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Review

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A systematic review of chemical weed management in peanut (*Arachis hypogaea*) in the United States: challenges and opportunities

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Abstract

Herbicides are the primary tool for controlling weeds in peanut (*Arachis hypogaea* L.) and are crucial to sustainable peanut production in the United States. The literature on chemical weed management in peanut in the past 53 yr (1970 to 2022) in the United States was systematically reviewed to highlight the strengths and weaknesses of different herbicides and identify current research gaps in chemical weed management. Residual weed control in peanut is achieved mainly with dimethenamid-*P*, ethalfluralin, pendimethalin, and *S*-metolachlor. More recently, the use of the protoporphyrinogen oxidase inhibitor flumioxazin and acetolactate synthase inhibitors, such as diclosulam, for residual weed control in peanut has increased considerably. Postemergence broadleaf weed control in peanut is achieved mainly with acifluorfen, bentazon, diclosulam, imazapic, lactofen, paraquat, and 2,4-DB, while the graminicides clethodim and sethoxydim are the major postemergence grass weed control herbicides in peanut. Although several herbicides are available for weed control in peanut, no single herbicide can provide season-long weed control due to limited application timing, lack of extended residual activity, variability in weed control spectrum, and rotational restrictions. Therefore, effective weed management in peanut often requires herbicide mixtures and/or sequential application of preplant-incorporated, preemergence, and/or postemergence herbicides. However, the available literature showed a substantive range in herbicide efficacy due to variations in environmental conditions and flushes of weed germination across years and locations. Despite the relatively high efficacy of herbicides, the selection of herbicide-resistant weeds is another area of increasing concern. Future research should focus on developing new strategies for preventing or delaying the development of resistance and improving herbicide efficacy within the context of climate change and emerging constraints such as water shortages, rising temperatures, and increasing CO_2 concentration.

Introduction

Peanut (*Arachis hypogaea* L.) is an important oilseed and cash crop in the United States. The United States is the fourth largest producer of peanut in the world with a market value of more than $1 billion (USDA-NASS 2022). Peanut production in the United States increased from 2,800 kg ha^{-1} in the 1970s to 4,600 kg ha^{-1} in 2021 (USDA-NASS 2022) due to improved cultivars and cultural practices, more effective pest management, and increased per capita consumption (Holbrook 2019). Although more-effective herbicides are available, weed interference remains a major constraint for peanut production in the United States despite continuous research efforts in weed science. Season-long weed interference can cause 60% to 80% peanut yield reduction through competition for light, water, and nutrients and decreased harvest efficiency (Everman et al. 2008a, 2008b).

Peanut has characteristics that make weed control challenging compared with other row crops such as cotton (*Gossypium hirsutum* L.), corn (*Zea mays* L.), or soybean [*Glycine max* (L.) Merr.]. It has a low canopy, allowing weeds to be more competitive for light, particularly during the early stage of crop growth (Wilcut et al. 1995). Peanut also requires a long growing season (140 to 160 d) for development and maturity (Chaudhari et al. 2018), and residual herbicides registered for use in peanut do not provide season-long weed control, leading to heavy late-season weed infestation (Grichar 2007). The prostrate growth habit of peanut, with its stems growing parallel to the soil, restricts cultivation to the early season (Boyer et al. 2011). Cultivation can also introduce wounds to the plant tissue, which can increase access for pathogens and disease incidence (Wilcut et al. 1995). Weed control could be accomplished by hand weeding, but this is expensive, time-consuming, laborious, and impractical under modern-day circumstances (Johnson et al. 2012a, 2012b). Consequently, weed management in peanut is overwhelmingly achieved with herbicides, and research in the United States has focused primarily on chemical weed control. Although herbicides are not a complete solution to the complex weed management challenges in peanut production, they are effective and have contributed significantly to increased peanut yields (Gianessi and Reigner 2007).

Numerous studies have evaluated various herbicides for weed control in peanut in the United States. However, a systematic review of existing literature on this subject is lacking. The biology and management of weeds in peanut, including chemical weed control, was reviewed by Wilcut et al. (1995), but this review was published almost three decades ago. Since that publication, several herbicides such as acetochlor, carfentrazone, diclosulam, dimethenamid-*P*, flumioxazin, fluridone, fluazifop-*P*, imazapic, lactofen, pyroxasulfone, and *S*-metolachlor have been registered in peanut (Anonymous 2017, 2023; Prostko et al. 2011). Considerable progress has been made in developing herbicides to increase the number of tools available for weed control in peanut, including the recent registration of one new herbicide mode of action (Group 12, fluridone) (Anonymous 2023).

No single herbicide application can provide sufficient weed control in all situations due to a narrow window of application, low residual activity, variability in weed control, and rotational restrictions. Therefore, effective weed control in peanut is generally obtained by using herbicide programs that consist of herbicide mixtures and sequential applications of preplant-incorporated or preemergence, early-postemergence, and/or late-postemergence herbicides (Chaudhari et al. 2018). Growers use a broad combination of preplant-incorporated, preemergence, and postemergence herbicides based on the weed community composition, dominant weed species, rotational restrictions, environmental conditions, and economic benefits (Leon et al. 2019).

In addition to the earlier review by Wilcut et al. (1995), Leon et al. (2019) provided an overview of sustainable weed management in peanut, but focused particularly on weed prevention, avoidance, monitoring, and suppression as parts of successful integrated weed management in peanut. The current paper presents a systematic review of weed management research in peanut in the United States in the last five decades, specifically focusing on chemical weed management methods. This review aims to compile existing literature and access the research progress and achievements in peanut chemical weed management, highlight the strengths and weaknesses of various herbicides used in peanut to assist in augmenting herbicide recommendations for research and extension, and identify current research gaps and prospects for future research.

Systematic Literature Search

The literature search was done using a four-step filtering process.

Step 1

The databases of Scopus, Web of Science, and *Peanut Science* (journal of the American Peanut Research and Education Society) covering 53 yr (from 1970 to July 2022, accessed July 12, 2022) were searched using predefined search terms (Table 1). *Peanut Science* was included because it is currently not indexed in Scopus or Web of Science but publishes peer-reviewed results of peanut research.

Step 2

The total record (2,171 peer-reviewed articles) from the three databases was screened to identify each article's relevance for the review by refining the search terms based on exclusion criteria (Table 1). This resulted in a refined cohort of 555 peer-reviewed publications.

Step 3

The refined cohort of 555 peer-reviewed publications from the three databases was exported and combined in Excel, with the year of publication as rows and contents (journal, research focus, weeds studied, herbicides tested, study type [field, greenhouse, or laboratory], study location, number of site-years, research methods, and abstract) as columns.

Step 4

Duplicates (78 peer-reviewed publications) were removed, and the remaining publications (477) were further screened by two independent researchers for their relevance by reviewing the titles and abstracts. This resulted in 317 unique and relevant publications that were subsequently reviewed. Of the 317 publications reviewed, 245 (77%) focused on chemical weed management, while the remaining 72 (23%) focused on nonchemical weed management. Only the 245 peer-reviewed publications focused on chemical weed management are discussed in the current paper. To help the readers determine specific herbicide/weed efficacy data and associated publication, tables for each herbicide MOA and application method have been constructed (Tables 2–10). Discussions on nonchemical weed management are covered in the first part of this publication series (Daramola et al. 2023a).

Chemical Weed Control in Peanut in the United States

Peanut can tolerate herbicides from various modes of action, including acetyl-CoA carboxylase (ACCase), acetolactate synthase (ALS), carotenoid biosynthesis, fatty-acid and lipid biosynthesis, mitosis, phytoene desaturase (fluridone), photosystem I (PSI) electron diverter, and protoporphyrinogen oxidase (PPO) inhibitors, and the synthetic auxin 2,4-DB, allowing selective weed control with these herbicides in peanut (Leon et al. 2019). However, peanut is susceptible to herbicides such as photosystem II (PSII) inhibitors (e.g., metribuzin, atrazine), enolpyruvyl shikimate3-phosphate synthase (EPSPS) inhibitors (e.g., glyphosate), and glutamine synthase inhibitors (e.g., glufosinate), which are commonly used in crops such as cotton, corn, and soybean in rotation with peanut (Daramola et al. 2023b, 2023c; Leon et al. 2019).

Research progress and developments in chemical weed control over the years have led to significant changes in the herbicide options available for weed control in peanut. Wilcut et al. (1995) presented a historical perspective describing the herbicide changes that occurred between the late 1940s and early 1990s along with a list of herbicide registrations and cancellations. Except for an overview, we will not duplicate this information. Rather, we will discuss new developments in peanut weed control since that

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Table 1. Search terms and exclusion criteria used to identify relevant articles in the databases of Scopus, Web of Science, and *Peanut Science* (accessed: July 12, 2022).

Search terms Language: English only, within the article title, abstract, and key words	Number of sources Scopus	Web of Science	*Peanut Science*	Total
TS = ("weed" OR "weed management" OR "weed control" OR "herbicides" OR "cultural method" OR "mechanical method" OR "biological method" OR "integrated" AND "peanut" OR "*Arachis hypogaea*")	993	933	245	2,171
Exclusion criteria				
Refined to include the United States only; other countries excluded				
Refined to 1970 to 2022 duration				
Refined to only research articles; excluded other literature types such as books, book chapters, review articles, and conference proceedings.				
Refined to only agronomy and agricultural and biological sciences; excluded other subject areas				
	202	232	121	555

publication. Alachlor, benefin, chloramben, dinoseb, metolachlor, naptalam, naptalam plus dinoseb, pendimethalin, trifluralin, and vernolate are among the first group of herbicides evaluated for efficacy and peanut tolerance between the late 1940s and early 1980s (Wilcut et al. 1995). During this period, preplant-incorporated applications of the dinitroaniline herbicides benefin, pendimethalin, and trifluralin (used only in Texas and Oklahoma and not in the U.S. Southeast region) or preemergence applications of the chloroacetamide herbicides alachlor and metolachlor were used to control annual grasses and small-seeded broadleaf weeds. Vernolate applied preplant incorporated provided effective control of yellow (*Cyperus esculentus* L.) and purple (*Cyperus rotundus* L.) nutsedge (Buchanan et al. 1982; Wilcut et al. 1995), while broadleaf weeds were controlled with the postemergence herbicides acifluorfen, bentazon, chloramben, dinoseb, dinoseb plus naptalam, and 2,4-DB (Wilcut et al. 1995). Dinoseb was identified as one of the most promising postemergence herbicides in peanut in early research and was used extensively for selective weed control, particularly for troublesome weeds species such as Florida beggarweed [*Desmodium tortuosum* (Sw.) DC.] and sicklepod [*Senna obtusifolia* (L.) Irwin & Barneby] until 1986, when dinoseb registration was cancelled due to toxicity issues (Wilcut et al. 1995). Similarly, toxicity or injury concerns have eliminated alachlor, benefin, chloramben, naptalam, and vernolate from U.S. peanut production. The removal of these herbicides encouraged the development and registration of safer herbicides such as bentazon, chlorimuron, ethalfluralin, fenoxaprop, imazethapyr, norflurazon, paraquat, pyridate, and sethoxydim between the late 1980s and early 1990s (Wilcut et al. 1995). Reviews on the use of these herbicides in peanut can be found elsewhere (Buchanan et al. 1982; Wilcut et al. 1995). The past two decades have also witnessed significant progress in chemical weed control in peanut with registration of more herbicides such as acetochlor, carfentrazone, diclosulam, dimethenamid-*P*, fluazifop-*P*, fluridone, flumioxazin, imazapic, lactofen, pyroxasulfone, and *S*-metolachlor (Table 2). However, there are still gaps and limitations in chemical weed control in peanut with the currently registered herbicides.

Soil-applied Herbicides

Soil-applied herbicides are used to provide residual weed control and prevent weed establishment. Residual weed control in peanut is achieved mainly with very-long-chain fatty-acid (VLCFA) inhibitors from the chloroacetamide chemical family (e.g., acetochlor, dimethenamid-*P*, pyroxasulfone, and *S*-metolachlor), mitosis inhibitors from the dinitroaniline chemical family (e.g., ethalfluralin and pendimethalin), and less frequently with the carotenoid inhibitor norflurazon from the pyridazinone chemical family. The use of the PPO inhibitor flumioxazin from the *N*-phenylphthalimide chemical family and ALS inhibitors from the triazolopyrimidine (e.g., diclosulam) and imidazolinone (e.g., imazapic, imazethapyr) chemical families for residual weed control have increased considerably. Likewise, the phytoene desaturase inhibitor fluridone has recently been registered for preemergence application in peanut (Anonymous 2017).

Chloroacetamides (Acetochlor, Dimethenamid-P, Pyroxasulfone, and S-metolachlor)

The chloroacetamides acetochlor, dimethenamid-*P*, pyroxasulfone, and *S*-metolachlor are soil-applied herbicides that inhibit long-chain fatty-acid biosynthesis (Shaner 2014). They are applied preplant incorporated, preemergence, or in conjunction with postemergence herbicides in peanut to control annual grasses and small-seeded broadleaf weeds and provide suppression of nutsedge (*Cyperus* spp.) and large-seeded broadleaf weeds such as bristly starbur (*Acanthospermum hispidum* DC.), common ragweed (*Ambrosia artemisiifolia* L.), *D. tortuosum*, and *S. obtusifolia* (Basinger et al. 2021; Clewis et al. 2007; Grichar et al. 2000; Robinson et al. 2006; Wehtje and Brecke 2004). Incorporating these herbicides into the soil ensures activity in situations where preemergence applications may fail from the absence of irrigation or inadequate rainfall; however, compared with activated preemergence applications, control or suppression of some weeds is lower (Grichar et al. 2000). The microencapsulated formulation of acetochlor registered for use in peanut provides longer residual activity and higher crop safety than emulsifiable concentrate formulations (Anonymous 2010; Grichar et al. 2015). In general, most preemergence herbicide applications, such as *S*-metolachlor and acetochlor applied preemergence, in peanut require adequate rainfall or irrigation for activation and optimum efficacy. *S*-metolachlor (12:80 mixture of R-inactive and S-active stereoisomers formulation) was registered in 1997 and provides weed control efficacy similar to metolachlor (50:50 mixture of R and S stereoisomers formulation) in peanut (Grichar et al. 2001, 2008). It is applied at lower rates (1.1 to 1.4 kg ha^{-1}) due to a greater concentration of *S*-stereoisomers in the formulation (Anonymous 2004; O'Connell et al. 1998).

Our systematic review of the literature showed that acetochlor and *S*-metolachlor provide >70% control of barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv.], hemp sesbania [*Sesbania herbacea* (Mill.) McVaugh; syn.: *Sesbania exaltata* (Raf.) Rydb. ex A.W. Hill], horse purslane (*Trianthema portulacastrum* L.), Palmer amaranth (*Amaranthus palmeri* S. Watson), pitted morningglory (*Ipomoea lacunosa* L.), and prickly sida (*Sida spinosa* L.), but control of several other annual grasses and

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Table 2. Mode of action (MOA), chemical family, application timings, and application rates of herbicides labeled for use in peanut since 1995.

Herbicide	MOA	WSSA[a] Group	Chemical family	Application timing	Application rates	Year registered
					kg ai ha^{-1}	
Acetochlor	Mitosis inhibitor	15	Chloroacetamide	Preemergence	1.125	2017
Carfentrazone-ethyl	Inhibition of protoporphyrinogen oxidase (PPO)	14	Triazolinone	Postemergence	0.031–0.156	2003
Clethodim	Acetyl-CoA carboxylase (ACCase inhibitor)	1	Cyclohexanedione	Postemergence	0.10–0.20	1996
Diclosulam	Acetolactate synthase (ALS) (acetohydroxyacid synthase AHAS)	2	Imidazolinone	Preemergence Postemergence	0.024	2000
Dimethenamid-*P*	Inhibition of very-long-chain fatty-acids (VLCFAs) (inhibition of cell division)	15	Chloroacetamide	Preemergence	0.63–0.93	1999
Fluazifop-*P*-butyl	ACCase inhibitor	1	Aryloxyphenoxy-propionate	Postemergence	0.125–0.375	2009
Fluridone	Inhibition of phytoene desaturase (PDS)	12	Phenlpyridine	Preemergence	0.16	2023
Flumioxazin	Inhibition of PPO	14	*N*-phenylphthalimide	Preemergence	0.06–0.10	2001
Imazapic	Inhibition of ALS (acetohydroxyacid synthase AHAS)	2	Imidazolinone	Preemergence Postemergence	0.07	1996
Lactofen	Inhibition of PPO	14	Diphenylether	Postemergence	0.1–0.2	2005
Pyroxasulfone	Inhibition of many elongation steps catalyzed by VLCFA elongases	15	Isoxazoline	Postemergence	0.08–0.1	2017
S-metolachlor	Inhibition of VLCFAs (inhibition of cell division)	15	Chloroacetamide	Preemergence	1–1.33	1997

[a]Weed Science Society of America, https://wssa.net/wssa/weed/herbicides.

small-seeded broadleaf weeds with acetochlor and *S*-metolachlor is often <70% (Tables 3 and 4). Peanut growers generally do not observe >70% control of *I. lacunosa* and *S. exaltata* with *S*-metolachlor; however, Chaudhari et al. (2018) and Seale at al. (2020) observed >70% control, probably due to low weed pressure in the soil seedbank or because control was evaluated very early in the season (19 to 21 d after planting). Dimethenamid-*P* controls some weed species with efficacy similar to acetochlor and *S*-metolachlor; however, dimethenamid-*P* is less effective on *Ipomoea* spp., *S. spinosa*, and *C. esculentus* (Burke et al. 2002; Clewis et al. 2002; Robinson et al. 2006). The available literature showed that dimethenamid-*P* provides poor (0% to 67%) control of entireleaf morningglory (*Ipomoea hederacea* var. *integriuscula* A. Gray), ivyleaf morningglory [*Ipomoea hederacea* (L.) Jacq.], *I. lacunosa*, and *S. spinosa* in peanut (Tables 3 and 4). Although acetochlor, dimethenamid-*P*, and *S*-metolachlor provide good control of most annual grasses, they have limited activity on Texas panicum [*Urochloa texana* (Buckley) R. Webster; syn.: *Panicum texanum* Buckley], which can be problematic in peanut (Clewis et al. 2007; Grichar et al. 1994; Johnson et al. 2002). Both acetochlor and *S*-metolachlor applied preemergence provided <70% control of *U. texana* in irrigated strip-tillage peanut (Grichar et al. 1994; Johnson et al. 2002). Similarly, dimethenamid-*P* applied preemergence did not control *U. texana* compared with a nontreated control in strip-tillage peanut despite optimum activation with irrigation (Johnson et al. 2002).

While these herbicides provide effective weed control, peanut injury, stunting, and delayed emergence can occur depending on the method, timing, and rate of application (Chaudhari et al. 2018; Grichar and Dotray 2012). Peanut injury is also influenced by environmental factors such as soil moisture, temperature, pH, and organic matter (Cardina and Swann 1988; Chaudhari et al. 2018). *S*-metolachlor has been observed to cause greater injury and growth suppression at higher rates under wet conditions (Basinger et al. 2021; Chaudhari et al. 2018). Variable peanut injury ranging from <5% to 33% was reported from preemergence application of *S*-metolachlor up to 1.40 kg ai ha^{-1} (Basinger et al. 2021; Chaudhari et al. 2018; Clewis et al. 2007; Grichar et al. 2008). Although various levels of peanut injury have been observed from chloroacetamide herbicides, yields were not negatively impacted, except at rates higher than label recommended (Chaudhari et al. 2018; Clewis et al. 2007; Grichar et al. 2015). In studies evaluating peanut tolerance to preemergence applications of *S*-metolachlor at 1.1, 1.4, and 2.8 kg ha^{-1}, Basinger et al. (2021) observed yield reduction (8.9%) only at the 2.6X (2.8 kg ha^{-1}) recommended rate.

Pyroxasulfone is another chloroacetamide herbicide used to control grasses and small-seeded broadleaf weeds in peanut (Dotray et al. 2018; Eure et al. 2015) and is similar in activity to acetochlor, dimethenamid-*P*, and *S*-metolachlor. Pyroxasulfone has a similar weed control spectrum but has a higher specific activity, allowing for a much lower application rate compared with dimethenamid-*P* (Grichar et al. 2019). Peanut generally has good tolerance to pyroxasulfone; however, preemergence applications caused 8% to 18% early-season peanut stunting (Eure et al. 2015; Grichar et al. 2019; Prostko et al. 2011). Several factors, including rates, soil type, environmental conditions, and cultivars, may influence early-season stunting or injury, with greater stunting following preemergence applications in heavy soils under wet

Table 3. Cumulative results on efficacy of very-long-chain fatty-acid inhibitors applied preemergence in peanut.

	Weed species	Efficacy[a]	References
Acetochlor	*Amaranthus palmeri*	78–95	Chaudhari et al. (2018); Grichar et al. (2015); Seale et al. (2020)
	Cucumis melo	40–75	Grichar et al. (2015)
	Echinochloa crus-galli	78–79	Seale et al. (2020)
	Ipomoea lacunosa	72–89	Chaudhari et al. (2018); Seale et al. (2020)
	Senna obtusifolia	49	Chaudhari et al. (2018)
	Sesbania exaltata	90–91	Seale et al. (2020)
	Sida spinosa	93–98	Seale et al. (2020)
	Urochloa platyphylla	70	Chaudhari et al. (2018)
	Urochloa texana	77–90	Grichar et al. (2015)
Dimethenamid-*P*	*Acanthospermum hispidum*	55	Wehtje and Brecke (2004)
	Amaranthus palmeri	67–100	Dotray et al. (2018); Grichar (2008); Grichar et al. (2005); Kharel et al. (2022)
	Ambrosia artemisiifolia	82	Grichar (2008)
	Chenopodium album	0–59	Clewis et al. (2002)
	Citrullus lanatus	51–54	Grichar et al. (2002)
	Cucumis melo	47	Grichar (2008)
	Cyperus esculentus	17–100	Clewis et al. (2002); Price and Wilcut (2002); Robinson et al. (2006); Wehtje and Brecke (2004)
	Desmodium tortuosum	35	Wehtje and Brecke (2004)
	Digitaria sanguinalis	97	Robinson et al. (2006)
	Eclipta prostrata	31–100	Clewis et al. (2002); Price and Wilcut (2002); Robinson et al. (2006)
	Eleusine indica	95	Robinson et al. (2006)
	Ipomoea hederacea	0–17	Clewis et al. (2002); Price and Wilcut (2002); Robinson et al. (2006)
	Ipomoea lacunosa	0–67	Clewis et al. (2002); Price and Wilcut (2002); Robinson et al. (2006)
	Senna obtusifolia	5–20	Lanier et al. (2004); Wehtje and Brecke (2004)
	Sida spinosa	0–30	Clewis et al. (2002); Price and Wilcut (2002); Robinson et al. (2006)
	Trianthema portulacastrum	51	Grichar (2008)
	Urochloa texana	66	Johnson et al. (2002)
	Verbesina encelioides	71	Grichar and Sestak (2000)
Pyroxasulfone	*Amaranthus palmeri*	93–100	Dotray et al. (2018); Grichar et al. (2019); Kharel et al. (2022)
	Cucumis melo	41–96	Grichar et al. (2019)
	Urochloa texana	55–92	Baughman et al. (2018)
S-metolachlor	*Acanthospermum hispidum*	15	Wehtje and Brecke (2004)
	Amaranthus palmeri	69–100	Dotray et al. (2018); Grichar (2007); Grichar et al. (2005, 2015)
	Chenopodium album	64	Clewis et al. (2007)
	Cucumis melo	47	Grichar (2008)
	Cyperus esculentus	49–84	Grichar et al. (2008); Seale et al. (2020); Wehtje and Brecke (2004)
	Cyperus rotundus	64	Clewis et al. (2007)
	Desmodium tortuosum	47	Wehtje and Brecke (2004)
	Digitaria ciliaris	90–97	Johnson et al. (2012b)
	Digitaria sanguinalis	84	Clewis et al. (2007)
	Echinochloa crus-galli	92–95	Seale et al. (2020)
	Eclipta prostrata	56	Clewis et al. (2007)
	Eleusine indica	68–95	Clewis et al. (2007); Johnson et al. (2012b)
	Ipomea spp.	64	Clewis et al. (2007)
	Ipomoea lacunosa	69–93	Chaudhari et al. (2018); Seale et al. (2020); Wehtje and Brecke (2004)
	Jacquemontia tamnifolia	59–79	Johnson et al. (2012b)
	Senna obtusifolia	15–54	Chaudhari et al. (2018); Wehtje and Brecke (2004)
	Sesbania exaltata	93–94	Seale et al. (2020)
	Trianthema portulacastrum	59	Grichar (2008)
	Urochloa platyphylla	76–86	Chaudhari et al. (2018); Seale et al. (2020)
	Urochloa texana	66	Clewis et al. (2007)

[a]Efficacy range across all references listed from 0% to 100%, where 0 = no control, 100 = complete control.

conditions (Prostko et al. 2011). Prostko et al. (2011) reported significant peanut stunting preemergence (48% at 480 g ai ha^{-1}, representing 4X use rate) in a sandy loam soil with 16% clay content, but no significant injury in a Tifton sand soil type with 2% clay content. Eure et al. (2015) observed significant stunting (38% to 55%) following preemergence applications at 240 g ai ha^{-1} (2X use rate) when peanut emergence coincided with heavy rain events.

Dinitroaniline (Ethalfluralin and Pendimethalin)

Dinitroaniline herbicides such as ethalfluralin and pendimethalin are Group 3 herbicides that block mitosis through inhibition of microtubule polymerization. These herbicides are readily absorbed by roots and emerging shoots and are commonly used to control annual grasses and small-seeded broadleaf weeds in peanut (Johnson and Mullinix 1999). Dinitroanilines have low water solubility (<1 ppm) and are moderately volatile and susceptible to photodegradation (Weber 1990). As such, these herbicides are usually incorporated with rainfall, irrigation, or mechanically to prevent loss via evaporation (Johnson and Mullinix 1999). They can also be applied preemergence, but results are inconsistent compared with control by preplant-incorporated applications (Brecke and Currey 1980; Johnson and Mullinix 1999). Ethalfluralin and pendimethalin provide >80% control of annual grasses such as crowfootgrass [*Dactyloctenium aegyptium* (L.) Willd.], *Digitaria* spp., *E. crus-galli*, fall panicum (*Panicum*

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Table 4. Cumulative results on efficacy of acetolactate synthase (diclosulam and imazethapyr), seedling root growth (ethalfluralin and pendimethalin), very-long-chain fatty-acid (dimethenamid-*P*, pyroxasulfone, and *S*-metolachlor), and protoporphyrinogen oxidase (sulfentrazone) inhibitors applied preplant incorporated in peanut.

	Weed species	Efficacy[a]	References
Diclosulam	*Acanthospermum hispidum*	94	Grey et al. (2003)
	Amaranthus hybridus	100	Ducar-Tredaway et al. (2006)
	Amaranthus palmeri	95–99	Grichar et al. (1999)
	Ambrosia artemisiifolia	58–100	Price and Wilcut (2002); Price et al. (2002); Scott et al. (2001)
	Anoda cristata	26–100	Price and Wilcut (2002)
	Chenopodium album	67–100	Bailey et al. (1999a); Grey et al. (2003)
	Croton glandulosus	65–95	Grey et al. (2001)
	Cyperus esculentus	25–99	Grey et al. (2001, 2003, 2004); Grichar et al. (1999)
	Cyperus rotundus	53–87	Grey et al. (2004); Grichar et al. (1999, 2004)
	Desmodium tortuosum	66–95	Grey et al. (2003, 2004)
	Eclipta prostrata	99–100	Bailey et al. (1999a); Grichar et al. (2004)
	Euphorbia heterophylla	84–95	Grey et al. (2001, 2004)
	Harpagophytum procumbens	91–99	Grichar et al. (1999)
	Ipomea spp.	85–89	Grey et al. (2003)
	Ipomoea hederacea	88–87	Bailey et al. (1999a)
	Ipomoea lacunosa	95–100	Bailey et al. (1999a); Grichar et al. (1999, 2004)
	Jacquemontia tamnifolia	88–99	Bailey et al. (1999a); Grey et al. (2003)
	Senna obtusifolia	44–90	Grey et al. (2001, 2003)
	Sida spinosa	95–99	Bailey et al. (1999a); Grey et al. (2001)
	Urochloa texana	75–99	Grichar et al. (1999, 2004)
Imazethapyr	*Acanthospermum hispidum*	84–100	Richburg et al. (1995a, 1996); Wilcut et al. (1994b)
	Citrullus lanatus	64	Grichar et al. (2002)
	Cyperus esculentus	44–96	Grichar (1997); Grichar et al. (1992); Richburg et al. (1995b, 1996); Wilcut et al. (1994b)
	Cyperus rotundus	90–99	Grichar (1997); Grichar et al. (1992)
	Desmodium tortuosum	0–37	Richburg et al. (1996); Wilcut et al. (1994b)
	Ipomoea lacunosa	93–97	Richburg et al. (1995a); Wilcut et al. (1994b)
	Jacquemontia tamnifolia	96–100	Richburg et al. (1995a, 1996); Wilcut et al. (1994b)
	Senna occidentalis	71–97	Richburg et al. (1995a); Wilcut et al. (1994b)
	Senna obtusifolia	15–78	Richburg et al. (1995a, 1996); Wilcut et al. (1994b)
	Sida spinosa	89–100	Richburg et al. (1995a); Wilcut et al. (1994b)
Ethalfluralin	*Amaranthus hybridus*	0–71	Bailey and Wilcut (2002)
	Amaranthus palmeri	72–100	Grichar et al. (1999, 2005); Grichar and Sestak (2000); Grichar and Dotray (2012); Kharel et al. (2022)
	Ambrosia artemisiifolia	0–29	Jordan et al. (1994); Wilcut and Swann (1990)
	Anoda cristata	0–7	Bailey and Wilcut (2002); Jordan et al. (1994)
	Chenopodium album	0–85	Bailey and Wilcut (2002); Burke et al. (2002)
	Cyperus esculentus	0	Grichar and Dotray (2012); Grichar et al. (2004); Scott et al. (2002); Wilcut and Swann (1990)
	Dactyloctenium aegyptium	95–98	Prostko et al. (2001)
	Desmodium tortuosum	0	Main et al. (2005)
	Digitaria spp.	33–100	Brecke and Currey (1980); Jordan et al. (1994); Prostko et al. (2001); Scott et al. (2002)
	Eclipta prostrata	43–49	Grichar et al. (2000, 2004)
	Eleusine indica	100	Brecke and Currey (1980)
	Euphorbia heterophylla	0–38	Grichar and Dotray (2012); Grichar et al. (1999);
	Ipomea spp.	80–85	Brecke and Currey (1980)
	Ipomoea hederacea	0–17	Burke and Wilcut (2003); Burke et al. (2002); Scott et al. (2002)
	Ipomoea lacunosa	0–81	Burke et al. (2002); Grichar et al. (2002, 2004); Main et al. (2005)
	Jacquemontia tamnifolia	74–100	Burke et al. (2002); Jordan et al. (1994)
	Panicum dichotomiflorum	91	Jordan et al. (1994)
	Richardia scabra	98–100	Burke et al. (2002)
	Senna obtusifolia	0	Main et al. (2005)
	Sida spinosa	0–18	Bailey and Wilcut (2002); Burke et al. (2002); Jordan et al. (1994); Main et al. (2005)
	Urochloa texana	67–98	Grichar (2005); Grichar et al. (1999, 2004, 2005); Prostko et al. (2001)
	Verbesina encelioides	71–83	Grichar (1994); Grichar et al. (1994)
Pendimethalin	*Amaranthus palmeri*	41	Grichar (2008)
	Anoda cristata	15	Wilcut (1991a)
	Citrullus lanatus	49–51	Grichar et al. (2002)
	Cucumis melo	41	Grichar (2008)
	Dactyloctenium aegyptium	65–98	Prostko et al. (2001)
	Digitaria spp.	94–98	Prostko et al. (2001)
	Eclipta prostrata	12	Wilcut (1991a)
	Ipomea spp.	17	Wilcut (1991a)
	Ipomoea hederacea	18	Baughman et al. (2018)
	Sida spinosa	12	Wilcut et al. (1991b)
	Trianthema portulacastrum	67	Grichar (2008)

(*Continued*)

Table 4. (*Continued*)

	Weed species	Efficacy[a]	References
	Urochloa texana	18–96	Baughman et al. (2018); Johnson et al. (2002); Prostko et al. (2001)
Dimethenamid-*P*	*Chenopodium album*	51	Burke et al. (2002)
	Citrullus lanatus	49–51	Grichar et al. (2000)
	Cyperus esculentus	53–99	Grichar et al. (2000)
	Ipomoea hederacea	0	Burke and Wilcut (2003)
Pyroxasulfone	*Ipomoea hederacea*	71–83	Baughman et al. (2002)
	Urochloa texana	11	Baughman et al. (2002)
S-metolachlor	*Amaranthus hybridus*	73	Ducar-Tredaway et al. (2006)
	Chenopodium album	70	Ducar-Tredaway et al. (2006)
	Cyperus esculentus	76	Grichar et al. (2008)
	Ipomoea hederacea	0	Ducar-Tredaway et al. (2006)
	Ipomoea lacunosa	2	Ducar-Tredaway et al. (2006)
	Urochloa texana	54	Grichar et al. (2005)
Sulfentrazone[b]	*Cyperus esculentus*	92–98	Grichar et al. (2006)
	Ipomoea lacunosa	74–98	Grichar et al. (2006)

[a]Efficacy range across all references listed from 0% to 100%, where 0 = no control, 100 = complete control.
[b]No longer registered for U.S. peanut production.

dichotomiflorum Michx.), and *U. texana* (data from conventional tillage) and small-seeded broadleaf weeds such as *Amaranthus* spp., common lambsquarters (*Chenopodium album* L.), and Florida pusley (*Richardia scabra* L.) (Tables 4 and 5). Dinitroanilines do not provide adequate control of *A. artemisiifolia*, *Cyperus* spp., *D. tortuosum*, eclipta [*Eclipta prostrata* (L.) L.], *Ipomoea* spp., *S. spinosa*, *S. obtusifolia*, and tropic croton (*Croton glandulosus* L.) (Grichar and Colburn 1996; Scott et al. 2002; Wilcut et al. 1995). Grichar et al. (1994) found dinitroaniline herbicides were ineffective in controlling *U. texana* in conservation-tillage peanut production. Both ethalfluralin and pendimethalin applied preemergence or preplant incorporated provided poor early-season control of *U. texana* in non-irrigated minimum-tillage peanut (Wilcut et al. 1990b). Similarly, in irrigated strip-tillage peanut, *U. texana* control with pendimethalin was not >75%, while control in plots treated with ethalfluralin was not better compared with the untreated control (Johnson et al. 2002). The reduced efficacy of these dinitroaniline herbicides in conservation-tillage peanut was attributed to adsorption by cover crop residues and organic matter, resulting in greater concentration of the herbicide in the seed germination zone (Johnson et al. 2002).

Peanut injury, expressed as stunting, swollen hypocotyls, and abnormal lateral root growth, has been observed with dinitroaniline herbicides (Johnson et al. 1997; Johnson and Mullinix 1999). The level of injury from these herbicides can vary depending on the method, timing, and rates of application (Johnson and Mullinix 1999; Johnson et al. 2011). Ethalfluralin and pendimethalin were reported to be more injurious to peanut when applied preplant incorporated than preemergence, and injury increased with increasing rate of application from 0.6 to 2.2 kg ai ha^{-1} for each herbicide (Johnson and Mullinix 1999). Similarly, applications of ethalfluralin and pendimethalin delayed until 3 wk after emergence caused significant injury and reduced peanut yield compared with preemergence applications (Johnson et al. 2011). Dinitroaniline injury can also be undetected until harvest, because the vegetative growth may appear unaffected, but injured plants often have large numbers of pegs and very few pods (Johnson et al. 2011). Peanut gynophores (pegs) form aboveground and grow downward to penetrate the soil surface (pegging), where they contact damaging levels of the herbicide at the soil surface. These herbicides block cell division in the developing peg, thus preventing the peg from penetrating the soil and forming the pod (Johnson et al. 1997).

Although injury has been observed, several studies, especially in conventional tillage systems, reported preplant-incorporated or preemergence applications of ethalfluralin, pendimethalin, and trifluralin do not affect peanut yield when used at the recommended application timings and rates (Brecke and Currey 1980; Dotray et al. 2003; Grichar and Colburn 1993; Johnson et al. 1997). In a 3-yr study, Grichar and Colburn (1993) observed that yield and grade of five runner peanut cultivars were not affected by preplant-incorporated application of ethalfluralin, pendimethalin, and trifluralin. Similarly, peanut yield was not affected by preplant-incorporated application of ethalfluralin and pendimethalin at 0.67 to 1.68 kg ai ha^{-1} and trifluralin at 0.56 and 0.71 kg ai ha^{-1} in five runner-type cultivars. However, Johnson et al. (2011) showed that both ethalfluralin and pendimethalin have the potential to inhibit pod formation and reduce peanut yield in strip-tillage systems, especially when the application is delayed. Studies have also reported that cover crop debris present in strip-tillage systems can influence the availability of herbicide, which may cause the herbicide to be more injurious to peanut (Johnson et al. 2002; Weber 1990). The retention of cover crop residue in strip-tillage systems can increase soil-water content and cause cooler soil temperatures, which possibly resulted in higher peanut injury from the herbicides at ground cracking.

PPO Inhibitor (Flumioxazin)

Flumioxazin is an *N*-phenylphthalimide herbicide registered only for preemergence applications in peanut (Askew et al. 1999; Grichar and Colburn 1996). This herbicide is absorbed by plants mainly through seedling root and shoot uptake (Yoshida et al. 1991) and can provide 4 to 6 wk of broad-spectrum residual weed control. It is particularly effective against broadleaf weeds that are difficult to control in peanut such as *D. tortuosum* (Ducar et al. 2009; Grey et al. 2003; Johnson et al. 2010). Flumioxazin was also reported to provide >70% control of *A. artemisiifolia*, *A. hispidum*, *A. palmeri*, *C. album*, *C. glandulosus*, citron melon [*Citrullus lanatus* (Thunb.) Matsum. & Nakai], large crabgrass [*Digitaria sanguinalis* (L.) Scop.], *E. crus-galli*, *E. prostrata*, *Ipomoea* spp., *S. spinosa*, smellmelon (*Cucumis melo* L.), and *U. texana* in peanut

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Table 5. Cumulative results on the efficacy of seedling root growth (ethalfluralin and pendimethalin) and protoporphyrinogen oxidase (flumioxazin and sulfentrazone) inhibitors applied preemergence in peanut.

	Weed species	Efficacy[a]	References
Ethalfluralin	*Digitaria ciliaris*	88	Johnson et al. (2012b)
	Digitaria sanguinalis	93–100	Brecke and Currey (1980)
	Eleusine indica	90–98	Brecke and Currey (1980)
	Ipomoea purpurea	58–63	Brecke and Currey (1980)
	Jacquemontia tamnifolia	32–81	Brecke and Currey (1980); Johnson et al. (2012b)
	Richardia scabra L.	85–100	Brecke and Currey (1980)
	Urochloa texana	70	Johnson et al. (2002)
	Xanthium strumarium	25–53	Brecke and Currey (1980)
Pendimethalin	*Acanthospermum hispidum*	13–78	Askew et al. (1999)
	Amaranthus palmeri	44–100	Grichar et al. (1994, 2015); Kharel et al. (2022)
	Citrullus lanatus	51–54	Grichar et al. (2002)
	Cucumis melo	89–96	Grichar et al. (2022)
	Cynodon dactylon	0–33	Askew et al. (1999)
	Cyperus esculentus	0–63	Askew et al. (1999); Grey and Wehtje (2005)
	Dactyloctenium aegyptium	55–98	Askew et al. (1999); Prostko et al. (2001)
	Desmodium tortuosum	0–76	Askew et al. (1999); Grey and Wehtje (2005); Jordan et al. (1993)
	Digitaria ciliaris	87–98	Johnson et al. (2010); Prostko et al. (2009)
	Digitaria sanguinalis	62–96	Askew et al. (1999)
	Ipomea spp.	0–21	Grey and Wehtje (2005)
	Ipomoea purpurea	0–68	Askew et al. (1999)
	Jacquemontia tamnifolia	0–24	Askew et al. (1999)
	Senna obtusifolia	0–55	Askew et al. (1999); Grey and Wehtje (2005)
	Trianthema portulacastrum	84	Grichar et al. (2015)
	Urochloa texana	37–100	Grichar et al. (2015); Johnson et al. (2010); Grichar et al. (1994); Johnson et al. (2002); Kharel et al. (2022); Prostko et al. (2001)
Flumioxazin	*Acanthospermum hispidum*	40–87	Grey and Wehtje (2005); Johnson et al. (2010); Wehtje and Brecke (2004)
	Amaranthus palmeri	72–100	Grey and Wehtje (2005); Grey et al. (2003); Grichar (2008); Kharel et al. (2022); Morichetti et al. (2012); Seale et al. (2020)
	Amaranthus spp.	95	Grichar and Colburn (1996)
	Ambrosia artemisiifolia	76	Scott et al. (2001)
	Chenopodium album	95–100	Askew et al. (1999); Robinson et al. (2006); Scott et al. (2001)
	Croton glandulosus	86–97	Grey et al. (2002); Johnson et al. (2010)
	Cucumis melo	52–63	Grichar (2008)
	Cyperus esculentus	20–85	Ducar et al. (2009); Grey and Wehtje (2005); Grey et al. (2002, 2003, 2004); Grichar et al. (2004); Robinson et al. (2006); Wehtje and Brecke (2004)
	Desmodium tortuosum	46–97	Ducar et al. (2009); Grey and Wehtje (2005); Grey et al. (2002, 2003, 2004); Johnson et al. (2010); Wehtje and Brecke (2004)
	Digitaria ciliaris	43–94	Grichar and Colburn (1996)
	Digitaria sanguinalis	97	Scott et al. (2001)
	Echinochloa crus-galli	76–81	Seale et al. (2020)
	Eclipta prostrata	42–100	Grichar (2004); Grichar and Colburn (1996); Robinson et al. (2006)
	Euphorbia heterophylla	45–99	Grey and Wehtje (2005); Grey et al. (2004)
	Indigofera hirsute	81–94	Willingham et al. (2008)
	Ipomea spp.	77–88	Askew et al. (1999); Grey et al. (2003)
	Ipomoea hederacea	55–85	Ducar et al. (2009); Scott et al. (2001); Robinson et al. (2006)
	Ipomoea lacunosa	42–99	Grichar and Colburn (1996); Grichar et al. (2004); Robinson et al. (2006); Seale et al. (2020); Wehtje and Brecke (2004)
	Ipomoea purpurea	82	Grey et al. (2004)
	Jacquemontia tamnifolia	92	Grey et al. (2003)
	Senna obtusifolia	20–77	Ducar et al. (2009); Grey and Wehtje (2005); Grey et al. (2002, 2003); Johnson et al. (2010); Wehtje and Brecke (2004); Willingham et al. (2008)
	Sesbania exaltata	97–99	Seale et al. (2020)
	Sida spinosa	79–99	Askew et al. (1999); Robinson et al. (2006)
	Trianthema portulacastrum	64–73	Grichar (2008)
	Urochloa fasciculata	80–84	Grichar and Colburn (1996)
	Urochloa texana	80–100	Kharel et al. (2022); Grichar and Colburn (1996); Grichar et al. (2004)
Sulfentrazone	*Acanthospermum hispidum*	74–95	Grey and Wehtje (2005)
	Amaranthus palmeri	95–99	Grey and Wehtje (2005)
	Cyperus esculentus	75–99	Grey and Wehtje (2005); Grey et al. (2004); Grichar et al. (2006)
	Desmodium tortuosum	50–99	Grey and Wehtje (2005);Grey et al. (2004)
	Euphorbia heterophylla	78–99	Grey and Wehtje (2005); Grey et al. (2004)
	Ipomoea lacunosa	69–97	Grichar et al. (2006)
	Ipomoea purpurea	97–99	Grey and Wehtje (2005)
	Jacquemontia tamnifolia	78–99	Grey and Wehtje (2005)
	Senna obtusifolia	0–56	Grey and Wehtje (2005)
	Urochloa texana	29–34	Grichar et al. (2006)

[a]Efficacy range across all references listed from 0% to 100%, where 0 = no control, 100 = complete control.

(Table 5). It can be used to provide effective control of ALS inhibiting herbicide–resistant weeds, particularly *A. palmeri* (Grichar and Dotray 2013; Seale et al. 2020). Flumioxazin does not effectively control *C. esculentus* (Ducar et al. 2009; Grey et al. 2004), *S. obtusifolia* (Grey and Wehtje 2005; Johnson et al. 2010; Willingham et al. 2008), and wild poinsettia (*Euphorbia heterophylla* L.) (Grey et al. 2004), and annual grass control is inconsistent (Grichar and Colburn 1996).

Flumioxazin selectivity in tolerant species and peanut is achieved through rapid metabolism (Yoshida et al. 1991). In a laboratory study evaluating differential tolerance of *I. hederacea*, *S. obtusifolia*, and peanut, Price et al. (2004) observed more rapid metabolism of root-absorbed [^{14}C]flumioxazin in peanut and *S. obtusifolia* (tolerant species) compared with *I. hederacea* (susceptible species). Peanut metabolism was three times faster than *I. hederacea* metabolism, with only 11% of the parent compound retained 72 h after treatment compared with 41% retained in *I. hederacea* at the same time point (Price et al. 2004). This suggests peanut metabolizes root-absorbed flumioxazin before any visible injury is observed. Price et al. (2004) also showed that peanut germination was not affected by the direct exposure of peanut seed to flumioxazin at field application rates. Flumioxazin injury characterized by stunting and leaflet discoloration was <30% when applied preemergence at recommended rates (Askew et al. 1999; Burke et al. 2002; Grey et al. 2004; Grey and Wehtje 2005; Hurdle et al. 2020; Teuton et al. 2004; Umphres et al. 2018; Wilcut et al. 2001). However, delaying application until germination initiation increases the risk of direct contact with emerged plants, which is highly injurious to peanut (Burke et al. 2002; Jordan et al. 2009a). Flumioxazin applied at 6, 8, and 10 d after planting caused significant peanut injury (20% to 59%) compared with applications at 0, 2, and 4 d after planting (0% to 29%) (Burke et al. 2002).

Peanut injury from flumioxazin is also influenced by soil organic matter and clay content (Leon and Tillman 2015). Planting depth and flumioxazin placement depth has also been shown to influence injury potential (Ferrell et al. 2005). Greater injury is also associated with cool weather or rainfall occurring during or soon after flumioxazin application due to increased absorption and decreased metabolism (Hurdle et al. 2020; Umphres et al. 2018; Wilcut et al. 2001). In studies conducted with three runner-type peanut cultivars, Wilcut et al. (2001) reported flumioxazin injury caused season-long reduction in peanut canopy, but yield was not adversely affected. Similarly, Burke et al. (2002) observed delayed peanut pod development due to injury from flumioxazin, but no reduction in peanut yield. Hurdle et al. (2020) reported yield reduction due to flumioxazin injury in one of three locations in a study conducted in North Carolina. At this site, injury of 50% to 67% was observed due to cool and wet conditions at the time of peanut emergence compared with <2% injury from the same studies at two other locations where environmental conditions were favorable for peanut emergence.

Heavy rainfall that results in splashing of flumioxazin-treated soil on peanut foliage can cause temporary injury (Grey et al. 2007). Generally, peanut injury from flumioxazin is transient, with recovery between 5 and 8 wk after treatment with no effect on peanut grade and pod yield regardless of flumioxazin application rate, timing, or peanut cultivar (Askew et al. 1999; Basinger et al. 2021; Ducar et al. 2009; Johnson et al. 2006; Main et al. 2005; Seale et al. 2020; Umphres et al. 2018; Wilcut et al. 2001). Despite preemergence activity, flumioxazin has relatively low soil persistence and does not have carryover concerns for rotation with corn, cotton, and soybean (Grey et al. 2002).

Sulfentrazone is another soil-applied PPO-inhibiting herbicide that has been evaluated but is no longer registered in peanut (Grey et al. 2007). Sulfentrazone applied preemergence or preplant incorporated provided effective control of many broadleaf weeds, including *A. hispidum*, *A. palmeri*, *D. tortuosum*, *Ipomoea* spp., and *E. heterophylla* (Tables 4 and 5). However, significant peanut injury and yield reduction from sulfentrazone was reported across the major peanut-growing regions (Grey et al. 2004; Grichar et al. 2006; Johnson and Mullinix 1994). Although sulfentrazone is effective for weed control, the unacceptable injury and rotational concerns, especially under coarse-textured soil typical of most peanut-growing regions, resulted in the registration being cancelled for peanut (Grey and Wehtje 2005; Grichar et al. 2006).

Foliar-applied Broadleaf Herbicides

Postemergence broadleaf weed herbicides are critical for successful weed management programs in peanut. Control of late-emerging broadleaf weeds and those that escape early-season control from soil-applied herbicides is critical to maintaining good yields and proper harvesting (Everman et al. 2006; Wilcut et al. 1995). Peanut growers often make two or more postemergence broadleaf herbicide applications due to peanut's long growing season and continuous broadleaf weed germination (Chaudhari et al. 2018). Postemergence broadleaf weed control in peanut is achieved using bentazon and paraquat (photosynthetic inhibitors), acifluorfen and lactofen (PPO inhibitors), 2,4-DB (synthetic auxin), and chlorimuron, diclosulam, imazapic, and imazethapyr (ALS inhibitors). The application timing of these herbicides is important for effective control to ensure efficacy and reduce the need for multiple applications. Acifluorfen, bentazon, lactofen, and paraquat have contact activity and only kill tissues with which the spray comes into contact. Therefore, maximum weed control is achieved when applied to smaller weeds between peanut ground crack (GC) and 2 to 3 wk after GC (Grey et al. 2001; Jordan et al. 2003a). Conversely, chlorimuron, diclosulam, imazapic, imazethapyr, and 2,4-DB have systemic activity, and weed size is not as critical, as the herbicide is absorbed and translocated to meristematic tissues, killing underground structures (Dotray and Keeling 1997; Everman et al. 2006).

Photosynthetic Inhibitors (Bentazon and Paraquat)

Bentazon kills susceptible species by blocking electron flow in PSII, inhibiting the production of NADPH + H and ATP needed for CO_2 fixation in the light-independent reactions (Shaner 2014). The blockage of electrons also elicits massive radical production, and this severe oxidative stress causes membrane disruption and cellular breakdown. Affected plants show chlorosis followed by necrosis and rapid plant death. Bentazon applied postemergence controls several broadleaf weeds in peanut (Table 6) and has activity on *C. esculentus* (Grichar 1992). However, it lacks residual activity and is ineffective for postemergence control of *Amaranthus* spp., *D. tortuosum*, *Ipomoea* spp., and *S. obtusifolia* (Grey et al. 2001; Richburg et al. 1993a). Bentazon is often applied in mixture with chloroacetamide herbicides such as metolachlor and dimethenamid-*P* to provide residual control and with other postemergence herbicides such as acifluorfen, lactofen, paraquat, and 2,4-DB to improve control of broadleaf weeds and increase weed control spectrum (Grichar et al. 1994). Bentazon applied in tank mixture with acifluorfen provided >90% control of

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Table 6. Cumulative results on efficacy of photosynthesis inhibitors applied postemergence in peanut.

	Weed species	Efficacy[a]	References
Bentazon	*Acanthospermum hispidum*	13–60	Grey et al. (1995); Wehtje et al. (2000a)
	Amaranthus palmeri	39–99	Eason et al. (2020); Grichar (2007)
	Amaranthus spinosus	7–38	Grichar (1992, 1994)
	Ambrosia artemisiifolia	65	Wilcut (1991a)
	Chenopodium album	26–33	Wilcut (1991a, 1991b)
	Croton glandulosus	61	Wilcut (1991b)
	Cucumis melo	38–100	Grichar (1994); Grichar and Dotray (2013)
	Cyperus esculentus	20–71	Grey et al. (1995); Wehtje et al. (2000b)
	Desmodium tortuosum	19–99	Eason et al. (2020); Richburg et al. (1993a); Wehtje (1992a); Wehtje et al. (2000a)
	Digitaria sanguinalis	93	Eason et al. (2020)
	Eclipta prostrata	97–100	Grichar (1997b)
	Ipomoea lacunosa	10–87	Eason et al. (2020); Grichar (1997b)
	Ipomoea spp.	46–100	Wilcut (1991b)
	Jacquemontia tamnifolia	58–100	Eason et al. (2020), Richburg et al. (1993a); Wehtje et al. (1992a)
	Senna obtusifolia	0–87	Eason et al. (2020); Ferrell et al. (2013); Richburg et al. (1993a); Wehtje et al. (1992a, 2000a)
	Sida spinosa	41–99	Eason et al. (2020); Wilcut (1991b)
	Verbesina encelioides	96–100	Grichar and Sestak (2000)
Paraquat	*Acanthospermum hispidum*	13–95	Eason et al. (2020); Grey et al. (1995); Wehtje et al. (2000a)
	Amaranthus palmeri	99	Eason et al. (2020)
	Ambrosia artemisiifolia	65	Wilcut (1991a)
	Chenopodium album	26–33	Wilcut (1991a, 1991b)
	Cucumis melo	43–100	Grichar and Dotray (2013)
	Cyperus esculentus	20–71	Grey et al. (1995); Wehtje et al. (1992a)
	Desmodium tortuosum	39–99	Eason et al. (2020); Wehtje et al. (2000a)
	Digitaria sanguinalis	93	Eason et al. (2020)
	Ipomoea lacunosa	87	Eason et al. (2020)
	Ipomoea spp.	46–58	Wilcut (1991a, 1991b)
	Jacquemontia tamnifolia	58–87	Eason et al. (2020); Wehtje et al. (1992a)
	Senna obtusifolia	41–91	Eason et al. (2020); Grey et al. (1995); Wehtje et al. (1992a, 2000a); Wilcut (1991a)
	Sida spinosa	41–99	Eason et al. (2020); Wilcut (1991b)
Paraquat + bentazon	*Acanthospermum hispidum*	34–98	Brecke et al. (2002); Grey et al. (1995); Richburg et al. (1993a, 1993b); Wehtje et al. (2000a)
	Amaranthus palmeri	96–100	Grichar et al. (1994); Richburg et al. (1993a)
	Ambrosia artemisiifolia	46–95	Grey et al. (2001); Wehtje et al. (2000a); Wilcut (1991b)
	Chenopodium album	70–100	Bailey et al. (1999a); Wilcut (1991a, 1991b); Wilcut et al. (1994a)
	Croton glandulosus	55–79	Grey et al. (2001); Wilcut (1991b)
	Cyperus esculentus	60–100	Brecke et al. (2002); Grey et al. (1995, 2001); Richburg et al. (1993a, 1993b, 1996); Wehtje et al. (2000a); Wilcut et al. (1994a)
	Cyperus rotundus	44–77	Richburg et al. (1996); Wilcut et al. (1994a)
	Desmodium tortuosum	46–94	Brecke et al. (2002); Grey et al. (2001); Richburg et al. (1996); Wehtje et al. (2000a, 2000b); Wilcut et al. (1994a)
	Eclipta prostrata	99	Bailey et al. (1999a)
	Euphorbia heterophylla	61–82	Grey et al. (2001)
	Ipomoea hederacea	96–98	Bailey et al. (1999a)
	Ipomoea lacunosa	97	Bailey et al. (1999b)
	Ipomoea spp.	72–95	Richburg et al. (1993b); Wilcut (1991a, 1991b); Wilcut et al. (1994a)
	Jacquemontia tamnifolia	80–100	Richburg et al. (1993b); Webster et al. (1997); Wilcut et al. (1994a)
	Senna obtusifolia	35–94	Brecke et al. (2002); Grey et al. (2001); Richburg et al. (1993a, 1993b); Webster et al. (1997); Wehtje et al. (2000a, 2000b); Wilcut et al. (1994a)
	Senna occidentalis	62–100	Richburg et al. (1993a, 1993b); Wilcut et al. (1994a)
	Sida spinosa	77–99	Bailey et al. (1999a); Grey et al. (2001); Richburg et al. (1993b); Webster et al. (1997); Wilcut (1991a); Wilcut et al. (1994a)
	Urochloa texana	50–71	Grichar et al. (1994)
	Xanthium strumarium	53–94	Bailey et al. (1999a); Webster et al. (1997)

[a]Efficacy range across all references listed from 0% to 100%, where 0 = no control, 100 = complete control.

A. artemisiifolia, *C. album*, *C. glandulosus*, and *Ipomoea* spp. (Wilcut 1991b) and >95% control of *A. palmeri* compared with <60% control from bentazon alone (Grichar 1997a). While the tank mixture of bentazon with residual or postemergence broadleaf herbicides increased weed control spectrum and provided a residual effect for an extended period, considerable injury to peanut can occur (Grichar et al. 2012; Jordan et al. 2003b). Grichar et al. (2012) reported 5% to 20% peanut injury with bentazon plus imazapic, while Jordan et al. (2003b) observed greater peanut injury with early postemergence application of bentazon plus acifluorfen and bentazon plus acifluorfen plus 2,4-DB. In addition, acifluorfen plus bentazon and acifluorfen plus bentazon plus 2,4-DB reduced yield by 200 and 150 kg ha^{-1}, respectively, when compared with a nontreated control in a 3-yr weed-free trial (Jordan et al. 2003b). Similarly, late postemergence application of bentazon plus acifluorfen reduced peanut yield by at least 23% compared with a weed-free control (Jordan et al. 1993). Wilcut (1991a) also observed up to 37% reduction in peanut yield with delayed application of bentazon plus acifluorfen until 4 wk after GC compared with application at GC.

Paraquat is a nonselective postemergence herbicide commonly used in peanut production, particularly in the southeastern United States (Eason et al. 2020; Wilcut et al. 1995; Wehtje et al. 1991). Paraquat was demonstrated to be a suitable replacement for dinoseb for control of annual broadleaf weeds in peanut (Wilcut et al. 1995). It is rapidly absorbed into plant foliage, killing susceptible species by diverting electrons in PSI and the production of highly reactive oxygen species (Shaner 2014). It can be applied from peanut hypocotyl emergence until 28 d after emergence to control early-emerging weeds (Jordan et al. 2003a). Paraquat provides good to excellent control of several annual broadleaf weeds, including *D. tortuosum*, *S. obtusifolia*, and *Ipomoea* spp. (Table 7) in addition to its activity on grass weed species (Wilcut 1991b). However, it does not control *A. hispidum*, coffee senna [*Senna occidentalis* (L.) Link], *S. spinosa*, and smallflower morningglory [*Jacquemontia tamnifolia* (L.) Griseb.] (Wilcut et al. 1990c, 1995). Paraquat lacks residual activity; therefore, subsequent herbicide applications are often required to maintain season-long weed control. While paraquat provides consistent control of several annual grass and broadleaf weeds prevalent in the southeastern United States, it causes peanut stunting and foliar injury characterized by chlorosis, necrosis, and bronzing. However, plants recover rapidly under good environmental conditions, and yield is not affected in most cases if it is applied before pegging and fruit development (Carley et al. 2009; Eason et al. 2020; Knauft et al. 1990; Wehtje et al. 1994). Conversely, studies conducted with Virginia peanut types showed paraquat may affect peanut grade by delaying maturity (Carley et al. 2009; Knauft et al. 1990). In addition, paraquat injury can interact with other stressors, resulting in significant yield reduction. Brecke et al. (1996) reported significant reduction in peanut yield when paraquat was applied to peanut with damage from thrips. Similarly, paraquat application after 28 d of peanut emergence increases the chances of significant yield reduction (Brecke et al. 1996; Johnson et al. 1993). When paraquat application was delayed until 2 wk after GC, *A. artemisiifolia* control was reduced by 30% and peanut yield by 1,200 kg ha^{-1}, with a consequent net loss of about \$400 ha^{-1} compared with application at GC (Wilcut and Swann 1990).

Depending on weed community composition, paraquat is often combined with imazapic or *S*-metolachlor to increase residual activity (Carley et al. 2009; Grichar and Dotray 2012; Wehtje et al. 2000a, 2000b). Although tank mixtures of paraquat and residual herbicides can improve weed control, significant injury and stunting may occur (Eason et al. 2020; Grichar and Dotray 2013; Grichar et al. 2012). Eason et al. (2020) reported significant peanut stunting up to 25% with paraquat plus *S*-metolachlor compared with paraquat alone (6% to 15%). Paraquat is also commonly applied in tank mixture with other postemergence broadleaf herbicides such as bentazon and 2,4-DB to reduce foliar injury to peanut, improve control of larger weeds, and broaden the weed control spectrum (Eason et al. 2020; Price et al. 2020; Wehtje et al. 1992a, 1992b). Co-application of paraquat and 2,4-DB improved control of larger *S. obtusifolia* plants than paraquat applied alone (Wehtje et al. 1992b). Similarly, paraquat applied in tank mixture with bentazon controlled a broader spectrum of broadleaf weeds including such as *A. hispidum*, *C. rotundus*, common cocklebur (*Xanthium strumarium* L.), *S. occidentalis, S. spinosa,* and *J. tamnifolia*, (Table 7) and reduced foliar injury from paraquat compared with paraquat applied alone (Eason et al. 2019; Grey et al. 1995; Wehtje et al. 1992a; Wilcut et al. 1991b, 1994a). However, bentazon applied with paraquat can act as an antagonist by reducing the absorption of paraquat on the leaf surface, thereby reducing paraquat efficacy on certain species (Wehtje et al. 1992a). In greenhouse and field studies, bentazon reduced the efficacy of paraquat for the control of *D. tortuosum*, *S. obtusifolia,* and *U. texana* in peanut (Wehtje et al. 1992a).

Paraquat is not commonly used in the southwestern United States because peanut injury from paraquat applied during the hotter periods can significantly reduce peanut yield and grade characteristics (Knauft et al. 1990; Wilcut and Swann 1990; Wilcut et al. 1995). Likewise, paraquat alone or in mixture with bentazon or 2,4-DB is not a common herbicide program in the Virginia-North Carolina region because paraquat does not provide adequate control of *A. artemisiifolia, C. album*, *C. glandulosus* and spurred anoda [*Anoda cristata* (L.) Schltdl.] which are commonly found in the region (Wilcut et al. 1994a, 1995).

PPO Inhibitors (Acifluorfen, Carfentrazone, and Lactofen)

Acifluorfen and lactofen are used for postemergence control of annual broadleaf weeds in peanut. They are classified as diphenyl ether (cell membrane disrupter) that kill weeds rapidly by interfering with protoporphyrinogen IX oxidase synthesis and causing accumulation of protoporphyrin IX in the cytoplasm (Shaner 2014). This molecule reacts with light, resulting in the production of toxic singlet oxygen species, which deteriorate cell membranes. Acifluorfen and lactofen provide >70% control of several annual broadleaf weeds such as *A. palmeri*, *A. spinosus*, *A. artemisiifolia*, *C. glandulosus, C. melo,* and *S. spinosa* (Table 7). They also provide effective control of ALS herbicide– resistant weeds in peanut and rotated crops such as cotton and soybean especially, in the southwestern and Virgina-North Carolina peanut growing regions of the United States (Culpepper et al. 2006; Wise et al. 2009). Acifluorfen and lactofen do not have residual activity at the rate used postemergence in peanut, thus sequential applications are often required for season long weed control (Dotray et al. 2012; Wilcut et al. 1990a). Sequential application of lactofen provides better weed control than single application (Jordan et al. 1993; Sperry et al. 2017) but can cause reduction in peanut yield (Sperry et al. 2017; Wilcut 1991b).

The efficacy of acifluorfen and lactofen is influenced by weed size or stage of weed growth at the time of application (Wilcut and Swann 1990; Wilcut 1991a, 1991b). For example, efficacy of acifluorfen and lactofen on *E. prostrata* decreased with delayed applications, as larger weeds (>10 cm) escaped control (Grichar 1997b). Lactofen controlled *C. album* 86% when applied at the cotyledon to 2-leaf stage, but control declined to 34% when *C. album* was 10-cm high (Wilcut 1991b). In the same study, lactofen controlled *S. spinosa* 87% to 95% and *Ipomoea* spp. 83% to 86% when applied at the 2-leaf stage, but control declined to 0% when applications were made at the 3- to 7-leaf stages.

Acifluorfen and lactofen can cause reduced canopy growth and visible peanut injury characterized by leaf bronzing, cupping and crinkling of leaf margins, and necrotic spots/lesions. Plant recover within 2 to 4 wk after application, and yield penalties are rarely observed if applications are made before full seed fill (Chaudhari et al. 2018; Ferrell et al. 2013; Grichar 1994). However, yield reduction can occur with sequential applications and applications made later in the season, especially between the R5 (beginning seed) to R6 (full seed) growth stages (Grichar 1997a; Jordan et al. 1993; Sperry et al. 2017; Wilcut 1991b). Peanut yield was reduced by 49% with late postemergence application of acifluorfen plus bentazon and by 45% with sequential application of lactofen (Jordan et al. 1993). Wilcut et al. (1990b) reported 39% and 45%

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Table 7. Cumulative results on efficacy of protoporphyrinogen oxidase inhibitors (acifluorfen and lactofen) and synthetic auxin (2,4-DB) applied postemergence in peanut.

	Weed species	Efficacy[a]	References
Acifluorfen	*Amaranthus palmeri*	17–100	Grichar (1997a, 2007); Grichar et al. (2005); Sperry et al. (2017)
	Amaranthus spinosus	91–98	Grichar (1994)
	Ambrosia artemisiifolia	70–93	Wilcut (1991b)
	Chenopodium album	50–77	Wilcut (1991b)
	Citrullus lanatus	69–94	Grichar et al. (2001)
	Croton glandulosus	86–92	Wilcut (1991b, 1991c)
	Eclipta prostrata	25–100	Altom et al. (1995); Grichar (1997b)
	Ipomoea lacunosa	0–95	Grichar (1997b)
	Ipomoea spp.	67–86	Wilcut (1991b)
	Trianthema portulacastrum	17–77	Grichar (1993, 2007)
	Urochloa texana	10	Grichar et al. (2005)
	Verbesina encelioides	55–100	Grichar and Sestak (1998)
Lactofen	*Amaranthus palmeri*	45–100	Berger et al. (2014); Carter and Prostko (2019); Chahal et al. (2011); Eure et al. (2013); Grichar (1994, 1997a, 2007); Grichar and Dotray (2011); Morichetti et al. (2012); Seale et al. (2020); Sperry et al. (2017)
	Ambrosia artemisiifolia	97	Eure et al. (2013)
	Chenopodium album	33–86	Jordan et al. (1993); Wilcut et al. (1991a)
	Citrullus lanatus	58–96	Grichar et al. (2010)
	Cucumis melo	82–97	Grichar and Dotray (2011)
	Eclipta prostrata	41–100	Grichar (1997b); Jordan et al. (1993)
	Euphorbia heterophylla	57–95	Moore et al. (1990)
	Ipomoea hederacea	90–93	Eure et al. (2013)
	Ipomoea lacunosa	0–58	Grichar (1997b)
	Ipomoea spp.	80–92	Jordan et al. (1993)
	Senna obtusifolia	75–89	Carter and Prostko (2019)
	Sesbania exaltata	86–100	Seale et al. (2020)
	Sida spinosa	88–100	Jordan et al. (1993); Seale et al. (2020) Wilcut et al. (1991a)
	Trianthema portulacastrum	68–100	Grichar (1993, 2007); Grichar and Dotray (2011)
	Verbesina encelioides	91–100	Grichar and Sestak (1998)
2,4-DB	*Amaranthus palmeri*	46–96	Chahal (2012a); Grichar et al. (2005, 2006); Grichar and Dotray (2011)
	Amaranthus spinosus	71–94	Grichar (1994)
	Citrullus lanatus	98	Grichar and Dotray (2011)
	Cucumis melo	98	Grichar and Dotray (2011)
	Desmodium tortuosum	0–44	Wehtje et al. (1992b, 1993)
	Digitaria ciliaris	0	Grichar and Boswell (1987)
	Eclipta prostrata	5–91	Grichar (1997b)
	Ipomoea hederacea	93	Lancaster et al. (2005c)
	Ipomoea lacunosa	37–75	Grichar (1997b)
	Ipomoea purpurea	96	Chahal et al. (2012b)
	Ipomoea spp.	99–100	Wehtje et al. (1993)
	Senna obtusifolia	46–100	Hicks et al. (1998); Lancaster et al. (2005a); Wehtje et al. (1992b, 1993)
	Trianthema portulacastrum	13–84	Grichar (1993, 2007)
	Urochloa texana	0	Grichar and Boswell (1987)
	Verbesina encelioides	80–100	Grichar and Dotray (2011); Grichar and Sestak (1998)

[a]Efficacy range across all references listed from 0% to 100%, where 0 = no control, 100 = complete control.

reduction in peanut yield when application of acifluorfen plus bentazon and lactofen was delayed until 4 wk after GC compared with GC application, respectively. Other studies have reported similar yield reductions following sequential application of lactofen in peanut (Boyer et al. 2011; Grichar 1997b: Sperry et al. 2017; Wilcut et al. 1990b). Acifluorfen and lactofen are frequently tank mixed with 2,4-DB and crop oil concentrate (COC) (Ferrell et al. 2013; Grichar 1997b). Applying acifluorfen or lactofen with 2,4-DB increases efficacy, especially for ALS herbicide– resistant weeds, because 2,4-DB provides systemic activity. However, these herbicide treatments can cause visible peanut injury, although yield is not affected in most cases (Boyer et al. 2011; Ferrell et al. 2013). Application of lactofen with COC resulted in 48% injury and 10-d delay in peanut canopy closure (Boyer et al. 2011).

Carfentrazone is another PPO-inhibiting herbicide labeled for use in peanut. It has little or no residual effect but exhibits rapid contact activity, causing desiccation of susceptible weed species within hours of treatment and, consequently, plant death within days (Anonymous 2008, 2020). Carfentrazone is used to control *Ipomoea* species in peanut (Grichar et al. 2021; Kharel et al. 2022), but only as a burndown treatment before planting (Anonymous 2008; Grichar et al. 2010). Carfentrazone has been shown to cause stunting and peanut injury ranging from 7% to 62% and significant yield reduction in various studies (Chaudhari et al. 2017; Dotray et al. 2010, Grichar et al. 2010, 2021; Kharel et al. 2022; Price et al. 2021). Injury from carfentrazone can be substantially greater than injury from lactofen and paraquat plus bentazon, which is often considered as unacceptable by peanut growers (Dotray et al. 2010; Grichar et al. 2010). Several factors, including rates and timing of application, planting dates, and environmental factors, can influence peanut stunting or injury from carfentrazone. Carfentrazone causes more severe injury to peanut when applied early season rather than late season (Dotray et al. 2010; Grichar et al. 2010). Dotray et al. (2010) reported greater peanut injury ranging from 14% to 19% following early postemergence (28 to 51 d after planting) application of carfentrazone at 27 and 36 g ai ha^{-1} compared with 6% to 8% injury from late postemergence (93 to 121 d after planting) application. Similarly, Grichar et al. (2010) reported greater peanut injury ranging from 7% to 52% following early postemergence (35 d after planting) application of carfentrazone at 30 and 40 g ai ha^{-1} compared with 9% to 16% injury from late postemergence (56 d after planting) application. Injury from carfentrazone at these application rates and timings resulted in as much as 22% reduction in peanut yield, but peanut grade characteristics were not affected (Grichar et al. 2010). Yield losses up 27% were observed with carfentrazone-ethyl plus a high surfactant oil concentrate at 75 and 90 d after planting as compared with the nontreated check (Price et al. 2021). Similarly, carfentrazone application during the pod-filling stage (4 wk before digging) caused 10% reduction in peanut yield, whereas yield was not affected when applied at 1 or 2 wk before digging (Chaudhari et al. 2017). This research suggests carfentrazone may be an appropriate herbicide for late-season weed control to reduce weed interference with peanut digging and inversion.

Carfentrazone plus pyroxasulfone has recently been labeled as a commercially available premixed herbicide combination for post emergence application in peanut (Anonymous 2020). Available literature showed that carfentrazone plus pyroxasulfone can control small-seeded annual broadleaf weeds, including ALS herbicide– resistant *A. palmeri* in peanut (Grichar et al. 2021). *Amaranthus palmeri* control with carfentrazone plus pyroxasulfone preemergence was at least 78% season-long, while postemergence applications were inconsistent (24% to 100%). Pendimethalin plus premixed carfentrazone plus pyroxasulfone controlled *C. melo* at least 80% late season.

Synthetic Auxin (2,4-DB)

The herbicide 2,4-DB is a selective systemic phenoxyalkanoic acid Group 4 herbicide registered for use in peanut throughout the growing season (Jordan 2004). Several troublesome broadleaf weeds, including *A. palmeri*, *C. melo*, *S. obtusifolia*, *Ipomoea* spp., *T. portulacastrum*, golden crownbeard [*Verbesina encelioides* (Cav.) Benth. & Hook. f. ex A. Gray], and *X. strumarium*, are controlled with 2,4-DB applied postemergence in peanut (Table 7). However, 2,4-DB rarely provides complete control of *S. obtusifolia* and *X. strumarium* with a single application (Wilcut et al. 1995). Phenoxy herbicides are generally toxic to broadleaf weeds or crops, but legumes such as peanut exhibit high tolerance to 2,4-DB, and significant foliar injury is rarely observed (Dotray et al. 2004; Faircloth and Prostko 2010). Tolerant legumes cannot convert the butyric acid side chain as readily as other broadleaf plants (Hawf and Behrens 1974). Peanut tolerance to 2,4-DB has also been attributed to reduced spray retention, absorption, and translocation and less beta-oxidation within plant tissue, resulting in less conversion to the phytotoxic secondary metabolite (2,4-D) (Hawf and Behrens 1974; Ketchersid et al. 1978). Earlier studies indicated that 2,4-DB was not readily absorbed by peanut leaves, was slowly metabolized to 2,4-D, and was not accumulated in the nut at harvest (Ketchersid et al. 1978). In contrast, 2,4-DB was rapidly absorbed and converted to 2,4-D and subsequently translocated to the apical region in redroot pigweed (*Amaranthus retroflexus* L.), a susceptible species, resulting in reduced growth and death of the plant (Ketchersid et al. 1978). Application of 2,4-DB is restricted within 60 d before peanut harvest. Peanut yield was not impacted when 2,4-DB was applied within recommended rates and timing (Baughman et al. 2002; Faircloth and Prostko 2010; Ferrell et al. 2013; Grichar et al. 1997; Jordan et al. 2003b; Lancaster et al. 2005c). In earlier studies, application of 2,4-DB at 0.95 kg ai ha^{-1} up to 62 d after planting reduced pod development in a Spanish cultivar, but yield was not reduced with sequential application at 0.45 kg ai ha^{-1} during pod fill (Ketchersid et al. 1978). However, peanut yield and grade characteristics were not adversely affected when 2,4-DB was applied at 0.45 kg ai ha^{-1} up to 120 d after planting in runner and Virginia market-type cultivars (Baughman et al. 2002; Grichar et al. 1997). Similarly, Jordan et al. (2003b) reported that 2,4-DB at 0.14 kg ai ha^{-1} did not adversely affect peanut pod yield and seed germination when applied at 3, 5, or 7 wk before digging.

The herbicide 2,4-DB is often applied in combination with other postemergence broadleaf weed herbicides such as acifluorfen, bentazon, lactofen, and paraquat to improve weed control spectrum (Burke et al. 2002; Jordan et al. 2007; Wilcut et al. 1994b). Application of 2,4-DB with these herbicides can also improve control of weeds larger than the recommended size for treatment with broadleaf herbicides (Ferrell et al. 2013; Jordan et al. 2003a). Application of 2,4-DB in tank mixture with acifluorfen plus bentazon improved the control of *A. palmeri* between 10- to 20-cm height (Ferrell et al. 2013). However, these herbicide treatments can cause visible peanut injury (Ferrell et al. 2013; Jordan et al. 2003b) and stunting manifested as reduced canopy width (Ferrell et al. 2013), but yield penalties are rarely observed (Baughman et al. 2002; Dotray et al. 2004; Ferrell et al. 2013).

Foliar-applied Graminicides (Clethodim, Fluazifop-P-Butyl, and Sethoxydim)

Clethodim, fluazifop-*P*-butyl, and sethoxydim are postemergence-applied herbicides commonly referred to as graminicides. They selectively inhibit lipid biosynthesis in susceptible species and are applied postemergence to control annual and perennial grasses in peanut throughout the majority of the growing season, especially grasses that escape control from soil-applied herbicides (Anonymous 2000a, 2000b; Chahal et al. 2013; Lancaster et al. 2005c; Prostko et al. 2001). The effectiveness of these herbicides in controlling annual and perennial grasses is important to minimize interference and increase the efficiency of peanut digging and inversion, because the dense, fibrous root systems of grasses can cause peanut pods to be stripped from the vines (Wilcut et al. 1995). Clethodim and sethoxydim can provide >80% control of the most prevalent grass weed species in peanut, including broadleaf signalgrass [*Urochloa platyphylla* (Munro ex C. Wright) R.D. Webster], common bermudagrass [*Cynodon dactylon* (L.) Pers.], *E. crus-galli*, goosegrass [*Eleusine indica* (L.) Gaertn.], *D. sanguinalis*, *P. dichotomiflorum*, southern crabgrass [*Digitaria ciliaris* (Retz.) Koeler], and *U. texana* (Table 8). Similarly, >80% control of *C. dactylon*, *D. ciliaris*, *U. platyphylla*, and *U. texana* can be achieved with fluazifop-*P*-butyl (Table 8). Additionally, sequential application(s) can provide excellent (>90%) control of perennial grasses such as johnsongrass [*Sorghum halepense* (L.) Pers.] (York et al. 1993).

Graminicides are often applied in mixture with broadleaf herbicides and other pesticides to reduce the number of application trips over the field, saving time and fuel and increasing the spectrum of weed control and overall weed management (Burke et al. 2004; Grichar et al. 2002; Holshouser and Coble 1990). However, this practice can affect weed control when the tank mix contains herbicides that are not compatible (Chahal et al. 2012b, 2013; Lancaster et al. 2008). Efficacy of the graminicides clethodim and sethoxydim may be reduced when applied in tank mixture with broadleaf herbicides such as acifluorfen, bentazon, acifluorfen plus bentazon, phenoxyalkanoic acid, 2,4-DB, or herbicides that inhibit ALS such as imazapic and imazethapyr (Burke and Wilcut

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Table 8. Cumulative results on the efficacy of acetyl-CoA carboxylase inhibitors applied postemergence in peanut.

	Weed species	Efficacy[a]	References
Clethodim	*Cynodon dactylon*	43–99	Grichar (1995); Seale et al. (2020); Wilcut (1991c)
	Digitaria ciliaris	87–98	Grichar (1991a); Grichar et al. (2002); Prostko et al. (2001)
	Digitaria sanguinalis	81–100	Burke et al. (2002, 2004); Chahal et al. (2012a, 2013); Jordan et al. (2012); Lancaster et al. (2005b, 2007)
	Echinochloa crus-galli	95–98	Prostko et al. (2001)
	Eleusine indica	93–100	Burke et al. (2002, 2004); Chahal et al. (2013)
	Panicum dichotomiflorum	100	Burke et al. (2004)
	Sorghum halepense	100	York et al. (1993)
	Urochloa platyphylla	93–100	Burke et al. (2004); Grichar et al. (2002); Lancaster et al. (2008); York et al. (1993)
	Urochloa texana	56–99	Burke et al. (2002, 2004); Chahal et al. (2012a); Grichar (1991a); Johnson et al. (2002); Prostko et al. (2001)
Fluazifop-*P*	*Cynodon dactylon*	56–99	Grichar (1995); Grichar and Boswell (1986)
	Digitaria ciliaris	43–97	Grichar (1991a)
	Digitaria sanguinalis	28–99	Grichar and Boswell (1986)
	Urochloa platyphylla	73–97	Grichar and Boswell (1986)
	Urochloa texana	73–96	Grichar (1991a); Grichar and Boswell (1986)
Sethoxydim	*Cynodon dactylon*	32–99	Grichar (1995); Grichar and Boswell (1987); Wilcut (1991b)
	Dactyloctenium aegyptium	95–98	Prostko et al. (2001)
	Digitaria ciliaris	63–98	Grichar (1991a, 1991b); Prostko et al. (2001)
	Digitaria sanguinalis	70–98	Chahal et al. (2012a, 2013); Grichar and Boswell (1986); Lancaster et al. (2005d)
	Eleusine indica	63–95	Chahal et al. (2013); Lancaster et al. (2005d)
	Sorghum halepense	97–100	York et al. (1993)
	Urochloa platyphylla	80–97	Grichar and Boswell (1986); York et al. (1993)
	Urochloa texana	55–99	Grichar (1991a, 1991b); Grichar and Boswell (1986); Johnson et al. (2002); Prostko et al. (2001)

[a]Efficacy range across all references listed from 0% to 100%, where 0 = no control, 100 = complete control.

2003; Burke et al. 2004; Jordan 1995; York et al. 1993), due to reduced absorption, translocation, or metabolism (Ferreira et al. 1995). Weed species, weed size at the time of herbicide application, rates, adjuvants, and environmental conditions can affect the interaction between graminicides and broadleaf herbicides (Burke and Wilcut 2003; Jordan 1995). Chlorimuron antagonized clethodim for *E. crus-galli* and *S. halepense* control but *U. platyphylla* control with clethodim was not affected (Jordan 1995). In the same study, Jordan (1995) reported reduction in *E. crus-galli* and *U. platyphylla* control with fluazifop-*P* when applied in tank mixture with chlorimuron compared with fluazifop-*P* alone. Also, bentazon antagonized sethoxydim and clethodim efficacy for *E. crus-galli*, *S. halepense*, and *U. platyphylla* control (Jordan 1995). Imazapic in mixture with clethodim reduced clethodim efficacy on *D. sanguinalis*, *E. indica*, *P. dichotomiflorum*, and *U. texana*, but *U. platyphylla* was not affected (Burke et al. 2004). Imazapic applied 1 d before and up to 3 d after clethodim reduced efficacy of clethodim on *P. dichotomiflorum* and *D. sanguinalis* >30 cm in height (Burke et al. 2004). Similarly, imazapic applied 3 d before and up to 7 d after clethodim reduced *E. indica* control compared with clethodim alone (Burke et al. 2004). Burke and Wilcut (2003) showed imazapic did not affect absorption or translocation of clethodim in treated *E. indica* but antagonized imazapic efficacy by reducing the photosynthetic rate of *E indica* and therefore the sensitivity of ACCase to clethodim (Burke and Wilcut 2003). Bentazon and 2,4-DB tank mixed with clethodim reduced *P. dichotomiflorum* and *U. platyphylla* control compared with clethodim alone (Burke et al. 2004). In a similar study, *U. platyphylla* control with clethodim was <65% when applied in mixture with acifluorfen, acifluorfen plus bentazon, imazethapyr, imazapic, or lactofen (Grichar et al. 2002). Ammonium sulfate and other adjuvants can be tank mixed to alleviate the antagonistic effect of broadleaf herbicides on the efficacy of clethodim and sethoxydim (Burke et al. 2004; Jordan 1995).

Herbicides with Soil and Foliar Activity—ALS Inhibitors (Chlorimuron, Diclosulam, Imazapic, and Imazethapyr)

The introduction of the ALS inhibitors diclosulam, chlorimuron, imazapic, and imazethapyr is one of the most important developments in the history of weed control in peanut production in the United States. These herbicides provide effective control of monocotyledonous and dicotyledonous weed species and exhibit residual activity for preventing weed seedling emergence and foliar activity for control of emerged weeds (Grey and Wehtje 2005; Grey et al. 2003). In addition to broad-spectrum weed control, considerable safety to peanut is achieved (Grey and Wehtje 2005). These features may explain the peanut growers' high reliance on these herbicides during the last 20 yr, which in fact favored increased selection pressure and subsequently the evolution of resistance in important and problematic species, including *A. palmeri* (Clewis et al. 2007; Everman et al. 2006). However, the application of these herbicides is limited by rotational restrictions when rotation to sensitive crops such as cotton is anticipated (Grichar et al. 1999). Numerous researchers have reported the weed control spectrum of ALS-inhibiting herbicides in peanut (Tables 9 and 10), as these continue to be the backbone of weed control in peanut.

Chlorimuron is labeled for late postemergence application in peanut and is primarily used to control *D. tortuosum* to prevent yield loss and harvest interference (Wehtje et al. 2000a, 2000b; Wilcut et al. 1994a). Chlorimuron is restricted to use only from 60 d after emergence to 45 d before peanut harvest (Johnson et al. 1992a, 1992b). During this application window, chlorimuron absorption in peanut is minimal and readily metabolized (Wilcut et al. 1989). However, by 60 d after peanut emergence, *D. tortuosum* plants are often about 90 to 120 cm (Cardina and Brecke 1991), which is significantly larger than the 25-cm height recommended on the chlorimuron label (Anonymous 2009). The application restriction of chlorimuron was established based on peanut injury and yield reductions following early-season

Table 9. Cumulative results on efficacy of acetolactate synthase inhibitors applied preemergence in peanut.

	Weed species	Efficacy[a]	References
Diclosulam	*Desmodium tortuosum*	86–93	Sims et al. (1987)
	Senna obtusifolia	87–93	Sims et al. (1987)
	Acanthospermum hispidum	87–97	Brecke et al. (2002); Grey and Wehtje (2005); Grey et al. (2003)
	Amaranthus palmeri	87–99	Grey and Wehtje (2005)
	Chenopodium album	62–100	Bailey et al. (1999b); Jordan et al. (2009b); Price et al. (2002)
	Cyperus esculentus	25–100	Besler et al. (2008); Brecke et al. (2002); Ducar et al. (2009); Grey and Wehtje (2005); Grey et al. (2002, 2003); Grichar et al. (2002, 2006)
	Cyperus rotundus	65–73	Grey et al. (2003)
	Desmodium tortuosum	50–99	Brecke et al. (2002); Ducar et al. (2009); Grey and Wehtje (2005); Grey et al. (2002, 2003); Willingham et al. (2008)
	Digitaria sanguinalis	95–100	Price et al. (2002)
	Eclipta prostrata	100	Bailey et al. (1999b); Grichar et al. (2004); Jordan et al. (2009b); Price and Wilcut (2002)
	Eleusine indica	53–100	Grey et al. (1995)
	Euphorbia heterophylla	62–96	Grey and Wehtje (2005); Scott et al. (2001)
	Euphorbia nutans	99	Jordan et al. (2009b)
	Indigofera hirsuta	32–80	Willingham et al. (2008)
	Ipomea spp.	99	Grey et al. (2003)
	Ipomoea hederacea	12–99	Bailey et al. (1999b); Ducar at al. (2009); Grey and Wehtje (2005); Price and Wilcut (2002); Price et al. (2002); Scott et al. (2001)
	Ipomoea lacunosa	14–100	Bailey et al. (1999b); Ducar at al. (2009); Grichar et al. (2004, 2006); Jordan et al. (2009b); Price and Wilcut (2002); Price et al. (2002)
	Ipomoea purpurea	87–96	Grey and Wehtje (2005)
	Jacquemontia tamnifolia	96	Grey et al. (2003)
	Senna obtusifolia	30–76	Ducar et al. (2009); Grey and Wehtje (2005); Grey et al. (2002); Willingham et al. (2008)
	Sida spinosa	63–100	Price and Wilcut (2002); Price et al. (2002)
	Urochloa texana	71–83	Grichar et al. (2004, 2006)
Imazapic	*Acanthospermum hispidum*	51	Brecke et al. (2002)
	Cyperus esculentus	9	Brecke et al. (2002)
	Desmodium tortuosum	70–90	Brecke et al. (2002)
	Senna obtusifolia	72	Brecke et al. (2002)
Imazethapyr	*Amaranthus palmeri*	100	Grichar et al. (2008)
	Chenopodium album	85	Wilcut (1991a)
	Citrullus lanatus	54	Grichar et al. (2002)
	Cucumis melo	63	Grichar et al. (2008)
	Cyperus esculentus	50–96	Grichar et al. (1992)
	Cyperus rotundus	74–99	Grichar et al. (1992, 1997)
	Eclipta prostrata	5–53	Grichar et al. (1997)
	Ipomea spp.	77	Wilcut (1991a)
	Ipomoea lacunosa	44–91	Grichar et al. (1997)
	Sida spinosa	92	Wilcut (1991a)
	Trianthema portulacastrum	65	Grichar et al. (2008)

[a]Efficacy range across all references listed from 0% to 100%, where 0 = no control, 100 = complete control.

applications in studies conducted using 'Florunner'—a now-obsolete cultivar that has been replaced by newer cultivars in the U.S. Southeast peanut-growing region (Wilcut et al. 1989). However, chlorimuron can cause peanut injury even when applied at the recommended timing (Wehtje and Grey 2004). Reduction in peanut growth has been reported following chlorimuron application at the recommended timing, although no consistent reduction in peanut yield was observed (Johnson et al. 1992b; Prostko et al. 2009). However, studies conducted with newer cultivars such as 'Georgia-06G' and 'Tifguard' indicated 7% to 11% peanut yield reduction following chlorimuron application at 60 to 99 d after emergence, which is within the recommended window for application (Prostko et al. 2012). Similarly, Grichar and Dotray (2010) in one of two trials, observed significant yield reduction in 'Tamrun 96' peanut cultivar following chlorimuron application at 60 to 95 d after peanut emergence. Additionally, incidence of tomato spotted wilt virus (TSWV) caused by thrips moving from dying weeds was reported following chlorimuron application in 'AP-3', 'Georgia-02C', and 'Georgia Green' peanut cultivars in 15 field trials in Georgia (Prostko et al. 2009).

It is also noteworthy that the recommended window of chlorimuron application is later than the 4- to 6-wk critical period of *D. tortuosum* control in peanut (Hauser et al. 1975). This indicates that an irreversible yield reduction is expected, even if chlorimuron controls *D. tortuosum* late in the growing season. Wehtje et al. (2000a) showed late-season control with chlorimuron after significant early-season interference did not improve peanut yield but resulted in a significant reduction in net return. Research conducted to evaluate the possibility of applying chlorimuron earlier than 60 d after peanut emergence showed that peanut cultivars such as 'AT 201' and Georgia Green exhibited acceptable tolerance to chlorimuron applied early in the growing season in three of four trials (Wehtje and Grey 2004). In that study, peanut yield reduction from early-season application of chlorimuron was observed only in one of four trials associated with plant stress, which suggests that chlorimuron possesses yield-reducing risk only when the crop has been stressed by other factors (Wehtje and Grey 2004). Differences in TSWV tolerance among cultivars may also be a confounding factor in accessing tolerance to chlorimuron. In another study, Johnson et al. (2010) reported better *D. tortuosum* control and greater yield in 'C99R' and Georgia Green peanut

Table 10. Cumulative results on the efficacy of acetolactate synthase inhibitors applied postemergence in peanut.

	Weed species	Efficacy[a]	References
Chlorimuron	*Acanthospermum hispidum*	20–50	Johnson et al. (2010)
	Croton glandulosus	38–62	Johnson et al. (2010)
	Cyperus rotundus	59–69	Jordan (1996)
	Desmodium tortuosum	28–86	Johnson et al. (2010); Wehtje et al. (1993)
	Ipomoea spp.	20–68	Wehtje et al. (1993)
	Senna obtusifolia	35–70	Johnson et al. (2010); Wehtje et al. (1993)
Diclosulam	*Acanthospermum hispidum*	75	Brecke et al. (2002)
	Amaranthus palmeri	52–98	Grichar (2007)
	Ambrosia artemisiifolia	66–100	Everman et al. (2006)
	Chenopodium album	57–62	Everman et al. (2006)
	Conyza canadensis	45–90	Lancaster et al. (2007)
	Cucumis melo	55–63	Grichar (2007)
	Cyperus esculentus	16–100	Brecke et al. (2002); Grichar et al. (2004); Lancaster et al. (2007)
	Desmodium tortuosum	76–89	Brecke et al. (2002)
	Eclipta prostrata	20–100	Grichar et al. (2004); Lancaster et al. (2007)
	Euphorbia nutans	95	Lancaster et al. (2007)
	Ipomoea hederacea	44–88	Everman et al. (2006)
	Ipomoea lacunosa	62–74	Grichar et al. (2004)
	Senna obtusifolia	32	Brecke et al. (2002)
	Trianthema portulacastrum	7–73	Grichar (2007)
	Urochloa texana	45–56	Grichar et al. (2004)
Imazapic	*Acanthospermum hispidum*	80–97	Brecke et al. (2002); Grey et al. (2003); Grey and Wehtje (2005); Grichar et al. (2012); Wehtje et al. (2000b)
	Amaranthus palmeri	33–100	Grey and Wehtje (2005); Grichar (2007); Grichar et al. (1999, 2005, 2012, 2018)
	Ambrosia artemisiifolia	26–58	Grichar et al. (2012)
	Chenopodium album	48–85	Bailey et al. (1999a)
	Commelina benghalensis	98	Stephenson et al. (2011)
	Cucumis melo	82–100	Grichar et al. (2006, 2012, 2018)
	Cyperus esculentus	45–100	Besler et al. (2008); Brecke et al. (2002); Ducar et al. (2009); Grey and Wehtje (2005); Grey et al. (2002, 2003, 2004); Grichar and Sestak (2000); Grichar et al. (1999, 2002, 2004, 2012); Wehtje et al. (2000a); Willingham et al. (2008)
	Cyperus rotundus	75–100	Grey et al. (2003); Grichar and Sestak (2000); Grichar et al. (1999)
	Desmodium tortuosum	54–99	Brecke et al. (2002); Ducar et al. (2009); Grey and Wehtje (2005); Grey et al. (2002, 2003, 2004); Wehtje and Grey (2004); Willingham et al. (2008)
	Digitaria ciliaris	54–92	Johnson and Luo (2019)
	Digitaria sanguinalis	76–95	Burke et al. (2004)
	Eclipta prostrata	18–98	Bailey et al. (1999b); Grichar et al. (2004); Jordan (1999)
	Eleusine indica	37–95	Grey and Wehtje (2005); Grey et al. (2004)
	Euphorbia heterophylla	96–99	Grey and Wehtje (2005)
	Harpagophytum procumbens	99	Grichar et al. (1999)
	Ipomoea hederacea	53–99	Bailey et al. (1999a, 1999b); Grey and Wehtje (2005); Jordan (1999)
	Ipomoea lacunosa	23–100	Bailey et al. (1999a, 1999b); Ducar et al. (2009); Grichar (2008); Grichar et al. (1999); Grichar and Dotray (2013); Grichar et al. (2004, 2012); Stephenson and Brecke (2011)
	Ipomoea purpurea	89–99	Grey and Wehtje (2005)
	Ipomoea spp.	97	Grey et al. (2003)
	Jacquemontia tamnifolia	91	Grey et al. (2003)
	Panicum dichotomiflorum	82	Burke et al. (2004)
	Senna obtusifolia	71–99	Burke et al. (2002); Ducar et al. (2009); Grey and Wehtje (2005); Grey et al. (2002); Grichar (2008); Stephenson and Brecke (2011); Wehtje et al. (2000b); Willingham et al. (2008)
	Sida spinosa	17–98	Bailey et al. (1999b); Grichar et al. (2012)
	Trianthema portulacastrum	7–62	Grichar (2007, 2008)
	Commelina benghalensis	98	Grichar (2008)
	Urochloa ramose	98	Grichar (2008); Stephenson and Brecke (2011)
	Urochloa texana	74–100	Grichar et al. (2004, 2012)
	Verbesina encelioides	27–100	Grichar and Sestak (1998); Grichar et al. (1999, 2012)
Imazethapyr	*Acanthospermum hispidum*	0–98	Grey at al. (1995); Wilcut et al. (1994a, 1995)
	Amaranthus palmeri	23–100	Dotray and Keeling (1997); Grichar (1994, 1997b, 2007); Grichar and Nester (1997); Grichar et al. (2005); Jordan (1996)
	Ambrosia artemisiifolia	92	Grichar et al. (1999)
	Chenopodium album	58	Wilcut (1991b)
	Citrullus lanatus	73–83	Grichar et al. (2001)
	Croton glandulosus	4	Wilcut (1991b)
	Cucumis melo	61–76	Grichar (2007)
	Cyperus esculentus	80–93	Grey et al. (1995); Wilcut et al. (1994b)
	Cyperus rotundus	63–99	Grichar and Nester (1997); Wilcut et al. (1994a)
	Desmodium tortuosum	0–30	Wilcut et al. (1994a, 1994b)
	Eleusine indica	0–63	Grichar (1997b)
	Ipomoea lacunosa	40–100	Grichar (1997b); Richburg et al. (1993a)
	Ipomoea spp.	92–98	Wilcut (1991b); Wilcut et al. (1994a)
	Jacquemontia tamnifolia	99–100	Wilcut et al. (1994a, 1994b)

(*Continued*)

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Table 10. (*Continued*)

Weed species	Efficacy[a]	References
Senna obtusifolia	5–46	Grey et al. (1995); Wilcut et al. (1994a, 1994b)
Senna occidentalis	99–100	Wilcut et al. (1994a, 1994b)
Sida spinosa	94–97	Wilcut et al. (1994a, 1994b)
Trianthema portulacastrum	13–27	Grichar (2007)
Urochloa texana	67	Grichar et al. (2005)
Xanthium strumarium	91	Wilcut et al. (1994a, 1994b)

[a]Efficacy range across all references listed from 0% to 100%, where 0 = no control, 100 = complete control.

cultivars when chlorimuron was applied at 21 and 35 d after peanut emergence compared with the recommended application window. This suggests that the risk of early-season application of chlorimuron may be worth the potential benefits of controlling *D. tortuosum* during the critical period of interference when the weeds are smaller in size, particularly in situations with dense populations.

Chlorimuron can be applied in tank mixture with other late-season herbicides, especially 2,4-DB. The interaction of chlorimuron and co-applied herbicides may be beneficial or detrimental to crop safety and weed control depending on the herbicide, application timing, and weed species (Wehtje et al. 1993). The tank mixture of chlorimuron and 2,4-DB improved the control of *D. tortuosum*, *Ipomoea* spp., and *S. obtusifolia*, but peanut injury was not affected (Wehtje et al. 1993). In the same study, a tank mixture of chlorimuron and 2,4-DB improved peanut yield when applied at 11 wk after planting, but yield was reduced when the tank mix was applied at 7 wk after planting (Wehtje et al. 1993).

Diclosulam is a triazolopyrimidine sulfonanilide ALS-inhibiting herbicide (Bailey et al. 1999a). It is often used in peanut as a preplant-incorporated or preemergence treatment to provide broadleaf and perennial sedge weed control, but it can also be used early postemergence (Baily and Wilcut 2002; Grey and Wehtje 2005; Lancaster et al. 2007). Diclosulam provides broad-spectrum weed control at a much lower recommended use rate (27 g ha^{-1}) than other herbicides used in peanut, and it is less restrictive compared with other ALS inhibitors with respect to cotton rotational limitations (Anonymous 2000c; Brecke et al. 2002). The rotation interval for cotton following imazethapyr and imazapic is 18 mo but it is only 10 mo for diclosulam (Anonymous 2000c). Our systematic review of the literature showed that diclosulam applied preplant incorporated or preemergence provides >70% control of *Amaranthus* spp., *A. artemisiifolia*, *A. hispidum*, *C. album*, *D. tortuosum*, *D. sanguinalis*, *E. prostrata*, *Ipomoea* spp., nodding spurge [*Chamaesyce nutans* (Lag.) Small], *S. spinosa*, *U. texana*, *V. encelioides*, and *E. heterophylla* in peanut (Tables 4 and 9). However, it does not provide effective control of *S. obtusifolia*, a major problematic weed in peanut in the United States (Brecke et al. 2002; Grey and Wehtje 2005; Main et al. 2005). Also, control of annual grasses and *C. esculentus* with diclosulam is inconsistent (Baily and Wilcut 2002; Brecke et al. 2002; Grichar et al. 1999). Some studies reported >80% *C. esculentus* control with diclosulam applied preplant incorporated or preemergence (Baily and Wilcut 2002; Clewis et al. 2002; Grey et al. 2004; Price and Wilcut 2002; Price et al. 2002), whereas others observed <70% control (Brecke et al. 2002; Grey et al. 2001; Grichar et al. 1999; Price and Wilcut 2002). Variations in *C. esculentus* control with diclosulam are attributed mainly to differences in application rates, with greater control observed with increasing rate of application (Ducar-Tredaway et al. 2006; Grey et al. 2001; Grichar et al. 1999), and application method, with preplant-incorporated applications often resulting in more consistent control than preemergence applications (Grey and Wehtje 2005; Grey et al. 2001, 2004; Grichar et al. 1999; Main et al. 2002). The efficacy of diclosulam applied preemergence depends on the availability of soil moisture from rainfall or irrigation to move the herbicide to the active zone of weed germination (Grey and Wehtje 2005; Grey et al. 2004; Main et al. 2002). Although diclosulam is mostly applied preplant incorporated or preemergence, research has indicated that timely postemergence applications can provide effective control of several problematic weeds in peanut (Brecke et al. 2002; Everman et al. 2006; Lancaster et al. 2007). Lancaster et al. (2007) reported good to excellent control of *A. artemisiifolia*, *C. esculentus*, *C. nutans*, and *I. hederacea* following a postemergence application of diclosulam at 3 wk after planting at 9, 13, 18, and 27 g ha^{-1}, but smooth pigweed (*Amaranthus hybridus* L.) and *C. album* control was <35%. Diclosulam applied early postemergence controlled *A. palmeri* at least 85%, whereas control was 75% with late postemergence application at 30 g ai ha^{-1} (Grichar 2007). Diclosulam applied postemergence at 4, 9, 13, or 27 g ai ha^{-1} controlled *A. artemisiifolia* 92% when applied within 7 wk after planting, whereas control was 89% with 13 and 27 g ai ha^{-1} rates and 63% to 66% with 4 and 9 g ai ha^{-1} rates when the application was delayed until 9 wk after planting (Everman et al. 2006). Regardless of application rate, *I. hederacea* control with diclosulam was reduced by >50% when applied at 7 to 9 wk after planting (8- to 10-leaf stage) as compared with early application at 5 wk after planting (Everman et al. 2006).

Peanut cultivars exhibit good tolerance to diclosulam due to their ability to metabolize the herbicide (Bailey and Wilcut 2002; Grey et al. 2001; Grichar et al. 1999). However, minor, and transient injury characterized by necrosis and peanut stunting has been reported in Florida (Main et al. 2002; Teuton et al. 2004), Georgia (Grey et al. 2001, 2003), North Carolina (Bailey et al. 1999a, 2000; Price et al. 2002), and south Texas (Grichar et al. 1999). Diclosulam injury resulted in reduced peanut root biomass and canopy diameter (Bailey et al. 2000; Grey et al. 2007), but yield and grade characteristics are generally not affected in popular Virginia- and runner-type cultivars (Bailey et al. 2000; Grey et al. 2007; Main et al. 2002, 2005). Main et al. (2002) reported peanut canopy width, yield, and percentage of extra-large kernels were not affected by diclosulam applied preplant incorporated at 18, 27, or 54 g ai ha^{-1} in peanut runner-type cultivars: Georgia Green, 'C99R', and 'MDR-98'. Similarly, Bailey et al. (2000) reported diclosulam applied preplant incorporated at 36 g ai ha^{-1} did not reduce peanut yields in eight Virginia-type cultivars. Diclosulam applied postemergence at 27 and 54 g ha^{-1} caused peanut injury ranging from 11% to 30%, but the injury was transient, and peanut yield was not affected (Everman et al. 2006)

Imazapic and imazethapyr are Group 2 imidazolinone herbicides that kill susceptible weed species by inhibiting ALS, an enzyme involved in the biosynthesis of branched-chain amino acids (Senseman 2007). Imazapic and imazethapyr are registered in peanut for annual broadleaf weed and *Cyperus* spp. control (Richburg et al. 1995c). Imazethapyr applied preplant incorporated, preemergence, or postemergence and imazapic applied preemergence or postemergence are used to provide residual weed control in peanut in addition to their foliar activity (Richburg et al. 1994, 1995c; Wilcut et al. 1996). Imazethapyr applied preplant incorporated or preemergence at rates ranging from 35 to 72 g ai ha^{-1} provides >70% control of *A. cristata*, *A. hispidum*, *C. album*, *C. lanatus*, *C. melo*, *E. prostrata*, *Ipomoea* spp., *S. occidentalis*, *S. spinosa*, *X. strumarium*, and *Amaranthus* species, including *A. palmeri* (Tables 4 and 9). Wilcut et al. (1991b) reported >90% control of *A. cristata*, *E. prostrata*, *Ipomoea* spp., and *S. spinosa* with preplant-incorporated and preemergence applications of imazethapyr at 71 g ai ha^{-1}. Similarly, postemergence application of imazethapyr provided >90% control of these weed species (Table 10), particularly when applied to small weeds within 10 d of weed emergence (Grey et al. 1995; Wilcut et al. 1994a). Regardless of application timing, imazethapyr does not provide good control of *D. tortuosum* and *S. obtusifolia*, the two most prevalent and troublesome weeds in peanut in the southeastern United States (Klingaman et al. 1992; Richburg 1995a, 1995b, 1996; Wilcut et al. 1991b, 1994a). It also shows poor control of *A. artemisiifolia*, a prevalent weed species in North Carolina and Virginia peanut fields (York et al. 1995). Regardless of application method, *A. artemisiifolia* control with imazethapyr at 70 g ha^{-1} was not >67% even with sequential applications consisting of preplant incorporated before GC or preemergence followed by postemergence application (York et al. 1995). Similarly, imazethapyr did not control *D. tortuosum* and *S. obtusifolia* adequately with preplant-incorporated (Richburg et al. 1996) or early postemergence (Wilcut et al. 1994b) applications, with control generally <50%. In a greenhouse study evaluating differential tolerance of *D. tortuosum*, *S. obtusifolia*, and *A. retroflexus* to imazethapyr, Cole et al. (1989) observed reduced root absorption and greater half-life for foliar-applied [^{14}C] imazethapyr in *D. tortuosum*, and *S. obtusifolia* compared with *A. retroflexus* (a susceptible species). This suggests that *D. tortuosum* and *S. obtusifolia* tolerance of imazethapyr is based on reduced root absorption of the herbicide when applied preplant incorporated or preemergence and a greater capacity to metabolically inactivate the herbicide when applied postemergence (Cole et al. 1989).

The efficacy of imazethapyr for weed control in peanut is influenced by weed size; environmental factors; and method, timing, and rates of application (Dotray and Keeling 1997; Grichar et al. 1992; Richburg et al. 1993b, 1996). As discussed previously, tolerance to imazethapyr is based on differential metabolism among weed species. The amount of imazethapyr metabolized and, subsequently, the efficacy of the herbicide can vary with weed species and the site of uptake, which is influenced by the application method (Wilcut et al. 1991b). Grichar et al. (1992) reported a greater and more consistent *C. esculentus* and *C. rotundus* control with imazethapyr applied preplant incorporated compared with preemergence application. Similarly, York et al. (1995) observed a greater (>90%) and more consistent control of *A. cristata* and *S. spinosa* with imazethapyr applied preplant incorporated or preemergence compared with postemergence application (<60%). Environmental factors may account for the variation in the efficacy of imazethapyr following different application methods. Exposure to sunlight has been reported to degrade or alter the structure of imazethapyr (Basham and Lavy 1987), which may explain the reduced efficacy of the herbicide on *Cyperus* spp. when applied preemergence compared with preplant incorporated application. Furthermore, the efficacy of soil applied imazethapyr depend on the availability of moisture from rainfall or irrigation within a few days of application to activate the herbicide and enhance root absorption (Wilcut et al. 1994a). Also, water stress that enhances the development of thicker cuticles can reduce the uptake of foliar-applied herbicides (Shaner 1989), which may explain the reduced efficacy of imazethapyr applied postemergence compared with preplant-incorporated or preemergence applications. In addition, imazethapyr applied postemergence often does not kill weeds completely but rather causes distorted terminal growth and inhibits further weed development (York et al. 1995). However, postemergence application of imazethapyr has been shown to provide more consistent weed control in highly susceptible species such as *A. hispidum* (Wilcut et al. 1994a) and *Ipomoea* spp. (Grichar et al. 1992) compared with preplant-incorporated or preemergence applications. Postemergence application of imazethapyr provided >80% control of *A. hispidum* and *Ipomoea* spp. even at 0.5X the label rate (Richburg et al. 1995c). Poor weed control following postemergence application of imazethapyr may also be due to larger weed size (Wilcut et al. 1991b). Efficacy of translocated herbicides is influenced by weed size (York et al. 1995). Foliar absorption of imidazolinone herbicides is limited by the amount of herbicide that passes through the cuticle (Shaner 1989). Weed species such as *A. cristata*, *C. album*, *S. spinosa*, and *S. occidentalis* become tolerant of imazethapyr when larger after the 2-leaf growth stage (Wilcut et al. 1991a, 1991b, 1994b).

Peanut has been shown to have excellent tolerance to imazethapyr due to its high capacity for metabolizing the herbicide (Cole et al. 1989; Grichar et al. 1997). Therefore, peanut injury from imazethapyr is usually minor and transient with no impact on yield and grade characteristics (Jordan et al. 2003b; Richburg et al. 1995c; Wilcut et al. 1991a, 1991b; York et al. 1995). Richburg et al. (1995c) observed only 10% peanut injury following postemergence application of imazethapyr at 72 g ha^{-1}. Peanut injury was not >11% in studies conducted with five runner-, three Virginia-, and four Spanish-type peanut cultivars in the southeastern and southwestern United States, although imazethapyr caused a slight reduction in canopy width in the Southeast (Richburg et al. 2006). Similarly, peanut injury from imazethapyr was not >11% even at 2X the label rate (140 g ha^{-1}) (York et al. 1995). However, peanut stunting is associated with cool weather, high humidity, dew, or rainfall occurring during or soon after imazethapyr application due to increased absorption and slowed metabolism, but yield and grade are often not affected (Klingaman et al. 1992; Grichar 1997a, 1997b).

Imazethapyr is often tank mixed with acifluorfen, bentazon, metolachlor, and 2,4-DB to increase the weed spectrum controlled and with paraquat to improve *D. tortuosum* and *S. obtusifolia* control (Grey et al. 1995; Grichar et al. 1992; Wilcut et al. 1991b, 1994a). However, the interaction of imazethapyr and co-applied herbicides may be additive, synergistic, or antagonistic on weed control depending on the targeted weed species and method of application (Grey et al. 1995; Grichar et al. 1992). Imazethapyr plus metolachlor as preemergence application improved control of *Ipomoea* spp. by 14% compared with imazethapyr applied alone (Wilcut et al. 1991b). Control of *S. obtusifolia* with imazethapyr applied early postemergence was not >24%, whereas imazethapyr plus paraquat provided at least 53% control (Wilcut et al. 1994a).

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Similarly, *D. tortuosum* control with early postemergence application of imazethapyr was not >30%, whereas imazethapyr plus paraquat provided 53% to 74% control (Wilcut et al. 1994a). In contrast, early postemergence application of imazethapyr plus paraquat reduced *A. hispidum* control by 15% compared with imazethapyr applied alone, whereas *C. esculentus*, *C. rotundus*, *Ipomoea* spp., *S. halepense*, *S. occidentalis*, *S. spinosa*, and *X. strumarium* were not affected (Wilcut et al. 1994a). Grichar et al. (1992) also reported that the addition of metolachlor to imazethapyr applied preplant incorporated did not result in any improvement in *C. esculentus* and *C. rotundus* control.

Imazapic is probably the preferred postemergence herbicide for most peanut growers in the United States. Since its introduction in 1996, imazapic has been widely utilized, because it provides effective control of the most troublesome weed species in peanut without the need to tank mix it with other herbicides (Grey et al. 2003). Additionally, it has a longer residual effect compared with other ALS-inhibiting herbicides registered for use in peanut (Richburg et al. 1994). Imazapic applied postemergence provides good (80%) to excellent (99%) control of a wide range of weed species, including *A. hispidum*, *A. palmeri*, *A. spinosus*, *C. melo*, *C. esculentus*, *C. rotundus*, *S. obtusifolia*, *Ipomoea* spp., *L. lacunosa*, *S. occidentalis*, *S. spinosa*, *U. texana*, and *V. encelioides* in peanut (Table 10). Imazapic controls *C. esculentus* and *C. rotundus* better than diclosulam and imazethapyr and also provides suppression of *D. tortuosum* and *S. obtusifolia*, which are not adequately controlled by imazethapyr (Grey et al. 2001, 2004). Imazapic generally provides effective weed control and exhibits excellent safety on peanut when applied postemergence (Grichar and Nester 1997). However, Richburg et al. (1994) reported excellent control of *C. esculentus* and *C. rotundus* with imazapic regardless of application method (preemergence, postemergence, or preemergence and postemergence), indicating imazapic is readily absorbed by both roots and foliage of targeted weeds (Richburg et al. 1994). Grichar et al. (2012) also reported at least 92% control of *A. hispidum* from imazapic applied preemergence, similar to the control reported from postemergence application in other studies (Table 10). In addition to effective broadleaf weed control, imazapic can suppress or in some instances control annual and perennial grasses such as *D. ciliaris*, *D. sanguinalis*, and *P. texana* (Wilcut et al. 1995).

Imazapic's recommended use rate is 71 g ai ha^{-1}; however, a rate as low as 40 g ai ha^{-1} provided at least 95% control of *A. palmeri*, similar to a 50 g ai ha^{-1} application rate (Grichar 1997a). Similarly, imazapic at 40 g ai ha^{-1} controlled *C. esculentus* at least 90% (Grichar and Nester 1997). In a similar study, imazapic at 1/2X the recommended rate provided at least 82% control of *A. hispidum*, *C. esculentus*, *C. rotundus*, *S. occidentalis*, *S. spinosa*, *J. tamnifolia*, and *X. strumarium* regardless of application method (preplant incorporated, preemergence, or postemergence) (Richburg et al. 1995c; Webster et al. 1997). Ducar et al. (2009) also observed >87% *I. hederacea* control with imazapic applied early postemergence at 1/2X the recommended rate. Although imazapic is one of the most expensive herbicides for weed control in peanut, it provides the greatest net return due to improved weed control when compared with most other herbicides (Grichar et al. 2005). However, it does not provide adequate control of *A. artemisiifolia*, *C. album*, and *E. prostrata* (Jordan et al. 2009a, 2009b; Wilcut et al. 1995). Jordan et al. (2009b) reported only 25% and 33% control of *C. album* and *E. prostrata*, respectively, from imazapic at 72 g ai ha^{-1}, while Grichar et al. (2012) observed <70% control of *A. artemisiifolia* with imazapic. In addition, control of *D. tortuosum* with imazapic is inconsistent across years and locations (Richburg et al. 1995c, 1996; Webster et al. 1997; Wilcut et al. 1996; Willingham et al. 2008). In some instances, imazapic controlled *D. tortuosum* up to 90% (Brecke et al. 2002; Richburg et al. 1995c, 1996; Wehtje et al. 2000b), but control was sometimes <50% in other studies (Grey and Wehtje 2005; Richburg et al. 1995c, 1996; Wilcut et al. 1996). Moisture variability across years and locations and differential weed size were hypothesized as possible reasons for the inconsistent *D. tortuosum* control with imazapic (Richburg et al. 1995b, 1995c; Wehtje et al. 2000a, 2000b; Wilcut et al. 1996). Wilcut et al. (1996) reported that *D. tortuosum* control with imazapic was reduced when the plants were growing under moisture stress conditions compared with plants growing under adequate soil moisture. Reduction in root absorption and, consequently, efficacy of imazapic under drought stress conditions have also been reported with other weed species such as *C. esculentus* and *C. rotundus* (Richburg et al. 1994). In a greenhouse experiment, imazapic was less effective on *D. tortuosum* when the seedlings produced trifoliate rather than unifoliate leaves (Wehtje et al. 2000b). Although absorption of [^{14}C]imazapic by unifoliate and trifoliate *D. tortuosum* was not different, Wehtje et al. (2000b) observed reduced translocation of [^{14}C]imazapic in trifoliate compared with unifoliate *D. tortuosum*, which possibly contributed to imazapic tolerance in older *D. tortuosum* seedlings (Wehtje et al. 2000a). Similarly, research with other weed species such as *A. palmeri*, *A. hispidum*, and *Ipomoea* spp. showed that control with imazapic is less effective when the weeds are large (Chahal et al. 2011; Lancaster et al. 2005b, 2007). Imazapic applied to *A. hispidum* taller than 4 cm killed only the terminal stem, resulting in rapid plant recovery (Richburg et al. 1995c).

Imazapic has been evaluated in tank mixtures with other herbicides such as acifluorfen, bentazon, diclosulam, and paraquat for weed control in peanut with variable results. Imazapic applied in tank mixture with acifluorfen, diclosulam, and 2,4-DB did not affect *D. sanguinalis*, *C. esculentus*, *C. rotundus*, *I. hederacea*, and *I. lacunosa* control with imazapic (Jordan et al. 2009b). Similarly, imazapic applied in combination with bentazon or paraquat did not improve *C. esculentus* control compared with imazapic alone (Grichar et al. 2012; Wilcut et al. 1996). However, imazapic in combination with paraquat increased *T. portulacastrum* control to at least 96% compared with 37% to 45% control from imazapic alone (Grichar et al. 2012). Co-application of imazapic and 2,4-DB also increased annual grass control in peanut compared with imazapic alone (Clewis et al. 2007). Imazapic in combination with bentazon resulted in reduced *D. tortuosum* control compared with imazapic applied alone (Wilcut et al. 1996).

Peanut exhibits excellent tolerance to imazapic, with no reports of significant long-term injury or yield reduction in popular Spanish-, Virginia-, and runner-type cultivars (Brecke et al. 2002; Ducar et al. 2009; Grichar et al. 2004; Wehtje et al. 2000b) even at 2X the label rate (Brecke et al. 2002). Yield, grade, or incidence of TSWV were not affected by imazapic applied at 71 g ha^{-1} in research conducted with Georgia Green, Georgia 01K, and C99R peanut cultivars (Faircloth and Prostko 2010). However, early-season injury from imazapic ranging from 3% to 23% (Dotray et al. 2001; Grey and Wehtje 2005; Teuton et al. 2004; Wilcut et al. 1996) and reduction in canopy width and percentage of jumbo and extra-large kernels in Florunner and 'Sunrunner' peanut cultivars has been reported (Richburg et al. 1995a).

Herbicide-Resistance Issues

The spread of ALS herbicide– resistant and PPO herbicide-resistant *Amaranthus* species has been prevalent since the 1990s (Heap 2023). The increased incidence of herbicide-resistant weeds is due mainly to the repeated use of herbicides from the same mechanisms of action not only within peanut fields but also in rotational crops and inadequate integration with other forms of weed control (e.g., cultural and mechanical). Most of the postemergence herbicides used in peanut, especially those with both residual and systemic activity, are ALS inhibitors, without which there are only a few alternatives. These herbicides are more susceptible to resistance selection due to their extended residual activity and active-site mutation (Saari et al. 2018). Repeated exposure of weeds to these herbicides led to increased selection pressure and the selection of resistant individuals. There are currently 159 weed species resistant to ALS-inhibiting herbicides, some of which seriously threaten peanut production (Berger et al. 2015; Heap 2023). *Amaranthus palmeri* resistance to ALS-inhibiting herbicides was reported in 21 peanut-growing counties in Georgia (Wise et al. 2009) and 97% of the agronomic counties in Florida and North Carolina (Poirier et al. 2014; Sperry et al. 2017). Resistance to ALS-inhibiting herbicides in *A. artemisiifolia* has also been confirmed in peanut fields across the southeastern United States (Berger et al. 2015; Chandi et al. 2012). While there are more options for alternative weed control with herbicides from other mechanisms of action in corn, cotton, and soybean, only a few alternatives, particularly the PPO-inhibiting herbicides, are available in peanut. Although the PPO inhibitors such as acifluorfen, flumioxazin, and lactofen have improved the control of ALS herbicide– resistant weeds in peanut fields, there is a possibility of overusing this group of herbicides, which could result in resistance evolution and, consequently, limited options for weed control in peanut. Resistance to PPO-inhibiting herbicides has been reported in soybean (Heap 2023), suggesting that the use of PPO-inhibiting herbicides to manage ALS herbicide– resistant weeds in peanut might not be sustainable. The weed resistance situation is one of the reasons residual herbicides will continue to play a critical role in peanut weed management programs. Although paraquat remains an important option for weed control in peanut, as discussed previously, it is limited to use only within the first 28 d after peanut emergence. It is apparent, therefore, that growers cannot continue to rely only on chemical weed control, which will necessitate the integration of nonchemical weed control methods and a diverse and properly designed integrated weed management program in peanut production systems.

Synthesis, Conclusion, and Future Outlook

Although there is increased advocacy for integrated weed management, herbicides remain the dominant tool for weed management in peanut in the United States, as in most other field crops. Hence, the need to synthesize research results to understand the strengths, weaknesses, and effects of different herbicides to develop optimal, field-specific weed management programs. Several herbicides are available for weed control in peanut. However, our systematic review of the literature showed that no single herbicide application can provide sufficient weed control in all situations due to a narrow window of application, low residual activity, variability in weed control, and rotational restrictions. The chloroacetamide herbicides acetochlor, dimethenamid-*P*, and *S*-metolachlor and dinitroanilines such as ethalfluralin and pendimethalin provide residual control of many annual grasses and small-seeded broadleaf weeds in peanut but have limited activity on *U. texana*, especially in conservation-tillage peanut, which can be problematic. Flumioxazin, a PPO inhibitor, is particularly effective against troublesome broadleaf weeds such as *D. tortuosum* but is not effective on other important species, including *C. esculentus* and *S. obtusifolia*. The photosynthetic inhibitors bentazon and paraquat applied alone or in combination provide postemergence control of a wide range of annual grasses and broadleaf weeds, including dominant and troublesome species such as *A. palmeri*, *D. tortuosum*, *S. obtusifolia*, and *Ipomoea* spp., but lack residual activity and can only be applied within 28 d after peanut cracking. Similarly, the PPO inhibitors acifluorfen and lactofen provide excellent control of numerous annual broadleaf weeds and have improved control of ALS herbicide– resistant weeds in peanut fields. However, they do not provide residual effects at the rate used postemergence in peanut. The synthetic auxin 2,4-DB provides broadleaf weed control but also lacks residual activity and cannot be applied within 60 d before peanut harvest. Chlorimuron, an ALS inhibitor, provides late postemergence control of several broadleaf weeds, including *D. tortuosum* and *S. obtusifolia*, but cannot be applied until 60 d after crop emergence due to phytotoxicity to peanut. Other ALS inhibitors such as diclosulam, imazapic, and imazethapyr also provide effective control of many broadleaf, grassy, and sedge weed species. They have both residual and foliar activity and exhibit considerable safety to peanut. However, crop rotational restrictions must be considered before the application of these herbicides. Graminicides such as clethodim, fluazifop-*P*, and sethoxydim control annual and perennial grasses but do not control dicot weeds and lack residual activity. Due to these limitations, effective weed control in peanut often requires herbicide mixtures and/or sequential applications of preplant incorporated, preemergence, early postemergence, and/or late postemergence herbicides. Mixture of two or more herbicides in peanut often increases weed control and reduces the number of application trips over the field, saving time and fuel. However, this practice can affect weed control when the tank mix contains herbicides that are not compatible. Depending on the targeted weed species, weed size, application rates, and environmental factors, efficacy of graminicides on grass weed species can be reduced when applied in tank mixture with broadleaf herbicides such as acifluorfen, bentazon, acifluorfen plus bentazon, 2,4-DB, imazapic, and imazethapyr due to reduced absorption and translocation of graminicides. Adjuvants can alleviate the antagonistic effect of broadleaf herbicides on efficacy of graminicides, but the response can be inconsistent with the herbicide chemistry and weed species. Although there are numerous publications on weed control with herbicides in peanut in the United States, there is a substantive range in efficacy and weed spectrum controlled due to variations in environmental conditions and flushes of weed germination across years and locations. Most studies provided soil characteristics of the research location; however, in some cases, background information on weed pressure and detailed weather conditions before, at, and after herbicide application were not provided. This information is important to understand the differences in efficacy or peanut injury among the studies.

Despite the relatively high efficacy of herbicides, the evolution of herbicide-resistant weeds is another area of increasing concern. There are currently 159 weed species resistant to ALS-inhibiting herbicides, some of which seriously threaten peanut production (Berger et al. 2015; Heap 2023). The weed resistance situation highlights the need for greater stewardship of the active ingredients

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available as well as the need for investing in further research of nonchemical alternatives and new effective active ingredients. The available options for nonchemical weed control and their potential limitations in peanut are covered in the first part of this publication series (Daramola et al. 2023a). Although integrating herbicides with nonchemical weed management strategies and applying tank mixes of herbicides from various mode of actions is important to reduce the incidence of herbicide-resistant weeds, future research should focus on developing new strategies for preventing or delaying the development of resistance. For long-term effect, these strategies should be addressed within the context of climate change and emerging constraints such as water shortages, drought, and flooding and the effects of rising temperatures and increased CO_2 concentration on peanut–weed interactions and herbicide efficacy.

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References

Altom JV, Westerman RB, Murray DS (1995) Eclipta (*Eclipta prostrata*) control in peanuts (*Arachis hypogaea*). Peanut Sci 22:114–120

Anonymous (2000a) PoastPlus® product label. BASF Publication No. 7969-88. Research Triangle Park, NC: BASF Corporation. 12 p

Anonymous (2000b) Select® product label. Valent Publication No. 59639-3. Walnut Creek, CA: Valent U.S.A. Corporation. 7 p

Anonymous (2000c) Strongarm® product label. Dow Publication No. 62719-288. Indianapolis, IN: Dow Agrosciences. 6 p

Anonymous (2004) Dual Magnum® product label. Publication No. SCP 816A-L1N 0403. Greensboro, NC: Syngenta Crop Protection. 8 p

Anonymous (2008) Aim® product label. FMC Publication No. 279-3242. Philadelphia, PA: FMC Corporation, 19103. 9 p

Anonymous (2009) Classic® product label. Dow Publication No. 352-436. Indianapolis, IN: Dow AgroSciences. 14 p

Anonymous (2010) Warrant® product label. Monsanto Publication No 524-591. St. Louis, MO: Monsanto Corp. 12 p

Anonymous (2017) Supplemental label-for use in peanut Zidua® herbicide. BASF Publication No. 7969-338. Research Triangle Park, NC: BASF Corporation. 7 p

Anonymous (2020) Anthem Flex® product label. FMC Publication No. 279-3464. Philadelphia, PA: FMC Corporation. 7 p

Anonymous (2023) Brake® product label. SePro Publication No. 67690-78. Carmel, IN: SePro Corporation. 6 p

Askew SD, Wilcut JW, Cranmer JR (1999) Weed management in peanut (*Arachis hypogaea*) with flumioxazin preemergence. Weed Technol 13:594–598

Bailey WA, Wilcut JW (2002) Diclosulam systems for weed management in peanut (*Arachis hypogaea*). Weed Technol 16:807–814

Bailey WA, Wilcut JW, Jordan DL, Swann CW, Langston VB (1999a) Response of peanut (*Arachis hypogaea*) and selected weeds to diclosulam. Weed Technol 13:771–776

Bailey WA, Wilcut JW, Jordan DL, Swann CW, Langston VB (1999b) Weed management in peanut (*Arachis hypogaea*) with diclosulam preemergence. Weed Technol 13:450–456

Bailey WA, Wilcut JW, Spears JF, Isleib TG, Langston VB (2000) Diclosulam does not influence yields in eight Virginia market-type peanut (*Arachis hypogaea*) cultivars. Weed Technol 14:402–405

Basham GW, Lavy TL (1987) Microbial and photolytic dissipation of imazaquin in soil. Weed Sci 35:865–870

Basinger NT, Randell TM, Prostko EP (2021) Peanut response to flumioxazin and *S*-metolachlor under high moisture conditions. Peanut Sci 48:113–117

Baughman T, Grichar W, Dotray P (2018) Weed control and peanut tolerance using pyroxasulfone in Oklahoma. J Exp Agric Int 21:1–11

Baughman TA, Grichar WJ, Jordan DL (2002) Tolerance of Virginia-type peanut to different application timings of 2,4-DB. Peanut Sci 29:126–128

Berger ST, Ferrell JA, Dittmar PJ, Leon R (2015) Survey of glyphosate- and imazapic-resistant Palmer amaranth (*Amaranthus palmeri*) in Florida. Crop Forage Turfgrass Manag 1:1–5

Besler BA, Grichar WJ, Senseman SA, Lemon RG, Baughman TA (2008) Effects of row pattern configurations and reduced (1/2×) and full rates (1×) of imazapic and diclosulam for control of yellow nutsedge (*Cyperus esculentus*) in peanut. Weed Technol 22:558–562

Boyer JA, Ferrell J, MacDonald G, Tillman B, Rowland D (2011) Effect of acifluorfen and lactofen application timing on peanut injury and yield. Crop Manag 10:1–6

Brecke B, Wehtje G, Paudel K (2002) Comparison between diclosulam-and imazapic-based weed control systems in peanut. Peanut Sci 29:52–57

Brecke BJ, Currey WL (1980) Weed control in peanuts with ethalfluralin. Peanut Sci 7:124–127

Brecke BJ, Funderburk JE, Teare ID, Gorbet DW (1996) Interaction of early-season herbicide injury, tobacco thrips injury, and cultivar on peanut. Agron J 88:14–18

Buchanan GA, Murray DS, Hauser EW (1982) Weeds and their control in peanuts. Pages 209–249 *in* Pattee HE, Stalker HT, eds. Peanut Science and Technology. Yoakum, TX: American Peanut Research and Education Society

Burke IC, Askew SD, Wilcut JW (2002) Flumioxazin systems for weed management in North Carolina peanut (*Arachis hypogaea*). Weed Technol 16:743–748

Burke IC, Price AJ, Wilcut JW, Jordan DL, Culpepper AS, Tredaway-Ducar J (2004) Annual grass control in peanut (*Arachis hypogaea*) with clethodim and imazapic. Weed Technol 18:88–92

Burke IC, Wilcut JW (2003) Physiological basis for antagonism of clethodim by imazapic on goosegrass (*Eleusine indica*). Pestic Biochem Physiol 76:37–45

Cardina J, Brecke BJ (1991) Florida beggarweed (*Desmodium tortuosum*) growth and development in peanuts (*Arachis hypogaea*). Weed Technol 3:147–153

Cardina J, Swann CW (1988) Metolachlor effects on peanut growth and development. Peanut Sci 15:57–60

Carley DS, Jordan DL, Brandenburg RL, Dharmasri LC (2009) Factors influencing response of Virginia market type peanut (*Arachis hypogaea*) to paraquat under weed-free conditions. Peanut Sci 36:180–189

Carter OW, Prostko EP (2019) Time of day effects on peanut herbicide efficacy. Peanut Sci 46:174–181

Chahal GS, Jordan DL, Shew BB, Brandenburg RL, Burton JD, Danehower D, Eure PM (2012a) Influence of selected fungicides on efficacy of clethodim and 2,4-DB. Peanut Sci 39:121–126

Chahal GS, Jordan DL, Shew BB, Brandenburg RL, York AC, Burton JD, Danehower D (2012b) Interactions of agrochemicals applied to peanut; part 1: Effects on herbicides. Crop Prot 41:134–142

Chahal GS, Jordan DL, York AC, Brandenburg RL, Shew BB, Burton JD, Danehower D (2013) Interactions of clethodim and sethoxydim with other pesticides. Peanut Sci 40:127–134

Chahal GS, Jordan DL, York AC, Prostko EP (2011) Palmer amaranth control with combinations of 2,4-DB and diphenylether herbicides. Crop Manag 10:1–7

Chandi A, Jordan DL, York AC, Lassiter BR (2012) Confirmation and management of common ragweed (*Ambrosia artemisiifolia*) resistant to diclosulam. Weed Technol 26:29–36

Chaudhari S, Jordan D, Jennings K (2017) Peanut (*Arachis hypogaea*) response to carfentrazone-ethyl and pyraflufen-ethyl applied close to harvest. Peanut Sci 44:47–52

Chaudhari S, Jordan DL, Grey TL, Prostko EP, Jennings KM (2018) Weed control and peanut (*Arachis hypogaea*) response to acetochlor alone and in combination with various herbicides. Peanut Sci 45:45–55

Clewis SB, Askew SD, Wilcut JW (2002) Economic assessment of diclosulam and flumioxazin in strip- and conventional-tillage peanut. Weed Sci 50:378–385

Clewis SB, Everman WJ, Jordan DL, Wilcut JW (2007) Weed management in North Carolina peanuts (*Arachis hypogaea*) with *S*-metolachlor, diclosulam, flumioxazin, and sulfentrazone systems. Weed Technol 21:629–635

Cole TA, Wehtje GR, Wilcut JW, Hicks TV (1989) Behavior of imazethapyr in soybeans (*Glycine max*), peanuts (*Arachis hypogaea*), and selected weeds. Weed Sci 37:639–644

Culpepper AS, Grey TL, Vencill WK, Kichler JM, Webster TM, Brown SM, York AC, Davis JW, Hanna WW (2006) Glyphosate-resistant Palmer amaranth (*Amaranthus palmeri*) confirmed in Georgia. Weed Sci 54:620–626

Daramola OS, Iboyi JE, MacDonald GE, Kanissery RG, Singh H, Tillman BL, Devkota P (2023a) Competing with the competitors in an endless competition: a systematic review of non-chemical weed management research in peanut (*Arachis hypogea*) in the United States. Weed Sci 71: 284–300

Daramola OS, Kharel P, Iboyi JE, Devkota P (2023b) Peanut response to 2,4-D plus glyphosate. Weed Technol 37(1):46–52

Daramola OS, Kharel P, Iboyi JE, Devkota P (2023c) Response of peanut (*Arachis hypogaea* L.) to sublethal rates of dicamba plus glyphosate at different growth stages. Agron J 115:1694–1704

Dotray P, Baughman T, Grichar W, Woodward J (2018) Performance of pyroxasulfone to control *Amaranthus palmeri* and *Salsola kali* in peanut. J Exp Agric Int 23:1–10

Dotray PA, Baughman TA, Grichar WJ (2010) Peanut response to carfentrazone-ethyl and pyraflufen-ethyl applied postemergence. Peanut Sci 37:52–57

Dotray PA, Baughman TA, Keeling JW, Grichar WJ, Lemon RG (2001) Effect of imazapic application timing on Texas peanut (*Arachis hypogaea*). Weed Technol 15:26–29

Dotray PA, Grichar WJ, Baughman TA, Prostko EP, Grey TL, Gilbert LV (2012) Peanut (*Arachis hypogaea*) response to lactofen at various postemergence timings. Peanut Sci 39:9–14

Dotray PA, Keeling JW (1997) Purple nutsedge control in peanut as affected by imazameth and imazethapyr application timing. Peanut Sci 24:113–116

Dotray PA, Keeling JW, Grichar WJ, Prostko EP, Lemon RG, Everrit JD (2003) Peanut response to ethalfluralin, pendimethalin, and trifluralin preplant incorporated. Peanut Sci 30:34–37

Dotray PA, Porter BL, Keeling JW (2004) Peanut response to 2,4-DB plus crop oil at various application timings. Texas J Agric Natural Res 17:40–45

Ducar JT, Clewis SB, Wilcut JW, Jordan DL, Brecke BJ, Grichar WJ, Johnson WC, Wehtje GR (2009) Weed management using reduced rate combinations of diclosulam, flumioxazin, and imazapic in peanut. Weed Technol 23:236–242

Ducar-Tredaway JA, Wilcut JW, Jordan DL, Faircloth J, Swann CW (2006) Evaluation of diclosulam and *S*-metolachlor applied preplant incorporated in peanut (*Arachis hypogaea*). Peanut Sci 33:137–141

Eason KM, Grey TL, Tubbs RS, Prostko EP, Li X (2020) Peanut and weed response to postemergence herbicide tank-mixtures including paraquat and inorganic liquid nutrients. Peanut Sci 47:94–102

Eason KM, Tubbs RS, Grey TL, Li XS (2019) Irrigated and non-irrigated peanut (*Arachis hypogaea*) cultivar response to postemergence paraquat tank-mixtures. Peanut Sci 46:50–55

Eure P, Prostko EP, Merchant RM (2015) Peanut cultivar response to preemergence applications of pyroxasulfone. Peanut Sci 42:39–43

Eure PM, Jordan DL, Fisher LR, York AC (2013) Efficacy of herbicides when spray solution application is delayed. Int J Agron 2013:1–7

Everman WJ, Burke IC, Clewis SB, Thomas WE, Wilcut JW (2008a) Critical period of grass vs. broadleaf weed interference in peanut. Weed Technol 22:68–73

Everman WJ, Clewis SB, Taylor ZG, Wilcut JW (2006) Influence of diclosulam postemergence application timing on weed control and peanut tolerance. Weed Technol 20:651–657

Everman WJ, Clewis SB, Thomas WE, Burke IC, Wilcut JW (2008b) Critical period of weed interference in peanut. Weed Technol 22:63–67

Faircloth WH, Prostko EP (2010) Effect of imazapic and 2,4-DB on peanut yield, grade, and seed germination. Peanut Sci 37:78–82

Ferreira KL, Burton JD, Coble HD (1995) Physiological basis for antagonism of fluazifop-P by DPX-PE350. Weed Sci 43:184–191

Ferrell JA, Leon RG, Sellers B, Rowland D, Brecke B (2013) Influence of lactofen and 2,4-DB combinations on peanut injury and yield. Peanut Sci 40:62–65

Ferrell JA, Vencill WK, Xia K, Grey TL (2005) Sorption and desorption of flumioxazin to soil, clay minerals, and ion-exchange resin. Pest Manag Sci 61:40–46

Gianessi LP, Reigner NP (2007) The value of herbicides in US crop production. Weed Technol 21:559–566

Grey TL, Bridges DC, Eastin EF (2001) Influence of application rate and timing of diclosulam on weed control in peanut (*Arachis hypogaea*). Peanut Sci 28:13–19

Grey TL, Bridges DC, Eastin EF, MacDonald GE (2002) Influence of flumioxazin rate and herbicide combinations on weed control in peanut (*Arachis hypogaea*). Peanut Sci 29:24–29

Grey TL, Bridges DC, Hancock HG, Davis JW (2004) Influence of sulfentrazone rate and application method on peanut weed control. Weed Technol 18: 619–625

Grey TL, Bridges DC, Prostko EP, Eastin EF, Johnson WC III, Vencill WK, Brecke BJ, MacDonald GE, Ducar JT, Everest JW, Wehtje GR (2003) Residual weed control with imazapic, diclosulam, and flumioxazin in southeastern peanut (*Arachis hypogaea*). Peanut Sci 30:22–27

Grey TL, Dotray PA, Grichar WJ (2007) Soil and residual herbicide affect peanut seedling development. Peanut Sci 34:65–70

Grey TL, Wehtje GR (2005) Residual herbicide weed control systems in peanut. Weed Technol 19:560–567

Grey TL, Wehtje GR, Walker RH, Paudel KP (1995) Comparison of imazethapyr and paraquat-based weed control systems in peanut (*Arachis hypogaea*). Weed Technol 9:813–818

Grichar WJ (1991a) Control of Texas panicum (*Panicum texanum*) and southern crabgrass (*Digitaria ciliaris*) in peanuts (*Arachis hypogaea*) with postemergence herbicides. Peanut Sci 18:6–9

Grichar WJ (1991b) Sethoxydim and broadleaf herbicide interaction effects on annual grass control in peanuts (*Arachis hypogaea*). Weed Technol 5: 321–324

Grichar WJ (1992) Yellow nutsedge (*Cyperus esculentus*) control in peanuts (*Arachis hypogaea*). Weed Technol 6:108–112

Grichar WJ (1993) Horse purslane (*Trianthema portulacastrum*) control in peanut (*Arachis hypogaea*). Weed Technol 7:570–572

Grichar WJ (1994) Spiny amaranth (*Amaranthus spinosus* L.) control in peanut (*Arachis hypogaea* L.). Weed Technol 8:199–202

Grichar WJ (1995) Comparison of postemergence herbicides for common bermudagrass (*Cynodon dactylon*) control in peanut (*Arachis hypogaea*). Weed Technol 9:825–828

Grichar WJ (1997a) Control of Palmer amaranth (*Amaranthus palmeri*) in peanut (*Arachis hypogaea*) with postemergence herbicides. Weed Technol 11:739–743

Grichar WJ (1997b) Influence of herbicides and timing of application on broadleaf weed control in peanut (*Arachis hypogaea*). Weed Technol 11:708–713

Grichar WJ (2005) Using herbicides in a peanut strip-tillage production system. Crop Manag 4:1–6

Grichar WJ (2007) Horse purslane (*Trianthema portulacastrum*), smellmelon (*Cucumis melo*), and Palmer amaranth (*Amaranthus palmeri*) control in peanut with postemergence herbicides. Weed Technol 21:688–691

Grichar WJ (2008) Herbicide systems for control of horse purslane (*Trianthema portulacastrum* L.), smellmelon (*Cucumis melo* L.), and Palmer amaranth (*Amaranthus palmeri* S. Wats) in peanut. Peanut Sci 35:38–42

Grichar WJ, Besler BA, Brewer KD, Baughman TA (2002) Grass control in peanut (*Arachis hypogaea*) with clethodim and selected broadleaf herbicide combinations. Peanut Sci 29:85–88

Grichar WJ, Besler BA, Brewer KD, Langston VB (2004) Using diclosulam in a weed control program for peanut in south Texas. Crop Prot 23: 1145–1149

Grichar WJ, Besler BA, Dotray PA (2006) Weed control and peanut (*Arachis hypogaea*) response to sulfentrazone. Crop Prot 25:753–757

Grichar WJ, Besler BA, Lemon RG, Brewer KD (2005) Weed management and net returns using soil-applied and postemergence herbicide programs in peanut (*Arachis hypogaea* L.). Peanut Sci: 32:25–31

Grichar WJ, Boswell TE (1986) Postemergence grass control in peanut (*Arachis hypogaea*). Weed Sci 34:587–590

Grichar WJ, Boswell TE (1987) Herbicide combinations in peanut (*Arachis hypogaea*). Weed Technol 1:290–293

Grichar WJ, Colburn AE (1993) Effect of dinitroaniline herbicides upon yield and grade of five runner cultivars. Peanut Sci. 20:126–128

https://doi.org/10.1017/wsc.2023.71 Published online by Cambridge University Press

Grichar WJ, Colburn AE (1996) Flumioxazin for weed control in Texas peanuts (*Arachis hypogaea*). Peanut Sci 23:30–36

Grichar WJ, Colburn AE, Kearney NS (1994) Herbicides for reduced tillage production in peanut (*Arachis hypogaea*) in the Southwest. Weed Technol 8:212–216

Grichar WJ, Dotray PA, Baughman T (2021) Carfentrazone plus pyroxasulfone combinations for weed control in peanut (*Arachis hypogaea*). J Exp Agric Int 43:52–63

Grichar WJ, Dotray PA (2010) Response of Texas peanut to chlorimuron alone and in various combinations. Peanut Sci 37:26–31

Grichar WJ, Dotray PA (2011) Controlling weeds found in peanut with lactofen. Crop Manag 10:1–8

Grichar WJ, Dotray PA (2012) Peanut cultivar response to *S*-metolachlor and paraquat alone and in combination. Peanut Sci 39:15–21

Grichar WJ, Dotray PA (2013) Smellmelon control and peanut response to flumioxazin and paraquat alone and in combination. Peanut Sci 40:135–141

Grichar WJ, Dotray PA, Baughman TA (2008) Yellow nutsedge (*Cyperus esculentus*) control and peanut tolerance to *S*-metolachlor and diclosulam combinations. Weed Technol 22:442–447

Grichar WJ, Dotray PA, Baughman TA (2010) Peanut variety response to postemergence applications of carfentrazone-ethyl and pyraflufen-ethyl. Crop Prot 29:1034–1038

Grichar WJ, Dotray PA, Baughman TA (2018) Evaluation of weed control efficacy and peanut tolerance to pyroxasulfone herbicide in the south Texas peanut production area. J Exp Agric Int 9:1–10

Grichar WJ, Dotray PA, Baughman TA (2019) Evaluation of weed control efficacy and peanut tolerance to pyroxasulfone herbicide in the south Texas peanut production area. J Exp Agric Int 29:1–10

Grichar WJ, Dotray PA, Etheredge LM (2015) Weed control and peanut (*Arachis hypogaea*) cultivar response to encapsulated acetochlor. Peanut Sci 42:100–108

Grichar WJ, Dotray PA, Sestak DC (1999) Diclosulam for weed control in Texas peanut. Peanut Sci 26:23–28

Grichar WJ, Jordan DL, Prostko EP (2012) Weed control and peanut (*Arachis hypogaea*) response to formulations of imazapic. Crop Prot 36:31–36

Grichar WJ, Lemon RG, Brewer KD, Minton BW (2001) *S*-metolachlor compared with metolachlor on yellow nutsedge (*Cyperus esculentus*) and peanut (*Arachis hypogaea*). Weed Technol 15:107–111

Grichar WJ, Lemon RG, Sestak DC, Brewer KD (2000) Comparison of metolachlor and dimethenamid for yellow nutsedge (*Cyperus esculentus* L.) control and peanut (*Arachis hypogaea*) injury. Peanut Sci 27:26–29

Grichar WJ, Nester PR (1997) Nutsedge (*Cyperus* spp.) control in peanut (*Arachis hypogaea*) with AC 263,222 and imazethapyr. Weed Technol 11:714–719

Grichar WJ, Nester PR, Colburn AE (1992) Nutsedge (*Cyperus* spp.) control in peanuts (*Arachis hypogaea*) with imazethapyr. Weed Technol 6:396–400

Grichar WJ, Sestak DC (1998) Control of golden crownbeard (*Verbesina encelioides*) in peanut (*Arachis hypogaea*) with postemergence herbicides. Peanut Sci 25:39–43

Grichar WJ, Sestak DC (2000) Herbicide systems for golden crownbeard (*Verbesina encelioides*) control in peanut. Peanut Sci 27:23–26

Grichar WJ, Sestak DC, Besler BA (1997) Effects of various timings of 2,4-DB on runner-type peanut development and yield. Peanut Sci 24:105–106

Hauser EW, Buchanan GA, Ethredge WJ (1975) Competition of Florida beggarweed and sicklepod with peanuts I. Effects of periods of weed-free maintenance or weed competition. Weed Sci 23:368–372

Hawf LR, Behrens R (1974) Selectivity factors in the response of plants to 2,4-DB. Weed Sci 22:245–249

Heap I (2023) The International Herbicide-Resistant Weed Database. www.weedscience.org. Accessed: January 7, 2023

Hicks TV, Wehtje GR, Grey TL (1998) The interaction of pyridate and 2,4-DB in peanut (*Arachis hypogaea*), Florida beggarweed (*Desmodium tortuosum*), and sicklepod (*Senna obtusifolia*). Weed Sci 19:284–288

Holbrook CC (2019) Peanut yield gains over the past fifty years. Peanut Sci 46(1A):73–77

Holshouser DL, Coble HD (1990) Compatibility of sethoxydim with five postemergence broadleaf herbicides. Weed Technol 4:128–133

Hurdle NL, Grey TL, Pilon C, Monfort WS, Prostko EP (2020) Peanut seed germination and radicle development response to direct exposure of flumioxazin across multiple temperatures. Peanut Sci 47:89–93

Johnson WC, Luo X (2019) Integrating cultivation using a tine weeder with herbicides in conventional peanut production. Weed Technol 33:374–379

Johnson WC, Mullinix BG, Brown SM (1992a) Phytotoxicity of chlorimuron and tank mixtures on peanut (*Arachis hypogaea*). Weed Technol 6:404–408

Johnson WC, Prostko EP, Mullinix BG (2006) Phytotoxicity of delayed applications of flumioxazin on peanut (*Arachis hypogaea*). Weed Technol 20:157–163

Johnson WC III, Colvin DL, Wehtje GR, Littlefield TA, Mullinix BG Jr (1997) Peanut response to ethalfluralin: rates and methods of application. Peanut Sci 24:101–104

Johnson WC III, Boudreau MA, Davis JW (2012a) Cultural practices to improve in-row weed control with cultivation in organic peanut production. Weed Technol 26:718–723

Johnson WC III, Boudreau MA, Davis JW (2012b) Implements and cultivation frequency to improve in-row weed control in organic peanut production. Weed Technol 26:334–340

Johnson WC III, Colvin DL, Mullinix BG Jr (1993) Comparative response of three peanut cultivars to multiple herbicide applications. Peanut Sci 20:17–20

Johnson WC III, Holbrook CC, Mullinix BG Jr, Cardina J (1992b) Response of eight genetically diverse peanut genotypes to chlorimuron. Peanut Sci 19:111–115

Johnson WC III, Mullinix B (1994) Sulfentrazone for peanut weed control. Peanut Sci 21:31–35

Johnson WC III, Mullinix BG Jr (1999) Peanut seedling response to dinitroaniline herbicides applied preplant incorporated and preemergence. Peanut Sci 26:28–32

Johnson WC III, Prostko EP, Davis J (2011) Phytotoxicity of delayed applications of dinitroaniline herbicides in strip-tillage peanut production. Peanut Sci 38:57–60

Johnson WC III, Prostko EP, Davis JW (2010) Comparing the risks and benefits of early applications of chlorimuron for weed control in peanut. Peanut Sci 37:58–62

Johnson WC III, Prostko EP, Mullinix BG Jr (2002) Texas panicum (*Panicum texanum*) control in strip-tillage peanut (*Arachis hypogaea*) production. Peanut Sci 29:141–145

Jordan DL (1995) Influence of adjuvants on the antagonism of graminicides by broadleaf herbicides. Weed Technol 9:741–747

Jordan DL (1996) Adjuvants and growth stage affect purple nutsedge (*Cyperus rotundus*) control with chlorimuron and imazethapyr. Weed Technol 10:359–362

Jordan DL (1999) Influence of adjuvants on efficacy of imazapic and 2,4-DB. Peanut Sci 26:1–4

Jordan DL (2004) Weed Management in Peanuts, Peanut Information. Raleigh, NC: North Carolina State University Coop. Ext. Ser. Series AG-331. https://content.ces.ncsu.edu/peanut-information/peanut-weed-management. Accessed: August 24, 2023

Jordan DL, Culpepper AS, Grichar WJ, Ducar JT, Brecke BJ, York AC (2003a) Weed control with combinations of selected fungicides and herbicides applied postemergence to peanut (*Arachis hypogaea*). Peanut Sci 30:1–7

Jordan DL, Lancaster SH, Lanier JE, Johnson PD, Beam JB, York AC, Brandenburg RL (2012) Influence of application variables on efficacy of manganese-containing fertilizers applied to peanut (*Arachis hypogaea* L.). Peanut Sci 39:1–8

Jordan DL, Lancaster SH, Lanier JE, Lassiter BR, Johnson PD (2009a) Peanut and eclipta (*Eclipta prostrata*) response to flumioxazin. Weed Technol 23:231–235

Jordan DL, Lancaster SH, Lanier JE, Lassiter BR, Johnson PD (2009b) Weed management in peanut with herbicide combinations containing imazapic and other pesticides. Weed Technol 23:6–10

Jordan DL, Spears JF, Wilcut JW (2003b) Tolerance of peanut (*Arachis hypogaea*) to herbicides applied postemergence. Peanut Sci 30:8–13

Jordan DL, Wilcut JW, Fortner LD (1994) Utility of clomazone for annual grass and broadleaf weed control in peanut (*Arachis hypogaea*). Weed Technol 8:23–27

Jordan DL, Wilcut JW, Swann CW (1993) Application timing of lactofen for broadleaf weed control in peanut (*Arachis hypogaea*). Peanut Sci 20:129–131

Ketchersid ML, Boswell TE, Merkle MG (1978) Effects of 2,4-DB on yield and pod development in peanuts. Peanut Sci 5:35–39

Kharel P, Devkota P, Macdonald GE, Tillman BL, Mulvaney MJ (2022) Influence of planting date, row spacing, and reduced herbicide inputs on peanut canopy and sicklepod growth. Agron J 114:717–726

Klingaman TE, King CA, Oliver LR (1992) Effect of application rate, weed species, and weed stage of growth on imazethapyr activity. Weed Sci 40: 227–232

Knauft DA, Colvin DL, Gorbet DW (1990) Effect of paraquat on yield and market grade of peanut (*Arachis hypogaea*) genotypes. Weed Technol 4: 866–870

Lancaster SH, Beam JB, Lanier JE, Jordan DL, Johnson PD (2007) Weed and peanut (*Arachis hypogaea*) response to diclosulam applied POST. Weed Technol 21:618–622

Lancaster SH, Jordan DL, Johnson PD (2008) Influence of graminicide formulation on compatibility with other pesticides. Weed Technol 22: 580–583

Lancaster SH, Jordan DL, Spears JF, York AC, Wilcut JW, Monks DW, Batts RB, Brandenburg RL (2005a) Sicklepod (*Senna obtusifolia*) control and seed production after 2,4-DB applied alone and with fungicides or insecticides. Weed Technol 19:451–455

Lancaster SH, Jordan DL, York AC, Burke IC, Corbin FT, Sheldon YS, Wilcut JW, Monks DW (2005b) Influence of selected fungicides on efficacy of clethodim and sethoxydim. Weed Technol 19:397–403

Lancaster SH, Jordan DL, York AC, Wilcut JW, Brandenburg RL, Monks DW (2005c) Interactions of late-season morningglory (*Ipomoea* spp.) management practices in peanut (*Arachis hypogaea*). Weed Technol 19:803–808

Lancaster SH, Jordan DL, York AC, Wilcut JW, Monks DW, Brandenburg RL (2005d) Interactions of clethodim and sethoxydim with selected agrichemicals applied to peanut. Weed Technol 19:456–461

Lanier JE, Jordan DL, Spears JF, Wells R, Johnson PD, Barnes JS, Hurt CA, Brandenburg RL, Bailey JE (2004) Peanut response to planting pattern, row spacing, and irrigation. Agron J 96:1066–1072

Leon RG, Jordan DL, Bolfrey-Arku G, Dzomeku I, Korres NE, Burgos NR, Duke SO (2019) Sustainable weed management in peanut. Pages 345–366 *in* Korres NE, Burgos NR, Duke SO, eds. Weed Control: Sustainability, Hazards, and Risks in Cropping Systems Worldwide. Boca Raton, FL: CRC Press

Leon RG, Tillman BL (2015) Postemergence herbicide tolerance variation in peanut germplasm. Weed Sci 63:546–554

Main CL, Ducar JT, Macdonald GE (2002) Response of three runner market-type peanut cultivars to diclosulam. Weed Technol 16:593–596

Main CL, Ducar JT, Whitty EB, MacDonald GE (2005) Weed management in southeastern peanut with diclosulam and flumioxazin. Weed Technol 19:870–874

Moore JD, Banks PA, Pinnell-Alison CL (1990) Wild poinsettia (*Euphorbia heterophylla*) control in peanut (*Arachis hypogaea*). Weed Sci 38:536–540

Morichetti S, Ferrell J, MacDonald G, Sellers B, Rowland D (2012) Weed management and peanut response from applications of saflufenacil. Weed Technol 26:261–266

O'Connell PJ, Harms CT, Allen JRF (1998) Metolachlor, *S*-metolachlor and their role within sustainable weed-management. Crop Prot 17:207–212

Poirier AH, York AC, Jordan DL, Chandi A, Everman WJ, Whitaker JR (2014) Distribution of glyphosate-and thifensulfuron-resistant Palmer amaranth (*Amaranthus palmeri*) in North Carolina. Int J Agron 2014:1–7

Price AJ, Wilcut JW (2002) Weed management with diclosulam in strip-tillage peanut (*Arachis hypogaea*). Weed Technol 16:29–36

Price AJ, Wilcut JW, Cranmer JR (2004) Physiological behavior of root-absorbed flumioxazin in peanut, ivyleaf morningglory (*Ipomoea hederacea*), and sicklepod (*Senna obtusifolia*). Weed Sci 52:718–724

Price AJ, Wilcut JW, Swann CW (2002) Weed management with diclosulam in peanut (*Arachis hypogaea*). Weed Technol 16:724–730

Price K, Li X, Price A, Chen C, Grey T (2020) Evaluation of runner-type peanut cultivar tolerance to paraquat tank mixes. Peanut Sci 47:103–110

Price KJ, Li X, Price AJ, Browne F, Balkcom K, Chen CY (2021) Evaluation of peanut tolerance to mid-season applications of PPO-inhibitor herbicides mixed with different surfactants. Crop Prot 143:105557

Prostko EP, Grey TL, Webster TM, Kemerait RC (2011) Peanut tolerance to pyroxasulfone. Peanut Sci 38:111–114

Prostko EP, Johnson WC, Mullinix BG (2001) Annual grass control with preplant incorporated and preemergence applications of ethalfluralin and pendimethalin in peanut (*Arachis hypogaea*). Weed Technol 15:36–41

Prostko EP, Kemerait RC, Jost PH, Johnson WC III, Brown SN, Webster TM (2009) The influence of cultivar and chlorimuron application timing on spotted wilt disease and peanut yield. Peanut Sci 36:92–95

Prostko EP, Kemerait RC, Webster TM (2012) Georgia-06G, Florida-07, and Tifguard peanut cultivar response to chlorimuron. Weed Technol 26: 429–431

Richburg JS, Wilcut JW, Culbreath AK, Kvien CK (1995a) Response of eight peanut (*Arachis hypogaea* L.) cultivars to the herbicide AC 263,222. Peanut Sci 22:76–80

Richburg JS, Wilcut JW, Eastin EF (1993a) Weed control and peanut (*Arachis hypogaea*) response to nicosulfuron and bentazon alone and in mixture. Weed Sci 41:615–620

Richburg JS, Wilcut JW, Eastin EF (1995b) Weed management in peanut (*Arachis hypogaea*) with imazethapyr and metolachlor. Weed Technol 9:807–812

Richburg JS, Wilcut JW, Grichar WJ (2006) Response of runner, Spanish, and Virginia peanut cultivars to imazethapyr. Peanut Sci 33:47–52

Richburg JS, Wilcut JW, Vencill WK (1996) Imazethapyr systems for peanut (*Arachis hypogaea* L.). Peanut Sci 23:9–14

Richburg JS, Wilcut JW, Wehtje GR (1993b) Toxicity of foliar and/or soil applied imazethapyr to purple (*Cyperus rotundus*) and yellow (*C. esculentus*) nutsedge. Weed Technol 7:900–905

Richburg JS, Wilcut JW, Wehtje GR (1994) Toxicity of AC 263,222 to purple (*Cyperus rotundus*) and yellow nutsedge (*C. esculentus*). Weed Sci 42: 398–402

Richburg JS, Wilcut JW, Wiley GL (1995c) AC 263,222 and imazethapyr rates and mixtures for weed management in peanut (*Arachis hypogaea*). Weed Technol 9:801–806

Robinson BL, Clewis SB, Wilcut JW (2006) Weed management with flumioxazin in strip-tillage peanut (*Arachis hypogaea*). Peanut Sci 33: 41–6

Saari LL, Cotterman JC, Thill DC (2018) Resistance to acetolactate synthase inhibiting herbicides. Pages 83–140 *in* Powles SB, Holtum JAM, eds. Herbicide Resistance in Plants: Biology and Biochemistry. Boca Raton, FL: CRC Press

Scott GH, Askew SD, Wilcut JW (2001) Economic evaluation of diclosulam and flumioxazin systems in peanut (*Arachis hypogaea*). Weed Technol 15: 360–364

Scott GH, Askew SD, Wilcut JW, Bennett AC (2002) Economic evaluation of HADSS™ computer program in North Carolina peanut. Weed Sci 50:91–100

Seale JW, Bararpour T, Bond JA, Gore J, Golden BR (2020) Evaluation of preemergence and postemergence herbicide programs on weed control and weed seed suppression in Mississippi peanut (*Arachis hypogea*). Agronomy 10:1058

Senseman SA (2007) Herbicide Handbook. 9th ed. Lawrence, KS: Weed Science Society of America. 458 p

Shaner DL (1989) Factors Affecting Soil and Foliar Bioavailability of Imidazolinones. Wayne, NJ: American Cyanamid Company. 46 p

Shaner DL (2014) Herbicide Handbook. 10th ed. Lawrence, KS: Weed Science Society of America. 513 p

Sims GR, Wehtje G, McGuire JA, Hicks TV (1987) Weed control and response of peanuts (*Arachis hypogaea*) to chlorimuron. Peanut Sci 14:42–45

Sperry BP, Ferrell JA, Smith HC, Fernandez VJ, Leon RG, Smith CA (2017) Effect of sequential applications of protoporphyrinogen oxidase-inhibiting herbicides on Palmer amaranth (*Amaranthus palmeri*) control and peanut response. Weed Technol 31:46–52

Stephenson DO IV, Brecke BJ (2011) Weed management in evenly-spaced 38- vs. 76-cm row peanut (*Arachis hypogaea*). Peanut Sci 38:66–72

Teuton TC, Main CL, MacDonald GE, Ducar JT, Brecke BJ (2004) Green peanut tolerance to preemergence and postemergence herbicides. Weed Technol 18:719–722

Umphres AM, Steckel LE, Mueller TC (2018) Control of protoporphyrinogen oxidase inhibiting herbicide resistant and susceptible Palmer amaranth

(*Amaranthus palmeri*) with soil applied protoporphyrinogen oxidase-inhibiting herbicides. Weed Technol 32:95–100

[USDA-NASS] U.S. Department of Agriculture–National Agricultural Statistics Service (2022) Statistics by Subject: National Statistics for Peanuts. https://www.nass.usda.gov/Statistics_by_Subject/result.php?1D23AB5E-F5EE-3968-AD2E-0CA01BF49986&sector=CROPS&group=FIELD%20CROPS&comm=PEANUTS. Accessed: August 26, 2022

Weber JB (1990) Behavior of dinitroaniline herbicides in soils. Weed Technol 4:394–406

Webster TM, Wilcut JW, Coble HD (1997) Influence of AC 263,222 rate and application method on weed management in peanut (*Arachis hypogaea*). Weed Technol 11:520–526

Wehtje G, Brecke B (2004) Peanut weed control with and without acetolactate synthase-inhibiting herbicides. Peanut Sci 31:113–119

Wehtje G, Brecke B, Bostick JP (1994) Peanut tolerance to paraquat as influenced by seed size. Peanut Sc 21:12–16

Wehtje G, Brecke BJ, Martin NR (2000a) Performance and economic benefit of herbicides used for broadleaf weed control in peanut. Peanut Sci 27: 11–6

Wehtje G, Grey TL (2004) Response of new cultivars to early postemergence chlorimuron applications. Peanut Sci 31:119–123

Wehtje G, Padgett D, Martin NR Jr (2000b) Imazapic-based herbicide systems for peanut and factors affecting activity on Florida beggarweed. Peanut Sci 27:17–22

Wehtje G, Wilcut JW, McGuire JA (1992a) Influence of bentazon on the phytotoxicity of paraquat to peanuts (*Arachis hypogaea*) and associated weeds. Weed Sci 40:90–95

Wehtje G, Wilcut JW, McGuire JA (1992b) Paraquat behavior as influenced by 2,4-DB in peanut (*Arachis hypogaea*) and selected weeds. Peanut Sci 19:51–5

Wehtje G, Wilcut JW, McGuire JA, Hicks TV (1991) Foliar penetration and phytotoxicity of paraquat as influenced by peanut cultivar. Peanut Sci 18:67–71

Wehtje GR, Wilcut JW, McGuire JA (1993) Absorption, translocation, and phytotoxicity of chlorimuron and 2,4-DB mixtures in peanut (*Arachis hypogaea*) and selected weed species. Weed Sci 41:347–52

Wilcut JW (1991a) Economic yield response of peanut (*Arachis hypogaea*) to postemergence herbicides. Weed Technol 5:416–420

Wilcut JW (1991b) Efficacy and economics of common bermudagrass (*Cynodon dactylon*) control in peanut (*Arachis hypogaea*). Peanut Sci 18:106–109

Wilcut JW (1991c) Tropic croton (*Croton glandulosus*) control in peanut (*Arachis hypogaea*). Weed Technol 5:795–798

Wilcut JW, Askew SD, Bailey WA, Spears JF, Isleib TG (2001) Virginia market-type peanut (*Arachis hypogaea*) cultivar tolerance and yield response to flumioxazin preemergence. Weed Technol 15:137–140

Wilcut JW, Richburg JS, Eastin EF, Wiley GR, Walls FR, Newell S (1994a) Imazethapyr and paraquat systems for weed management in peanut (*Arachis hypogaea*). Weed Sci 42:601–7

Wilcut JW, Richburg JS, Wiley GL, Walls FR (1996) Postemergence AC 263,222 systems for weed control in peanut (*Arachis hypogaea*). Weed Sci 44:615–621

Wilcut JW, Richburg JS III, Wiley G, Walls FR Jr, Jones SR, Iverson MJ (1994b) Imidazolinone herbicide systems for peanut (*Arachis hypogaea* L.). Peanut Sci 21:23–28

Wilcut JW, Swann CW (1990) Timing of paraquat applications for weed control in Virginia-type peanuts (*Arachis hypogaea*). Weed Sci 38:558–562

Wilcut JW, Swann CW, Hagwood HB (1990a) Lactofen systems for broadleaf weed control in peanuts (*Arachis hypogaea*). Weed Technol 4:819-823

Wilcut JW, Walls FR, Horton DN (1991a) Weed control, yield, and net returns using imazethapyr in peanuts (*Arachis hypogaea*). Weed Sci 39:238–42

Wilcut JW, Walls FR Jr, Horton DN (1991b) Imazethapyr for broadleaf weed control in peanuts (*Arachis hypogaea*). Peanut Sci 18:26–30

Wilcut JW, Wehtje GR, Hicks TV (1990b) Evaluation of herbicide systems in minimum-and conventional-tillage peanuts (*Arachis hypogaea*). Weed Sci 38:243–248

Wilcut JW, Wehtje GR, Hicks TV, Cole TA (1990c) Postemergence weed management systems for peanuts (*Arachis hypogaea*). Weed Technol 4: 239–244

Wilcut JW, Wehtje GR, Patterson MG, Cole TA, Hicks TV (1989) Absorption, translocation, and metabolism of foliar-applied chlorimuron in soybeans (*Glycine max*), peanuts (*Arachis hypogaea*), and selected weeds. Weed Sci 37:175–180

Wilcut JW, York AC, Grichar WJ, Wehtje GR (1995) The biology and management of weeds in peanut (*Arachis hypogaea*). Pages 207–244 *in* Pattee HE, Stalker HT, eds. Advances in Peanut Science. Stillwater, OK: American Peanut Research and Education Society

Willingham SD, Brecke BJ, Treadaway-Ducar J, MacDonald GE (2008) Utility of reduced rates of diclosulam, flumioxazin, and imazapic for weed management in peanut. Weed Technol 22:74–80

Wise AM, Grey TL, Prostko EP, Vencill WK, Webster TM (2009) Establishing the geographical distribution and level of acetolactate synthase resistance of Palmer amaranth (*Amaranthus palmeri*) accessions in Georgia. Weed Technol 23:214–220

Yoshida R, Sakaki M, Sato R, Haga T, Nagano E, Oshio H, Kamoshita K (1991) S-53482—a new N-phenyl phthalimide herbicide. Pages 12–13 *in* Proceedings of the Brighton Crop Protection Conference, Weeds. Alton, UK: British Crop Production Council

York AC, Wilcut JW, Grichar WJ (1993) Interaction of 2,4-DB with postemergence graminicides. Peanut Sci 20:57–61

York AC, Wilcut JW, Swann CW, Jordan DL, Walls FR (1995) Efficacy of imazethapyr in peanut (*Arachis hypogaea*) as affected by time of application. Weed Sci 43:107–116