil is moist on the surface, so the need for 2,4-D to control annual broadleaf weeds in drip-irrigated orchards is probably reduced.

Finally, although there are several more herbicide active ingredients registered for use in tree and vine crops than previously, most of those products provide only limited control of perennial broadleaf weed species. Taken together, these factors suggest that while not of critical importance to this crop sector overall, 2,4-D provides important weed control opportunities in specific crops and situations. The impact of a loss of 2,4-D registration in tree, vine, and berry crops could range from virtually unnoticed in some crops to great economic and production challenges in others.

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