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Author for correspondence:
W. Carroll Johnson III,
Email: Carroll.Johnson@ars.usda.gov

Integrating cultivation using a tine weeder with herbicides in conventional peanut production

W. Carroll Johnson III[1] and Xuelin Luo[2]

[1]Research Agronomist, USDA-ARS, Crop Protection and Management Research Unit, Tifton Campus, Tifton, GA, USA and [2]Research Statistician, University of Georgia, Tifton Campus, Tifton, GA, USA

Abstract

Research from the 1980s reported sweep cultivation being a cost-effective component in an integrated system to manage weeds in peanut. Previous weed management research conducted on organic peanut indicated that repeated cultivation with a tine weeder was an effective component in that production system. Studies were conducted in Tifton, GA, from 2014 through 2017 to determine whether tine weeding can be integrated with herbicides in conventional peanut production to supplement herbicides. Experiments evaluated a factorial arrangement of eight herbicide combinations and two levels of cultivation using a tine weeder. Herbicides were labeled rates of ethalfluralin PRE, *S*-metolachlor PRE, imazapic POST, ethalfluralin PRE + *S*-metolachlor PRE, ethalfluralin PRE + imazapic POST, *S*-metolachlor PRE + imazapic POST, ethalfluralin PRE + *S*-metolachlor PRE + imazapic POST, and a nontreated control. The herbicides chosen were based on knowledge of the weed species composition at the research sites and their common use in peanut. Cultivation regimes were cultivation with a tine weeder (six times at weekly intervals) and a noncultivated control. Benefits of tine weeding supplementing control from herbicides varied according to herbicide and weed species. For example, annual grasses were effectively controlled (88% to 97%) by ethalfluralin or *S*-metolachlor and did not need cultivation to supplement control provided by the herbicides. However, imazapic alone did not effectively control (54% to 75%) annual grasses and needed supplemental control from cultivation with the tine weeder. Similarly, imazapic effectively controlled (84% to 93%) smallflower morningglory and did not require cultivation to supplement control from the herbicide. However, cultivation with the tine weeder improved smallflower morningglory control (76% to 95%) when supplementing ethalfluralin or *S*-metolachlor. Peanut yields did not respond to any of the herbicide combinations integrated with cultivation using the tine weeder. During the time period when peanut was cultivated, there was greater total rainfall and more days of rainfall events in 2014 and 2017 compared with the other years. Rainfall and wet soils reduced the performance and weed control benefits of the tine weeder. This highlights the risk of depending on cultivation for weed control.

Introduction

Cultivation as a form of mechanical weed control was commonly used in crop production for many years. When cultivation using sweeps was integrated with herbicides into a weed management system, control of troublesome weeds in soybean [*Glycine max* (L.) Merr.] improved. Sicklepod [*Senna obtusifolia* (L.) H. S. Irwin & Barneby] was historically a troublesome weed of soybean, and control improved when sweep cultivation was used with metribuzin, alachlor, and 2,4-DB (Shaw and Coats 1988). Similarly, sweep cultivation plus imidazolinone herbicides improved sicklepod control over the imidazolinone herbicides alone (Newsom and Shaw 1994, 1996; Shaw et al. 1991). Control of troublesome weeds in cotton (*Gossypium hirsutum* L.) using diuron or fluometuron was improved when cultivated with sweeps after herbicide treatment (Snipes et al. 1984). In each of these cases, herbicides were marginally effective in controlling the troublesome species, and cultivation targeted escapes.

In peanut production, cultivation was also integrated with herbicides to control troublesome weed species. Bridges et al. (1984) studied an integrated system of herbicides and sweep cultivation for broad-spectrum weed control in peanut. The herbicides used in those studies were various combinations of benefin, vernolate, alachlor, dinoseb, naptalam, and chloramben. A system of herbicides plus sweep cultivation provided the best weed control, greatest peanut yield, and net return compared with any of the herbicides alone or cultivation alone. Follow-up trials using a similar array of herbicides and cultivation were conducted at a site with heavy infestations of Texas millet [*Urochloa texana* (Buckley) R. Webster] (Wilcut et al. 1987). In those trials, the results were similar to those previously reported; herbicides integrated with sweep cultivation were superior to herbicides alone and cultivation alone. It is worth noting that in both trials (Bridges et al. 1984; Wilcut et al. 1987), none of the herbicides evaluated are currently used to any significant degree in peanut production, and most are no longer commercially available

(Holbrook et al. 2013). These results paralleled grower experiences during that time period when county agent surveys reported approximately 73% of the 1985 Georgia peanut acreage was cultivated (WCJ, unpublished data). Peanut is inherently vulnerable to injury from sweeps and increased incidence of stem rot (*Sclerotium rolfsii* Sacc.) caused by soil movement onto the peanut crown (Boyle 1952, 1956, 1961). Despite the heightened disease risk of cultivating peanut, the weed management benefit of cultivation to supplement older herbicide technologies during that era was substantial.

During the 1990s and 2000s, imazethapyr, imazapic, diclosulam, and flumioxazin were registered for use on peanut and provided broad-spectrum control of many troublesome weeds compared with earlier herbicide technologies (Holbrook et al. 2013). Those herbicide registrations, along with others for specific weed infestations, improved overall weed control in peanut, and escapes were less common compared with previous time periods. In many cases cultivation was no longer necessary. While weed control improved, a result was greater reliance on herbicides compared with earlier systems. Relying solely on chemical weed control in peanut creates a condition that promotes weed resistance to commonly used herbicides.

Weed management research in organic peanut has systematically studied many diverse methods to improve weed management, and cultivation with a tine weeder offered promise as a useful weed control tool in that production system. The tine weeder is a high-speed and lightweight implement made of series of spring-steel rods arranged in multiple rows that displaces seedling weeds using vibratory action of the tines. Repeated cultivation with a tine weeder effectively controlled annual grasses and small-seeded broadleaf weeds in organic peanut (Johnson and Davis 2015; Johnson et al. 2012a, 2012b; Wann and Tubbs 2014; Wann et al. 2011). While the soil surface is thoroughly disturbed to a depth of 1.0 cm by the tine weeder, very little soil is displaced. Interestingly, intensive cultivation with the tine weeder did not consistently affect incidence of stem rot in organic peanut (Johnson et al. 2018), which was contradictory to long-standing peanut production philosophies (Boyle 1952, 1956, 1961).

With the heavy dependence on herbicides for weed management in conventional peanut production and consistent weed control benefits of cultivation using the tine weeder in organic peanut, there are opportunities to integrate cultivation using the tine weeder into conventional peanut production to improve overall weed management and perhaps lessen the need for multiple herbicide applications. An additional benefit would be a better balanced weed control system that would lessen selection pressure for herbicide resistance. Therefore, studies were conducted for four growing seasons beginning in 2014 to evaluate combinations of herbicides and tine weeding in an integrated system of weed control in conventional peanut production.

Materials and methods

Irrigated field trials were conducted at the University of Georgia Ponder Research Farm near Ty Ty, GA (31.510551°N, 83.642605°W) from 2014 through 2017. Specific sites of experiments each year on the research farm differed but remained in close proximity. Soil at each location was a Tifton loamy sand (fine-loamy, kaolinitic, thermic Plinthic Kandiudults) with 90% sand, 6% silt, 4% clay, and 0.8% organic matter. The soil at this location is representative of soils in the southeastern U.S. peanut-producing region and infested with weeds that are common pests of the crop.

Table 1. Monthly rainfall summaries during the cultivation period.[a]

	Monthly rainfall total (cm)				Rainfall days			
	2014	2015	2016	2017	2014	2015	2016	2017
May	12.9	2.1	6.6	7.9	6	3	6	6
June	14.1	10.2	12.2	24.9	22	14	11	22
July	3.7	22.9	3.9	4.6	11	14	7	11
Total	30.7	35.2	22.7	37.4	39	31	24	39

[a]Data were recorded at the University of Georgia Ponder Farm (known as "Ty Ty" station) of the Georgia Automated Weather Network, approximately 300 m from the location of these experiments; www.georgiaweather.net.

The experimental design was a factorial arrangement of eight herbicide regimes and two levels of cultivation in a randomized complete block design with four replications. Herbicide treatments were tailored to the weed history of the research site. Herbicides evaluated were ethalfluralin (Sonalan HFP®, Dow AgroSciences, 9330 Zionsville Road, Indianapolis, IN) (0.8 kg ai ha^{-1}) PRE, *S*-metolachlor (Syngenta Crop Protection, P.O. Box 18300, Greensboro, NC) (1.4 kg ai ha^{-1}) PRE, imazapic (Cadre®, BASF, 26 Davis Drive, Research Triangle Park, NC) (71 g ai ha^{-1}) EPOST, ethalfluralin PRE + *S*-metolachlor PRE, ethalfluralin PRE + imazapic EPOST, *S*-metolachlor PRE + imazapic EPOST, ethalfluralin PRE + *S*-metolachlor PRE + imazapic EPOST, and a nontreated control. PRE treatments were applied immediately after peanut planting and activated with overhead sprinkler irrigation (7.6 mm) the same day as application. Imazapic EPOST was applied approximately 3 wk after peanut emergence, when the majority of the emerged weeds were at the cotyledon to 4-leaf stage of growth and included a nonionic surfactant (0.25% v/v). Herbicide treatments were applied with a tractor-mounted CO_2-pressurized plot sprayer, calibrated to deliver 234 L ha^{-1} at 207 kPa using low-drift Turbo TeeJet® spray tips (TeeJet® Technologies, 200 W. North Avenue, Glendale Heights, IL).

Cultivation regimes used a tine weeder (Aerostar Tined Weeder, Einböck GmbH & CoKG, Schatzdorf 7, 4751 Dorf an der Pram, Austria) six times at weekly intervals and a noncultivated control. Cultivations began 4 d after peanut was seeded. The tine weeder used in these trials tilled the width of the seedbed—a swath 1.8-m wide. Downward tension of tines located immediately above the crop row was adjusted by the use of mechanical hangers, each having several hooks on which tines over the row were lifted to prevent crop damage. Gauge wheels were attached to the front of the tine weeder to add lateral stability to the implement.

Individual plots were 1.8-m wide and 6.1-m long. 'Georgia-06G' peanut was seeded mid-May each year in rows spaced 91 cm apart, to a depth of 5 cm. Other than weed control, peanut production and pest management practices were consistent with those recommended by the Georgia Extension Service (Beasley et al. 1997).

Visible estimates of weed control compared with nontreated plots were assessed in midseason using a scale of 0 to 100, where 0 = absolutely no weed control and 100 = complete weed control. Peanut yields were obtained by preharvest mowing to cut tops of tall weeds, digging, inverting, air-curing to 12% to 15% moisture, and combining peanut from the entire plot using commercial two-row equipment. Yield samples were mechanically cleaned to remove foreign material, particularly weed biomass, with yields reported as cleaned farmer stock peanut.

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Table 2. Interactive effects of herbicides and cultivation with a tine weeder on annual grass control in peanut at Ty Ty, GA, 2014 to 2017.

Herbicide treatment[a]	Cultivation[b]	Southern crabgrass control[c,d]			Goosegrass control[c,d]
		2014	2015	2016	2017
		%			
Ethalfluralin					
	Cultivated	95 a	94 ab	95 a	94 a
	Noncultivated	93 ab	88 abc	93 a	94 a
S-metolachlor					
	Cultivated	95 a	94 ab	95 a	95 a
	Noncultivated	97 a	90 ab	95 a	95 a
Imazapic					
	Cultivated	62 bc	90 ab	92 a	95 a
	Noncultivated	59 c	75 bcd	54 b	61 b
Ethalfluralin + *S*-metolachlor					
	Cultivated	94 a	92 ab	94 a	94 a
	Noncultivated	97 a	92 ab	95 a	95 a
Ethalfluralin + imazapic					
	Cultivated	94 a	93 ab	95 a	95 a
	Noncultivated	95 a	70 cd	95 a	95 a
S-metolachlor + imazapic					
	Cultivated	97 a	95 a	95 a	95 a
	Noncultivated	91 ab	45 ef	95 a	95 a
Ethalfluralin + *S*-metolachlor + imazapic					
	Cultivated	98 a	93 ab	95 a	95 a
	Noncultivated	97 a	54 de	95 a	95 a
Nontreated					
	Cultivated	73 abc	91 ab	92 a	95 a
	Noncultivated	43 c	26 f	24 b	34 c

[a]Ethalfuralin (0.8 kg ai ha^{-1}) applied PRE (immediately after planting), imazapic (71 g ai ha^{-1}) applied EPOST (approximately 3 wk after crop emergence), *S*-metolachlor (1.4 kg ai ha^{-1}) applied PRE.
[b]Cultivation six times with a tine weeder at weekly intervals beginning 4 d after planting.
[c]Weed densities: goosegrass, 1 plant m^{-2} in 2017; southern crabgrass, 5, 10, and 5 plants m^{-2} in 2014, 2015, and 2016, respectively.
[d]Means in a column followed by the same letter are not different according to Tukey-Kramer LSD ($P \leq 0.05$).

Data were analyzed using PROC GLIMMIX (SAS Institute, 100 SAS Campus Drive, Cary, NC). Degrees of freedom were partitioned to test singularly and in combination the effects of herbicides and cultivation on visible estimates of weed control and peanut yield. Means were separated using Tukey-Kramer LSD ($P \leq 0.05$).

Results and discussion

There were multiple interactions between herbicide treatments and tine weeding for all parameters measured. Therefore, interactive means for all data are presented. Total rainfall and days with rainfall events during the periods when peanut was cultivated differed among years, which affected both the timing of cultivation and overall performance of the tine weeder (Table 1). For that reason, data are presented by year for all parameters.

Annual grass control

Southern crabgrass [*Digitaria ciliaris* (Retz.) Koeler] was present from 2014 through 2016. For each herbicide treatment evaluated in 2014, there was no difference in southern crabgrass control between cultivation with a tine weeder and noncultivated (Table 2). However, southern crabgrass control differed among herbicide treatments. Herbicide treatments that included ethalfluralin and/or *S*-metolachlor controlled southern crabgrass in 2014 better than imazapic alone, with southern crabgrass control from imazapic alone not differing from the nontreated control. In 2015, tine weeding improved southern crabgrass control over noncultivated peanut when treated with ethalfluralin + imazapic, *S*-metolachlor + imazapic, and ethalfluralin + *S*-metolachlor + imazapic and in the nontreated control (Table 2). For the remaining herbicide treatments, tine weeding did not improve southern crabgrass control. In 2016, tine weeding improved southern crabgrass control over the noncultivated check only when treated with imazapic alone or when not treated with herbicides. Otherwise, treatments that included ethalfluralin and/or *S*-metolachlor did not need tine weeding to improve southern crabgrass control.

Goosegrass [*Eleusine indica* (L.) Gaertn.] was the predominant annual grass in 2017. Goosegrass control was improved by tine weeding when treated with imazapic alone or not treated with herbicides (Table 2). Herbicide treatments that included ethalfluralin and/or *S*-metolachlor effectively controlled goosegrass, and tine weeding was not needed to improve control. These results with goosegrass are similar to results with southern crabgrass in 2016.

Smallflower morningglory control

Smallflower morningglory was present each year of the study, from 2014 through 2017. In 2014, smallflower morningglory control from each of the herbicide treatments was not improved by tine weeding (Table 3). In 2015, smallflower morningglory control was improved by tine weeding after treatment with ethalfluralin and/or *S*-metolachlor. In those cases, ethalfluralin and/or *S*-metolachlor did not adequately control smallflower morningglory unless supplemented with tine weeding. Smallflower morningglory control in 2015 from herbicide treatments that included imazapic was generally acceptable and was not improved by tine weeding. In 2016, results similar to those of the previous year were seen.

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Table 3. Interactive effects of herbicides and cultivation with a tine weeder on smallflower morningglory control in peanut at Ty Ty, GA, 2014 to 2017.

Herbicide treatment[a]	Cultivation[b]	Smallflower morningglory control[c,d]			
		2014	2015	2016	2017
		—%			—
Ethalfluralin					
	Cultivated	76 abc	87 abc	95 a	87 ab
	Noncultivated	61 bc	39 f	79 b	32 d
S-metolachlor					
	Cultivated	80 abc	90 ab	94 a	93 a
	Noncultivated	59 cd	63 e	79 b	59 c
Imazapic					
	Cultivated	90 ab	92 ab	95 a	91 ab
	Noncultivated	86 abc	84 abcd	93 a	84 ab
Ethalfluralin + *S*-metolachlor					
	Cultivated	86 abc	90 ab	95 a	92 a
	Noncultivated	79 abc	70 de	84 ab	70 bc
Ethalfluralin + imazapic					
	Cultivated	90 ab	95 a	95 a	92 a
	Noncultivated	87 ab	87 abc	95 a	92 a
S-metolachlor + imazapic					
	Cultivated	90 ab	90 ab	95 a	92 a
	Noncultivated	86 abc	86 abc	95 a	91 ab
Ethalfluralin + *S*-metolachlor + imazapic					
	Cultivated	89 ab	94 ab	96 a	91 ab
	Noncultivated	87 ab	82 bcd	95 a	95 a
Nontreated					
	Cultivated	68 abc	74 cde	91 a	80 abc
	Noncultivated	32 c	23 f	27 c	22 d

[a]Ethalfuralin (0.8 kg ai ha^{-1}) applied PRE (immediately after planting), imazapic (71 g ai ha^{-1}) applied EPOST (approximately 3 wk after crop emergence), *S*-metolachlor (1.4 kg ai ha^{-1}) applied PRE.
[b]Cultivation six times with a tine weeder at weekly intervals beginning 4 d after planting.
[c]Weed densities: smallflower morningglory, 3, 5, 2, and 3 plants m^{-2} in 2014, 2015, 2016, and 2017, respectively.
[d]Means in a column followed by the same letter are not different according to Tukey-Kramer LSD ($P \leq 0.05$).

Treatments that included imazapic did not need tine weeding to adequately control smallflower morningglory. In contrast, neither ethalfluralin nor *S*-metolachlor adequately controlled smallflower morningglory in 2016 unless cultivated with a tine weeder. Results in 2017 were similar to those of 2015, with smallflower morningglory control using any treatment that included imazapic not differing when cultivated with the tine weeder or not cultivated. Treatments that included ethalfluralin and/or *S*-metolachlor did not adequately control smallflower morningglory in the absence of cultivation. However, plots treated with ethalfluralin and/or *S*-metolachlor followed by tine weeding had smallflower morningglory control equivalent to imazapic plots.

Peanut yield

There were no differences in 2014 peanut yield among all possible combinations of herbicide treatments and tine weeding (Table 4). When herbicides were applied in 2015, there were no differences in peanut yield among all the herbicide and cultivation treatment combinations. In plots not treated with herbicides in 2015, tine weeding improved peanut yield by 73% over yield from noncultivated peanut. Similar results were seen in 2016. In each of the herbicide combinations evaluated in 2016, peanut yields did not differ between cultivation with a tine weeder and noncultivated. However, in plots not treated with herbicides, cultivation with a tine weeder increased peanut yield by 42% over noncultivated peanut. In 2017, there were no yield differences among any of the possible combinations of herbicides and tine weeding.

The premise of this study was that the demonstrated effectiveness of cultivation using a tine weeder from organic peanut weed control research could supplement herbicides in conventional peanut production and lessen herbicide dependence. Results from this 4-yr study are inconclusive. There is evidence that tine weeding improves overall control of some weeds with herbicides that are not overly effective on those species. One example is annual grass control using imazapic being improved by tine weeding in 2 out of 4 yr (Table 2). The other example would be smallflower morningglory control using ethalfluralin and/or S-metolachlor being improved by tine weeding 3 out of 4 yr (Table 3). These results are with two annual grasses (southern crabgrass and goosegrass) and one dicot species (smallflower morningglory). While these species are common in the peanut-producing region of the southeastern United States, they are not considered troublesome (Webster 2013).

It was surprising that peanut yields were largely nonresponsive to the interactive effects of herbicide treatments and tine weeding (Table 4). The only yield differences in this 4-yr study were between peanut cultivated with a tine weeder and not cultivated, both in the absence of herbicides. However, there were no yield differences among peanut treated with any of the herbicide combinations and between cultivation regimes, despite the occasional differences in weed control. Control of both southern crabgrass and smallflower morningglory in 2014 did not differ among all the possible combinations of herbicides and tine weeding (Tables 2 and 3), and no peanut yield effects were seen (Table 4). In 2014, there were 39 rainfall events totaling 30.7 cm recorded from May through July (Table 1). Out of 92 d during that period, there were 39 d of rainfall; rainfall nearly 1 out of 3 d. Similar results were noted in 2017; 39 d of rainfall events totaling 37.4 cm. The reason for the discrepancy between weed control results and peanut yield response may be due to rainfall events

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Table 4. Interactive effects of herbicides and cultivation with a tine weeder on peanut yield at Ty Ty, GA, 2014 to 2017.

Herbicide treatment[a]	Cultivation[b]	Peanut yield[c]			
		2014	2015	2016	2017
		kg ha^{-1}			
Ethalfluralin					
	Cultivated	4,140 a	5,540 ab	5,480 a	4,360 a
	Noncultivated	3,980 a	4,090 ab	5,130 ab	4,970 a
S-metolachlor					
	Cultivated	4,160 a	5,870 a	5,360 ab	4,810 a
	Noncultivated	3,540 a	4,350 ab	5,740 a	4,790 a
Imazapic					
	Cultivated	3,960 a	5,080 ab	5,540 a	4,990 a
	Noncultivated	3,950 a	5,700 a	4,820 ab	4,480 a
Ethalfluralin + *S*-metolachlor					
	Cultivated	4,250 a	5,920 a	4,980 ab	4,160 a
	Noncultivated	4,240 a	4,470 ab	5,380 ab	5,030 a
Ethalfluralin + imazapic					
	Cultivated	3,870 a	5,850 a	5,230 ab	4,120 a
	Noncultivated	4,250 a	5,770 a	5,910 a	4,730 a
S-metolachlor + imazapic					
	Cultivated	4,290 a	5,820 a	5,640 a	4,190 a
	Noncultivated	3,950 a	4,050 ab	5,590 a	5,320 a
Ethalfluralin + *S*-metolachlor + imazapic					
	Cultivated	4,300 a	5,940 a	5,180 ab	4,480 a
	Noncultivated	4,200 a	4,350 ab	5,580 a	5,200 a
Nontreated					
	Cultivated	3,620 a	6,060 a	5,140 ab	4,100 a
	Noncultivated	3,800 a	3,500 b	3,630 c	4,380 a

[a]Ethalfuralin (0.8 kg ai ha^{-1}) applied PRE (immediately after planting), imazapic (71 g ai ha^{-1}) applied EPOST (approximately 3 wk after crop emergence), *S*-metolachlor (1.4 kg ai ha^{-1}) applied PRE.
[b]Cultivation six times with a tine weeder at weekly intervals beginning 4 d after planting.
[c]Means in a column followed by the same letter are not different according to Tukey-Kramer LSD ($P \leq 0.05$).

during the cultivation period that may have negated the benefits of tine weeding. With the experiments being planted in mid-May, the majority of the six weekly cultivations were in May and June, with the last cultivation in early July. Rainfall events altered cultivation scheduling and caused delays that were detrimental to overall weed control from tine weeding. Additionally, moist or wet soils affect ability of the tine weeder to fatally displace emerging weed seedlings, with many weed seedlings reestablishing in moist soil after tine weeding. While rainfall events affecting tine weeding cannot fully explain all of the weed control and peanut yield responses in these studies, it is clear that frequent rainfall adds risk to depending on this form of mechanical weed control.

The herbicides evaluated in these trials were chosen based on knowledge of the weed histories at the location of the experiments. Given the depth of weed control options available for use on conventional peanut and the diversity of weed species in the region, extensive research is needed to fully determine the value of cultivation with a tine weeder in conventional peanut production. Expanded research will also determine whether the tine weeder will broaden options for the management of weeds with documented resistance to commonly used herbicides, specifically Palmer amaranth (*Amaranthus palmeri* S. Watson), hopefully adding stability to the overall weed management system.

Author ORCID. W. Carroll Johnson https://orcid.org/0000-0003-0254-3220

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