Impact of Weed Management on Peanut Yield and Weed Populations the Following Year

A.T. Hare[1], D.L. Jordan[2*], R.G. Leon[3], K.L. Edmisten[4], A.R. Post[3], D.J. Mahoney[5], and D. Washburn[6]

ABSTRACT

Field studies were conducted in 2016 and 2017 at two locations in North Carolina to evaluate common ragweed (*Ambrosia artemiisifolia* L.) (Lewiston-Woodville) and Palmer amaranth (*Amanthus palmeri* S. Wats) control (Rocky Mount), peanut (*Arachis hypogaea* L.) yield, and estimated economic return when herbicides were applied postemergence (POST) at 2 or 6 weeks after planting (WAP); 2 and 4 WAP; 4 and 6 WAP; and 2, 4, and 6 WAP. During the following growing season, cotton (*Gossypium hirsutum* L.) was planted directly into the same plots to determine the impact of weed management during the previous season on weed density. In absence of herbicides, peanut yield was 880 and 1110 kg/ha at Lewiston-Woodville and Rocky Mount, respectively. When weed control depended on a single herbicide application, yield ranged from 1760 to 2660 kg/ha at Lewiston-Woodville, and 2080 to 2480 kg/ha at Rocky Mount. When herbicides were applied twice, peanut yield ranged from 2690 to 3280 kg/ha at Lewiston-Woodville and 3420 to 3840 kg/ha at Rocky Mount. The greatest yields were recorded when herbicides were applied two or three times. Applying herbicides increased the estimated economic return of peanut compared to the non-treated control (NTC). In cotton the following year, common ragweed populations at Lewiston-Woodville were greater following the NTC or a single herbicide application 2 WAP compared to more intensive herbicide programs. Palmer amaranth density at Rocky Mount the following year in cotton was not affected by weed management the previous year in peanut. These results illustrate the relative importance of timing and duration of weed management for peanut and how they influence weed emergence in the following cotton rotational crop.

Key Words: Timing of herbicide application, estimated economic return.

INTRODUCTION

Timely and effective herbicide spray programs are essential for adequate weed control in crop production (Wilcut and Askew, 1999). However, the rapid growth of many problematic broadleaf weeds influences the effectiveness of control (Horak and Loughin, 2000). A major concern in the southeastern United States is crop interference from Palmer amaranth (*Amaranthus palmeri* S. Wats) and common ragweed (*Ambrosia artemisiifolia* L.). Weeds compete with crops for light and other resources and can complicate mechanical harvest (Horak *et al*., 1994; Morgan *et al*., 2001; Young *et al*., 1982). Weeds must be controlled throughout the growing season to avoid yield losses in peanut (*Arachis hypogaea* L.) (Jordan, 2018; Wilcut *et al*., 1995). As the duration of interference from weeds increases, yield of peanut and other crops often decreases (Zimdahl, 2004). Minimizing contributions of weed seed to the soil seedbank is important in managing weeds in succeeding crops and addressing evolved resistance to herbicides. One of the main concerns in peanut production is interference of common ragweed and Palmer amaranth with peanut and how in-season control practices affect weed density in the following rotational crop.

Palmer amaranth, which originated in southern California and Mexico, is difficult to control in peanut and crops rotated with peanut in the United States (Leon *et al*., 2019). Morphological features and capacity to produce flowers at almost any growth stage makes Palmer amaranth successful in exploiting diverse environments (Sauer, 1957). In California, Keeley *et al*. (1987) reported that Palmer amaranth can emerge in early March when soils have reached a temperature of 18 C and continue to infest fields into October. In Georgia,

[1]Graduate Research Technician, Department of Crop and Soil Sciences, Raleigh, NC 27695.
[2]William Neal Reynolds Professor, Department of Crop and Soil Sciences, Department of Crop and Soil Sciences, Raleigh, NC 27695.
[3]Assistant Professors, Department of Crop and Soil Sciences, Department of Crop and Soil Sciences, Raleigh, NC 27695.
[4]Professor, Department of Crop and Soil Sciences, Department of Crop and Soil Sciences, Raleigh, NC 27695.
[5]Graduate Student, Department of Crop and Soil Sciences, Department of Crop and Soil Sciences, Raleigh, NC 27695.
[6]North Carolina Farm School Associate, Department of Agricultural and Resource Economics, North Carolina State University, Raleigh, NC 27695.
*Corresponding author e-mail: david_jordan@ncsu.edu

Webster and Grey (2015) found that glyphosate-resistant Palmer amaranth planted in early May produced 446,000 seeds per plant, while Palmer amaranth planted six weeks later produced 50 percent fewer seed. Palmer amaranth planted 9 and 12 weeks later had 89 and 99% fewer seeds, respectively (Webster and Grey, 2015). Horak and Loughin (2000) found that under natural growing conditions and in the absence of other weed or crop species, Palmer amaranth grew 0.18 to 0.21 cm/growing degree day (GDD). Because of its rapid growth rate, the application window for optimum control of Palmer amaranth may be relatively short (Horak and Loughin, 2000). The application interval for effective control of Palmer amaranth could be as soon as one week after weed emergence based on maximum height recommended for herbicides used on peanut (Jordan, 2018).

Morgan *et al.* (2001) reported that when 1.1 Palmer amaranth plants/m^2 were present, cotton (*Gossypium hirsutum L.*) yield was reduced by 54%. Yield loss of field corn (*Zea mays* L.) ranged from 11 to 91% at 0.66 to 10 plants/m^2 when Palmer amaranth emerged with the corn (Massinga *et al.*, 2001). At a density of one plant/m of row, yield loss in peanut was predicted to be 28% (Burke *et al.*, 2007). Yield of soybean [*Glycine max* (L.) Merr.] was reduced 79% when 10 plants/m^2 were present (Bensch *et al.*, 2003). Palmer amaranth can also reduce harvesting efficiency, which is problematic for agronomic crops that are mechanically harvested (Young *et al.,* 1982). Smith *et al.* (2000) reported that when 0.33 Palmer amaranth plants/m^2 were present in cotton, harvest time increased by 3.5 times compared to weed-free conditions. The increased harvest time was a result of the operator having to stop the machine to dislodge stalks from moving parts (Smith *et al.*, 2000). When Palmer amaranth density exceeds 0.66 plants/m^2, damage to harvest equipment can occur (Morgan *et al.*, 2001).

Common ragweed is a monoecious annual plant native to North America and is common to the temperate regions of the United States (Oosting, 1942). Common ragweed will generally dominate in the second year if soil disturbance is halted, shading out some of the species that dominated in the first year (Oosting, 1942), which relates to the increase of common ragweed problems in no-till or reduced tillage systems in soybean and corn (Jordan *et al.*, 2014). Common ragweed can emerge in late April as soil warms and will continue to emerge until temperatures become unfavorable sending the seeds back into dormancy (Jordan *et al.*, 2014).

Coble et al. (1981) reported that 0.11 common ragweed/m^2 reduced soybean yield by 32.5 kg/ha on average. When grown in 30% shade, common ragweed has been noted to grow just as well as sweet corn (*Zea mays* L. var. *rugosa*) and dry bean (*Phaseolus vulgaris* Herrm) but much poorer than these crops in 73% shade (Dickerson, 1968). Predicted yield loss in peanut is 40% when 1 common ragweed is present/m^2 for the entire season (Clewis et al., 2001). Everman et al. (2008) reported the critical period of weed control in peanut for mixed broadleaf populations that included common ragweed of 2.6 to 8 WAP.

The 2- to 3-week period after flowering is the critical time for weed management in most of the weed species to prevent weeds from producing viable seeds (Hill *et al.*, 2016). Most weed management studies only evaluate a single growing season failing to quantify the impact these weed management strategies may have on contributions to the soil seedbank (Inman *et al.*, 2016). Information relative the impact of weed management in peanut on succeeding crops is limited. This study was designed to evaluate the effects that timing of weed management have on weed control, peanut yield, estimated economic returns, and weed populations and cotton lint yield in the following growing season.

MATERIALS AND METHODS

The experiments were conducted in North Carolina near Lewiston-Woodville (36.135 N, -77.177 W) and Rocky Mount (35.897 N, -77.675 W) during 2016 and 2017 growing seasons. Adjacent areas of the same fields were used for different years at both locations. Soils included a Norfolk sandy loam (fine-loamy, siliceous, thermic Typic Paleudult) at Lewiston-Woodville and an Aycock very fine sandy loam (fine-silty, siliceous, subactive, thermic Typic Paleudult) at Rocky Mount. Soil pH ranged from 5.7 to 6.1 at the two locations with soil organic matter content of 1.8% and 2.4% at these respective locations. The Lewiston-Woodville and Rocky Mount sites were naturally infested with common ragweed (129 plants/m^2 in 2016 and 61 plants/m^2 in 2017) and Palmer amaranth (54 plants/m^2 in 2016 and 65 plants/m^2 in 2017), respectively. Peanut cultivar 'Bailey' (Isleib *et al.*, 2011) was planted into conventionally-tilled, raised seedbeds at a seeding rate designed to provide a final in-row population of 15 plants/m. Plot size was 4 rows (spaced 91 cm apart) by 9 m at both locations. Other than herbicide treatments for the experiment, peanut

Table 1. Herbicide active ingredient, trade name, formulation, application rate, and manufacturer.

Herbicides	Trade name	Formulation concentration	Application rate/ha	Manufacturer
bentazon sodium salt	Basagran®	479 g ai/L	115 or 225 g ai[a]	Arysta LifeScience
clethodim	Select 2EC	240 g ai/L	210 g ai	Valent U.S.A Corp.
imazapic salt of ammonia	Cadre®	240 g ai/L	70 g ai	BASF Chemical Co.
lactofen	Cobra®	240 g ai/L	210 g ai	Valent U.S.A Corp.
paraquat dichloride	Gramoxone® SL 2.0	240 g ae/L	140 g ae	Syngenta Crop Protection

[a]Bentazon at 115 g/ha applied 2 WAP or 225 g/ha applied 4 WAP.

was managed according to North Carolina Cooperative Extension Service recommendations (Jordan *et al.*, 2018).

Treatments were arranged in a randomized complete block design and replicated 4 times at Lewiston-Woodville and 3 times at Rocky Mount. Herbicide treatments consisted of a single application of paraquat plus bentazon at 2 weeks after planting (WAP); a single application of imazapic plus lactofen at 6 WAP; applications of paraquat plus bentazon at 2 WAP followed by bentazon plus lactofen at 4 WAP; bentazon plus lactofen at 4 WAP followed by imazapic plus lactofen at 6 WAP; and paraquat plus bentazon at 2 WAP followed by bentazon plus lactofen at 4 WAP followed by imazapic plus lactofen at 6 WAP. A NTC was included. Clethodim was applied over the entire test area 6 WAP to control annual grasses. At 2 and 4 WAP, peanut was in the vegetative growth stage while at 6 WAP peanut was in the flower (R1) growth stage (Balota, 2019; Boote, 1982). Herbicide rates and manufacturer details are listed in Table 1. Nonionic surfactant (Induce®, Helena Chemical Co., Collierville, TN) at 0.125% (v/v) was applied with paraquat plus bentazon. Crop oil concentrate (Agri-Dex®, Helena Chemical Co., Collierville, TN) at 1.0% (v/v) was applied with bentazon plus lactofen, imazapic plus lactofen, and clethodim. Herbicides were applied using a CO_2-pressurized backpack sprayer equipped with flat-fan nozzles (AIXR 11002 TeeJet® Air Induction XR flat-spray nozzles, TeeJet Technologies, Wheaton, IL) calibrated to deliver 140 L/ha at 152 kPa.

Prior to the first herbicide application, initial weed densities were recorded from 15 randomly determined sections across the entire test area using a 0.3 by 0.3 m square. After herbicides were applied, weed control was visually estimated 7, 10, and 20 WAP using a 0 to 100% scale where 0 was equal to no control and 100 to complete control. Foliar chlorosis, necrosis, and density were considered when recording the visual estimates. Peanut pods were dug and vines inverted at optimum maturity based on pod mesocarp color (Williams and Drexler, 1981). Within two weeks prior to digging and vine inversion, weeds were mowed above the canopy to improve efficiency of digging and vine inversion.

During the year following peanut, cotton cultivar DP 1522 (Monsanto Co., St. Louis, MO) was planted into the previous year's plots on 4 May and 11 May during 2017 at Lewiston-Woodville and Rocky Mount, respectively. In 2018, the cotton cultivar DP 1646 (Monsanto Co., St. Louis, MO) was planted 10 May and 15 May at Lewiston-Woodville and Rocky Mount, respectively. Cotton was planted in conventionally-tilled, raised seedbeds. Within each plot, density of common ragweed at Lewiston-Woodville and density of Palmer amaranth at Rocky Mount were determined 3, 7, and 20 WAP. Density at 3 and 7 WAP was measured using a 0.3 by 0.3 m square in three randomly determined sections of each plot and then the average of each plot was converted to a m^2 basis. Due to reduced weed densities at 20 WAP, populations were determined by counting common ragweed or Palmer amaranth present in the center two rows of the entire plot area and then converted to a m^2 unit. After initial weed densities were recorded 3 and 7 WAP in cotton, glyphosate was applied at Lewiston-Woodville. Glyphosate plus dicamba was applied 3 WAP followed by glyphosate only 7 WAP at Rocky Mount. These herbicides were applied over the entire test area.

Economic returns were estimated using a modified North Carolina State University enterprise budget for conventional Virginia market type peanut to accommodate a 400-ha operation in North Carolina (Washburn, 2019). Costs were calculated for the different treatments with respect to varying costs of herbicides and adjuvants quoted from major suppliers in the region. Costs associated with hauling, drying and cleaning peanut, state check-off fee, and national assessment costs based on yield varied by treatment. A base cost of \$1502/ha for peanut production before these respective inputs was used. A ten-year average price of \$0.57/kg received for Virginia market type peanuts in the

Table 2. Analysis of variance (F statistic) for common ragweed control 7, 10, and 20 WAP; pod yield; and estimated economic return as influenced by timing of herbicide applications in peanut at Lewiston-Woodville.

	F-statistic[a]				
	Common ragweed control				
Source of variation	7 WAP	10 WAP	20 WAP	Yield kg/ha	Estimated economic return $/ha
Year	0.1	0.1	1.9*	31.4*	31.4*
Timing of herbicide applications	67.9*	62.9*	47.7*	12.3*	9.3*
Year*Timing of herbicide applications	0.8	0.3	1.1	0.9	0.9

[a]* indicates significance at $p \leq 0.05$.

United States was used for estimated economic return analysis (USDA-NASS, 2018).

Data for common ragweed and Palmer amaranth control, peanut yield, estimated economic return, broadleaf densities in cotton the following year, and cotton lint yield were subjected to analysis of variance using PROC GLIMMIX and PROC CORR procedures of SAS (version 9.4; SAS Institute INC., Cary, NC). Data for each location with the same broadleaf weeds were also subjected to ANOVA for a 2 (year) by 6 (timing of herbicide application) factorial arrangement of treatments. Timing of herbicide application treatments and locations were fixed factors whereas replications were treated as random. Means for significant main effects and interactions were separated using Fisher's Protected LSD at $\alpha = 0.05$.

RESULTS AND DISCUSSION

The interaction of year by timing of herbicide application was not significant for common ragweed control 7, 10, and 20 WAP; pod yield; and estimated economic return at Lewiston-Woodville or for Palmer amaranth control 10 and 20 WAP; pod yield; and estimated economic return at Rocky Mount (Tables 2 and 3). The interaction of year by timing of herbicide application was significant for Palmer amaranth control 7 WAP. Therefore, data for common ragweed control 7, 10, and 20 WAP, pod yield, and estimated economic return at Lewiston-Woodville (Table 4) and Palmer amaranth control 10 and 20 WAP, pod yield, and estimated economic return at Rocky Mount (Table 5) are presented pooled over years. Palmer amaranth control 7 WAP was analyzed by year at Rocky Mount.

Common ragweed control at Lewiston-Woodville and peanut pod yield as well as common ragweed control and estimated economic returns were positively correlated ($p \leq 0.0001$; $R = 0.60$ to 0.68) regardless of when the visual estimates of weed control were recorded (Table 6). As was noted for the experiments at Lewiston-Woodville for common ragweed, peanut yield and estimated economic returns were positively correlated with Palmer amaranth control 7, 10, and 20 WAP at Rocky Mount ($p \leq 0.0001$, $R = 0.60$ to 0.68) (Table 7).

Weed control. At Lewiston-Woodville, common ragweed control 7 WAP was at least 97% when 2 or more herbicide applications were administered or at least one application was made at 6 WAP (Table 4). Common ragweed control 10 WAP was 98% or greater when 2 or more herbicide applications were made. A single herbicide application 2 WAP was approximately 52% less effective as a single application 6 WAP. Control of common ragweed was optimum at 20 WAP when at least 2 herbicide applications were made. Common ragweed 20 WAP was controlled less effectively when a single herbicide application was

Table 3. Analysis of variance (F statistic) for Palmer amaranth control 7, 10, and 20 WAP; pod yield; and estimated economic return as influenced by timing of herbicide applications in peanut at Rocky Mount.

	F-statistic[a]				
	Palmer amaranth control				
Source of variation	7 WAP	10 WAP	20 WAP	Yield kg/ha	Estimated economic return $/ha
Year	0.3	3.6	10.8*	93.8*	93.8*
Timing of herbicide applications	36.8*	21.5*	6.1*	24.0*	19.8*
Year*Timing of herbicide applications	5.9*	1.0	0.7	1.7	1.7

[a]* indicates significance at $p \leq 0.05$.

Table 4. Common ragweed control 7, 10, and 20 WAP; pod yield; and estimated economic return as influenced by timing of herbicide applications in peanut at Lewiston-Woodville.[a]

Timing of herbicide applications	Common ragweed control			Peanut yield	Estimated economic return
	7 WAP	10 WAP	20 WAP		
WAP	%			kg/ha	$/ha
None	8 c	5 c	2 d	880 d	-433 c
2	58 b	46 b	33 c	1760 c	-262 b
6	97 a	92 a	67 b	2660 b	-96 ab
2 and 4	99 a	98 a	95 a	2690 b	-103 ab
4 and 6	100 a	100 a	98 a	3280 ab	0 a
2, 4, and 6	100 a	100 a	98 a	3680 a	70 a

[a]Means within a column for common ragweed control 7, 10, and 20 WAP, peanut yield, and estimated economic return followed by the same letter are not significantly different according to Fisher's Protected LSD test at P ≤ 0.05. Data are pooled over years.

made 2 WAP compared to a single application made 6 WAP.

Palmer amaranth control 7 WAP was at least 82% when herbicides were applied at least twice, regardless the timing in 2016 and 2017 (Table 5). In 2016, Palmer amaranth control from a single herbicide application 6 WAP was greater than control from a single application 2 WAP, while in 2017 the opposite occurred. In 2016, Palmer amaranth control was greater when any herbicide application was administered compared to the NTC. In 2017, Palmer amaranth control was similar following a single herbicide application 6 WAP or when no herbicides were applied. At 10 WAP, Palmer amaranth control was at least 89% when herbicide applications were administered at least twice regardless of timing. Palmer amaranth control at 10 WAP was at least 40% greater when a single application was administered compared to the NTC.

Peanut yield. At Lewiston-Woodville, peanut yield was at least 3,280 kg/ha when herbicide applications were made three times at 2, 4, and 6 WAP or when applications were made twice at 4 and 6 WAP (Table 4). Peanut yield following a single application 6 WAP or two applications at 2 and 4 or 4 and 6 WAP was similar. Yields were greater any time herbicides were applied compared to the NTC.

At Rocky Mount, a yield of 5,030 kg/ha was achieved when herbicides were applied three times at 2, 4, and 6 WAP (Table 5). Yield was greater when at least two applications were administered compared to when a single application was made 2 WAP only. Yields were similar when a single herbicide application was made regardless of the timing. Yields were also similar when two herbicide applications were made irrespective of the timing.

In these experiments the NTC reflected interference from broadleaf weeds only because clethodim was applied across the entire experiment, but there was approximately 6 weeks of interference in some plots. For mixed weed populations in peanut, Everman *et al*. (2008) found that the critical timing of weed removal was 3.1 WAP in order to produce at least 95% of the maximum yield. They also reported the critical-weed free period in peanut under interference with combined grass and broad-

Table 5. Palmer amaranth control 7, 10, and 20 weeks after planting (WAP); pod yield; and estimated economic return as influenced by timing of herbicide applications in peanut at Rocky Mount[a].

Timing of herbicide applications	Palmer amaranth control				Yield	Estimated economic return
	7 WAP					
	2016	2017	10 WAP	20 WAP		
WAP	%				kg/ha	$/ha
None	10 d	15 b	27 c	45 d	1110 d	-385 e
2	50 c	81 a	70 b	69 bc	2480 c	-114 cd
6	77 b	30 b	67 b	55 cd	2080 c	-218 d
2 and 4	88 ab	99 a	90 a	83 ab	3840 b	134 b
4 and 6	96 a	82 a	89 a	65 bcd	3420 b	28 bc
2, 4, and 6	100 a	100 a	99 a	97 a	5030 a	349 a

[a]Means within a year for Palmer amaranth control 7 WAP or within a column for Palmer amaranth control 10 and 20 WAP, Yield, and Estimated economic return followed by the same letter are not significantly different according to Fisher's Protected LSD test at P ≤ 0.05. Data for Palmer amaranth control 10 and 20 WAP, yield, and estimated economic return are pooled over years.

Table 6. Pearson correlation coefficients for common ragweed control, peanut pod yield, estimated economic returns, common ragweed densities 3 weeks after planting (WAP) in cotton, and cotton lint yield at Lewiston-Woodville.

Parameters	P > F	R
Common ragweed control 3 WAP in peanut versus peanut yield	< 0.0001	0.66
Common ragweed control 10 WAP in peanut versus peanut yield	< 0.0001	0.68
Common ragweed control 20 WAP in peanut versus peanut yield	< 0.0001	0.64
Common ragweed control 3 WAP in peanut versus estimated economic returns	< 0.0001	0.63
Common ragweed control 10 WAP in peanut versus estimated economic returns	< 0.0001	0.64
Common ragweed control 20 WAP in peanut versus estimated economic returns	< 0.0001	0.60
Common ragweed control 3 WAP in peanut versus common ragweed density 3 WAP in cotton	0.0013	-0.46
Common ragweed control 10 WAP in peanut versus common ragweed density 3 WAP in cotton	0.0010	-0.47
Common ragweed control 20 WAP in peanut versus common ragweed density 3 WAP in cotton	0.0058	-0.40
Peanut yield versus cotton lint yield	0.0005	-0.49
Peanut yield versus common ragweed density 3 WAP in cotton	<0.0001	-0.73

leaf weeds, mixed grass species, and mixed broadleaf species to be 3.1 to 7.5 WAP, 4.3 to 9 WAP, and 2.6 to 8 WAP, respectively. Hill and Santleman (1969) found that when large crabgrass [*Digitaria sanguinalis* (L.) Scop.] was removed 3 WAP and control persisted for at least 6 WAP, peanut yield was not reduced compared to weed-free peanut. Based on percent of maximum yield noted for the herbicide programs in these experiments, the percent yield loss from season-long interference by common ragweed and Palmer amaranth was 77% and 78%, respectively. These yield loss assessments compare relatively well with yield loss predictions associated with the decision tool WebHADSS (WebHADSS, 2019). At similar average densities for each site year, yield loss based on WebHADSS was 80% and 79% for common ragweed at Lewiston-Woodville in 2016 and 2017, respectively. Yield loss based on WebHADSS was 79% in both 2016 and 2017 from Palmer amaranth interference at Rocky Mount.

Estimated economic return. At Lewiston-Woodville, estimated economic returns were similar when a single herbicide application was made irrespective of the timing or when two applications were made at 2 and 4 WAP (Table 4). A single herbicide application 6 WAP produced similar estimated economic returns as herbicides applied at least twice, either at 2 and 4 WAP or 4 and 6 WAP. Also, no difference was noted when herbicide was applied 6 WAP compared with three applications. Estimated economic returns were greater when two applications were made 4 and 6 WAP or when three applications were made 2, 4, and 6 WAP compared to a single application 2 WAP. Greater estimated economic returns were observed when any herbicide application sequence was made compared to non-treated peanut.

At Rocky Mount, estimated economic return was $349/ha when herbicides were applied 2, 4, and 6 WAP (Table 5). Estimated economic returns were similar when two herbicide applications were made irrespective of the timing. Two herbicide applications made at 4 and 6 WAP produced similar estimated economic returns as a single herbicide application made 2 WAP. Estimated economic returns were greater when at least two herbicide applications were made irrespective of the timing compared to when a single herbicide application was made 6 WAP.

Table 7. Pearson correlation coefficients for Palmer amaranth control, peanut pod yield, estimated economic returns, Palmer amaranth densities 3 weeks after planting (WAP) in cotton, and cotton lint yield at Rocky Mount.

Parameters	P > F	R
Palmer amaranth control 3 WAP in peanut versus peanut yield	< 0.0001	0.63
Palmer amaranth control 10 WAP in peanut versus peanut yield	0.004	0.47
Palmer amaranth control 20 WAP in peanut versus peanut yield	< 0.3563	0.16
Palmer amaranth control 3 WAP in peanut versus estimated economic returns	0.0001	0.60
Palmer amaranth control 10 WAP in peanut versus estimated economic returns	0.0081	0.44
Palmer amaranth control 20 WAP in peanut versus estimated economic returns	0.4276	0.14
Palmer amaranth control 3 WAP in peanut versus Palmer amaranth density 3 WAP in cotton	0.2149	-0.22
Palmer amaranth control 10 WAP in peanut versus Palmer amaranth density 3 WAP in cotton	0.1915	-0.23
Palmer amaranth control 20 WAP in peanut versus Palmer amaranth density 3 WAP in cotton	0.1047	-0.28
Peanut yield versus cotton lint yield	0.6361	-0.08
Peanut yield versus Palmer amaranth density 3 WAP in cotton	0.0792	-0.31

Table 8. Analysis of variance (F statistic) for common ragweed density 3, 7, and 20 weeks after planting (WAP); and cotton lint yield as influenced by timing of herbicide applications in peanut at Lewiston-Woodville.

Source of variation	F-statistic[a]			
	Common ragweed density (plants/m^2)			Cotton lint yield (kg/ha)
	3 WAP	7 WAP	20 WAP	
Year	43.9*	28.0*	7.8*	167.2*
Timing of herbicide applications	4.2*	3.1*	0.2	0.9
Year*Timing of herbicide applications	1.1	4.7*	0.2	0.9

[a]* indicates significance at $p \leq 0.05$.

Weed density the year following peanut. The interaction of year by timing of herbicide application was not significant for common ragweed densities at 3 and 20 WAP at Lewiston-Woodville (Table 8) or for Palmer amaranth densities at 3, 7, and 20 WAP at Rocky Mount (Table 9). The main effect of herbicide application timing was not significant for common ragweed densities at 20 WAP at Lewiston-Woodville or for Palmer amaranth densities at 3, 7, and 20 WAP at Rocky Mount. Therefore, common ragweed densities at 3 and 20 WAP are presented pooled over years while common ragweed densities at 7 WAP are presented by year (Table 10). Palmer amaranth densities at 3, 7, and 20 WAP are presented pooled over years (Table 11).

Common ragweed control in peanut and subsequent weed density in cotton the following year were negatively correlated ($p \leq 0.05$, R = -0.40 to -0.47) regardless of when the visual estimates of percent control were recorded in peanut (Table 6). Peanut yield was a predictor of common ragweed density 3 WAP in cotton the following year ($p \leq 0.0001$, R = -0.73). This is not surprising because weed control is a relatively good predictor of peanut yield, hence lowering the contributions of seed to the soil seedbank. Palmer amaranth control, regardless of timing, was not a good predictor of Palmer amaranth densities in cotton the following year (Table 7). However, peanut yield was a marginal predictor of Palmer amaranth density 3 WAP in cotton the following year.

At Lewiston-Woodville in cotton 3 WAP, common ragweed densities ranged from 95 to 189 plants/m^2 (Table 10). Common ragweed densities were at least 47% lower when herbicides were

Table 9. Analysis of variance (F statistic) for Palmer amaranth density 3, 7, and 20 weeks after planting (WAP); and cotton lint yield as influenced by timing of herbicide applications in peanut at Rocky Mount.

Source of variation	F-statistic[a]			
	Palmer amaranth density (plants/m^2)			Cotton lint yield (kg/ha)
	3 WAP	7 WAP	20 WAP	
Year	5.1*	18.8*	10.9*	0.8
Timing of herbicide applications	0.3	0.1	0.7	0.4
Year*Timing of herbicide applications	0.1	0.1	0.5	0.8

[a]* indicates significance at $p \leq 0.05$.

Table 10. Common ragweed density 3, 7, and 20 weeks after planting (WAP) in cotton as influenced by timing of herbicide applications in peanut at Lewiston-Woodville[a].

Timing of herbicide applications	Common ragweed density				Cotton lint yield
	3 WAP	7 WAP		20 WAP	
		2017	2018		
WAP	plants/m^2				kg/ha
None	189 a	18 a	1 b	0.07 a	1640 a
2	179 ab	17 a	1 b	0.01 a	1590 a
6	98 c	1 c	2 ab	0.07 a	1690 a
2 and 4	126 bc	11 ab	3 ab	0.04 a	1600 a
4 and 6	118 c	5 bc	5 a	0.06 a	1590 a
2, 4, and 6	95 c	7 bc	0 b	0.06 a	1540 a

[a]Means within a column for common ragweed density 3 and 20 WAP and cotton lint yield or within a year for common ragweed density 7 WAP followed by the same letter are not significantly different according to Fisher's Protected LSD test at $P \leq 0.05$. Data for common ragweed density 3 and 20 WAP and cotton lint yield are pooled over years.

Table 11. Palmer amaranth density 3, 7, and 20 weeks after planting (WAP) as influenced by timing of herbicide applications in peanut at Rocky Mount[a].

Timing of herbicide applications	Palmer amaranth densities			Cotton lint yield
	3 WAP	7 WAP	20 WAP	
WAP	plants/m^2			kg/ha
None	94 a	13 a	0.65 a	920 a
2	107 a	10 a	0.40 a	970 a
6	88 a	8 a	0.58 a	1020 a
2 and 4	101 a	10 a	0.22 a	1090 a
4 and 6	96 a	8 a	0.58 a	1020 a
2, 4, and 6	66 a	6 a	0.28 a	970 a

[a]Means within a column for Palmer amaranth density 3, 7, and 20 WAP and for cotton lint yield followed by the same letter are not significantly different according to Fisher's Protected LSD test at $P \leq 0.05$. Palmer amaranth density 3, 7, and 20 WAP and cotton lint yield data are pooled over years.

applied 2, 4, and 6 WAP compared to when herbicides were not applied or when a single herbicide application was made 2 WAP only. Common ragweed densities were lower when herbicides were applied at least twice the previous year or when a single application was made 6 WAP compared to when no herbicides were applied or when a single application was made 2 WAP. Densities recorded 3 WAP most likely are the best indicator of how weed management in peanut the previous season affected weed populations the following season in cotton. However, comparing weed emergence during the following year may not reflect fully the impact of weed management on the soil seedbank. In addition to seed fecundity, dormancy could impact the amount of weed escapes over a longer period of time than a single season. However, this measurement was recorded prior to any weed control actions were administered in cotton during the subsequent season.

At 7 WAP, common ragweed densities ranged from 1 to 18 plants/m^2 in 2017 and 0 to 5 plants/m^2 in 2018 (Table 10). In 2017, Common ragweed densities following a single herbicide application 6 WAP, 2 applications 4 and 6 WAP, or 3 herbicide applications the previous year were lower than densities following no herbicides or a single application 2 WAP. In 2018, common ragweed densities were similar following no herbicide applications, a single herbicide application 2 or 6 WAP, applications 2 and 4 WAP, or applications 2, 4, and 6 WAP.

By 20 WAP, common ragweed populations were less than 1 plant/m^2 and timing of weed management in peanut the previous season had no effect on densities (Table 10). In some cases, secondary dormancy of seeds can occur when the non-dormant seeds are exposed to favorable temperature and moisture, but an overriding factor inhibits the seed from germinating (Willemsen, 1975). Baskin and Baskin (1980) reported common ragweed seed viability of 39 years once in the seedbank.

At Rocky Mount the year after peanut, Palmer amaranth densities ranged from 66 to 107 plants/m^2, 6 to 13 plants/m^2, and less than 1 plant/m^2 3, 7, and 20 WAP, respectively (Table 11). Weed management in peanut the previous season did not have an effect on Palmer amaranth densities in cotton 3, 7, or 20 WAP.

Menges (1987) reported that it may take up to 6 years of weed-free Palmer amaranth management to reduce the seedbank by 98%. Sosnoskie et al. (2013) reported that 36 months were required for Palmer amaranth seed burial to deplete the seedbank. Therefore, a two-year study may not have been long enough to observe the complete effect of weed management due to the abundance of seeds present in the seedbank.

Cotton lint yield the year following peanut. Yield of peanut negatively affected cotton yield the following year at Lewiston-Woodville ($p = 0.0005$, $R = -0.49$) (Table 6). Yield of peanut at Rocky Mount the previous year was not a good predictor of cotton yield the following year (Table 7).

At Lewiston-Woodville, cotton lint yield ranged from 1540 to 1690 kg/ha (Table 10), while at Rocky Mount cotton lint yield ranged from 920 to 1090 kg/ha (Table 11). Timing of weed management in peanut the previous year did not influence cotton lint yield at either location. Applying effective herbicides to cotton 3 WAP may have masked the potential impact of weed management the previous year on cotton yield. Weeds in cotton were controlled within the critical weed-free period for cotton in presence of Palmer amaranth and common ragweed, the predominant broadleaf weeds in this experiment. Glyphosate was applied at Lewiston-Woodville for each timing of application in cotton. Glyphosate-resistant biotypes of common ragweed were not present at Lewiston-Woodville. The combination of glyphosate plus dicamba was used at Rocky Mount because these populations of Palmer amaranth were resistant to glyphosate (Inman *et al.*, 2016).

CONCLUSIONS

The presented research reinforces the importance of timely and effective weed management in peanut. Effective control of common ragweed and Palmer amaranth can be achieved with proper timing of herbicide applications. Usually, the more intensive herbicide programs generated the greatest weed control, yield, and estimated economic returns. In the case of common ragweed, an intensive weed management approach in peanut the previous season showed a reduction in weed emergence the following year in cotton. Due to the abundance of Palmer amaranth seed in the seedbank, multiple years of implementation are likely needed to observe the full benefits of an intensive weed management program.

Acknowledgements

This research was funded by the North Carolina Peanut Growers Association, Inc. The authors would like to thank the staff members of the Peanut Belt Research Station and the Upper Coastal Plains Research Station for technical assistance.

Literature Cited

Balota, M. 2019. Agronomic recommendations and procedures. Pages 7–42 in Virginia Peanut Production Guide. Virginia Coop. Ext. Prog. Pub. SPES-67NP.

Baskin, J.M. and C.C. Baskin. 1980. Ecophysiology of secondary dormancy in seeds of *Ambrosia artemisiifolia*. Ecology. 61:475–480. Doi:10.2307/1937410.

Bensch, C.N., M.J. Horak, and D. Peterson. 2003. Interference of redroot pigweed (*Amaranthus retroflexus*), Palmer amaranth (*A. palmeri*), and common waterhemp (*A. rudis*) in soybean. Weed Sci. 51:37–43.

Boote, K.J. 1982. Growth stages of peanut (*Arachis hypogaea* L.). Peanut Sci. 9:35–40.

Burke, I.C., M. Schroeder, W.E. Thomas, and J.W. Wilcut. 2007. Palmer amaranth interference and seed production in peanut. Weed Technol. 21:367–371.

Clewis, S.B., S.D. Askew, and J.C. Wilcut. 2001. Common ragweed interference in peanut. Weed Sci. 49:768–772.

Coble, H.D., F.M. Williams, and R.L. Ritter. 1981. Common ragweed (*Ambrosia artemisiifolia*) interference in soybeans (*Glycine max*). Weed Sci. 29:339–342.

Dickerson, C.T. 1968. Studies on the germination, growth, development and control of common ragweed (*Ambrosia artemisiifolia* L.). Ph.D. thesis. Cornell University, Ithaca, NY.

Everman, W.J., S.B. Clewis, W.E. Thomas, I.C. Burke, and J.C. Wilcut. 2008. Critical period of weed interference in peanut. Weed Technol. 22:63–67.

Hill, E.C., K.A. Renner, M.J. VanGessel, R. Bellinder, and B.A. Scott. 2016. Late-season weed management to stop viable weed seed production. Weed Sci. 64:112–118.

Hill, L.V. and P.W. Santelmann. 1969. Competitive effects of annual weeds in Spanish peanuts. Weed Sci. 17:1–2.

Horak, M.J. and T.M. Loughin. 2000. Growth analysis of four *Amaranthus* species. Weed Sci. 48:347–355.

Horak. M.J., D.E. Peterson, D.J. Chessman, and L.M. Wax. 1994. Pigweed identification: A pictorial guide to common pigweeds in the Great Plains. Manhattan, KS: Kansas State University S-80 Cooperative Extension Service. Pages 1, 9.

Inman, M.D., D.L. Jordan, A.C. York, K.M. Jennings, D.W. Monks, W.J. Everman, S.L. Bollman, J.T. Fowler, R.M. Cole, and J.K. Soteres. 2016. Long-term management of Palmer amaranth (*Amaranthus palmeri*) in dicamba-tolerant cotton. Weed Sci. 64:161–169.

Isleib, T.G., S.R. Milla-Lewis, H.E. Pattee, S.C. Copeland, M.C. Zuleta, B.B. Shew, J.E. Hollowell, T.H. Sanders, L.O. Dean, K.W. Hendrix, M. Balota, and J.W. Chapin. 2011. Registration of 'Bailey' peanut. J. Plant Reg. 5:27–39.

Jordan, D.L. 2018. Peanut weed management. Pages 46–79 *in* 2018 Peanut Information. North Carolina Coop. Ext. Ser. AG-331. 170 pages.

Jordan, D.L., R. Brandenburg, B. Brown, G. Bullen, G. Roberson, and B. Shew. 2018. 2018 Peanut Information. North Carolina Cooperative Extension Service Pub. AG-331. 170 pages.

Jordan, T., G. Nice, R. Smeda, C. Sprague, M. Loux, B. Johnson. 2014. Biology and management of common ragweed. *In* the glyphosate, weeds, and crops series. Purdue University Extension. GWC-14. p. 1–15.

Keeley, P.E., C.H. Carter, and R.J. Thullen. 1987. Influence of planting date on growth of Palmer amaranth (*Amaranthus palmeri*). Weed Sci. 35:199–204.

Leiblein-Wild, M.C., R. Kaviani, O. Tackenberg. 2014. Germination and seedling frost tolerance differ between the native and invasive range in common ragweed. Oecologia. 174:739–750.

Leon R.G., D.L. Jordan, G. Bolfrey-Arku, and I. Dzomeku. 2019. Sustainable weed management in peanut. *In* N.E. Korres, N.R. Burgos, and S.O. Duke, eds. Weed Control: Sustainability, Hazards and Risks in Cropping Systems Worldwide. CRC Press/ Taylor and Francis Group. Pages 345–366.

Massinga, R.A., R.S. Currie, M.J. Horak, and J. Boyer. 2001. Interference of Palmer amaranth in corn. Weed Sci. 49:202–208.

Menges, R.M. 1987. Weed seed population dynamics during six years of weed management systems in crop rotations on irrigated soil. Weed Sci. 35:328–332.

Morgan, G.D., P.A. Baumann, and J.M. Chandler. 2001. Competitive impact of Palmer amaranth (*Amaranthus palmeri*) on cotton (*Gossypium hirsutum*) development and yield. Weed Technol. 15:408–412.

Oosting, H.J. 1942. An ecological analysis of plant communities of piedmont North Carolina. Amer. Midl. Nat. 28:1–126.

Sauer, J.D. 1957. Recent migration and evolution of the dioecious amaranths. Evolution 11:11–31.

Smith, D.T., R.V. Baker, and G.L. Steele. 2000. Palmer amaranth (*Amaranthus palmeri*) impacts on yield, harvesting, and ginning in dryland cotton (*Gossypium hirsutum*). Weed Technol. 14:122–126.

Sosnoskie, L.M., T.M. Webster, A.S. Culpepper. 2013. Glyphosate resistance does not affect Palmer amaranth (*Amaranthus palmeri*) seedbank longevity. Weed Sci. 61:283–288.

USDA-NASS. 2018. Crop production 2017 summary [online]. Available at http://usda.mannlib.cornell.edu/usda/current/CropProdSu/CropProdSu-01-12-2018.pdf (accessed 21 Aug. 2018).

Washburn, D. 2019. Enterprise budgets. Available at https://cals.ncsu.edu/are-extension/business-planning-and-operations/enterprise-budgets/

WebHADSS. 2019. Web version of Herbicide Application Decision Support System 2004.0.3. Available at webhadss.ncsu.edu (Accessed January 24, 2019).

Webster, T.M. and T.L. Grey. 2015. Glyphosate-resistant Palmer amaranth (*Amaranthus palmeri*) morphology, growth, and seed production in Georgia. Weed Sci. 63:264–272.

Wilcut, J.W., A.C. York, W.J. Grichar, and G.R. Wehtje. 1995. The biology and management of weeds in peanut (*Arachis hypogaea*). *In* H. E. Pattee and H. T. Stalker, eds. Advances in Peanut Science. Stillwater, OK: American Peanut Research and Education Society. P. 207–244.

Wilcut, J.W. and S.D. Askew. 1999. Chemical approaches to weed management. *In* J. R. Ruberson, ed. Handbook of Pest Management. Marcel Dekker: New York, NY: Marcel Dekker. p. 627–661.

Willemsen, R. W. 1975. Dormancy and germination of common ragweed seeds in the field. Amer. J. Bot. 62:639–643.

Williams, E.J. and J.S. Drexler. 1981. A non-destructive method for determining peanut pod maturity, pericarp, mesocarp, color, morphology, and classification. Peanut Sci. 8:134–141.

Young, J.H., N.K. Person, J.O. Donald, and W.H. Mayfield. 1982. Harvesting, curing, and energy utilization. p. 458–487 *in* H.E. Pattee and C.T. Young, eds. Peanut Science and Technology. Yoakum, TX: American Peanut Research and Education Society.

Zimdahl, R.L. 2004. Weed-crop competition: a review. Ames, IA: Blackwell Publishing Professional, p. 220.