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Full Paper

Weed Management Practices and Herbicide Resistance in Weeds in Florida Citrus

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Herbicide-resistant weeds have been confirmed in some crop production systems in Florida but not in citrus groves. A grower survey was conducted in 2012 to determine the current weed management practices in Florida citrus and to determine awareness of citrus growers about herbicide-resistant weeds. A questionnaire was sent to 60 randomly selected growers, of which 33 turned in their responses representing 20% of the citrus growing area in Florida. Most of the respondents (47%) indicated that weed problem and species in Florida citrus did not change over the years with the top 3 problematic weeds: Spanishneedle (*Bidens* spp.), balsam apple (*Momordica charantia* L.), and panicums (*Panicum* spp.). Weed control in citrus groves is primarily with the use of herbicides applied alone, in tank-mixes, or applied sequentially in a year. Diuron, simazine, and indaziflam are the top 3 PRE herbicides while glyphosate, paraquat, and saflufenacil are the top 3 POST herbicides applied in Florida citrus. Glyphosate is the most commonly applied herbicide in the vast majority of citrus groves and as frequently as 3-5 times in a year. Citrus growers in Florida are aware of herbicide resistant weeds and their negative impact on citrus production. Although, there are no confirmed herbicide resistant weeds in Florida citrus, few weeds including Spanishneedle, ragweed parthenium (*Parthenium hysterophorus* L.), and nightshade (*Solanum* spp.) are inadequately controlled with the recommended rate of glyphosate, thus, should be tested for possible resistance.

Keywords: citrus, glyphosate, herbicide, herbicide resistance, weed survey

INTRODUCTION

Florida ranks first in citrus (*Citrus* spp.) production in the United States. Citrus is an important crop in Florida as it accounts for 20% of total value of farm production in the state. In 2014, area planted to citrus in the state was approximately 195,000 ha with production value of US$1.5B (USDA 2015). Weeds are major problem in citrus production due to favorable warm weather and frequent rainfall in Florida. Application of fertilizer and irrigation further enhance weed vigor and growth. Weeds can cause 23-33% yield loss in citrus, hence, weed management is estimated to be 11-14% of the total production cost (Muraro 2013). Limited information is available on the current weed management practices used by citrus growers in Florida to off-set yield loss associated with weeds.

Herbicide resistance is a phenomenon whereby weeds are not controlled by labeled rate of herbicide that have been previously known to control the wild type at the same application rate (Vencill et al. 2012). Herbicide resistant weeds is a global issue and its occurrence has been documented in 66 countries involving 86 crops. As of 2015, there are 461 unique cases of herbicide resistant weeds worldwide involving 247 weed species and 157 herbicide chemistries belonging to 22 of the 25 herbicide sites of action (Heap 2015). Herbicide resistance results from an increased selection of resistant weed biotypes brought by the repeated use of a single herbicide or herbicides with the same mode of action for a prolonged period of time. There are several confirmed cases of herbicide resistant weeds in row crops and aquatic environment in Florida namely: Palmer amaranth (*Amaranthus palmeri* S. Wats.) resistant to imazapic and pyrithiobac-sodium, American black nightshade (*Solanum americanum* P. Mill) and goosegrass [*Eleusine indica* (L.) Gaertn.] resistant to paraquat, dotted duckweed [*Landoltia punctate* (G. Mey.) Les & D.J.Crawford] resistant to diquat and paraquat, and hydrilla [*Hydrilla verticillata* (L. f.) Royle] resistant to fluridone (Heap 2015). Glyphosate resistant Palmer amaranth and ragweed parthenium (*Parthenium hysterophorus* L.) were also reported to be present in row crop fields, industrial sites, and roadsides in Florida (Heap 2015). In recent years, citrus growers have expressed concerns on some weeds not controlled by labeled rate of glyphosate, however, currently there is no confirmed report of glyphosate-resistant weed in Florida citrus. It is important to document if herbicide resistant weed is present because it would impact weed management decisions and herbicides options in citrus groves.

Surveys are important source of information for agriculture stakeholders and growers. Weed surveys are conducted for numerous reasons which include: to document weed occurrence, assess the extent of

weed infestations, determine current as well as possible weed problems (Loux and Berry 1991), identify farmer perceptions and concern with problematic weed species (Gibson et al. 2005), document growers' management practices and identify herbicide resistant weed biotypes (Baumgartner et al. 1999; Heap 2015). Additionally, surveys are helpful in identifying priority areas for developing weed management strategies in many cropping situations.

The Southern Weed Science Society has been conducting an annual survey of the most common and troublesome weeds in various crops of the southern United States since the 1970s. However, there is no survey report in Florida citrus since the 1990s (SWSS 2002; 2006; 2010). The latest survey in Florida citrus was conducted in 1998 to 1999 to evaluate the relative dominance of Brazil pusley [*Richardia brasiliensis* (Moq.) Gomez] and Florida pusley (*R. scabra* L.) in citrus groves (Chandra and Singh 2003). The survey focused on the top 14 citrus producing counties in central Florida and reported that Brazil pusley was more predominant than Florida pusley. The last weed survey in citrus was conducted more than a decade ago, it is therefore essential to acquire new information not only on the important weed species in citrus, but also on the current state of weed management and herbicide-resistant weeds in citrus groves. The objectives of this survey were to document the current weed management practices in Florida citrus and to determine grower's perspective on herbicide resistant weeds and identify possible herbicide resistance issues to develop a pro-active herbicide-resistant weed management strategy in Florida citrus groves.

MATERIALS AND METHODS

Citrus groves that were deemed to be at high risk of evolving herbicide resistance were the focus of this survey. To be considered at high risk, fields needed to satisfy one of the following criteria: continuous dependence on herbicides in the past 10 yr and/or grower's suspicion of resistant weeds. Based on these criteria, 60 citrus growers were randomly selected. Of the 60 growers, 33 growers completed the 3-page, 6 sections questionnaire on weed problem, management practices in the tree row and middles (methods, chemical use, type, frequency and rate), herbicide resistance and tolerance awareness, and cases of herbicide resistance.

Responses for each question in each section was tabulated and whenever warranted expressed as the percentage of the respondents. On the question regarding weed problems, respondents were asked to list 10 weed species and rank them according to its importance (in terms of being problematic), with A being the most problematic and J being the least problematic. Each weed species was then scored by giving each letter (A to J) a corresponding numeric equivalent: A being 10 and J being 1. Scores received for each weed species were then multiplied by the size of the area where it was reported to obtain the relative importance score. Each score was then summed for each weed species and the top 10 weed species that received the highest scores were considered as the top 10 problematic weeds in Florida citrus. In some cases, respondents did not identify individual species but weedy genera. For example, the terms Spanish-needle, Panicum, and pigweed are often used to refer to several species in the genus *Bidens*, *Panicum* and *Amaranthus*, respectively, hence these weed species are grouped based on their genus.

RESULTS AND DISCUSSION

Survey Respondents

Out of the 60 randomly selected citrus growers, 33 sent back their responses. The 33 respondents represented 20% of the citrus acreage in Florida. The size of the groves represented in this survey ranged from 14 to 5,670 ha. A great majority of the respondents came from central Florida (Figure 1). Citrus in Florida is grown in 27 counties and it is estimated that citrus acreage in 2012 was greater than 200,000 ha (FASS 2013). Seven out of the top ten citrus producing counties are represented in this survey.

Problem Weeds in Florida Citrus

Based on the survey results, the most problematic weed in Florida citrus groves is Spanishneedle (*Bidens* spp.), followed by the *Panicum* spp complex (guineagrass, narrowleaf guineagrass, and torpedograss), and a vine weed, balsam-apple (*Momordica charantia* L.) (Table 1). The list is composed of weeds belonging to nine taxonomic families, with Asteraceae represented by two species (Spanishneedle complex and common ragweed), and the remaining families represented by one species each. Except for the *Panicum* spp. complex, the rest of weed species completing the list were broadleaf weeds. Similarly, Olorunmaiye et al. (2011) observed the predominance of broadleaf weeds (72%) particularly those belonging to the Asteraceae family in surveyed citrus orchards and nurseries in Nigeria. Additionally, *P. maximum* was found to be the dominant grass weed. Except for phasey bean (*Macroptilium lathyroides* (L.) Urb.) and dayflower (*Commelina benghalensis* L.), these problematic weeds were also previously listed as common weeds in citrus production in the United States (Mersie and Singh 1989). Two of the top 10 problematic weeds were vine weeds (No. 3: balsam apple and No. 8: milk-weed vine [*Morrenia odorata* (Hook. & Arn.) Lindl.]). Vine weeds pose a significant problem in citrus groves due to their high adaptation to shaded conditions under the tree canopy, prolific seed production, rapid seed dispersal, ability to regenerate from root pieces that survived disking or hoeing, and tolerance to herbicides (Futch 2006; Philips and Tucker 1970). Wunderlin and Hansen (2008) reported that milkweed vine or strangler vine are generally found in the central part of the state (17 counties) while balsam-apple has a wider distribution being found in 29 counties from the most northwestern county (Escambia) down to the southern key counties.

Figure 1. Geographic location of survey respondents represented by the shaded counties in Florida citrus.

The most damaging effect of poor weed control on citrus production was best described by growers as reduction in productivity. Respondents have expressed weed interference in various ways. Ninety percent had indicated that weeds compete with young and old citrus trees for critical resources needed for growth, while 10% had indicated that weeds hinder certain grove operations such as spraying, harvesting and mowing. Among the resources, competition for nutrients and water ranks the highest (95%) while only 5% of the respondents listed competition for space as being impacted by weeds. Previous studies indicated that weeds affect citrus growth, yield and fruit quality, with the magnitude of effects depending on weed density and species (Horowitz 1973; Jordan and Russell 1981; Singh and Tucker 1988). For example, Spanishneedle at 20 plants m^{-2} can cause 10% reduction in growth to newly established citrus trees (Buker 2005), while bermudagrass [*Cynodon dactylon* (L.) Pers.] not only reduced yield of Valencia oranges (*Citrus sinensis* Rutaceae) but also reduced leaf nitrogen and fruit acids more than annual weeds (Jordan and Russell 1981). Furthermore, Horowitz (1973) reported that bermudagrass impacted citrus growth more than other perennial weeds such as purple nutsedge (*Cyperus rotundus* L.) and shattercane [*Sorghum halepense* (L.) Pers.] and also suggested that weeds competitive effects could be due to production of toxic substances on the leaves.

Table 1. Ten most problematic weeds in Florida citrus groves based on a weed survey

Rank	Name	Scientific name	Family
1	Spanishneedle	*Bidens bipinnata* L.	Asteraceae
2	Panicum (Guineagrass, narrowleaf guineagrass, torpedograss)	*Panicum maximum* Jacq., *P. repens* L.	Poaceae
3	Balsam-apple vine	*Momordica charantia* L.	Cucurbitaceae
4	Pusley (Florida and Brazil pusley)	*Richardia scabra* L., *R. brasiliensis* (Moq.) Gomez	Rubiaceae
5	Pigweed (smooth and green)	*Amaranthus hybridus* L., *A. powellii* S. Wats.	Amaranthaceae
6	Goatweed	*Scoparia dulcis* L.	Plantaginaceae
7	Phasey bean	*Macroptilum lathyroides* (L.) Urb.	Fabaceae
8	Milkweed vine	*Morrenia odorata* (Hook. & Arn.) Lindl.	Apocynaceae
9	Common ragweed	*Ambrosia artemisiifolia* L.	Asteraceae
10	Benghal dayflower	*Commelina benghalensis* L.	Commelinaceae

Forty-seven percent of the growers described the weed problem in citrus as not changing, 33% feel that it has gotten worse, and the rest (20%) expressed that weed control has gotten better (Figure 2). With respect to the weed composition in citrus groves, 46% of the grower respondents indicated that weeds found in most citrus groves are a mixture of long-standing weed and some new weed species becoming more predominant, while 33% of the growers signified it as the same, and a small proportion (6%) has indicated that some weed species that were previously predominant seemed to have disappeared over the last 5 yr. Lange et al. (1975) indicated that perennial grasses such as paragrass [*Bracharia mutica* (Forssk.) Stapf], and guineagrass were the focus of control efforts in the mid-1970s together with vine weeds such as Virginia creeper [*Parthenocissus quinquefolia* (L.) Planch.], milkweed vine, balsam-apple and moonflower (*Ipomoea alba* L.) vines. With the exception of paragrass and moonflower vine, the remaining weeds are still considered major weeds in Florida citrus.

Table 2. Most commonly used pre- and post-emergence herbicides in Florida citrus based on a weed survey

Rank	Common name	Trade name
Postemergence		
1	Glyphosate	various formulations
2	Paraquat	Gramoxone Inteon, Gramoxone SL 2.0
3	Saflufenacil	Treevix
4	Sethoxydim	Poast, Poast Plus
5	Glyphosate+2,4-D	Landmaster II
Preemergence		
1	Diuron	Direx, Diuron, Karmex
2	Simazine	Princep, Simazine
3	Indaziflam	Alion
4	Pendimethalin	Prowl H_20
5	Norflurazon	Solicam

Weed Management Practices in Citrus

Herbicide is the number one choice for weed control among citrus growers in Florida. All of the respondents use herbicides to control weeds in the tree row (Figure 3). Only 13% employed hand hoeing, manual removal of vines or mowing as additional weed control practices. Citrus growers use a variety of herbicides but glyphosate is the most commonly used herbicide. Fifty percent of the respondents use glyphosate up to 3 times a year, and 5% of the growers use glyphosate 5 times a year (Table 2 and Figure 3). Glyphosate is used either alone or in combination with other herbicides and has become the 'go-to' herbicide for many citrus groves. In the 1960s and 1970s, flaming and mechanical tillage practices such as chopping, and disking were used to manage weeds in groves (Tucker et al. 1980). However, these non-chemical control practices are known to increase labor costs, damage tree trunks and surface feeder roots, have shorter durations of control, and reduce tree growth prompting growers to adopt herbicides in many citrus groves, especially in tree rows (Tucker et al. 1980; Whitney et al. 1970).

Mowing, either chemical or mechanical, is the most commonly used method to control weeds in row middles. This is because vegetation in the row middles is needed to prevent soil erosion but must be maintained in such a way that vegetation does not hinder spraying, harvesting, and other operations. Chemical mowing involves the application of post emergence (POST) herbicides, particularly glyphosate, at rates lower than the recommended to suppress, but not entirely eradicate, vegetative regrowth (Futch 2002).

Topping the list of POST herbicides is glyphosate (Table 2). Glyphosate has been the mainstay herbicide for most growers because of its broad-spectrum weed control, effective control on grasses, and low cost. Paraquat is the second most commonly used POST herbicide in Florida citrus groves. It is a contact broad-spectrum herbicide with no residual activity. Saflufenacil is relatively a new contact herbicide that was commercialized in 2010 (Anonymous 2010). Saflufenacil has gained popularity among growers due to its ability to enhance POST

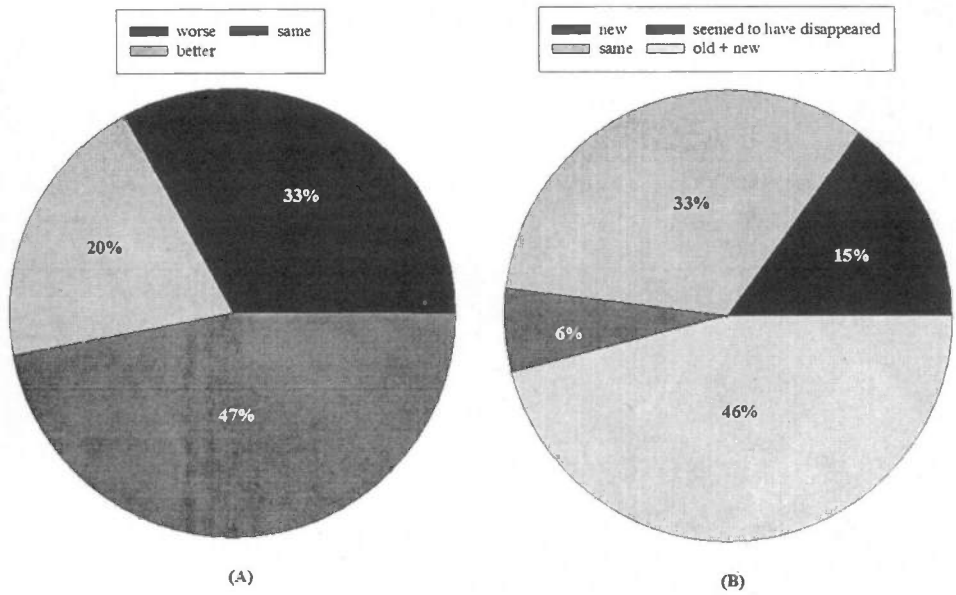

Figure 2. Growers' perception of the weed problem in Florida citrus groves (A) and grower's assessment on weed species composition (B) in citrus groves over the last 3 to 5 years

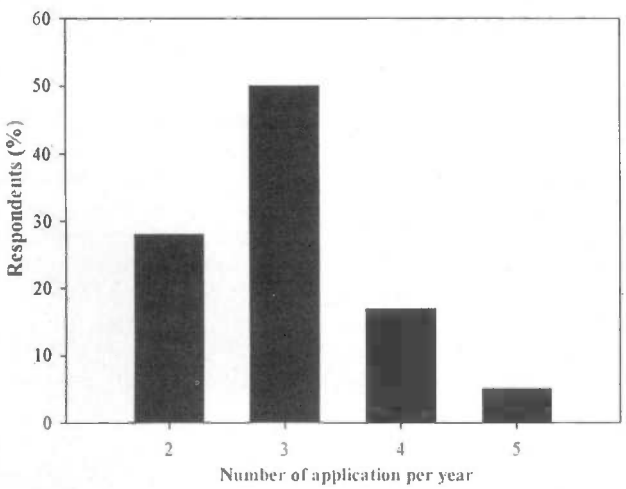

Figure 3. Number of glyphosate applications per year for weed control in Florida citrus groves.

efficacy; however, its activity is limited to broadleaf weeds, requiring that it be tank-mixed with a compatible grass herbicide such as sethoxydim to expand weed control spectrum. Sethoxydim is a grass herbicide that has been recommended to be an ideal tank mix partner of saflufenacil (Jhala et al. 2013).

Diuron, simazine, indaziflam, pendimethalin, and norflurazon are the top five preemergence (PRE) herbicides used in Florida citrus (Table 2). All of these active ingredients, except indaziflam are older chemistries. Indaziflam is a new broad spectrum soil applied herbicide with excellent residual activity against most weed species in citrus production. It controls weeds by inhibiting cellulose biosynthesis in plants (Anonymous 2013). It is very effective in controlling Spanishneedle, guineagrass, pusley species and common purslane (*Portulaca oleracea* L.) (Singh et al. 2011). PRE applications are typically followed by a POST or a combination of PRE and POST herbicide applications in citrus groves in Florida.

More than 50% of the respondents rotate herbicides. Decision to rotate herbicides depends on current weed situation, weather, and time of the year. Seventy-seven percent of the growers use different types of herbicides in various combinations while 18% solely rely on a single herbicide. Of the growers who use multiple herbicides, 74% use a combination of PRE and POST herbicides and 26% use a combination of POST herbicides. However, none of them rely on a single herbicide or combination of PRE herbicides only.

Herbicide Resistant Weeds: Growers' Perspective

A great awareness exists among respondents on the evolution of herbicide-resistant weeds. Failure to control grass weeds (bermudagrass, guineagrass, Johnsongrass), broadleaf weeds (dayflower, nightshade, Spanishneedle), and vine weeds (possum grapevine [*Cissus verticillata* (L.) Nicols and Jarvis] and milkweed vine) in their groves using herbicides at labeled rates was observed by 60% of the respondents. Furthermore, 15 and 50% of the respondents reported failure in control when weeds were treated at 15-30 and 30-60 cm, respectively (Figure 4). In the event of herbicide failure to control weeds, 39% of the respondents sprayed other herbicides with different mode of action, 32% use a higher rate of the same herbicide, 23% cut or mow uncontrolled weeds and the remaining 6% did nothing until the next scheduled spraying (Figure 5).

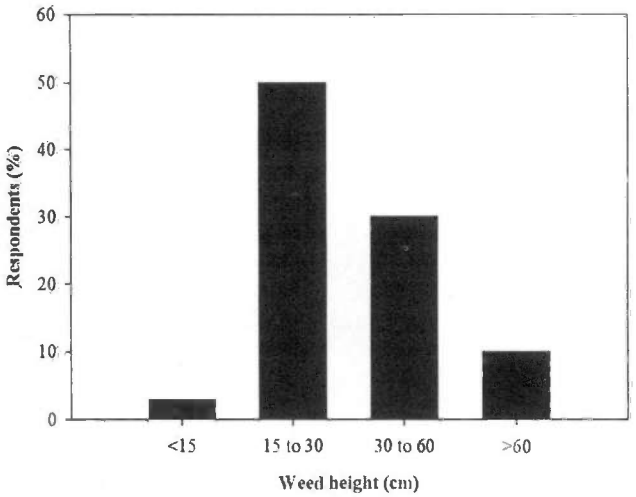

Figure 4. Weed height at the time of POST herbicide application when herbicide applied at recommended rate fails to control weeds in Florida citrus groves.

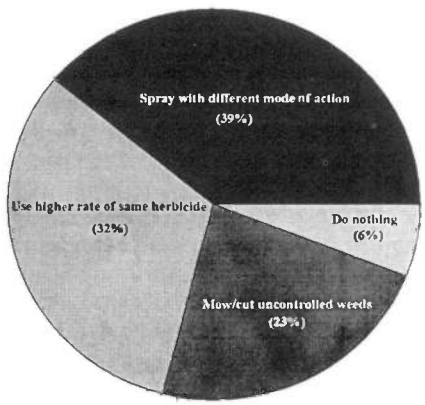

Figure 5. Growers' action in the event of herbicide failure for weed control in Florida citrus groves.

Table 3. List of weed species that have reduced susceptibility to glyphosate as reported by citrus growers

Common name	Scientific name
Spanishneedle	*Bidens bipinnata* L.
Ragweed parthenium	*Parthenium hysterophorus* L.
Phasey bean	*Macroptilium lathyroides* (L.) Urb.
Goatweed	*Scoparia dulcis* L.
Florida/Brazil pusley	*Richardia scabra* L. / *R. brasiliensis* L.
Spreading dayflower	*Commelina diffusa* Burm. f.
Benghal dayflower	*Commelina benghalensis* L.
West Indian nightshade	*Solanum ptychanthum* Dunal

Maintaining a proactive approach in controlling weeds by spraying herbicide with a different mode of action in the event of an herbicide failure greatly off-sets the possibility of herbicide resistant biotype to dominate.

Citrus growers have identified few weed species as suspected glyphosate resistant due to control failure with a labeled rate of glyphosate (Table 3). Continuous reliance on an herbicide or herbicides with the same mode of action leads to evolution of resistant weeds. This has been well documented with the evolution of glyphosate-resistant weeds in corn and soybean cropping systems in the Midwestern United States (Owen and Zelaya 2005; Heap 2015).

Based on the survey results, herbicide is a major component of weed management programs in Florida citrus. Glyphosate is the number one herbicide applied alone or in combination with either a PRE or POST herbicide. Saflufenacil and indaziflam are two of the newer herbicide chemistries that can provide excellent weed control when properly timed applications are applied to emerged weeds. Citrus growers in Florida are very responsive to newly introduced herbicides. The quick adoption may be because it has been a decade or more since a new active ingredient was labeled in citrus and that Florida citrus growers are willing to adopt new technology that would enable them to control weeds effectively.

Although there are reports of unsuccessful control of some weeds by herbicides particularly glyphosate, it cannot be determined whether these are actual cases of herbicide resistance for a number of reasons. First, failure to control weeds at the recommended rate was observed when herbicide was applied beyond the recommended weed size (30-60 cm). To be effective, herbicides must be applied at labeled weed growth stage. Second, some weeds that were identified as 'uncontrolled' were actually considered as naturally tolerant to the herbicide applied. It has been shown that a higher rate of glyphosate (4.5 kg ai ha^{-1}) is needed to control dayflower and goatweed (*Scoparia dulcis* L.) compared to other weeds which were controlled with 1 kg ai ha^{-1} (Sellers 2015). However, it is still necessary to confirm these reports of herbicide resistance to properly identify the broad and specific strategies to manage these weeds.

CONCLUSION

Despite the occurrence of herbicide resistant weeds in agronomic and some vegetable crops in Florida, currently, there is no documented report of herbicide-resistant weed in citrus groves. Citrus growers in Florida are well aware that the evolution of herbicide resistant weeds will pose a significant problem in their groves, especially considering limited herbicides are registered in citrus. Additionally, it is highly unlikely that an herbicide with a new mode of action will be available in Florida citrus in the near future. Therefore, it is important that citrus growers adopt a proactive, integrated weed management approach that may include use of PRE herbicides, tank-mixing

existing herbicides to avoid selection pressure of an individual herbicide, rotate herbicides with different mode of action, and even employ hand hoeing, mechanical removal of weed escapes and mowing as additional weed control measures.

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