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ARTICLE

Biology and Management of Weeds in Peanut (*Arachis hypogaea* L.)

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ABSTRACT

Weeds play a major role in determining yield and the efficiency of production practices in peanut (*Arachis hypogagea* L.), and effective and long-lasting weed management must be based on the biology of the weeds and the proper implementation of control practices. The present review provides a thorough description of weed control tools available in peanut and the different biotic, abiotic, and management factors that determine the outcome of their use. Also, current and future challenges for weed management in peanut are discussed based on principles of integration of pest control practices and agronomic efficiency. The overall analysis of the information available indicates that peanut weed management success must be assessed over several years considering the dynamics of the soil seed bank. For this reason, weed pressure in peanut is highly dependent on weed control in the other rotational crops. This is particularly evident in the way weeds that evolved herbicide resistance in other crops reduced the number of herbicides that are effective in peanut. Although herbicides continue being the most important weed control in peanut, it is likely that the addition of alternative practices such as cover cropping, and precision management technologies will be necessary to ensure adequate weed control over time.

INTRODUCTION

Peanut is an important crop for sustainable human nutrition and is an essential source of oil and protein in many countries around the world (Davis and Dean, 2016; Valentine, 2016). Production systems vary considerably depending on geography, climate and weather, and access to production resources such as irrigation, fertilizer and pesticides, and tillage and cultivation equipment (Leff *et al.*, 2004; Woodroof, 1966). Estimates of the percentage of variable cost for weed management through use of herbicides was 6.8 to 13.9% in Georgia (Liu *et al.*, 2025), 7.7 to 9.6% in North Carolina (Washburn and Jordan, 2025), and 5.3 to 13.9% in Oklahoma and Texas (OSU-AGECON, 2025; TAMU-EAE, 2025) depending upon the production system (irrigated, dry land, conventional tillage, minimum tillage). Although variation exists depending upon infestation of weeds, incidence of disease, and fluctuations in insect populations, pesticide expenditures for weed control exceed those for insect pest control but are less than costs for disease control. In other peanut producing countries such as Argentina, weed control cost may be the same or higher than disease control, while insect pests tend to be a lesser problem.

Success of weed management practices can be influenced by the ability of peanut to compete with weeds, cultural practices that minimize the soil seed bank and weed infestation, mechanical practices such as primary tillage prior to planting, cultivation during the growing season, and by efficacy of herbicides. Assessment of weed population dynamics in both the short and especially long-term is critical for identifying weed control practices that ensure long-lasting and cost-effective weed management.

WEED DIVERSITY AND INTERFERENCE WITH PEANUT

Weed communities associated with peanut production are predominantly comprised of annual herbaceous species that are propagated by seeds. Because the unavoidable soil disturbance resulting from digging peanut pods during harvest and the use of conventional and reduced tillage before planting, not only small-seeded weed species {e.g. *Amaranthus* spp., eclipta [*Eclipta prostrata* L.], goosegrass [*Eleusine indica* (L.) Gaertn.], crabgrass (*Digitaria* spp.}, but also large seeded species that can successfully emerge from deeper in the soil {e.g. sicklepod [*Senna obtusifolia* (L.) H.S. Irwin & Barneby], Benghal dayflower (*Commelina benghalensis* L.), morningglories [*Ipomoea* spp. and *Jacquemontia tamnifolia* (L.) Griseb.], and common ragweed (*Ambrosia artemisiifiolia* L.) are frequently found in peanut fields. Most of these weed species have temperature and soil moisture germination requirements similar to peanut, which favors their emergence and establishment before peanut canopy closure (Creel *et al.*, 1968; Prasad *et al.*, 2006; Webster *et al.*, 2005). The number of perennial weed species causing problems in peanut is considerably smaller than for annual species. However, there are several perennial species that can successfully establish dense populations and interfere with peanut, particularly those that produce vegetative propagules such as tubers and rhizomes and can be dispersed by tillage and cultivation {e.g. bermudagrass [*Cynodon dactylon* (L.) Pers.], nutsedge (*Cyperus* spp.), and johnsongrass [*Sorghum halepense* (L.) Pers.]}.

Most of weed management strategies in peanut tend to focus on dicotyledonous species such as Palmer amaranth [*Amaranthus palmeri* (S.) Wats.], sicklepod, Florida beggarweed [*Desmodium tortuosum* (Sw.) DC.], and morningglory species because they can form dense populations and are difficult to control (Barbour and Bridges, 1995; Cardina and Breckem, 1991; Webster and MacDonald, 2001). Their ability to produce large amounts of seed (e.g. Palmer amaranth and sicklepod) and form persistent seed banks due to their hard seed coats (e.g. sicklepod, morningglories, and Benghal dayflower) greatly increase their survival within not only peanut but also other rotational crops including cotton (*Gossypium hirsutum* L.), corn (*Zea mays* L.), and soybean (*Glycine max* L.). Furthermore, several of those species have high interference potential. For example, a single Palmer amaranth plant per meter-row can reduce peanut yield 30% and at 4-5 plants/m row peanut loss can reach 50 to 70% (Burke *et al.*, 2007). Similarly, at 1 plant per 10 m^{-2} (close to 1.1 plants m-row) sicklepod reduced peanut yield by 29-60% (Hauser *et al.*, 1982). Recently, the evolution of herbicide resistant biotypes has particularly benefited Palmer amaranth by limiting its control and allowing rapid explosions of its populations (Berger *et al.*, 2015; Poirier *et al.*, 2014; Wise *et al.*, 2009).

Problematic weed species

Weeds considered as the most problematic in peanut production are frequently limited to a small number of species (Table 1). However, depending on geography, environmental conditions, and especially weed management practices, there are other species that have been reported with the potential for causing significant yield losses or interfering with peanut management and harvest. Examples of those potentially problematic, but less frequent species, include bristly starbur (*Acanthospermum hispidum* D.C.), common cocklebur (*Xanthium strumarium* L.), common ragweed, golden crownbeard [*Verbesina encelioides* (Cav. Benth. & Hook. F. ex Gray)], horsenettle (*Solanum carolinense* L.), silverleaf nightshade (*Solanum elaeagnifolium* Cav.), and tropic croton (*Croton glandulosus* var. *septentrionalis* Muewll.-Ag.) (Clewis *et al.*, 2001; Farris and Murray, 2006; Hackett *et al.*, 1987a, 1987b; Royal *et al.*, 1997a; Walker *et al.*, 1989; Webster, 2013; Webster and MacDonald, 2001).

Weed communities have undergone dramatic changes during the last few years especially when considering troublesome species (Figure 1). Thus, species that are frequently found in peanut fields such as Florida beggarweed, sicklepod, and nutsedge, despite maintaining their frequency at similar levels during the last 15 years, their importance for management has progressively decreased, and other species exhibiting rapid population growth and evolved herbicide resistance such as Palmer amaranth have become the most challenging weed problems in peanut production (Webster, 2001, 2005, 2009, 2013; Figure 1). This trend has also been observed in Argentina where Palmer amaranth and smooth pigweed (*Amaranthus hybridus* L.) both have evolved resistance to herbicides used in peanut and its rotational crops and have quickly become the most troublesome species in that country (Table 1).

Grass weed species can reduce peanut yield from 7% to more than 60%, especially when not controlled in a timely manner (Everman *et al.*, 2008a; Johnson and Mullinex, 2005; York and Coble, 1977). However, the fact that there are multiple preemergence herbicides and selective postemergence systemic grass herbicides registered for peanut (e.g. clethodim, sethoxydim, and fluazifop-P-butyl) makes grass weeds a more manageable problem for peanut growers compared to key broadleaf species such as Palmer amaranth (Fig. 1). Some of the grass weed species often found in peanut farms include large crabgrass [*Digitaria sanguinalis* (L.) Scop.], goosegrass, crowfootgrass [*Dactyloctenium aegyptium* (L.) Wild.], browntop millet [*Urochloa ramosa* (L.) Nguyen], fall panicum (*Panicum dichotomiflorum* Michx.), and Texas millet [*Urochloa texana* (Buckl.) R. Webster] (Burke *et al.*, 2004; Grichar, 1991; Grichar and Boswell, 1986; Johnson and Mullinix, 2005). Crabgrass species are among the most frequent weeds in peanut, but they are easily managed, and they are not considered troublesome (Figure 1). Conversely, Texas millet is much less frequent than crabgrass, but it is more difficult to control mainly because of its tolerance to preemergence and less consistent control with postemergence herbicides. This last point underscores the importance of considering not only weed frequency and density, but also the impact on production and challenges for management when determining the need for weed control and investment in time and financial resources.

Table 1. Examples of ten weed species frequently associated with peanut production in the United States, and in Argentina, another large peanut producer in the American continent. List is organized alphabetically, and the order does not represent any ranking based on frequency or importance on peanut production.

Country	Species	Family	Life cycle	Class
USA	*Amaranthus palmeri* S. Wats.[AR, GR]	Amaranthaceae	annual	dicot
	Ambrosia artemisiifolia L.	Asteraceae	annual	dicot
	Commelina benghalensis L.	Commelinaceae	perennial	monocot
	Cucumis melo L.	Cucurbitaceae	annual	dicot
	Cyperus spp.	Cyperaceae	perennial	monocot
	Desmodium tortuosum (Sw.) DC	Fabaceae	annual	dicot
	Ipomoea spp.	Convolvulaceae	annual	dicot
	Senna obtusifolia (L.) H.S. Irwin & Barneby	Fabaceae	annual	dicot
	Urochloa texana (Buckl.) R. Webster	Poaceae	annual	monocot
	Verbesina encelioides (Cav.) Benth. & Hook f. ex Gray			
Argentina	*Amaranthus hybridus* L. AR, GR	Amaranthaceae	annual	dicot
	Amaranthus palmeri S. Wats. AR, GR	Amaranthaceae	annual	dicot
	Eleusine indica L.	Poaceae	annual	monocot
	Digitaria sanguinalis (L.) Scop.	Poaceae	annual	monocot
	Sorghum halepense (L.) Pers.	Poaceae	perennial	monocot
	Gomphrena pulchella Mart.	Amaranthaceae	annual	dicot
	Cynodon hirsutus Stent	Poaceae	perennial	monocot
	Chloris spp.	Poaceae	annual	monocot
	Euphorbia spp.	Euphorbiaceae	annual	dicot
	Salsola kali L.	Chenopodiaceae	annual	dicot

[AR] ALS-resistant
[GR] Glyphosate resistant
Source: Morichetti, 2017; Webster, 2013.

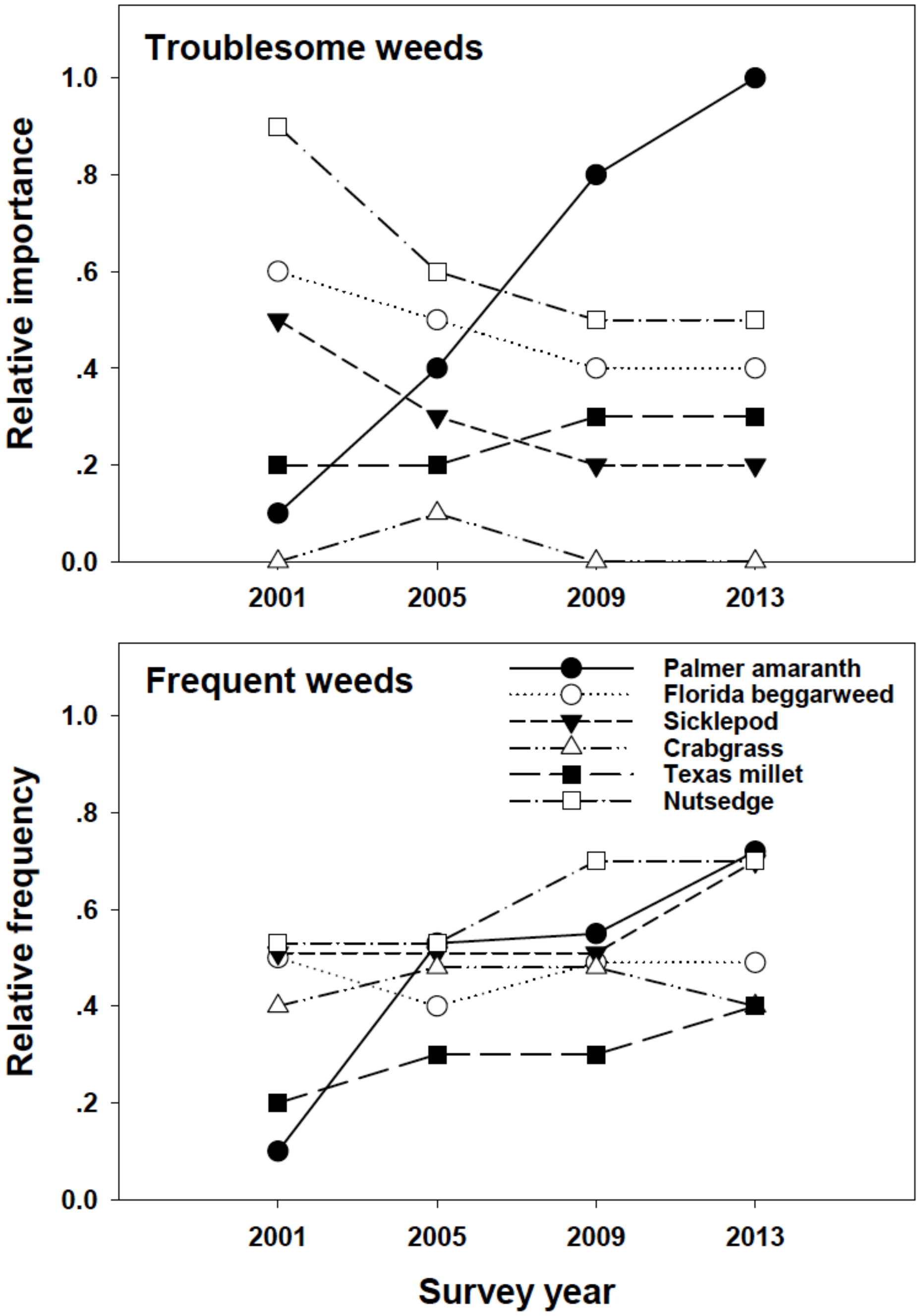

Figure 1. Relative importance of six weed species based on multiple Weed Surveys of the Southern Weed Science Society (WSSA) ranking the most frequent and troublesome weed species in peanut production in southern States (Webster, 2001, 2005, 2009, 2013). Relative values are the average of all states reporting the presence of the weed in their top 10 ranking weighed by their ranking position. Thus, a species ranked as number 1 by all states would have a relative frequency or importance of 1, a species reported by half of the states as number 1 or a species reported by all states as number 5 would have a relative value of 0.5, while a species with no reports or reported by all states at a ranking below 10 would have a relative value of 0.

Unlike most grass weeds, other monocotyledonous species such as purple nutsedge (*Cyperus rotundus* L.), yellow nutsedge (*Cyperus esculentus* L.), and Benghal dayflower (also known as Tropical spiderwort), can represent major challenges for peanut production because of fewer effective herbicides and their adaptations to survive and propagate under tillage and cultivation (Webster and MacDonald, 2001; Webster *et al.*, 2005, 2007). Nutsedge species are frequently found in peanut fields, and although their importance has decreased as Palmer amaranth issues increased, they are consistently ranked among the most problematic weeds in peanut (Fig. 1).

The prostrate growth habit of peanut contributes to its vulnerability to interference by weeds. Weeds interfere with peanut through direct competition for light, soil water, nutrients, essential gases, and space (Wilcut *et al.*, 1994a). Weeds can also interfere with peanut growth through allelopathy (Belel and Belel, 2015; Elmore, 1985; Sorecha and Bayissa, 2017). The requirement to dig pods and invert vines prior to mechanical harvest further underscores the need for effective season-long weed control. Annual and perennial grasses such as Texas millet can reduce peanut yield through direct competition and decreased harvest efficiency. The tight fibrous root system of Texas millet becomes intertwined with the peanut plant (Johnson and Mullinix, 2005), causing peanut pods to be stripped from the vine during digging. Pods that become detached from the plant remain unharvested in or on the soil (Buchanan *et al.*, 1982). Also, fungicides are applied multiple times to peanut fields to control stem rot disease (caused by *Sclerotium rolfsii* Sacc.), early and late leaf spot disease [caused by *Cercospora arachidicola* (Hori) and *Cercosporidium personatum* (Berk. & M.A. Curtis) Deighton, respectively], and it is suspected that weeds can interfere with uniform deposition of fungicides and subsequent pathogen control (Royal *et al.*, 1997b).

Regional differences in weed communities

According to the 2017 Weed Science Society of America common weeds in peanut survey, Palmer amaranth and nutsedge species were common in all reported cases, Texas millet/panicum and morningglory in all but one, crabgrass species were listed twice, and Florida beggarweed, common purslane (*Portulaca oleracea*), sicklepod, and smellmelon (*Cucumis melo* L.) once. Troublesome weeds not listed as common were horsenettle, Benghal dayflower, hairy indigo (*Indigofera hirsuta* Harvey), and common ragweed (WSSA, 2017). Nutsedge spp., annual morningglory, Palmer amaranth, and sicklepod are common in mid-Atlantic (North Carolina, South Carolina, and Virginia) and southeastern production states (Alabama, Florida, and Georgia). In the southwestern United States (New Mexico, Oklahoma, and Texas) nutsedge spp. (predominantly yellow nutsedge), pigweed species (mainly Palmer amaranth) and morningglories [ivyleaf (*Ipomoea hederacea* Jacp.) and pitted (*Ipomoea lacunosa* L.)] are also of great importance, but in this part of the country species such as Texas millet, Russian thistle (*Salsola tragus* L.), kochia [*Kochia scoparia* (L.) Schrad.], and wild sunflower (*Helianthus annuus* L.) can also be problematic in peanut production. When considered on a regional level, Benghal dayflower, Florida beggarweed, Palmer amaranth, Texas millet, and sicklepod are prominent in the southeastern USA, while common ragweed and eclipta are common in the mid-Atlantic region. In the southwestern USA, smellmelon and horse purslane (*Trianthema portulacastrum* L.) have become weeds of economic importance, but they are not as frequent in the eastern part of the country. All the aforementioned species are rarely found in single stands, instead often a complex of species exists, which thus requires a well-thought-out and executed weed management plan that provides adequate control of all the species present to minimize weed interference and protect peanut yields (Grichar, 1998b; Grichar and Sestak, 1998, 2000b).

Although the most important weed species in peanut tend to form tall canopies (e.g., common ragweed, Florida beggarweed, Palmer amaranth, sicklepod,), recent reports of changes in weed communities in peanut fields indicate that species with a prostrate growth habit or heights similar to peanut can interfere with the crop. For example, smellmelon is becoming more of a problem in south Texas peanut production fields (Grichar, 2007). The range of smellmelon extends from the Southeastern USA to the southern part of California and as far north as Arkansas (SWSS, 1999). Smellmelon can be a problem at peanut harvest as the melon can become broken apart when run through the combine and increase drying time because of the high moisture content of the melon itself (Grichar, 2007).

Horse purslane occurs in tropical and subtropical areas throughout the world (Balyan and Bahn, 1986). It has cylindrical green leaves, and the seeds germinate at 20 to 45 C (Chandra and Sahai, 1979). Seeds have essentially no dormancy and can germinate soon after they mature, thus allowing multiple generations in a single growing season (Balyan and Bhan, 1986). Although common purslane, a similar species, was rated as one of the ten most common weeds found in Texas peanut fields as early as 1989 (Elmore, 1989), horse purslane only recently has become a problem in certain peanut growing areas of south Texas (Grichar, 2007). This weed can be a stronger competitor with peanut early in the growing season than common purslane due to a more upright growth habit than that of common purslane (Grichar, 1993). In competition studies, horse purslane reduced mung bean [*Vigna radiate* (L.) R. Wilcdz.] yields by 50 to 60% when no control actions were implemented (Balyan and Malik, 1989).

Critical period of weed interference

Accurate identification of weeds and knowledge of field history and the soil seed bank are important in implementing effective weed management practices. Soil-applied herbicides prior to or after planting are selected based on knowledge of previous infestations in peanut or other crops in the rotation sequence. Proper selection of these herbicides is critical to reducing early season weed interference and reducing the potential for weed herbicide resistance. After emergence and when weeds infest fields, growers apply herbicides to control these populations to protect yield. The critical period of weed interference with peanut varies based on weed species with a weed-free period of 3 to 9 weeks after planting (WAP) needed to protect yield (Hauser *et al.*, 1975; Hauser and Buchanan, 1981). When weeds are controlled during this period yield reductions often can be maintained below 10%. Everman *et al.* (2008a,b) determined that the critical period of interference lasted approximately 5 weeks, but this period could occur earlier or later depending on weed community composition. Protection of yield when annual grasses were the predominant weeds required a weed-free period extending from 4.3 to 9 WAP, while the necessary period for broadleaf weeds was 2.6 to 8 WAP. In many farmer fields both annual grass and broadleaf weeds are components of the weed complex; therefore, effective management is required for the full duration of the weed-free intervals described by Everman *et al.* (2008a,b).

The presence of other pests can influence peanut-weed interactions. For example, tobacco thrips [*Frankliniella fusca* (Hinds)] and western flower thrips [*Frankliniella occidentalies*

(Pergande)] can negatively impact peanut growth and development and subsequently yield if left uncontrolled, especially early in the season during the critical period of weed interference (Herbert *et al.*, 2007; Tappan and Gorbet, 1979). Injury from these insects resulting from feeding in newer tissues within the first 4 weeks after emergence causes leaves in the terminal or growing point to emerge distorted and at a slower rate and sometimes resulting in less leaf area compared with plants protected from prolonged thrips damage by systemic insecticides (Lynch *et al.*, 1984.). Consequently, the competitive ability of peanut against weeds is diminished during the critical period of interference, and delays in canopy closure can occur. Tomato spotted wilt (a *Tospovirus*), for which thrips are the main vector, can result in stunted or dead plants later in the season decreasing the ability of peanut to compete with weeds and enabling prolonged emergence of weeds throughout the season, especially when herbicides providing residual weed control become ineffective. This is where cultivar selection can also impact weed management programs. The development and selection of cultivars that are tolerant to tomato spotted wilt virus can reduce the impact this virus has on both weed management and ultimately yield.

While weeds emerging after the critical period of interference often will have minimal impact on yield, these weeds can contribute seed and vegetative reproductive structures to the soil seed bank, increase harvest loss by exacerbating pod shed during digging and vine inversion, slow the harvest process, or damage harvesting equipment. Escaped weeds, whether emerging during the critical period of weed interference or later in the season are of particular concern with respect to the soil seed bank because some of the plants may express potential resistance. Growers often perceive that late infestations are well below economic injury levels with respect to application of herbicides or hand-removal and may not control these weeds. In some instances, allowing these weeds to produce seed can increase the rate at which weeds expressing herbicide resistance become dominant, or shifts in weed populations to more difficult to control weeds might occur. For example, the rapid increase of infestations of Palmer amaranth confirmed as resistant to herbicides most likely resulted from sub-threshold populations allowed to contribute progeny to the soil seed bank, which rapidly increased the frequency of resistant individuals (Culpepper *et al.*, 2006). Additionally, higher prevalence of Benghal dayflower in peanut in Florida and Georgia most likely resulted from a weed shift because of adoption of glyphosate-resistant crops and use of glyphosate which is minimally effective in controlling this weed. Concurrent with the adoption of glyphosate-resistant crops and increased use of glyphosate, there was a reduction in soil-applied herbicides used at planting, most notably *S*-metolachlor, which effectively controls Benghal dayflower (Webster *et al.*, 2005). Conversely, the use of glyphosate in-season in rotational crops, effectively reduced the populations and subsequent effects that silverleaf nightshade or johnsongrass have on the following peanut crop.

CROP ROTATION IMPACT ON WEED POPULATIONS

Minimizing the soil seed bank is unquestionably an important management strategy for peanut and other crops. The characteristics of the crops and the sequence in which they are rotated can impact weed populations and management. Crop rotation allows changing herbicides and in many cases rotation of herbicide mechanisms of action (MOA) to avoid or delay evolved resistance (Norsworthy *et al.*, 2012). This makes possible the use of herbicides in rotational crops prior to peanut that may be more effective than herbicides used in-season during the peanut growing season. For example, sicklepod, common ragweed, and eclipta can be difficult to control in peanut when they exceed 5 cm in height, because PPO herbicides are minimally effective in controlling small weeds (Altom *et al.*, 1995; Grichar and Colburn, 1996b). These weeds can be controlled in rotational crops including corn, cotton, and soybean when PSII inhibitors, glufosinate, and glyphosate are part of the weed management system (Hoffner *et al.*, 2012; Whitaker *et al.*, 2011). Perennial grasses such as bermudagrass and rhizomatous johnsongrass can also be controlled in crops receiving multiple applications of glyphosate over several growing seasons (Johnson, 1988; Salisbury *et al.*, 1991). Similarly, purple nutsedge can be difficult to control in peanut unless imazapic or imazethapyr are applied postemergence (Grichar and Nester, 1997; Grichar and Sestak, 2000a; Webster *et al.*, 2017). Grichar and Nester (1997) reported that imazethapyr provided more consistent control of purple nutsedge than yellow nutsedge. They also reported that imazapic provided purple nutsedge control equivalent to imazethapyr even at rates lower than suggested by the manufacturer (0.05 kg ha^{-1}). However, cotton can be injured by residues of imazapic if planted the following year (Grey *et al.*, 2005; Grichar *et al.*, 2004a). Therefore, the use of herbicides that effectively manage purple nutsedge in rotational crops can be beneficial in managing this weed in peanut. Furthermore, research by Grichar *et al.* (1999b) reported, in south Texas, that corn and sorghum [*Sorghum bicolor* (L.) Moench.] growth was not reduced by imazapic at 0.07 kg ha^{-1}. Matocha *et al.* (2003) indicated there was no significant carryover injury to the rotational crops cotton, sorghum, and corn in Florida, Georgia, and Texas. They concluded that the current rotational intervals for imazapic at 0. 07 kg ha^{-1} may be too restrictive.

Interactions of crop rotation with weeds and other pests

Pathogens and nematodes are often present in peanut fields and can negatively affect peanut growth, development, and yield when not effectively managed (Cantonwine *et al.*, 2006; Culbreath *et al.*, 1992a,b). Establishing a rotation sequence that favors peanut health by minimizing pathogen inoculum and nematode populations can promote competition of peanut against weeds. Although greater diversity of crops in the rotation sequence can reduce disease incidence and may allow use of a greater diversity of herbicides, some crops are more effective than others in minimizing overall pest impact. For example, corn is more effective (Davis and Timper, 2000; Ibrahim *et al.*, 1993) than small grains (Johnson and Motsinger, 1989), although small grains can be used as a cover crop to reduce weed seedling emergence in peanut. While some grass crops may not be as effective in reducing nematode populations, they will assist in reducing other disease problems. Vegetable crops may be effective rotation crops with peanut in terms of pathogens, but weed control may be more challenging in these crops because fewer herbicides are available and labor for hand-removal of weeds can be expensive or unavailable. Vegetables generally have a shorter growing season than agronomic crops such as corn, cotton, grain sorghum, or soybean, and the benefits of effective weed control in these crops can be compromised if weeds are allowed to re-infest fields and contribute to the soil seed bank. Ultimately, however, the economic value of crops grown in rotation with peanut drives selection (Johnson *et al.*, 2001). Realizing this, crop managers must be proactive in weed management for all crops not only for the short term but also for the long term to maintain sustainability.

CROP COMPETITION AS A WEED MANAGEMENT TOOL

Establishing adequate populations of peanut and closing the canopy as rapidly as possible greatly simplifies weed management by reducing the critical period of weed interference and suppressing weed germination and growth. Exposure of soil to sunlight over a longer period of time encourages multiple weed emergence events and greater infestation leading to complications in management. Peanut exhibiting slow emergence, or suffering predation of peanut seeds and plants, and other biotic and abiotic stresses might delay both emergence and canopy closure (Awal and Ikeda, 2002; Drake *et al.*, 2009).

Planting Considerations

Plant population and row configuration have been evaluated as practices with the potential to improve weed management in peanut (Besler *et al.*, 2008; Colvin *et al.*, 1985a; Hauser and Buchanan, 1981). Twin-row planting patterns (two rows spaced 8-22 cm apart on 96-cm centers, for example) often result in more rapid canopy closure and potential to minimize weed infestation and interference (Brecke and Stephenson, 2006; Colvin *et al.*, 1985b). However, cultivar selection can impact response to planting pattern. For example, a peanut cultivar with bunch-type growth habit increased yield and economic return in twin-row when compared with single-row planting patterns, while no response to planting arrangement was observed in a cultivar with prostrate growth habit (Jordan *et al.*, 2010). Despite the faster canopy closure achieved with twin-rows other weed management tools such as herbicides are still required to provide acceptable weed control (Besler *et al.*, 2008; Lanier *et al.*, 2004; Place *et al.*, 2010). Besler *et al.* (2008) reported that diclosulam and imazapic applied in a twin-row planting arrangement at 0.5X and 1X rates controlled yellow nutsedge more effectively than herbicide applications in a single-row spacing. In a similar study, Place *et al.* (2010) also observed greater weed control with a narrow twin-row pattern (rows spaced 18 cm apart on 46-cm centers), but no increase in yield was observed over the traditional twin-row planting pattern (18 cm apart on 91-cm centers). Cost of production increased substantially in the narrow twin-row pattern compared with single row or traditional twin-row patterns (91-cm centers) due to increased seed cost. Although single and conventional twin-row plantings have equivalent seed densities and consequently similar seed cost, twin-rows will have a higher planting cost due to higher in-furrow insecticide costs because of the additional treated row. In a study by Johnson *et al.* (2005), peanut yields were greater in narrow than wide rows even though weed density was not being affected by row spacing. These results underscored the importance of the suppressive effect the peanut crop exerts on the growth of emerged weeds as a component of comprehensive weed management. Increasing peanut canopy closure rate by using twin-row planting patterns or increasing the seeding rate can positively affect weed management and reduce incidence of tomato spotted wilt of peanut (Johnson *et al.*, 2005), but stem rot disease can increase when peanut plants are closer together at high-population plantings (Sconyers *et al.*, 2007; Wehtje *et al.*, 1994). The aforementioned benefits of twin-row arrangements may vary depending on environmental conditions and agricultural practices. For example, in South Texas, a yield advantage was only observed with a twin-row pattern in one of 3 years (Besler *et al.*, 2008). In this same study, changing row pattern did not affect yellow nutsedge control. While these planting patterns can be beneficial in some areas, they do require specialized equipment. Therefore, achieving a balance between weed suppression, optimum yield, pathogen spread, and overall economics is critical when deciding peanut planting patterns.

Cultivar Selection

Deployment of disease-resistant cultivars has proven to be a critical component of integrated pest management, but this approach has not proven effective for weed management. Although there are clear differences in canopy structure and growth habit among peanut botanical types and cultivars, these differences do not seem to significantly affect weed suppression or tolerance to weed interference under current planting arrangements (Agostinho *et al.*, 2006; Leon *et al.*, 2016; Place *et al.*, 2012). However, Leon *et al.* (2016), when studying weed suppression and interference tolerance for four different peanut types, noted that although weed interference reduced peanut yield, peanut plant dry weight was not affected. These results suggested that commercial cultivars sacrifice yield to maintain vegetative growth when experiencing weed interference. Those researchers proposed that it might be worth screening peanut germplasm to identify lines that will protect yield more under weed interference situations.

CULTIVATION AND TILLAGE

Cultivation during the critical period of weed interference can be effective in minimizing the impact of weeds in peanut (Johnson and Mullinix, 1995). However, in some regions, conservation or reduced tillage systems have become predominant, and thus in-season cultivation is not feasible. Also, even though cultivation after planting can be effective in controlling weeds between rows, follow up actions with alternative measures might be needed specially to control in-row weeds that are not eliminated with conventional cultivation (Bridges *et al.*, 1984; Wilcut *et al.*, 1987). In systems using preemergence herbicides, the use of cultivation must be assessed carefully because depending on the depth and intensity of cultivation, cultivators can disturb the soil and bring non-treated soil and weed seed from lower depths to the surface reducing residual activity resulting in weed infestation. Movement of soil-borne pathogens onto stems of peanut plants, which can hasten incidence of diseases such as stem rot, is also a concern when in-season cultivation is practiced (Boyle, 1952, 1956; Garren, 1961, 1964; Johnson *et al.*, 2001; Mixon, 1963). The concern of moving soil-borne pathogens onto the peanut plant decreases the effectiveness of cultivation compared to its use in other crops. With that being said, in-season cultivation using various implements and hand-weeding and hoeing, where labor is available and affordable, seem to be the most likely management options for minimizing weed interference in organic production systems (Johnson and Mullinix, 2008; Johnson *et al.*, 2013). Studies have evaluated the use of organic herbicides to increase in-row weed control in peanut, but the levels of control have been frequently unacceptable (Johnson *et al.*, 2013). Recent research conducted by Johnson and Davis (2015) on the use of tine-weeder cultivation in perpendicular orientation to the rows, showed that this approach increased overall weed control but not in-row control in organic peanut. However, tractor tracks caused considerable injury to peanut seedlings. Therefore, those researchers concluded that perpendicular cultivation does not provide major benefits compared with conventional parallel cultivation (i.e., between rows; Johnson and Davis, 2015).

In reduced tillage systems, the use of cover crops prior to planting peanut has been effective for soil conservation and weed suppression (Lassiter *et al.*, 2011; Price *et al.*, 2007). While initially developed in cotton (Keeling *et al.*, 1989), small grain cover crops have been utilized to reduce wind soil erosion and damage to seedling in peanut in the Southwest. Cover crops that generate adequate biomass can suppress weeds in peanut, although concern over pegging, digging and inversion of vines, and presence of foreign matter in the farmer stock peanut can limit adoption of this approach to weed management. Price *et al.* (2007) reported that the weed suppression provided by high-residue cover crops allowed a reduction in the number of herbicide applications without sacrificing weed control and peanut yield. Lassiter *et al.* (2011) reported a similar finding with several winter annual small grains in strip tillage systems. While these approaches do not eliminate herbicides, and in fact require more herbicides prior to planting than conventional tillage systems, reduced tillage systems contribute to protection of soil resources and in some instances to improve soil properties and water conservation. Like other cultural practices, consideration of the impact of tillage on overall production and pest management is important prior to adoption for weed management. For example, fewer thrips and lower incidence of tomato spotted wilt are often observed in conservation tillage systems compared with conventional tillage systems (Brandenburg *et al.*, 1998; Johnson *et al.*, 2001). However, soil temperature is often cooler early in the season in reduced tillage systems and stand establishment can be more challenging because of delays in germination and stress on seedlings that promote pathogens that cause seedling disease (Awal and Ikeda, 2002). Planting dates may need to be delayed in conservation tillage systems to ensure adequate stand establishment and subsequent canopy closure. In some regions of the USA and in most Argentine production the growing season suitable for peanut is limited and requires planting as soon as possible to enable kernels to reach optimum maturity prior to harvest. Therefore, assessing the risk of having maturity issues at the end of the season under those circumstances must also be considered when using cover cropping.

Deep tillage in the form of moldboard plowing has been used in peanut to bury plant material and suppress disease. Although information on the value of deep tillage is limited in peanut relative to weed management, in recent years deep tillage in cotton has proven effective in reducing weed populations the following year (Inman *et al.*, 2017; Sosnoskie and Culpepper, 2014). While this approach has been adopted in some areas it does create concerns in fields that have potential for erosion. This is the case in Argentina where peanut production is predominantly under no-tillage conditions and communities strongly oppose the use of conventional tillage. Hand-removal of weeds proved to be an economically similar approach relative to deep tillage in cotton but was more effective than deep tillage in maintaining a lower frequency of glyphosate-resistant Palmer amaranth (Inman *et al.*, 2017). Although not substantiated, it is plausible that the effectiveness of hand-removal in weeds in peanut would follow a similar trend as observations in cotton.

IRRIGATION

Approximately two thirds of the peanut growing area in the USA is rainfed with the remaining area being produced with some type of irrigation system (USDA, 2014). This varies by region with over 98% of peanut hectares being produced with irrigation in the Southwest. Irrigation is an effective risk management tool to optimize yield during periods of dry weather or when peanut is grown on coarse-textured soils with limited water-holding capacity. Additionally, access to overhead sprinkler irrigation can enable activation of preemergence herbicides and minimize stress of emerged weeds which can improve efficacy of postemergence herbicides (Prostko *et al.*, 2001; Smith *et al.*, 2016). In Florida, flumioxazin efficacy on Palmer amaranth control was dramatically reduced in coarse sandy soils when irrigation frequency was not sufficient to maintain soil moisture close to the soil surface. Therefore, in coarse texture soils, frequent irrigation may be needed to maintain weed control even when peanut still has access to soil moisture at deeper layers.

Application of herbicides through irrigation (chemigation) can increase efficiency of production systems by eliminating the need for applications by ground sprayers (Sumner *et al.*, 2000). Chemigation is a common practice in the Southwest to apply preplant or preemergence residual herbicides. Irrigation can also promote uniform, and in most cases, more rapid emergence of peanut. Following emergence, irrigation reduces the time to canopy closure and pod set, especially when rainfall is limited, which also can positively affect weed management. In addition, chloroacetamide herbicides like *S*-metolachlor are often applied postemergence in the Southwest region and followed immediately with overhead irrigation to control yellow nutsedge (Grichar et al. 1996, 2008b).

MANAGEMENT OF WEED ESCAPES

In some fields, weeds either escape early season management or emerge after management practices have been implemented. The short stature of peanut allows these weeds to become established and cause problems with digging and vine inversion or by increasing the soil seed bank. This must be considered when implementing practices to modify peanut canopy. For example, prohexadione calcium is a plant growth regulator that inhibits cell elongation by reducing gibberellin biosynthesis that when applied to peanut makes main stems shorter and the canopy more compact (Culpepper *et al.*, 1997; Jordan *et al.*, 2001; Mitchem *et al.*, 1996). However, weeds that may have been suppressed by the normal canopy can grow through the more compact and shorter canopy of peanut treated with prohexadione calcium causing problems later in the season.

The height differential offered by peanut relative to weeds such as Palmer amaranth, common ragweed, Florida beggarweed, and sicklepod makes movement across fields for hand-removal of escapes less challenging than other taller row crops. Also, because of this height difference between weeds and peanut, mowing the weeds is a viable option to prevent seed production and reduce pod shed during digging and vine inversion (Prostko, 2011b). However, implements used to mow weeds are narrower than sprayers, and traffic through fields to clip weeds after peanut canopy closure can injure vines and promote soil-borne pathogen incidence because portions of limbs of peanut are pushed into soil. Traffic through fields can also promote greater distribution of two-spotted spider mite (*Tetranychus urticae* Koch) and can decrease visibility of the natural growth of peanut which can make tracking rows during digging and vine inversion more challenging. Another advantage of the height differential that exists between peanuts and weeds is the fact that various non-selective applicators (NSA), such as rope-wick or carpet roller, can be used for late-season management of certain weed species such as Palmer amaranth, Florida beggarweed, and sicklepod (Johnson *et al.*, 1999; Prostko, 2011b). Carfentrazone can be applied close to harvest to desiccate morningglory to allow greater efficiency in digging peanut and inverting vines (Chaudhari *et al.*, 2017; Dotray *et al.*, 2010).

CHEMICAL WEED MANAGEMENT IN PEANUT

With the exception of a limited amount of land area under organic production, herbicides are the most widely used weed management practice in peanut in Argentina and the USA. Herbicides can be applied prior to planting in both conventional and conservation tillage systems. Systemic and contact herbicides are used to control cover crops, winter vegetation and emerged summer annual and perennial weeds in conservation tillage systems. Herbicides with residual activity are also applied preplant incorporated or preemergence after planting to minimize early season interference and provide greater flexibility in application timing of postemergence herbicides. The use of these residual herbicides is also critical as a tool for preventing or managing herbicide resistant weeds. In many fields, multiple herbicide applications are needed to protect yield throughout the growing season (Brecke and Stephenson, 2006; Clewis *et al.*, 2007; Colvin *et al.*, 1985a,b; Wehtje *et al.*, 2000).

As mentioned previously, knowledge of the soil seed bank and field histories combined with accurate identification of weed seedlings is the first step in developing effective herbicide programs. Equally important is a clear understanding of the logistical challenges posed by large modern farming operations. Thus, proper selection of herbicides and application timing are key for weed management strategies that are realistic and suitable for the operation.

Weed size is one of the most important factors in determining success of herbicides applied postemergence, especially contact herbicides, and the ability to treat all fields in a timely manner is critical and challenging (Grichar, 1997a, b; Grichar and Boswell, 1986; Grichar and Colburn, 1996a; Grichar and Dotray, 2011). For large operations with limited logistical capacity for applications, focusing on preplant incorporated, preemergence and in some instances postemergence herbicides with residual activity can add flexibility in timing of application with the greatest potential for success.

Peanut Response to Herbicides

Tolerance of the majority of peanut cultivars is adequate for treatment with herbicides that inhibit acetolactate-synthase (ALS or AHSA; Group 2), acetyl-coA-carboxylase (ACCase; Group 2), protoporphyrinogen oxidase (PPO or PROTOX; Group 14), phytoene desaturase (PDS; Group 12), microtubule assembly (Group 3), and very long-chain fatty acids (VLCFA, Group 15) biosynthesis (Dotray *et al.*, 2001, 2003, 2012; Faircloth and Prostko, 2010; Grichar *et al.*, 1999b, 2010a, 2013a; Richburg et al., 2006) (Table 2). Peanut can also tolerate paraquat, a photosystem I electron diverter (PSI, Group 22) (Grichar, 1998a; Grichar and Dotray, 2012; Prostko, 2011a) and the phenoxy herbicide 2,4-DB (synthetic auxin, Group 4) (Baughman *et al.*, 2002; Grichar *et al.*, 1997b; Ketchersid *et al.*, 1978; Tubbs *et al.*, 2010; Wilcut and Swann, 1990). In contrast, peanut is highly susceptible to most photosystem II–inhibitors (PSII, Groups 5 and 6) except bentazon (frequently used in peanut), glyphosate (inhibitor of enolpyruvyl shikimate-3-phosphate synthase, EPSPS, Group 9), and glufosinate (inhibitor of glutamine synthetase, Group 10) (Prostko *et al.*, 2013). Peanut is often rotated with crops that control weeds with MOAs not used in peanut and with other cultural and mechanical control practices. Peanut weed management benefits from use of those actions in a comprehensive program by maintaining the weed seed bank at manageable levels (Leon *et al.*, 2015). However, when weed management is ineffective in other crops even when these herbicides are available, weed control in peanut is compromised.

Soil Applied Preemergence Herbicides

Weed control by preplant incorporated or herbicides applied after planting but prior to emergence (preemergence) is achieved with herbicides that interfere with the cell division of emerging seedlings. These include microtubule inhibitors such as dinitroaniline herbicides (e.g. ethafluralin, pendimethalin; trifluralin) and VLCAF inhibitors such as chloroacetamides (e.g. acetochlor, alachlor,+- dimethenamid-P, *S*-metolachlor). Dinitroanilines are more effective when incorporated prior to planting either mechanically or with overhead irrigation. Chloroacetamide herbicides control weeds when applied either preplant incorporated or preemergence (Grichar *et al.*, 2000, 2001a, 2008a, 2015). These herbicides are widely used because they are very safe on peanut, have a broad spectrum of control and long soil residual activity (Grichar and Colburn, 1993; Grichar, 1997a,b; Grichar and Nester, 1997; Grichar and Sestak, 2000b; Richburg *et al.*, 1995, 1996; Wilcut *et al.*, 1996). Although ALS-inhibiting herbicides from the imidazolinone family, especially imazethapyr and imazapic, can be applied at preplant or preemergence to obtain effective control, they are frequently used for postemergence control early during the growing season, so they will be discussed below with other postemergence herbicides.

Table 2. Herbicides available for use in peanut.

Mechanism of action	WSSA[1]	Herbicide	Timing[2]	Weeds[3]
Acetyl CoA-carboxylase inhibitors	1	clethodim	POST	G
		fluazifop-P-butyl	POST	G
		sethoxydim	POST	G
Acetolactate synthase inhibitors	2	chlorimuron	POST	B
		diclosulam	PPI, PRE, Cracking	B, C
		imazapic	POST	G, B
		imazethapyr	PPI, PRE, Cracking, POST	B, C
Microtubule biosynthesis inhibitors	3	ethalfluralin	PPI, PRE	G, B
		pendimethalin	PPI, PRE	G, B
Synthetic auxin	4	2,4-DB	Cracking, POST	B, C
Photosystem II inhibitor (site B)	6	bentazon	Cracking, POST	B
Phytoene desaturase	12	fluridone	PRE	G, B
Protoporphyrinogen oxidase inhibitors	14	acifluorfen	Cracking, POST	B
		carfentrazone	PRE	B, C
		flumioxazin	PRE	B, C
		lactofen	POST	B
		sulfentrazone	PRE	B, C
Very long-chain fatty acids inhibitors	15	acetochlor	PPI, PRE, Cracking	G, B
		alachlor	PPI, PRE, Cracking	G, B
		dimethenamid-P	PPI, PRE, Cracking	G, B, C
		S-metolachlor	PPI, PRE, Cracking	G, B, C
		pyroxasulfone	POST	G, B, C
Photosystem I electron diverter	22	paraquat	Cracking	G, B, C

[1] Weed Science Society of America (WSSA) classification.

[2] Preplant incorporated (PPI), preemergence (PRE), cracking stage (Cracking), postemergence (POST).

[3] Grasses (G), broadleaves (B), and nutsedges and Cyperaceae species (C).

Among dinitroaniline herbicides, ethalfluralin, pendimethalin, and trifluralin are the most commonly used herbicides for preemergence control (Grichar, 2008; Grichar *et al.*, 2006; Grichar and Dotray, 2012). These herbicides can be applied immediately after planting, but they can also be applied before planting. In both cases, the herbicides must be incorporated into the soil to avoid photodegradation. For preplant applications, the preferred method for herbicide incorporation is a shallow cultivation (e.g. field cultivator, disking, roto-tiller). This method allows a uniform distribution of the herbicide in the upper soil layer from where most weed seedlings will emerge and protects the herbicide from ultraviolet (UV) light minimizing herbicide loss. Due to low water solubility, dinitroaniline herbicides require a sufficient amount of rainfall or irrigation to adequately move these herbicides into the soil for effective weed control. For preplant and preemergence applications, at least 13-25 mm of rainfall or irrigation shortly after application will incorporate the herbicide into the soil favoring more consistent weed control. Dinitroaniline herbicides can effectively control grassy weeds and several small seeded dicotyledonous species including common lambsquarters (*Chenopodium album* L.) and pigweed (*Amaranthus* spp.) species (Dotray *et al.*, 2004). Unfortunately, they provide limited control of other important weed species with larger seeds such as morningglories, Benghal dayflower, and sicklepod. In the case of these large-seeded weed species, preemergence control can be achieved with applications of alachlor, *S*-metolachlor, acetochlor, dimethenamid-P, or imazethapyr (Grichar *et al.*, 2005, 2015). Benghal dayflower and yellow nutsedge are two weeds frequently associated with peanut and for which effective herbicide options are limited. *S*-metolachlor not only provides effective control of these two species (Grichar *et al.* 1996, 2000, 2001c, 2008a, 2008b; Morichetti *et al.,* 2012) but also controls a wide range of other weeds. For this reason, *S*-metolachlor has become the most widely used chloroacetamide herbicide in peanut.

Despite its benefits for weed control, *S*-metolachlor safety on peanuts could be influenced by application timing and the environment. For example, cold and wet conditions during several days after preemergence applications can cause peanut stunting (Cardina and Swann, 1988; Grichar *et al.*, 2004c; Wehtje *et al.*, 1988). Peanut exposure to and uptake of *S*-metolachlor is usually higher during seed germination and before seedling emergence, so applying this herbicide immediately after planting increases the risk of phytotoxicity. To avoid this risk, applications soon after peanut emergence (i.e., at–cracking) are preferred (Grichar *et al.*, 1996); at this stage exposure of the peanut hypocotyl and radicle to *S*-metolachlor is reduced increasing the safety of the application. Often this application is used in combination with paraquat and bentazon to control any emerged weeds.

Pyroxasulfone is a new VLCFA herbicide of the isoxazoline family that recently received labeling for early postermegence use in peanut. Pyroxasulfone must be applied prior to weed emergence or used in combination with a postemergence herbicide like paraquat to assist controlling emerged weeds. Pyroxasulfone is not labeled for preplant or preemergence applications due to potential peanut injury (Eure *et al.*, 2015a). While injury was observed with pyroxasulfone applied postemergence, peanut yields were not affected (Eure *et al.*, 2015b).

Flumioxazin is a PPO-inhibitor used exclusively for preemergence control in peanut because of its safety at this stage (Askew *et al.*, 1999; Burke *et al.*, 2002a; Grichar and Colburn, 1996b). However, when applied in combination with *S*-metolachlor under cool, wet conditions severe peanut injury can occur (Grichar *et al.*, 2004c). Although flumioxazin has postemergence activity on multiple weeds, peanut plants are highly sensitive to foliar exposure to this herbicide limiting its use for postemergence control after peanut emergence (Johnson *et al.*, 2006; Leon and Tillman, 2015). Injury is sometimes observed from flumioxazin when heavy rainfall occurs after planting or from splashing of treated soil on to the peanut foliage. Despite its residual effect and preemergence activity during the growing season, flumioxazin soil persistence is low simplifying crop rotation and minimizing carryover issues (Grey *et al.*, 2002). Flumioxazin has activity on a broad spectrum of weed species, but it has the advantage of being particularly effective against important broadleaf species that are difficult to control in peanut (e.g., eclipta, Florida beggarweed, and Palmer amaranth) (Askew *et al.*, 1999; Grey *et al.*, 2003; Grichar and Colburn, 1996b; Grichar *et al.*, 2004a; Morichetti *et al.*, 2012; Tredaway-Ducar *et al.*, 2009).

Identifying proper herbicides that complement flumioxazin weed spectrum can greatly help ensure adequate control in fields with different weed species composition. For example, Grichar and Colburn (1996b) reported that flumioxazin alone provided inconsistent control of annual grasses; however, the addition of pendimethalin or trifluralin improved control considerably. Similarly, late-season eclipta control with flumioxazin was rate dependent, and 100% control was achieved with herbicide systems including lactofen. Citronmelon [*Citrullus lanatus* var. *citroides* (Bailey) Mansf.] control was at least 98% with all flumioxazin systems. The use of flumioxazin for preemergence control in peanut has increased dramatically mainly to control species that have evolved resistance to ALS-inhibitors and glyphosate particularly Palmer amaranth (Morichetti *et al.*, 2012). In fact, flumioxazin is currently the most commonly used herbicide in peanut (Anonymous, 2024).

Postemergence Herbicides

For most weed species, weed emergence extends for weeks and sometimes months, but individuals that emerge at the beginning of the emergence period are the ones that influence peanut yield the most. Weeds that emerge with the crop and survive or escape preemergence applications will be able to interfere with peanut for a longer time and will likely be taller than the crop thus reducing yield. Also, those early-emerging weeds, because of their larger size later, are more likely to survive postemergence control actions and reach maturity contributing to weed seed bank replenishment. These large weeds can also cause problems, delays, and machinery malfunctions during harvest. For these reasons, special attention must be paid to effectively controlling early emerging weeds. Applying herbicides to larger weeds that will not be controlled completely is equivalent to applying sublethal rates, which also hastens selection for evolved resistance to herbicides (Busi and Powles, 2009; Neve and Powles, 2005).

Paraquat is a contact herbicide (i.e., limited translocation inside the plant) used for postemergence control up to 30 days after peanut emergence that is classified as a photosystem I electron diverter (PSI). Paraquat is an effective herbicide for control of early emerging weeds that escape preemergence control because peanut plants can tolerate the injury caused by this herbicide when treated at-cracking (i.e., from peanut hypocotyl emergence to the 3– to 5–leaf stage) (Grichar, 1998a; Tubbs *et al.*, 2010; Wilcut and Swann, 1990). It is worth noting that peanut plants exhibit serious symptoms of injury after paraquat applications with significant levels of leaf burning and necrosis. However, those symptoms are transient, and plants recover shortly by producing new leaves (Johnson *et al.*, 1993). Although growers first trying paraquat applications at-cracking are usually concerned about the level of injury they observe, yield loss due to paraquat phytotoxicity is usually negligible, and when it has been documented, the reduction in yield is minimal compared with yield losses due to weed interference (Carley *et al.*, 2009; Wehtje *et al.*, 1991; Wilcut and Swann, 1990; Wilcut *et al.*, 1994b). Because paraquat cause a reduction in leaf area, and this represents a stress for peanut growth, it is important to make sure that other stresses are not present at the time of application. For example, it has been reported that peanut fields experiencing a combined stress from significant damage from thrips and paraquat injury had lower yields than fields with a single stress from either paraquat or from thrips feeding (Brecke *et al.*, 1996; Drake *et al.*, 2009). Paraquat can be combined with other herbicides to broaden the spectrum of control and to add residual activity. Herbicides that can be combined with paraquat include acifluorfen, 2,4-DB, bentazon and/or *S*-metolachlor for at-cracking applications to (Carley *et al.*, 2009; Wehtje *et al.*, 1992). Paraquat injury to peanut can be reduced by combining with bentazon, which decreases paraquat foliar absorption, although in some cases this may reduce absorption in certain weed species and lower weed control, as well (Wehtje *et al.*, 1992).

Although late emerging weeds impact yield less than those that emerge early in the growing season, they still should be controlled before the end of the critical period of weed interference to avoid peanut yield loss and weed seed bank growth (Bauer and Mortensen, 1992; Gallandt, 2006; Jones and Medd, 2000). The specific time when these postemergence control actions are implemented determines the number of actions needed and the success on weed control efficacy.

Application timing for postemergence herbicides should be chosen to maximize weed-free conditions until peanut canopy closure is reached while minimizing the number of applications. However, it is preferable to implement early control actions rather than delay postemergence applications to avoid letting weeds reach sizes that favor survival (Everman *et al.*, 2006; Wilcut, 1991). Herbicides commonly used for postemergence weed control in peanut include acifluorfen, lactofen, 2,4-DB, clethodim, sethoxydim, chlorimuron, diclosulam, imazethapyr, and imazapic (Grichar, 1997a,b; Grichar and Nester, 1997; Grichar and Sestak, 1998; Grichar and Dotray, 2010, 2011; Grichar *et al.*, 2001b, 2010b, 2012, 2013a).

Acetyl CoA-carboxylase (ACCase) inhibiting herbicides including clethodim, sethoxydim, and fluazifop-P-butyl provide effective grass weed control as well as high peanut safety (Burke *et al.*, 2004; Grichar, 1991, 1995). These herbicides are applied postemergence due to predominant leaf uptake, but they exhibit high levels of translocation, which helps killing growing points not directly exposed to the herbicide. ACCase inhibitors can be safely applied throughout peanut growing season without risk of reducing yield, but early season applications are preferred to ensure grass weed control. Despite their systemic activity, ACCase inhibitors are more effective controlling grass weeds at early growth stages (Grichar and Boswell, 1989).

Acifluorfen and lactofen are contact herbicides that block pigment biosynthesis by inhibiting the protoporhyrinogen oxidase (PPO). They must be applied preferably within two to three weeks after peanut emergence when weeds are small and have not produced many lateral buds to avoid weed recovery and regrowth (Jordan *et al.*, 1993). Because of their contact activity, these two herbicides are commonly combined with other herbicides such as 2,4-DB and bentazon and adjuvants such as crop oil concentrate to broaden the spectrum of weeds controlled, add systemic activity, and increase weed uptake and foliar necrosis (Burke *et al.*, 2002a; Ferrell *et al.*, 2013; Grichar, 1997b). The use in peanut fields of tank-mixes of acifluorfen or lactofen with 2,4-DB has been recommended to manage ALS–resistant weeds. However, acifluorfen, lactofen, and crop oil concentrate combinations applied early in the season cause variable levels of leaf burning on peanut, which only last 2 to 4 weeks without typically affecting yield (Ferrell *et al.*, 2013; Grey *et al.*, 2000; Grichar, 1997b; Dotray *et al.*, 2012). Dotray *et al.* (2012) reported that lactofen applied early in the growing season had no negative impact on peanut yield; however, lactofen applied between R5 (beginning seed) to R6 (full seed) stage of growth did result in approximately 5% yield loss, although peanut grade was not affected. Applications of acifluorfen caused similar yield reductions when applied at this same timing in previous research in Georgia (Baughman *et al.*, 2002). Despite the potential injury that postemergence PPO inhibitors might cause to peanut, their benefits on weed control tend to be larger. Grichar and Dotray (2011) reported that lactofen increased yield up to 22% over the weedy check due to effective weed control.

The discovery, in the 1990s, of herbicides that inhibit acetolactate synthase (ALS), provided a diverse group of selective herbicides for many crops. Among those chlorimuron, diclosulam, imazethapyr, and imazapic not only simplified production, but in many cases, increased weed control in peanut (Ducar *et al.*, 2009; Grichar, 1994, 1997a,c, 2008; Grichar *et al.*, 1992, 1999a, 2001a, 2001b, 2002a, 2005, 2012; Grichar and Nester, 1997; Grichar and Sestak, 2000a, Grichar and Dotray, 2015). These herbicides have two advantageous characteristics: i) they have a diverse group of susceptible weeds including broadleaf, grass and sedge species, and ii) they exhibit above and below ground control due to foliar and root uptake and soil residual activity (Grey *et al.*, 2003; Jordan *et al.*, 2009). Grichar *et al.* (2005) reported dimethenamid-P followed by imazapic or *S*-metolachlor followed by imazapic or imazethapyr, all applied postemergence, improved Texas millet control over those two soil-applied herbicides used alone. Palmer amaranth control was acceptable with imazapic or imazethapyr used alone (82 to 93%). However, imazapic applied postemergence following ethalfluralin improved Palmer amaranth control over ethalfluralin alone. Additionally, these ALS–inhibiting herbicides exhibit very consistent safety on peanut (Dotray *et al.*, 2001; Grey and Wehtje, 2005; Richburg *et al.*, 2006). Dotray *et al.* (2001) found that imazapic at 0.07

kg ha^{-1} applied weekly from ground cracking resulted in no reduction from the untreated check in peanut canopy height, canopy width, yield or grade. Because of all these benefits, growers have heavily relied on ALS–inhibiting herbicides not only for weed control in peanut but also in other rotational crops, which favored the evolution of ALS–resistant weeds making more challenging the control of resistant biotypes. Palmer amaranth and common ragweed ALS–resistant biotypes were first reported in peanut growing states in 1995 and 2006, respectively (Heap, 2025).

Imazapic is consistently among the top five most widely used herbicide in peanuts production in USA (Anonymous, 2024). Soon after its registration in 1996, peanut growers quickly incorporated imazapic into their herbicide programs because it effectively controlled the most common and challenging weed species without the need of tank-mixing other herbicides (Grichar, 1997a, 1997b, 1997c; Grichar and Sestak, 1998, 2000a). Moreover, among those ALS–inhibiting herbicides registered for use in peanut, imazapic provides the longest residual control. However, this residual activity also limits its use in some areas due to the fear of injury to subsequent rotational crops such as cotton. Another ALS–inhibiting herbicide also frequently used in peanut in the southeastern USA is diclosulam, which can be applied preemergence alone or in combination with other residual herbicides such as *S*-metolachlor or early postemergence (Bailey *et al.*, 1999; Besler *et al.*, 2008; Ducar *et al.*, 2009; Everman *et al.*, 2006; Grey *et al.*, 2001; Grichar *et al.*, 1999a; Grichar *et al.*, 2001b; Grichar *et al.*, 2004b; Grichar *et al.*, 2008a, 2008b). Grichar *et al.* (1999a) reported that diclosulam applied preplant incorporated in combination with ethalfluralin controlled Texas millet, Palmer amaranth, morningglory spp., and golden crownbeard >99%, devil's-claw [*Proboscidea louisianica* (Mill.) Thellung] 91%, and yellow nutsedge and purple nutsedge at least 89 and 72%, respectively. Diclosulam is also effective on troublesome weeds such as eclipta. Although widely used in the Southeastern region, due to injury concerns because of particular climatic and edaphic conditions diclosulam is not labeled for use in the Southwest peanut production regions.

Florida beggarweed can be difficult to control because it emerges considerably later than other weed species avoiding early season weed control (Cardina and Hook, 1989) and is capable of quickly covering the peanut plant right before canopy closure (Cardina and Brecke, 1991). In cases in which Florida beggarweed must be controlled late during the growing season, chlorimuron is an effective tool (Johnson *et al.*, 1992b). In these situations, chlorimuron is usually applied at or after peanut canopy closure (no sooner than 60 days after peanut emergence), but preferably before Florida beggarweed starts flowering. Chlorimuron can slightly decrease peanut growth and increase the incidence of tomato spotted wilt caused by a *Tospovirus* (Prostko *et al.*, 2009). Runner market types tend to be more affected by chlorimuron applications than Spanish and Valencia types usually exhibiting less elongation of lateral branches, sometimes preventing full canopy closure between rows (Johnson *et al.*, 1992a,b). Nonetheless, no consistent reductions in peanut yield have been reported (Prostko *et al.*, 2009; Wehtje and Grey, 2004).

Because peanut is a minor crop in comparison to other row crops such as field corn and soybeans, minimal effort from industry is devoted to the registration of herbicides for use in peanut. However, in response to the increase in herbicide resistance, efforts have been made to introduce new MOA. For example, fluridone, recently registered for use in peanut, has become a key preemergence herbicide for resistant weeds (Baughman *et al.*, 2016; Marshall *et al.*, 2016; Peterson *et al.*, 2016).

COMPATIBILITY OF HERBICIDES WITH OTHER PESTICIDES

Co-applying herbicides with other pesticides, plant growth regulators, and micronutrients is a common practice in peanut because of timing of application for abiotic and biotic stresses often overlap and because logistical challenges with large farming operations make tank-mixing attractive and convenient (Jordan *et al.*, 2011). However, this practice can negatively affect weed control in some instances (Chahal *et al.*, 2012b, 2013; Grichar, 1991; Grichar *et al.*, 2002b, 2013b; Jordan *et al.*, 2003a, 2011; Lancaster *et al.*, 2007, 2008). For example, efficacy of clethodim and sethoxydim on grass weed species and 2,4-DB and imazethapyr on broadleaf species can be reduced when copper-based fungicides are co-applied with these herbicides (Jordan *et al.*, 2003a; Lancaster *et al.*, 2005c, 2005d). Conversely, Lancaster *et al.* (2005a) found that tank-mixing 2,4-DB with different fungicides did not affect sicklepod control compared to 2,4-DB alone. These types of specific interactions between herbicides and other pesticides underscore challenges with determining whether certain tank mixtures are feasible. Applying herbicides with other pesticides sequentially or increasing the rate of the herbicide that is compromised by the tank mixture can compensate for the adverse interaction (Burke *et al.*, 2002b; Lancaster *et al.*, 2005b).

Grichar *et al.* (2013b) found that Texas millet, smellmelon, and southern crabgrass [*Digitaria ciliaris* (Retz. Koel] control was not influenced by the addition of pyraclostrobin, tebuconazole, or the premix of prothioconazole plus tebuconazole to clethodim or sethoxydim over either herbicide alone. Palmer amaranth control was variable with herbicide-fungicide antagonism noted with acifluorfen plus tebuconazole or imazethapyr plus pyraclostrobin over either herbicide alone. A fungicide by herbicide interaction in two of three years indicated that the combination of pyraclostrobin plus imazapic resulted in greater early leaf spot (*Cercospora arachidocola* S. Hori) than pyraclostrobin alone. The addition of acifluorfen to either tebuconazole or prothioconazole resulted in greater leaf spot than either of those fungicides alone in one of three years. No negative response for stem rot or Sclerotinia blight (*Sclerotinia minor* L.) control was noted with any combination. Peanut phytotoxicity (leaf chlorosis and necrosis) was greatest with combinations which included acifluorfen, lactofen, or 2,4-DB. No effect on peanut yield was noted with any herbicide-fungicide combinations.

In recent years, the complexity of tank mixtures has increased. McClean *et al.* (2017) reported that it was not uncommon for growers to co-apply 3 to 4 pesticides or other foliar-applied products to control weeds, insects and pathogens that cause disease in peanut or manage peanut growth. The issue of compatibility of 3 or more products when co-applied was addressed by Chahal *et al.* (2012a,c,d). While response was variable across pests, pesticides and other component mixtures, when performance was compromised, one product in the tank mixture affected efficacy, and including more components did not result in a complete loss of control (Chahal *et al.* 2012a,c,d). In most cases, weed control did not differ by more than 15% for most combinations when compared with herbicides applied alone. However, control did vary and application factors such as weed size, stress, water quality, and adjuvant can influence the degree of incompatibility (Jordan *et al.*, 2011). Chahal *et al.* (2012a,c,d) observed minimal effects of herbicides on efficacy of fungicides, insecticides, and plant growth regulators. Jordan *et al.* (2006, 2012) observed that herbicides did not adversely affect boron and manganese accumulation in peanut leaves or efficacy of fungicides, although the adjuvant used for herbicides (crop oil concentrate or nonionic surfactant) did affect the accumulation of those nutrients in tissue. Defining interaction of pesticides and other products applied to peanut continues to be a challenge in large part because of the number of products available for the major pest management disciplines, overlap of pests in the field that need to be controlled in a timely manner, and application variables that can affect response but may be unknown (Jordan *et al.*, 2011).

Weed control is affected not only by compatibility of co-application of herbicides but also by ability to safely apply herbicides based on peanut injury caused by other pests. For example, the ability of peanut to recover from early season injury caused by thrips can be reduced by paraquat (Brecke *et al.*, 1996; Chahal *et al.*, 2014; Drake *et al.*, 2009; Funderburk *et al.*, 1998; Herbert *et al.*, 1991). Drake *et al.* (2009) observed that peanut yield was especially vulnerable when thrips injury was moderate to severe and paraquat was applied. Yield loss by either injury from thrips feeding in absence of paraquat or by phytotoxicity from paraquat when injury from thrips was minor while the combination of both stresses affected yield substantially. Swann and Herbert (1999) reported that visible injury of peanut was greater when bentazon was applied to emerged peanut and phorate was applied in the seed furrow at planting than when aldicarb was the insecticide used.

FUTURE CHALLENGES FOR WEED MANAGEMENT IN PEANUT

Herbicide resistance evolution has resulted from the repeated use of herbicides with the same MOA without rotation or tank-mixing. This problem has been present in peanut as well as other crops rotated with peanut. Herbicide resistance has evolved faster and more frequently with ALS–inhibitors, which currently represent an important proportion of the most widely used postemergence herbicides in peanut. Thus, ALS–resistant weeds are perhaps the most important challenge for weed management in peanut production (Berger *et al.*, 2015; Wise *et al.*, 2009).

Postemergence herbicide options in peanut are limited if ALS–inhibitors are no longer effective. The fact that Palmer amaranth (all regions), cocklebur (Virginia-Carolina, Southwest), common ragweed (Virginia-Carolina), and prickly sida (Southwest), have been confirmed with resistance to ALS–inhibitors in peanut fields in southeastern USA (Berger *et al.*, 2015; Chandi *et al.*, 2012; Heap, 2025), indicates that a dramatic change in weed management will likely occur in the near future, especially considering the importance of herbicides such as imazapic and diclosulam in peanut production. Efforts to find alternative management strategies are extensive, but there are greater number of options available to manage ALS–resistant weeds in corn, cotton, and soybean than in peanut, for which the primary resistance management tool is PPO-inhibiting herbicides including acifluorfen, flumioxazin, and lactofen (Chandi *et al.*, 2012; Ferrell *et al.*, 2013). Unfortunately, other herbicides applied at planting or postemergence are only marginally effective on these weeds.

A common reaction by many growers, once ALS–resistant weeds are present in peanut fields, has been to shift to the use of PPO–inhibitors for preemergence and postemergence control because these herbicides can effectively control ALS–resistant individuals. However, there is concern that an overreliance on PPO–inhibitors will sooner rather than later favor resistance to this MOA. It is especially concerning that resistance to PPO-inhibitors is now present in Palmer amaranth populations (Heap, 2025), and this suggests that current strategies to manage ALS–resistant populations of this weed in peanut might not be sustainable. The problem is exacerbated because PPO–inhibitors are not only used in peanut, but also in other rotational crops such as cotton and soybean, which are including acifluorfen, lactofen, and flumioxazin to regain control of glyphosate– and ALS–resistant weed species (Culpepper *et al.*, 2006; Wise *et al.*, 2009). Therefore, integrated weed management programs that strongly emphasize not only herbicides, but also cultural practices will be critical to mitigate the impact of PPO–resistant weeds on peanut production.

Peanut used in a cotton rotation has been helpful to aid in the control of glyphosate resistant weeds that evolved in part due to overreliance on old cotton technology. New cotton and soybean cultivars with transgenic traits providing resistance to 2,4-D and dicamba will likely increase selection pressure for resistance to synthetic auxin herbicides. This might jeopardize the efficacy of 2,4-DB for the control of ALS–resistant weeds in peanut. If weeds evolve resistance to PPO–inhibitors and synthetic auxins, postemergence herbicides options for broadleaf weed control in peanut will be limited likely forcing growers to use more mechanical control, which could limit acreage and increase mechanical damage to the crop.

Demand for peanut by consumers in the USA and export markets for the Argentina peanut remain strong. However, consumers are more discriminating than ever before, especially in USA and European markets, and scrutiny over pesticide use may tighten, even for products that have been recently registered or have successfully completed the re-registration process. Demand by some consumers for organic peanut is high. Establishing adequate peanut populations and controlling weeds are the two most challenging aspects of peanut production in organic systems. Tolerance of peanut to insect damage and current cultivars with multiple disease resistance are adequate to produce acceptable peanut yield under many field conditions, especially when premiums for organically-produced peanut are available. However, improvements in weed control through more effective cultivation, use of cover crops, and optimization of other cultural practices will be necessary for sustainable production in this system.

The challenges offered by evolved resistance to herbicides used in peanut combined with the limited competitive ability of peanut with weeds creates a potentially devastating scenario for high-input, mechanized production systems. While continuing to use a diversity of herbicides with multiple mechanisms of action either sequentially or in tank-mixtures is important in managing evolved resistance to herbicides, developing effective crop rotations and managing herbicide resistance with emphasis on the soil seed bank in all crops in the rotation is also paramount. Deep tillage and the burial of weed seed enables more effective management when used in combination with other control practices including herbicides and cover cropping (Inman *et al.*, 2017; Price *et al.*, 2016). This approach may be effective in fields that are not susceptible to erosion or organic matter loss due to intense tillage. However, since peanut production often occurs in areas that are designated as highly erodible land by the Natural Resource Conservation Service, eliminating deep or intensive tillage might not be a desirable option.

Protecting peanut from other pests and maximizing emergence and row closure and incorporating in-season cultivation will be effective in some fields and with some weed communities. Hand-removal of escaped weeds early in the evolution of resistance may be the most important, last chance at managing resistance. However, this may be the most difficult approach, especially given other crops are experiencing similar issues with resistance and labor may be limited to remove escaped weeds before seed is produced. Mowing escaped weeds or using roller/wiper applicators to apply non-selective herbicides (e.g., paraquat) on weeds that are well above the canopy may become more important even though these practices are time consuming and not completely effective. As a whole, weed management in peanut, like other crops, will require a more holistic approach if the trend in herbicide resistance continues.

RESEARCH NEEDS AND FUTURE TECHNOLOGIES

Current and future challenges for weed management in peanut are undoubtedly linked to the decreasing number of effective herbicide options and the need to maximize the efficiency of control actions in larger farms. It is likely that weed escapes and more variability of weed populations in space and time will also complicate weed management. Therefore, technologies that enable fast and accurate monitoring of weed populations, and record keeping of efficacy of weed control actions, will greatly help make better use of available weed control options and to manage weed seed banks more effectively. Unmanned aerial vehicles (UAVs) including fixed-wing and copter drones coupled with remote sensing and imaging technologies are promising tools to increase our ability to detect, map, and quantify weed populations in peanut fields before, during, and after weed control actions at a relatively low cost and time (Huang *et al.*, 2017; Torres-Sánchez *et al.*, 2013). This information will be extremely valuable not only to plan and assess weed control actions within the peanut growing season, but more importantly to assess whether the weed management strategy is indeed maintaining weed populations at the desired levels. This latter point will only be possible if weed mapping is done regularly within and across years.

Weed management research in peanut will also have to change in the time scale in which weed control success is assessed. Traditionally, weed control is evaluated only during the growing season when the crop is present. This approach is valuable when control is high (e.g., >95%); however, as herbicide efficacy decreases over time and weed escapes become more frequent and serious, considering how weed seed banks can change will help identify trends and more importantly plan corrective actions. Combining weed mapping, databases, weed population dynamic models and decision aids based on automated digital technologies will allow peanut growers to acquire the necessary information to make better informed decisions in real-time at a relatively low cost (Fennimore *et al.*, 2016; Pongnumkul *et al.*, 2015; Shaw, 2005). There are efforts to help peanut growers improve weed management decision making. For example, the Herbicide Application Decision Support System (WebHADSS) is a threshold-based weed management decision system that uses a ranking of the competitiveness of major weeds in peanut to choose cost-effective postemergence herbicides (Bennett *et al.*, 2003). Although in the past, this type of decision-making tool has not been adopted by growers for day-to-day weed management, they have become a valuable tool for educational programs to describe how herbicide selection depends on the relationship between crop yield and the weed community, density and distribution (Jordan *et al.*, 2003b; Robinson *et al.*, 2007). Refinement and utilization of decision support systems in combination with multi-year data recording, automated technologies, and incorporating weed resistance into a model like WebHADSS will likely increase the ability of peanut growers to manage more variable weed populations optimizing the trade-off between weed control cost, time constraints and yield protection.

In other row crops, engineering resistance to herbicides with MOAs for which weeds have not evolved resistance seems to be the predominant solution to current weed problems, this option is unlikely to be implemented in peanut because of public concerns about genetic engineering in a crop of high importance for human nutrition. Therefore, the future of weed management in peanut seems to rely on robust integrated weed management programs that will depend less on herbicides and more on cultural and mechanical practices.

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