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Introduction

Richard Smith, Editor

This issue of the California Weed Science Society Journal deals with challenges in weed control. Herbicide resistance and lack of herbicide development in minor crops are some of the issues that weed control practitioners are currently confronting. But there are new developments such as robotic weeding technology which are cause for optimism. We have included articles that deal with these specific topics in this issue.
This is our first all electronic issue of the CWSS Journal. Contact Celeste Elliott at the CWSS managers office if you know someone that wants to be added to the email list: manager@cwss.org.

Be sure to mark your calendars for the CWSS annual meeting in Monterey on January 19-21, 2011 and don't miss the pre-conference tour on Tuesday, January 18th (for information visit the website at http://www.cwss.org).

Herbicide Resistance – An Evaluation of Hard-to-Control Weeds and a Discussion of What Might Be Coming Our Way

Brad Hanson, University of California, Davis, Cooperative Extension Specialist, bhanson@ucdavis.edu

The development of weed biotypes that are resistant to commonly used control measures is becoming an increasingly significant problem in California and around the world. As of January 2010, there have been 194 confirmed reports of herbicide resistance affecting 19 different herbicide mode of action families (Heap 2010). Of these cases, about 60% are broadleaf and 40% are grass or sedge weeds. In the U.S., 128 resistant species have been reported (also 60% broadleaf weeds) and 15 herbicide families are affected. California has 21 individual cases of resistant weeds impacting 7 herbicide families; however, in contrast to the rest of the world, two-thirds of California's resistant species are grasses and sedges due primarily to tremendous selection pressure for grass weeds in rice production.

When we consider what herbicide resistant weeds might become important in California in the future, we should focus on weeds that already have reports of resistance in other parts of the world.

The 10 most important herbicide resistant species in the world (Heap 2010) are all present in California and can be problematic weeds even without herbicide resistance (Table 1).

(Continued on next page)

Four of those (three grasses and one broadleaf) are already known to be resistant to at least one herbicide in California. These 10 species have individual reports of resistance to many different modes of action (MOA) and we can expect that new cases may show up in this state over time. Additionally, other important weeds in these genera also are a likely risk for resistance in California (eg. Lolium spp., Amaranth spp., Echinocloa spp., and Conyza spp.).

A relatively recent trend in the development of herbicide resistant weeds has been the discovery of glyphosate-resistant weeds. Although glyphosate (the active ingredient in RoundUp, and others) has been used for nearly 40 years, no resistance was reported until 1996. However, since 1996, sixteen glyphosate-resistant biotypes have been reported around the world (Table 2). Nine of these are already in the U.S. and four are known to be widespread in California. Similar to the earlier discussion, many of these species or close relatives are common throughout the state and are of great concern with regards to losing efficacy of this important broad-spectrum herbicide.

While this discussion is simply one guess as to which herbicide resistant weeds may become problems in California in the future, we can be certain that resistance is likely to remain a significant problem. Rapid and committed adoption of resistance management practices is critical for the preservation of important tools like glyphosate and other herbicides.

Table 1. Worst herbicide resistant weeds worldwide (based on number of infested sites).

	Present in CA	Resistance outside CA	Resistance in CA
Rigid ryegrass (*Lolium rigidum*)	☑	8 MOA	☑glyphosate
Wild oat (*Avena fatua*)	☑	6 MOA	☑ difenzoquat
Redroot pigweed (*Amaranthus retroflexus*)	☑	3 MOA	
Common lambsquarters (*Chenopodium album*)	☑	4 MOA	
Green foxtail (*Seteria viridis*)	☑	4 MOA	
Barnyardgrass (*Echinochloa crus-galli)*	☑	7 MOA	☑ACCase, thiocarbamate
Goosegrass (*Eleusine indica*)	☑	4 MOA	
Kochia (*Kochia scoparia*)	☑	3 MOA	
Horseweed (*Conyza canadensis*)	☑	5 MOA	☑ glyphosate, paraquat
Smooth pigweed (*Amaranthus hybridus*)	☑	2 MOA	

Table 2. Worldwide reports of glyphosate-resistant weeds.

	Resistance USA	Resistance CA
Palmer amaranth (*Amaranthus palmeri*)	☑	
Common waterhemp (*Amaranthus rudis*)	☑	
Common ragweed (*Ambrosia artemisifolia*)	☑	
Giant ragweed (*Ambrosia trifada*)	☑	
Hairy fleabane (*Conyza bonariensis*)	☑	☑
Horseweed (*Conyza canadensis*)	☑	☑
Sourgrass (*Digitaria insularis*)		
Junglerice (*Echinochloa colona*)		
Goosegrass (*Eleusine indica*)		
Wild poinsettia (*Euphorbia heterophylla*)		
Italian ryegrass (*Lolium multiflorum*)	☑	☑
Rigid ryegrass (*Lolium rigidum*)	☑	☑
Ragweed parthinium (*Parthinium hysterophorus*)		
Buckhorn plantain (*Plantago lanceolata*)		
Johnsongrass (*Sorghum halapense*)	☑	
Liverseedgrass (*Urochloa panicoides*)		

Heap, I. 2010. The International Survey of Herbicide Resistant Weeds. Accessed online January 11, 2010. Available at www.weedscience.com.

Hairy Fleabane in Central Valley of California, is there anything new in an old known problem?

Marcelo L. Moretti[1]; Bradley D. Hanson[2]; Kurt J. Hembree[3], and Anil Shrestha[1]

[1]California State University, Fresno; [2]UC Davis; [3]UCCE, Fresno.

Weeds have always been a concern in crop production and in the protection of aesthetic value of non-crop areas. Weedy plants of the *Conyza* genus are an example of such problematic weeds in crop and non-crop lands. This genus includes two important weedy species in California, horseweed (*C. canadensis*) and hairy fleabane (*C. bonariensis*). Both these species are found on canal banks, road sides, in orchards and vineyards, and other sites. Plants of these species are able to produce thousands of seeds that are easily dispersed by air movements. The preferred sites for these species seem to be relatively less disturbed which explain their prevalence in orchards, vineyards, and non-crop areas.

Several herbicides registered in California provide efficient control of these weeds; however some herbicides use may be regulated in certain areas such as Ground Water Protection Areas. Among the herbicides applied for control of *Conyzas*, glyphosate is one of the most common. This is because glyphosate is an excellent postemergence product that provides broad-spectrum weed control, is considered an 'environmentally-safe' product, and is more cost effective than several other herbicides. Therefore, it is the most sold herbicide around the world and in California. However, these same reasons have resulted in repeated applications of glyphosate. Inevitably, glyphosate resistance evolved, and the first cases of glyphosate-resistant (GR) biotypes of *Conyza* in California were reported in 2005 for horseweed and in 2007 for hairy fleabane. This evolution necessitated the control of GR weeds with alternate herbicides such as glufosinate or paraquat.

Burn-down applications of paraquat is considered as an alternative for control of glyphosate resistant weeds in perennial crops. However, in recent years, poor control of hairy fleabane was reported in Fresno County. Glyphosate-resistant populations of hairy fleabane have already been reported in California and in many other countries. Similarly, paraquat-resistant populations of hairy fleabane have been reported from Japan and Spain. However hairy fleabane populations resistant to both glyphosate and paraquat have not been documented in any part of the world. Therefore, a greenhouse dose-response study was conducted to ascertain whether the populations collected in the Central Valley had evolved resistance to both glyphosate and paraquat. Our results showed that 8 putative resistant populations of hairy fleabane from east Fresno county were resistant to paraquat and or glyphosate. All populations were exposed to increasing rates, up to 16-fold the label rate, of either glyphosate or paraquat. The plants were treated at the 5- to 8-leaf stage (approximately two month old plants), during late spring and summer of 2009. For either herbicide, the rates were based on the label recommendation for weed control in almonds. The label rate was considered as 0.45 lbs a.i. ac^{-1} and 0.98 lbs a.i. ac^{-1} for paraquat (Gramoxone Inteon, Syngenta Inc.) and glyphosate (Roundup Weathermax, Monsanto Inc.), respectively. Some populations of hairy fleabane showed resistance to only glyphosate or paraquat and in some cases, a single population showed resistance to both herbicides. This is the first known case of resistance to paraquat and glyphosate in the same biotype of hairy fleabane worldwide.

Unfortunately this finding is not pleasant news because it has direct impact on weed management, and a consequent increase in production costs. As previously cited, one of the reasons that made glyphosate the most sold herbicide worldwide was its low cost, and it is also one reason why paraquat is a good herbicide for rotation with paraquat. Such resistance to both herbicides, if not properly managed, may lead to a serious problem and in a worst case scenario result in the loss of effective control of both products.

A secondary study was conducted to test the response of these glyphosate and paraquat resistant hairy fleabane biotypes to glufosinate (Rely, Bayer) and saflufenacil (Treevix, BASF). We found that both these herbicides, at the recommended rate, provided good control of the resistant biotypes. Therefore, in the short-term, these herbicides may be good options for control of glyphosate- and paraquat-resistant and susceptible biotypes. However, relying solely on chemical control may lead us to evolvement of new resistance to these herbicides as well. Therefore, an integrated approach with planned herbicide rotations is necessary to avoid similar problems in future.

Controlling Difficult Weeds in Right-of-Ways and Non Cropland

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The unchecked growth of weeds in ditchbanks, fencerows roadsides, and other non-cropland areas can cause several problems for landowners. Poor weed management practices may increase weed seed reservoirs and the potential for weed problems if the land is ever brought into crop production, provide for a source of new weed problems in adjoining fields through seed dispersed by wind, animals or perennials creeping in from field edges, and lower economic land values. Glyphosate resistance of horseweed (*Conyza canadensis*) and hairy fleabane (*Conyza bonariensis*) populations have increased dramatically throughout California orchards, vineyards, and roadsides. This shift has occurred due to the usage of repeated applications of glyphosate, reduced tillage, less usage of residual herbicides, and less use of alternative chemistry.

Glyphosate resistant horseweed, fleabane and other species have shown up throughout the United States particularly in the cotton regions of the United States. From 2006-2009 ditchbank and roadside studies conducted in Tulare County demonstrated good control of horseweed when using Milestone, Transline at 10.6 oz., Krovar + Accord, Karmex + Accord, and Oust + Accord gave up to 100 percent control of horseweed. The higher rates of Milestone at 7 oz. /A was needed to give the most consistent control. Treatment combinations of Glyphosate at 2 lbs. ai. + Indicate, Citric Acid, ET, Shark, or Chateau gave improved control compared to Glyphosate + AMS. In all treatments glyphosate was an important addition for control of grasses that were present.

Sprangletop (*Leptochloa fascicularis*) is increasing rapidly in many ditch banks in the San Joaquin Valley. Research studies in 2009 in Kings County demonstrated that two applications of glyphosate at 44 oz. per acre plus glufosinate at 7 pints per acre gave outstanding control of sprangletop.

Conclusions

In summary, the non-crop weed management approach must incorporate resistance management strategies such as using minimum number of applications of any one herbicide per season. Also rotating herbicides and using tank mixes with different chemistry. Other strategies the non-crop weed management must include are controlling weed escapes by tillage, or hand when appropriate, and monitoring and mapping locations for patterns of weed escapes consistent with developing resistance.

Roundup Ready Canola as a Weed in California

Douglas Munier & Kent Brittan, UC Farm Advisors

Roundup Ready canola may be a new California crop at some point in time, but is currently one of California's newest weeds. Roundup Ready canola is a weed because of its ability to produce a significant percentage of secondary dormant seed when harvested under a Mediterranean climate (Lutman *et al.* 1998). This secondary seed dormancy in combination with its glyphosate resistance makes canola a new difficult California weed.

Most annual crops only produce volunteer plants during the year following production; however canola is known for shattering large amounts of seed before and during harvest (Mallory-Smith & Zappiola 2008) and when buried, some seed enters a "secondary dormancy." Even if all volunteer canola is controlled before it produces seed in the first year following canola, seedlings will continue to emerge for many years from dormant seed. Most of this dormant seed emerges in the first four years

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four years (Lutman 2003), but some can emerge up to 10 years after burial in the soil (D'Hertefeldt *et al.* 2008 and Lutman 2005. Canola is a higher quality oil developed out of oilseed rape. Canola varieties are selections from several mustard species, but most varieties produced in the United States originated from *Brassica napus*, commonly called rapeseed mustard. Rapeseed mustard and the other mustard species, to which canola is related, are present in California as wild weeds.

California Situation

In trial and commercial field locations since 2006, California canola has shown similar shattering losses and seed dormancy to those in Canada and England (Lutman 2003). In the fall of 2006, the University of California Cooperative Extension conducted four small plot canola variety trials in Butte, Yolo, Fresno, and Imperial Counties. In addition, growers in Colusa and Yolo Counties planted several commercial fields of canola. With high energy prices, the California interest in canola was primarily for biodiesel and for planting seed production, but this interest was short lived. Canola for oil/biodiesel is not an economically viable crop in California at the present time.

The Butte County trial was planted on one tenth of an acre, but one acre of land around it has been left fallow and no volunteering canola has been allowed to produce seed. Even though no additional seed has been produced since the summer 2007 harvest, in the fall of 2009 (3rd year of "weedy" volunteer) over 500 canola seedlings emerged from this small one tenth of an acre area planted to canola in the fall of 2006. Similar "weedy" volunteer canola emerged through 2009 at two of the monitored Yolo county locations.

The transportation of farm equipment to and from these 2007 trials and production fields scattered some canola along county roads and state highways. This scattering of seed along the roadside is typical of field crops production. However, unexpected reproducing roadside populations of canola were located during the winter of 2009. Roundup Ready corn and cotton have been widely planted over the past ten years in California, but have not become established along roadsides as reproducing weeds.

Aggressive control with effective herbicides and hand pulling of escapes along some of the county roads has resulted in very effective control, if not eradication. Some state highways with very limited control efforts have expanding canola populations along those roadsides. Disturbance of roadside soil promotes secondary dormant seed through shallow burial.

Importance of Glyphosate Resistance

Wild types of rapeseed mustard are not common weeds in California agricultural fields and at present are easily controlled by glyphosate. The seed dormancy of canola makes it a difficult weed to control, persisting in a field where it was once planted for years, if not indefinitely. Canola's glyphosate resistance in combination with canola's seed dormancy makes it a challenging weed for roadsides, orchards, vineyards, fallow fields, and Roundup Ready crop fields, anywhere where glyphosate is an important herbicide.

Glyphosate is one of the most common and valuable herbicides in California agriculture. Stephen Powles of the University of Western Australia has described glyphosate as "a once-in-a-century herbicide" (Powles *et al.* 2006). Glyphosate is effective on many broadleaf and grassy weeds, both annual and perennial weeds, with extensively proven animal and environmental safety. If glyphosate is a "once in a century herbicide" a replacement herbicide for glyphosate is likely decades into the future. Each time another weed, for example ryegrass (Powles *et al.* 2006), develops resistance to glyphosate it makes weed control more complicated, more expensive, and decreases the value of the herbicide. If Roundup Ready canola spreads along roadsides and into orchards and fields it will make glyphosate less valuable in those situations.

Canada and the northern United States

Canola is the most important oilseed crop in Canada (Harker *et al.* 2000), planted on millions of acres of farmland and has recently become an important crop in the northern United States. In these areas, canola is commonly grown in rotation with wheat where several phenoxy herbicides can be widely used to control volunteer canola. In California with cotton, grapes, and other phenoxy sensitive crops, all phenoxy herbicides are very restricted. This limits the available herbicides for controlling Roundup Ready canola. California's diverse agriculture and restricted phenoxy herbicides makes "weedy" Roundup Ready canola control much more difficult than in Canada and the northern cereal growing areas of the United States.

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Summary

As long as canola for oil is not an economically viable crop in California agriculture, avoiding establishing it as widespread glyphosate resistant weed is a reasonable goal. Industry, regulators, and Cooperative Extension can work together to prevent Roundup Ready canola in California from becoming a widespread weed. "Weedy" Roundup Ready canola would diminish the value of glyphosate wherever it became established on any of the millions of acres in California where glyphosate is an important herbicide.

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Evaluation of a Robotic Cultivator for Vegetable Production in California

Steve Fennimore, Richard Smith and John Rachuy
University of California Cooperative Extension

Weed control in vegetable crops is a constant pest that increases the cost of vegetable production. Weed control in conventionally produced vegetables consists of the use of preirrigation, herbicides, cultivation and removal of remaining weeds by hand. Any technique or production practice that can help reduce weed pressure helps to make weed removal cheaper and more efficient. Vegetable weed control faces many challenges such as availability of effective herbicides, labor and remunerative markets in order to cover costs. Few new herbicides are in development for any crop, and we are not aware of any new herbicides being developed for California vegetable crops. With no new products in the pipeline and the gradual loss of old high-rate vegetable herbicides the chemical option appears bleak. As a result, there are significant issues that face effective and economical weed control in vegetable production.

A positive development has been the application of electronic engineering technology to weed removal in vegetables. Robotic guided weed cultivators many advantages and as cultivators are classified as a "device" by USEPA is not a pesticide nor require registration. There are several robotic weed control strategies that have been developed in various parts of the world. In this article we will discuss the Tillet rotating cultivator which is a commercial unit developed by Garford Corp. in England (http://garford.com/). It employs a spinning disc that travels in the seedline of transplanted crops. It has a pie shaped piece

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removed from it that spins around the crop plants (Figure 1). This machine is used in Europe and is available in the US through Solex in Dixon, CA (http://www.solexcorp.com).

We have conducted several trials with this machine and in this article, we report on two trials: 1) transplanted tomatoes and 2) direct seeded lettuce. The rotating cultivator was used to weed the transplanted tomatoes and to weed and thin the direct seeded lettuce. Weed control, crop thinning, hand weeding times and crop yields were evaluated. The rotating cultivator removed more weeds than standard cultivation, but fewer crops plants (Table 1). Weeding time was not reduced in the rotating cultivator plots and no reductions in yield of tomatoes were observed. In direct seeded lettuce, the rotating cultivator removed more weeds than standard cultivation, but also had fewer crop plants (data not shown). The rotating cultivator reduced weeding time in this trial and did not reduce the yield of lettuce (Table 2).

These data indicate that robotic weeders have potential to improve the efficiency of weeding operations. There are concerns at this stage of the development of the technology that crop recognition may not be perfected to safeguard crop stands as well as hand weeding; it is hoped that as this technology develops, crop safety will improve and costs reduced. In general, robotic weeders are a promising new technology that provides an alternative to some of the challenges in controlling weeds in vegetable crops. As new iterations of this technology become available, they should provide more effective weed control. At this point, they are not foreseen to replace had weeding, but they can make subsequent hand weeding operations more efficient and economical.

Figure 1. Rotating cultivator

Rotating knives (not the notch that allows the blades to spin around a crop plant

Rotating cultivator thinning lettuce

Lettuce stand following rotating cultivator

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Table 1. Effect of cultivation type on weeding time and yield of transplanted tomatoes.

Cultivation Treatment	Cumulative weed time (sec/45ft)	Red Ripe (kg/33ft²)	Green Ripe (kg/33ft²)	Total Ripe (kg/33ft²)
Tillett	68.7	2.08	12.82	14.90
Standard	77.2	2.08	13.06	15.15
LSD (P=0.05)	24.4	2.62	4.85	2.50
Treatment Prob (F)	0.3479	0.9980	0.8828	0.7742

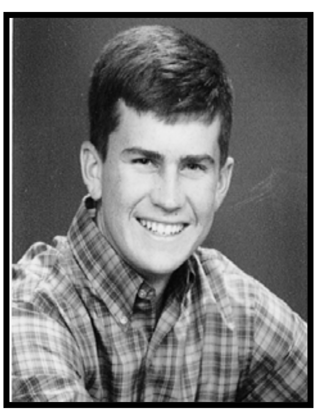
Table 2. Effect of cultivation type on weeding time and yield of head lettuce

Cultivation type Thinning / weeding procedure	Cumulative weed time (sec/50ft)	Market Heads (no./25ft²)	Market Heads (kg/25ft²)	Head Size (gr/head)
Tillett	81.3 b	9.0	7.36	800.5 a
Standard	123.2 a	9.0	6.89	668.0 b
LSD (P=0.05)	33.5	3.0	2.51	105.0
Treatment Prob (F)	0.0105	0.9758	0.5924	0.0277

2010 CWSS Student Scholarship Winners

The CWSS was pleased to make awards to deserving students this year. Undergraduate scholarships were awarded to 1st place ($2000) to Brad Redelfs, Cal State University, Fresno; 2nd place ($1000) to Evan Longstreth, Cal State University, Fresno. Graduate student scholarships were awarded to 1st place ($2000) to Kristen Weathers, University of California, Riverside; 2nd place ($1000) to Lindsay Clark, University of California, Davis; and 3rd place tie to ($500) Kai Palenscar, University of California, Riverside and Marcelo Moretti, Cal State University, Fresno. An undergraduate internship ($3000) was awarded to Claire D. Uke, Cal Poly, Pomona. Please be sure to encourage young people to apply for these awards in the coming year. Information on the award programs can be obtained by contacting Rob Wilson at rgwilson@ucdavis.edu or at the CWSS website www.cwss.org.

Undergraduate Students



Evan Longstreth

I am attending Fresno State, with a major in Plant Science and minor in Ag Business, under advisor Anil Shrestha. After graduation, I would like to get my PCA license and return to Escalon to help take over my dad's farming business with my brother. During that time I hope to start buying my own land and invest more into research and technology that will help farming in the future .

Claire Uke is a Plant Science student attending California State Polytechnic University, Pomona. After receiving her master's degree, Claire will be focusing her career in the fields of Arboriculture and Invasive Species Management. In her off-time she involves herself in the Los Rancheros Agronomy Club at Cal Poly Pomona. In the Summer of 2010, she will be working with Carl Bell in San Diego, California.

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Graduate Students

Kristen Weathers

I am currently pursuing a Ph.D in plant ecology in the Department of Botany and Plant Sciences at UC Riverside. I am co-advised by Milt McGiffen and Edie Allen. My dissertation investigates the role of invasive Erodium species and their impacts on the restoration of coastal sage scrub communities. Additionally, I am investigating chemical and non-chemical methods to control Erodium during the restoration process.

I hope to pursue a career with Cooperative Extension, USDA, or USGS researching and disseminating information on methods of invasive species control and natural resources restoration and management.

Lindsay Clark

I am working on my Ph.D. in Genetics at UC Davis as a member of Marie Jasieniuk's lab. In my dissertation project I am using genetic tools to better understand invasiveness in Rubus, in particular the Himalayan blackberry invasion on the West Coast. Specific topics of my project include clonal diversity and origins of Himalayan blackberry, spontaneous hybridization with native species, sexual reproduction vs. apomixis, and gene expression patterns diagnostic of invasiveness. I plan to pursue a career of teaching and research at an undergraduate-focused institution, where I can train students in the application of ecological genetics to invasive species management.

Kai Palenscar

I am a third year Ph.D. graduate student at the University of California, Riverside within the Department of Botany and Plant Sciences (BPSC). My adviser is Dr. Jodie S. Holt, professor and chair of BPSC. The invasive plant giant reed (*Arundo donax*) is an aggressive rhizomatous, hydrophyte found in the riparian plant munity of southern California and across the United States. My dissertation work seeks to utilize native vegetation to culturally control giant reed reestablishment within areas where it has been previously controlled. If it can be found that certain species inhibit the regrowth and establishment of giant reed land managers can use this information in restoration activities whereby minimizing pesticide application. My future career goals include wildlands management or related field involving conservation and invasive species management.

Marcelo Moretti

I am a master student at CSU Fresno State working with Dr. Anil Shrestha. My thesis work is the screening of paraquat and glyphosate resistance in hairy fleabane populations from San Joaquin Valley, and short term alternate chemical control of such biotypes. Also, I have participated in additional studies mapping the distribution of glyphosate resistant hairy fleabane in the valley, and weed management in organic orchards and vineyards. When graduated my plans are to work with research and extension related positions to gain experience before starting a PhD program. My long term career goals are to continue working mainly with herbicide resistance management, as well as other areas of weed science.

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