A Review of Weed Control Practices in Landscape Planting Beds: Part II—Chemical Weed Control Methods

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Abstract. Use of preemergence and postemergence herbicides is the most effective and economical method of weed control in landscape planting beds. When used correctly, herbicides can provide satisfactory weed control, reduce labor costs, and cause little or no negative environmental impacts. Major factors in herbicide efficacy include choosing the correct herbicide for the weed species present, following proper calibration procedures, and applying herbicides at the correct timing. The objective of this review is to provide a comprehensive analysis of the research pertaining to herbicide use in landscape planting beds and present 1) the advantages and disadvantages of common chemical weed control strategies, 2) the most effective preemergence and postemergence herbicides in various landscape scenarios, 3) potential environmental concerns pertaining to improper application of herbicides, and 4) highlight knowledge gaps where additional research is needed or improvements could be made.

Since 2,4-D was discovered in the 1940s, development and use of herbicides has continually increased (Timmons, 2005). Use of herbicides in residential landscapes is also increasing. From 1994 to 2007, there has been a 60% increase in sales of pesticides to the home and garden market sector with herbicides being the most purchased pesticide (EPA, 2011). Pesticides for nonstructural pests have been applied on residential landscapes of ≈50% of all U.S. households and the annual expenditure for pesticides in the home and landscape is continually increasing (EPA, 2011; Templeton et al., 1998). The primary motivation for controlling weeds is for aesthetic purposes and so people can more fully enjoy their landscapes for recreational activities (Beard and Green, 1994). Well-maintained landscapes also have been shown to increase property values (Henry, 1994).

Chemical weed control in landscape planting beds presents unique challenges not present in cropping systems. First, herbicides that are used in landscapes are applied primarily for aesthetic purposes and not solely to reduce weed competition or improve yields. Second, if herbicides are used, they must be carefully selected and applied to cause no plant injury as there is minimal tolerance for any phytotoxicity in most landscapes. Last, herbicides used in these areas must cause minimal mammalian toxicity as homeowners, small children, or pets will likely enter treated areas soon after application. Herbicides must also be selected with regard to their impact on ground or surface water sources which can become contaminated due to off-site movement and leaching (Koterba et al., 2010; Nielson and Smith, 2005).

In general, landscape planting areas (non-hardscape areas) can be divided into turf and nonturf areas (e.g., annual beds, groundcovers, woody ornamental landscape beds, and planters). Homeowners and landscapers have a variety of chemical weed control tools to choose from in turf areas, and consequently, several reviews and books pertaining to chemical weed control practices in turf have been published (Christians, 1998; McCarthy and Murphy, 1994; Turgeon, 1996). To our knowledge, no recent reviews have been published pertaining to chemical weed control practices in the nonturf planting areas of commercial or residential landscapes. The objective of this manuscript is to review chemical weed control strategies in landscape beds and identify areas in which further research and improvements are needed or where current practices could potentially be improved.

Chemical Weed Control

Current challenges. Few chemical options exist for weed control around or over-the-top of ornamentals, and the diversity of species in any one landscape planting bed makes finding safe and effective herbicides very difficult for landscapers. Homeowners may face greater challenges with weed control, as many lack the credentials and training required to obtain and safely use the most effective herbicides. However, there are several preemergence and postemergence herbicides labeled for use in and around ornamental plantings in residential landscapes. Many of the herbicides available for use in residential landscapes are available for both professional and homeowner use. However, products intended to be used by nonlicensed homeowners are typically granular, less concentrated formulations or packaged as more expensive, ready-to-use products. It is likely that very few new herbicide active ingredients are on the horizon specifically for the ornamental or landscape market (Fennimore and Doohan, 2008). Therefore, more data are needed on herbicides labeled in other markets for their suitability for use in landscape ornamentals, as well as determining the most effective and efficient ways in which current products can be used.

Preemergence weed control. Landscape professionals (and some homeowners) commonly make preemergence herbicide applications to landscape beds followed by postemergence applications to control escaped weeds. Many preemergence herbicides can offer some control of both grass and broadleaf weeds, but most are more effective or are primarily used to control one subclass or the other. Consequently, tank mixes or combination products are commonly used. Preemergence tank mixes of primarily broadleaf (e.g., isoxaben, oxadiazon, dithiobenil, and dimethenamid-p) and grass (e.g., oryzalin, pendimethalin, prodiamine, and trifluralin) herbicides or commonly sold combination granular products (e.g., isoxaben + trifluralin, oryzalin + benefit, and dimethenamid-p + pendimethalin) will generally offer broad-spectrum control and reduce the number of applications that must be made (Gallitano and Skroch, 1993; Gilliam et al., 1989; Monaco and Hodges, 1974). Tank mixes can also be more cost-effective than the components applied alone. In a study by Wehtje et al. (2010), a flumioxazin and prodiamine tank mixture was most cost-effective for control of spotted spurge (Chamaesyce maculata) and large crabgrass (Digitaria sanguinalis); however, prodiamine was shown to be antagonistic in this tank mixture for control of eclipta (Eclipta alba). Determining synergism or antagonism of other common landscape herbicide tank mixtures for weed control is much-needed information for assessing economically viable tank mixtures for the landscape industry.
A small subgroup of preemergence herbicides also offers control of perennial sedge species (*Cyperus spp.*) (Keeley and Thullen, 1974). The most common perennial sedge species, yellow (*Cyperus esculentus*) and purple nutsedge (*Cyperus rotundus*), are often the most difficult weeds to control preemergence due their ability to reproduce by underground tubers, which are long lived and difficult to kill while dormant (Bryson et al., 2003; Thullen and Keeley, 1979; Wills, 1987). Herbicides labeled for preemergence control of nutsedge species include dimethenamid-p (Tower®), as a component in FreeHand®; BASF Corporation, Research Triangle Park, NC), S-metolachlor (Pennant Magnum®; Syngenta Crop Protection, Inc., Greensboro, NC), S-etky diproplyphiocarbamate or EPTC (Eptam®; Gowan USA Turf and Ornamental Co., Yuma, AZ), and dichlobenil (Casoron®; OHP, Inc., Mainland, PA) (Vencill, 2002). All of these products differ in their efficacy and ornamental safety profile. In most cases, metolachlor is the most effective preemergence herbicide for control of yellow nutsedge (Allland et al., 2003). Both S-metolachlor and dimethenamid-p are safe for over-the-top applications to many different ornamental species, but neither product is labeled for control of purple nutsedge. Dichlobenil and EPTC have been shown to provide control of both nutsedge species (Chen et al., 2013; Hardcastle and Wilkinson, 1968; Pereira et al., 1987) but dichlobenil is only labeled for nutsedge control in noncrop areas and both products have a limited list of labeled ornamentals. Currently, there is not a wealth of information available on how these different preemergence nutsedge herbicides interact with other factors in landscape plantings. More research is needed on different nutsedge preemergence products used in combination with other control factors (i.e., mulch) in landscape settings, similar to the study conducted by Chen et al. (2013).

Several active ingredients have been labeled for use in landscapes in recent years. Dimethenamid-p (Tower® and FreeHand®) is labeled for control of grasses, broadleaves, and sedges in landscape beds and warm-season turf. Flumioxazin (SureGuard®; Valent U.S.A. Corp., Walnut Creek, CA) was registered for use in landscapes in 2009 and is gaining popularity with landscape managers. More research is needed on how these different preemergence nutsedge herbicides interact with other factors in landscape plantings. More research is needed on different nutsedge preemergence products used in combination with other control factors (i.e., mulch) in landscape settings, similar to the study conducted by Chen et al. (2013).

Turf herbicides have been shown to damage nearby ornamentals due to volatility (Busey et al., 2003) and root uptake (Patton et al., 2011). One of the more notorious instances of ornamental damage due to turf application was with the use of aminocyclopyrachlor (formerly sold as Imprelis®; Dupont, Willington, DE), which damaged or killed thousands of trees and shrubs across the United States (Patton et al., 2013). On the other hand, some herbicides safe for broadleaf ornamental species can significantly injure certain turfgrass species (Bhowmik and Bingham, 1990). Therefore, preemergence herbicides that are labeled for use in both landscape planting beds and over-the-top of ornamentals and turf sites are a valuable tool for landscape managers. Most commonly used products include isoxaben (Gallery®; Dow AgroSciences, Indianapolis, IN), dimethenamid-p (Tower®), dihtiypr (Dimension®; 2EW, Dow Agrosciences), pendimethalin (Pendulum® 3.3EC; BASF Corporation), and prodiamine (Barricade®; Syngenta Crop Protection) offer the ability to apply a single product to multiple areas on a given site, which saves time and reduces the need to transport multiple products or recalibrate on site and serves as a safeguard for crop injury in cases of misapplication.

**Preemergence herbicide and mulch interactions.** In most cases, preemergence herbicide applications are applied to landscape beds that are already mulched, which can impact the effectiveness of some preemergence herbicides. Mulches that are made up of coarse particle materials may be less likely to reduce herbicide efficacy compared with fine particle materials. Some herbicides are bound tightly by organic matter, which minimizes leaching (Knight et al., 2001), but it is still unknown whether this tight adsorption truly reduces herbicide efficacy as noted by Wilen and Elmore (2007). Chen et al. (2013) studied mulch and herbicide interactions by applying EPTC (Eptam 5G; Gowan USA Turf & Ornamental Co.) at two rates either above or below pine straw, pine nuggets, or shredded cypress mulch compared with a nonmulched control. Results indicated that EPTC provided better yellow nutsedge control when applied under mulch (12 weeks control) in comparison with applications above mulch (4 weeks control). A study in conservation tillage for rice production showed that herbicides oxadiazon and pendimethalin bound tightly with organic rice crop residues when applied on top of the residue mulch, reducing their effectiveness on some weed species (Chauhan and Abuhgo, 2012). Similar studies in other row crop situations have also shown varying effects of herbicide applications to organic matter on the soil surface, showing both increased (Crutchfield et al., 1985) and decreased (Banks and Robinson, 1986) efficacy depending on the herbicide and mulch material used. Somirreddy (2012) evaluated granular and spray formulations of trifluralin and isoxaben in combination with various organic mulches at different depths. Results indicated that these herbicides generally persisted longer and provided better weed control when applied underneath mulch compared with when herbicides were applied alone (without mulch) or on top of mulch, but results varied depending on formulation (liquid vs. granular) and mulch type. Almost complete weed control was achieved in the thickest mulch treatment (12 cm; 4.8 inches) regardless if herbicides were included or not, and herbicides were needed to achieve acceptable control at lower mulch levels (3 cm; 1 inch).

Currently, there are no “herbicide placement” recommendations on preemergence herbicide labels in terms of above or below mulch layers. There is a knowledge gap in this area and further research is needed on different mulch and herbicide combinations so that herbicide recommendations for different mulch materials can be developed. Specific questions that need to be answered include which herbicide active ingredients and formulations are most effective for different types of mulches, how particle size of different mulch materials impacts herbicide efficacy, and how irrigation practices should be managed for different mulch types. For example, most herbicides require at least 0.6 to 1.3 cm (0.25 to 0.5 inch) of irrigation after application for activation, but more irrigation may be needed when using certain formulations on different mulch types at varying depths to move the herbicide through the mulch layer to reach the soil below. It is also important to focus future efforts on identifying effective herbicides that can be applied on top of mulch, as there are limited opportunities to apply herbicides below mulch in landscape situations. As noted by Somirreddy (2012), the physiochemical properties of every herbicide and mulch are unique, and the adsorption-desorption relationship between different herbicide-mulch combinations will vary and influence how well herbicides are released into the soil, which will ultimately influence efficacy.

**Failure of preemergence herbicides.** Precise, timely applications of herbicides have been shown to be one of the most effective weed control measures in the landscape, but these herbicides can fail for one or more reasons. As stated by Allland et al. (2003), the primary reasons herbicides fail include 1) improper application timing, 2) improper application rate (not being correctly calibrated), and 3) not choosing the most effective herbicide for the most prevalent weed species. Preemergence herbicides are not likely to provide season-long control, and most provide control for only 10 to 14 weeks (Wehtje and Gilliam, 1991). In an intensive production system, such as container production, preemergence herbicides may only provide control for 4 to 6 weeks (Atwood et al., 2008; Judge et al., 2003). Therefore, follow-up applications are needed before the herbicide degrades. Previous research has shown that timing of preemergence applications is often more important than herbicide selection (Wehtje and Gilliam, 1991). These
applications should also be made to weed-free areas for the best control; however, several commonly used preemergence herbicides have been shown to provide early postemergence activity. Studies by Altland et al. (2000) show that small hairy bittercress (Cardamine hirsuta) (0.5 to 3 cm) can be controlled with applications of isoxaben. Spotted spurge has been successfully controlled in the cotyledon to one-leaf stage of growth with applications of herbicides including dimethenamid-p + pendimethalin, pendimethalin, and dimethenamid-p (Marble et al., 2011). An early study by Judge and Neal (2006) showed hairy bittercress and spotted spurge (C. maculata) can be con-
trolled successfully with the herbicides flu-
moxazin, oxyfluorfen + pendimethalin, and isoxaben + trifluralin at the cotyledon to one-
leaf stage of growth. The new herbicide indaziflam provides effective preemergence control of grass and broadleaf weeds (Marble et al., 2013; Myers et al., 2009) and has been shown to provide early postemergence control of common weeds in turfgrass and landscapes (Brosnan et al., 2011, 2012; Marble et al., 2013). Similarly, dithiopyr (Dimension®) is labeled to control crabgrass (Digitaria spp.) plants that have five leaves or less (Dow AgroSciences, 2010). With the exceptions of the liquid formulations of indaziflam and flu-moxazin, all of these active ingredients have broad over-the-top labels for a wide variety of landscape ornamentals, which give landscapers the advantage of controlling certain small weeds when making preemergence applications. The liquid formulations of flu-moxazin and indaziflam could also provide this benefit when used as a directed-spray application. Although earlier work offers some promising insights into new herbicide strategies, all of these studies were conducted on common weed species in container nurseries. More work is needed to determine if these preemergence herbicides can provide early postemergence control of weed species common in landscape plantings and to determine how a landscape setting impacts efficacy.

Postemergence weed control. Postemergence herbicides labeled for use in landscapes include nonselective herbicides such as the translocated glyphosate (RoundUp®, Monsanto Co., St. Louis, MO), or contact herbicides such as diquat (Reward®; Syngenta Crop Protection) or pelargonic acid (Scythe®; Gowen Co.). Glufosinate (Finale®; Bayer Environmental Sciences) is another nonselective herbicide that is minimally translocated (Mersey et al., 1990) and thus acts more as a contact herbicide. Graminicides such as clethodim (Envoy®; Valent USA Corp.), flazipof-P-butyl (Fusilade®; Syngenta Crop Protection), fenoxaprop-p-ethyl (Acclaim®; Bayer Environmental Sciences), or sethoxydim (Segment®; BASF Corporation) are also widely used because they provide selective control of grass species and are safe for over-the-top application to a wide variety of broadleaf ornamentals.

With the exception of graminicides, postemergence weed control in landscape beds primarily involves making directed or spot applications to avoid damage to nearby ornamentals. The most commonly used preemergence herbicide in landscape beds is glyphosate, which is economical, has little human or nontarget toxicity (other than to nontarget plants), and is immobile in soil (NPIC, 2014). As glyphosate is nonselective and will control most weed species, its use eliminates much of “guess work” by home-
owners or inexperienced applicators—it can be used as a stand-alone tool (in the absence of glyphosate resistant weeds). However, landscape ornamentals will usually recover faster following an inadvertent application with a contact herbicide (i.e., diquat) as opposed to a systemic herbicide (i.e., glyph-
osate) as minimal translocation will occur. Although glyphosate offers advantages, many ornamental species will not recover if exposed to even a small amount of glyphos-
ate (Hoogmoed et al., 2009). On the other hand, it should be noted that many com-
monly grown ornamental species have shown tolerance to over-the-top applica-
tions of glyphosate at low rates including lily turf (Liriope muscari), several holly (Ilex spp.) species, nandina (Nandina domestica), dwarf gardenia (Gardenia jas-
moides ‘Radicans’), juniper (Juniperus conferta ‘Blue Pacific’), Asiatic jasmine (Trachelospermum asiaticum), and camel-
ia (Camellia sasanqua ‘Shishigashira’) (Hoogmoed et al., 2009; Hoogmoed et al., 2013; Self, 1974; Self and Washington, 1977).

Selective nutsedge herbicides have been
developed in the last several decades (Pereira et al., 1987). Halosulfuron (SedgeHammer®; Gowan Co.), imazaquin (Image®; BASF Corporation), bentazon (Basagran® T/O; BASF Corporation), and sulfosulfuron (Certa-
tainty®; Monsanto Co.) are selective nutsedge herbicides that can be applied in turf areas and in and around landscape ornamenta-
tals. Similar to preemergence nutsedge her-
bicides, these products differ in their efficacy and safety to ornamentals. Imazaquin and halosulfuron are labeled for control of both purple and yellow nutsedge, although some reports suggest halosulfuron may be more effective (Blum et al., 2000). In contrast to halosulfuron that is labeled only for directed applications, imazaquin can be applied over the top of a small number of ornamental species, including common groundcovers such as Asiatic jasmine, mondo grass (Ophio-
pogon japonicas), and liriope (Liriope muscari ‘Evergreen giant’ and ‘Silvery sunproof’) in addition to several other peren-
ials, shrubs, and trees. Bentazon is only labeled for control of yellow nutsedge (and some broadleaf species) but can be applied as a directed spray around almost all ornamental species and applied over the top to more than 20 species of shrubs, trees, and perennials. In a study by Johnson (1975), bentazon pro-
vided 98% to 100% control of purple nut-
sedge following a spring application, but
control decreased to 28% to 68% following mid or late summer application, indicating that bentazon could provide some control of both yellow, and possibly purple nutsedge, depending on application timing and weed growth stage. Sulfosulfuron was originally a turf-only herbicide but now has a supplement-
mental landscape ornamental label. Sulfosul-
fonur is labeled for the control of both purple and yellow nutsedge and can be applied over the top of over 20 woody ornamentals, eight warm-season native grasses, and as a directed application to any established warm-season ornamental grass or ornamental species in landscapes areas (Monsanto Co., 2012).

Current industry trends. One of the pri-
mary downsides to glyphosate use in the landscape is that depending on weed species and stage of growth, symptoms may not be noticeable for 7 d or more after application (Frazz et al., 1997; Monsanto Co., 2010), which is unacceptable by some homeowners who want immediate confirmation that the product is working. As a result, numerous ready-to-use products are marketed that have glyphosate as their main component but also contain a faster-acting herbicide such as di-
quat or pelargonic acid (Wehtje et al., 2008, 2009). These products do in fact cause faster burn down, but in some cases may not allow glyphosate to fully translocate throughout the weed, and better long-term control may be achieved by using glyphosate alone. When tank mixtures of glyphosate and diquat were evaluated for control of longstalk phyllanthus (Phyllanthus tenellus), a summer annual weed (or perennial in subtropical environ-
ments), the amount of glyphosate had to be increased by ≈60% to compensate for diquat-based antagonism (Wehtje et al., 2008). In a similar study, Wehtje et al., (2009) con-
cluded that the addition of pelargonic acid to glyphosate neither increased nor decreased long-term control of four common annual weed species (large crabgrass, yellow nut-
sedge, long-stalked phyllanthus, and pro-
strate spurge). Similarly, antagonism has also been reported with glufosinate + glyphosate combinations (Chua et al., 2008). Based on these trials, it appears that in most cases, a more economical and effective approach would be to apply glyphosate alone. In cases where faster burn down was desired, applying a fast-acting contact herbicides alone could suit this purpose, but many of these products are not available to homeowners in concentrate form, and most products are more expensive than glyphosate. Applying tank mixes or contact + systemic products correctly may be useful if allowed on the label or sold premixed, but it is important to note that the most effective control may be achieved when using glyphosate alone. As antago-
nism of glyphosate + contact tank mixtures has been reported with annual species (Wehtje et al., 2008), it would likely be more pronounced in the case of some peren-
ni al species.

Environmental Impacts of Herbicide Use
and Public Perceptions

Using the correct herbicide at the appro-
piate rate is a critical step in weed manage-
ment (Altland et al., 2004). Chemical costs,
the likelihood of unintended phytotoxicity (Stamps and Neal, 1990), and pollution (Frick et al., 1998) can increase when too much herbicide is applied. In contrast, suboptimal application rates lead to poor weed control (Altland et al., 2004) and herbicide resistance development (Busi and Powles, 2009). Selecting the right product and applying the correct rate may be a challenge for homeowners who have not had training. In a study by North Carolina extension educators, the most often requested information by homeowners was how to select the correct product, how to understand pesticide labels, and how to know the proper amount to apply (Church et al., 2012). These three skills are critical for safe and effective herbicide application. In their work, Church et al. (2012) concluded that most homeowners do not have a complete understanding of the risks associated with pesticide use. The potential for widespread misuse is significant as the EPA estimates that 41 million households use herbicides (EPA, 2011). Sales of herbicides to the home and garden market increased from $456 million in 1994 to $749 million in 2007 (EPA, 2011). As herbicide use continues to increase, it is important to educate all applicators on correct usage, handling, storage, and disposal of these products to prevent point and nonpoint source pollution.

Numerous studies have pointed to the possibility of negative consequences from herbicide applications including exposure risks to people (Greenlee et al., 2004; Nishioka, et al., 2001), pets (Glickman, et al., 2004), nontarget organisms (Dewey, 1986), and water contamination (Frick et al., 1998; USGS, 1999). Herbicide runoff in urban areas can exceed that of agricultural areas due to frequent use and lack of consumer awareness (Wittmer et al., 2011). Some herbicides (and metabolites) commonly found in surface and groundwater can persist for decades and many are toxic to aquatic organisms and have adverse effects on human health (Jablonskiwski et al., 2011; Ochoa-Acuna et al., 2009). The top five most commonly used herbicide active ingredients in the home and garden market sector in 2007 included 2,4-D, glyphosate, mecoprop (MCPP), pendimethalin, and dicamba, in order of use (EPA, 2011). Not surprisingly, 2,4-D has been one of the most frequently detected herbicides in urban water sources (USGS, 1999). 2,4-D is a selective broadleaf herbicide and is commonly used for weed control in turf and often sold in combinations with MCPP and dicamba in popular “weed and feed” products, which contain various herbicide + fertilizer combinations for use in turf areas. Mecropop is also a common ingredient in widely used weed-and-feed products. Although all of the top five sold herbicide active ingredients have labels for both turf and landscape bed applications, with the exception of glyphosate and pendimethalin, these products are almost exclusively applied to turf areas. In addition, applications to turf areas will naturally be more frequent and require more product because of their larger area compared with ornamental beds in most landscapes. Most landscapes are composed largely of turf areas and homeowners may be required by local ordinance or homeowner association code to dedicate a portion of their landscape to turf (Schindler, 2014). In some cases, these sites can be poor areas for turfgrass establishment due to environmental or cultural factors. Removing turf requirements in these sites and allowing the use of alternative groundcovers, native plants, or landscape beds may help reduce the need for frequent pesticide applications and mitigate water contamination. However, overcoming informal norms, customs, and personal preferences may be more of a challenge than eliminating formal regulations or local codes (Larson and Brumand, 2014).

Assessing the Potential for Organic Landscaping and Herbicide Use

When used according to their labels, pesticides in general pose little threat for humans, animals, nontarget organisms, and the environment (Holland, 2012), but consumers are often still wary of their use and many now prefer organic or “natural” products. Consumers are becoming more willing to pay premium prices for organic foods (Butte et al., 2007), mostly because organic agriculture is thought to be less damaging to the environment, healthier for consumption (Williams and Hammit, 2001), and there are fewer perceived risks associated with consuming organically produced foods (Saba and Messina, 2003). Research has also shown that consumers often prefer environmentally friendly products (Yue et al., 2010) that were produced sustainably (Yue et al., 2009); however, a demand for organically produced ornamental plant materials has not yet been readily evident (Yue et al., 2011).

Organically produced ornamentals are currently not in high demand, likely because they are not consumed. However, there is a possibility that organically maintained landscapes could become more popular because many feel pesticides are “harmful” when being applied in close proximity to public buildings, schools, and homes (Arya, 2005). Many provinces in Canada began banning or highly restricting the use of nonessential or “cosmetic” pesticides in the 1990s and 2000s (Sandberg and Foster, 2005). Although these bans were highly debated and resulted in some negative consequences, such as public parks being unusable due to weed pressure (Holland, 2012), concentrations of herbicides in urban streams have significantly decreased in areas where bans were passed (Todd and Struger, 2014). Results from a survey of landscaping firms in Long Island, NY, indicate that there has recently been a wide adoption of organic landscaping practices, and that many of these companies are experiencing stable, albeit slow growth (Haas et al., 2013). These businesses generally cater to niche, often high-income markets and have clients that are very environmentally conscious, or otherwise have an aversion to chemical use on their landscape (i.e., chemical sensitivities, etc.). Because of these concerns, interest has increased in recent years pertaining to use of “natural” herbicides such as acetic acid (vinegar) and other products such as citric acid, d-limonene and clove, cinnamon, and lemon grass oil (Daniels and Fults, 2002; Evans and Bellinder, 2009; Lanini, 2012). These products are also often perceived to be safer for the applicator in comparison with synthetic herbicides; however, that is not necessarily the case. For example, acetic acid concentrations over 10% (the concentration generally needed for effective weed control) can cause severe burns and irreversible eye damage (Coban, 2007; Daniels and Fults, 2002). The majority of these herbicides work by contact, have no selective activity, and are not translocated throughout the weed, typically only controlling small annual species (Daniels and Fults, 2002; Lanini, 2012). In a study by Ferguson (2004), citric acid, clove oil, and thyme/clove oil were compared with glyphosate for control of common broadleaf and grass weeds. In this trial, organic herbicides provided 10% to 40% weed control compared with 100% control with glyphosate. A Minnesota survey reported that a typical homeowner tolerates up to 10% weeds in their lawns (Carpenter and Meyer, 1999), but customers who use organically maintained landscapes or herbicides may have to tolerate more than 10% weeds, and in some cases may still pay higher fees compared with conventional maintenance costs. However, if this type of service was known to have a wide appeal, landscape companies could begin to offer organic services, or new businesses could be developed and market themselves as organic as a way to differentiate themselves in a competitive marketplace. Many of these companies lack the resources needed to conduct a thorough market analysis, and currently there is a need to determine if organic landscaping maintenance would be a sustainable business model, and identify geographical areas in which these businesses could operate successfully.

Conclusion

Many different herbicides are available for providing weed control in landscape planting beds. However, no one herbicide will control all the weeds, and the best success will most likely be achieved by using a variety of chemical and nonchemical methods using an integrated approach. A review of the literature pertaining to weed control in landscapes reveals several knowledge gaps that offer potential for future progress. Compared with agronomic or food crops, weed control research, specifically herbicide safety and efficacy testing, in specialty crops receives little funding for research (Fennimore and Doohan, 2008), and weed control in landscapes is often an afterthought. However, determining new weed control methods in landscape plantings and improving on current practices could
potentially provide significant benefits including improved profit margins for landscapers, increased property values, and also help to mitigate negative environmental impacts from over application of herbicides in urban and suburban areas. Future research should be focused on determining the best integrated weed control practices and how different methods can be combined to improve weed control and reduce costs. Specific areas in which progress could be made include determining the best mulch + herbicide combinations, testing more herbicides for crop tolerance on additional ornamental species, and evaluating synergism and antagonism of common herbicide tank mixes for landscape applications. Continual training and education are needed not only for professional applicators but also for homeowners applying pesticides.

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