Peanut (*Arachis hypogaea* L.) Response to Carfentrazone-ethyl and Pyraflufen-ethyl Applied Close to Harvest

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ABSTRACT

Morningglory (*Ipomoea* spp.) and other weeds are often present at peanut harvest and can interfere with digging pods and inverting vines. Carfentrazone-ethyl and pyraflufen-ethyl control large morningglory and could be an effective strategy as harvest aids in peanut. However, crop response to these herbicides has not been determined for Virginia market type peanut cultivars in North Carolina. One experiment was conducted during 2012, 2013, and 2014 to determine peanut response to carfentrazone or pyraflufen-ethyl applied postemergence 1 and 2 weeks prior to digging peanut pods and inverting vines. In a second experiment conducted during 2014 and 2015, peanut response to carfentrazone-ethyl, diclosulam, pyraflufen-ethyl, lactofen, and 2,4-DB applied 4 wk before digging (WBD) was determined. Visible peanut injury from carfentrazone-ethyl and pyraflufen-ethyl did not exceed 40% regardless of application timing or rate, and peanut yield was not affected compared with non-treated peanut regardless of visible injury when applied 1 or 2 WBD. However, when applied 4 WBD, peanut yields were 9 to 10% lower when carfentrazone-ethyl or pyraflufen-ethyl were applied compared with non-treated peanut. Diclosulam, lactofen, and 2,4-DB did not adversely affect yield. These results show that carfentrazone-ethyl and pyraflufen-ethyl will not affect peanut yield within 2 WBD but can reduce yield when applied earlier in the season during pod fill.

Key Words: Crop injury, harvest aid, peanut tolerance.

Peanut is a valuable commodity in the United States with approximately 634,800 ha harvested with an estimated value of $1.19 million USD (USDA 2016a; USDA 2016b). Approximately 7% of national peanut ha is in North Carolina (USDA 2016a) with the majority Virginia market type cultivars (Brown, 2016). Weeds compete with peanut for sunlight, moisture, and nutrients throughout the growing season (Wilcut *et al.,* 1994). Peanut yield, quality, and economic value can be negatively affected by weeds (Everman *et al.,* 2008; Walker *et al.,* 1989). Season-long interference of combination of broadleaf and grass weeds can reduce peanut yield by 60 to 80% and reduced harvest efficiency in some instances (Everman *et al.,* 2008; Wilcut *et al.,* 1994). Common ragweed (*Ambrosia artemisiifolia* L.) (Clewis et al. 2001) and Palmer amaranth (*Amaranthus palmeri* L.) (Burke et al. 2007) at a density of one plant/m of row reduced peanut yield by 40 and 28%, respectively. The prostrate growth habit of peanut causes peanut to be vulnerable to interference from weeds throughout the season and requires effective season-long management strategies to protect yield and promote efficient digging and vine inversion (Walker *et al.,* 1989; Wilcut *et al.,* 1994).

Weed control programs often include preplant incorporated, preemergence, and postemergence (POST) herbicides to minimize interference of weeds with peanut and challenges with harvest (Clewis *et al.* 2007; Grichar and Dotray 2012; Henning *et al.* 1982; Jordan, 2016; Wilcut *et al.,* 1994). However, in spite of these herbicide intensive programs weed escapes still occur. Herbicide options available for late-season weed control are limited because of injury potential and labeled pre-harvest intervals (Cahoon and Jordan, 2016; Jordan, 2016). While Palmer amaranth is the most troublesome and difficult to control weed in peanut in North Carolina, primarily due to resistance to acetolactate synthase (ALS)-inhibiting herbicides (Webster, 2013; Poirier *et al.,* 2014), annual grasses and morningglory (*Ipomoea* spp.) are often found in fields late in the season (Jordan, 2016). Growers can apply diclosulam through the ground cracking stage in North Carolina (Anonymous, 2010) and up to 30 d after planting in other states to control Benghal dayflower (*Commelina benghalensis* L.) (Anonymous, 2004). Imazapic, lactofen, and 2,4-DB can be applied no closer to harvest than 90, 45, and 45 d, respectively (Anonymous, 2015; Anonymous, 2016; Anonymous, 2014a). Imazapic and lactofen are marginally effective on Palmer amaranth and morningglory that are large (Chahal *et al.,* 2011; Lancaster *et al.,* 2005 2007) or express resistance to ALS-inhibiting herbicides which is widespread in North Carolina (Poirier *et al.,* 2014).

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Diclosulam suppresses several broadleaf weeds including annual morningglory, common ragweed, and Benghal dayflower when applied POST (Prostko, 2004; Lancaster *et al.*, 2007). Of these herbicides 2,4-DB is applied late in the season more often to suppress Palmer amaranth and morningglory, although 2,4-DB is ineffective in controlling pitted morningglory (*Ipomoea lacunosa* L.) (Jordan, 2016). Determining efficacy of carfentrazone-ethyl and pyraflufen-ethyl herbicides against this weed and how peanut respond to these herbicides could lead to improved harvesting of peanut.

Carfentrazone-ethyl and pyraflufen-ethyl inhibit protoporphyrinogen oxidase (PPO) in sensitive plants including morningglory (Anonymous, 2011, Anonymous, 2014b; Dayan *et al.*, 1997; Reed *et al.*, 2004). However, carfentrazone-ethyl and pyraflufen-ethyl applied 28 to 51 d after planting injured peanut 62 to 48% when evaluated 14 d after treatment (Dotray *et al.*, 2010). Grichar *et al.* (2010) reported 7 to 52% injury and 4 to 26% stunting of peanut when carfentrazone-ethyl and pyraflufen-ethyl were applied 35 to 56 d after planting. Peanut injury from these herbicides at these timings of application reduced pod yield of runner market types, but did not impact peanut market grade characteristics (Dotray *et al.*, 2010; Grichar *et al.*, 2010). Grichar *et al.* (2010) reported that peanut tolerance to carfentrazone-ethyl and pyraflufen-ethyl was cultivar dependent. Response of large-seeded Virginia market-type peanut to carfentrazone-ethyl and pyraflufen-ethyl is limited in the peer-reviewed literature. Therefore, research was conducted to determine peanut tolerance to these two herbicides when POST applied at different rates within 2 weeks prior to digging peanut pods and inverting vines and how peanut respond to these herbicide compared with other herbicides that have potential for late–season use.

Materials and Methods

Peanut response to carfentrazone-ethyl and pyraflufen-ethyl application rate and timing. Field experiments to compare herbicide rate and timings of carfentrazone-ethyl and pyraflufen-ethyl were conducted in North Carolina during 2012, 2013, and 2014 at the Peanut Belt Research Station located near Lewiston-Woodville (36.1323 N, -77.1705W) and at the Upper Coastal Plain Research Station (35.8942N, -77.68011W) located near Rocky Mount. Soil at Lewiston-Woodville was a Norfolk sandy loam (fine loamy, siliceous, thermic, Aquic Paleudalts) with organic matter ranging from 0.5 to 1.2% and pH 6.1. Soil at

Rocky Mount was a Goldsboro loamy sand (fine loamy, mixed, semiactive, thermic, Typic Hapludults) with 1.5% organic matter and pH 5.9. The Virginia market type peanut cultivar 'Bailey' (Isleib *et al.*, 2011) was used for these experiments.

Peanut response to carfentrazone-ethyl and pyraflufen-ethyl were evaluated in separate experiments. The experiment with carfentrazone-ethyl was conducted at Lewiston-Woodville and Rocky Mount during 2012 and 2013 and during 2014 only at Lewiston-Woodville. Carfentrazone-ethyl (Aim® EC, FMC Corporation, Philadelphia, PA) at 17.5 and 35 g ai/ha was applied 1 and 2 weeks prior to digging peanut pods and inverting vines (WBD). The experiment with pyraflufen-ethyl was conducted at Lewiston-Woodville during 2012, 2013, and 2014. Pyraflufen-ethyl (ET®, Nichino America, Inc., Wilmington, DE) at 1.8 and 3.6 g ai/ha was applied 1 and 2 WBD. The selected herbicide rates were within the registered rate of these herbicides in peanut (Anonymous, 2011; Anonymous, 2014). At the time of application, peanut was at the R8 growth stage with 65-70% of pod mesocarp color in orange, brown, and black categories (Boote, 1982).

Peanut response to carfentrazone-ethyl and pyraflufen-ethyl compared with diclosulam, lactofen, and 2,4-DB. Another experiment was conducted in North Carolina during 2014 at the Border Belt Tobacco Research Station near Whiteville (34.4118 N, -78.7911W) on a Norfolk sandy loam soil and during 2015 in two different fields at Lewiston-Woodville to compare peanut response to carfentrazone-ethyl and pyraflufen-ethyl with diclosulam, lactofen, and 2,4-DB herbicides when applied 4 WBD. The cultivar 'Sullivan' (Isleib *et al.*, 2016) was used for this experiment. Carfentrazone-ethyl at 17.5 g/ha, pyraflufen-ethyl at 1.8 g/ha, diclosulam (Strongarm®, DowAgrosciences, Indianapolis, IN) at 30 g ai/ha, lactofen (Cobra®, Valent USA Corp., Richmond, CA) at 220 g ai/ha, and 2,4-DB (Butyrac 200, Albaugh Inc., Ankeny, IA) at 280 g ai/ha were applied 4 WBD at the late R6 to early R7 growth stages corresponding to seed filling the pod cavity and pod mesocarp in the orange color, respectively (Boote, 1982) .

All experiments were conducted in conventionally-prepared, raised seedbeds in rows spaced 91 cm apart. Plot size was 2 rows by 6 m long. Peanut cultivar was planted at a seeding rate designed to provide a final in-row population of 12 plants/m. Fertilization, insect, and disease management practices other than specific treatments were standard for peanut production in North Carolina. Experiments were maintained weed free using soil-applied and postemergence herbicides during the

Table 1. Peanut injury 1 week after treatment and pod yield as influenced by experiment and carfentrazone-ethyl rate and timing of application.

| Main effect | Treatment | Peanut injury | | | | | Pod yield |
| | | 2012 | | 2013 | | 2014 | |
		Lewiston-Woodville	Rocky Mount	Lewiston-Woodville	Rocky Mount	Lewiston-Woodville	
		%———————————————					kg/ha
Carfentrazone-ethyl (g/ha)	Non-treated	-	-	-	-	-	5220 a
	17.5	21 b[b]	19 a	16 a	3 a	9 b	5290 a
	35	33 a	21 a	24 a	3 a	16 a	5190 a
Application (WBD)[a]	Non-treated	-	-	-	-	-	5220 a
	1	24 a	25 a	28 a	3 a	8 b	5270 a
	2	30 a	16 b	13 b	3 a	18 a	5220 a
Rate × Time (P > F)		0.2152	0.8228	0.2099	0.0530	0.0010	0.2044

[a]Abbreviations: Weeks before digging peanut pods and inverting vines, WBD.

[b]Means within columns for main effects (rate or application timing) followed by the same letter are not significantly different according to Fisher's Protected LSD Test at $P \leq 0.05$.

season across the entire test area including non-treated plots. Pendimethalin (Prowl H2O herbicide, BASF Corp., Research Triangle Park, NC) at 1.1 kg ai/ha was applied preplant incorporated followed by *S*-metolachlor (Dual Magnum herbicide, Syngenta Crop Protection, Research Triangle Park, NC) at 1.1 kg ai/ha applied preemergence immediately after planting to the entire test area to prevent early season weed interference. To control weeds escaping herbicides applied at planting, acifluorfen plus bentazon (Storm herbicide, King of Prussia, PA) at $0.56 + 0.28$ kg ai/ha plus 2,4-DB (Albaugh LLC, Ankeny, IA) at 0.28 kg/ha, and clethodim (Cleanse 2EC herbicide, Direct Ag Solutions LLC, Edora, IA) at 0.14 kg ai/ha were applied POST. Hand-removal of weeds supplemented herbicides to maintain plots free of weeds. Herbicides were applied at 145 L/ha aqueous solution, with nonionic surfactant at 0.24% (v/v) and crop oil concentrate at 1.0% (v/v) using a CO_2-pressurized backpack sprayer set at 275 kPa. All experiments were conducted in a randomized complete block design with treatments replicated 4 times. A non-treated control was included in all the experiments.

Data collected and statistical analysis. In the experiment with carfentrazone-ethyl and pyraflufen-ethyl only, visible estimates of peanut injury were determined 1 and 2 week after treatment (WAT) using a scale of 0 to 100 where 0 = no injury and 100 = plant death. Peanut injury 2 WAT was only observed from carfentrazone-ethyl and pyraflufen-ethyl application that was made 2 WBD. Foliar chlorosis, necrosis, leaf defoliation, and plant stunting were considered when making the visible estimates. In the experiment with carfen-

trazone-ethyl and pyraflufen-ethyl compared with diclosulam, lactofen, and 2,4-DB, visible estimates of peanut injury were determined 2 WAT. Peanut pods were dug and vines inverted based on pod mesocarp color to obtain optimum yield (Williams and Drexler, 1981). Pod yield was determined 4-7 days after digging with final yield adjusted to 8% moisture.

Data were subjected to ANOVA using the PROC GLIMMIX procedure in SAS (SAS Institute Inc., Cary, NC) appropriate for the factorial treatment arrangement. Experiments were classified as specific combinations of year and/or location. Means of significant main effects and interactions were separated using Fisher's Protected LSD test at $P \leq 0.05$. The non-treated control was included in peanut yield analysis but not in peanut injury.

Results and Discussion

Peanut response to carfentrazone-ethyl and pyraflufen-ethyl rate and timing. Peanut injury from carfentrazone-ethyl 1 WAT was influenced by the interaction of experiment by rate ($P \leq 0.0371$) and experiment by application timing ($P \leq 0.0001$); therefore data are presented by experiments. The interaction of carfentrazone-ethyl rate by application timing was significant for peanut injury 1 WAT for 2014 at Lewiston-Woodville ($P = 0.0010$) but was not observed at Lewiston-Woodville and Rocky Mount during 2012 and 2013 (Table 1). However, at Lewiston-Woodville, the effect of carfentrazone-ethyl rate was significant for 2012 ($P = 0.0044$), with injury increasing as the rate carfentrazone-ethyl increased (Table 1). The effect

Table 2. Peanut injury 2 week after POST application of carfentrazone-ethyl.[a]

Herbicide	Rate	Peanut injury
	g/ha	%
Carfentrazone-ethyl	17.5	9 b
	35	17 a
P > F		<0.0001

[a]Means followed by the same letter are not significantly different according to Fisher's Protected LSD Test at $P \leq 0.05$. Data are combined over three years (2012, 2013, and 2014) and both locations. Carfentrazone-ethyl applied 2 week before digging peanut pods and inverting vines.

of application timing was significant for 2012 at Rocky Mount (P = 0.0055) and 2013 Lewiston-Woodville (P = 0.0035) and treatments applied 1 WBD caused higher injury (25 and 28%, respectively) when compared to treatments applied 2 WBD (16 and 13%) (Table 1). In 2014 at Lewiston-Woodville, carfentrazone-ethyl applied at 17.5 g/ha caused injury $\leq$ 10% regardless of application timing. However, increasing the carfentrazone-ethyl rate to 35 g/ha caused higher injury when applied 2 WBD than 1 WBD (25% versus 7%, data not shown in tables). The interaction of experiment by herbicide rate was not significant for peanut injury at 2 WAT (P = 0.0570); therefore, data are combined over experiments. Carfentrazone-ethyl at 35 g/ha caused more peanut injury than when applied at 17.5 g/ha (17% versus 9%) (Table 2).

In the experiment with pyraflufen-ethyl, the interaction of experiment $\times$ application timing and experiment $\times$ herbicide rate were significant for peanut injury at 1 WAT (P $\leq$ 0.0001) and 2WAT (P = 0.0197). Therefore, data are presented by each year. Peanut injury at 1 WAT was not affected by the interaction of pyraflufen-ethyl rate $\times$ application timing for experiments during 2012 and 2013 (P > 0.05); this interaction was significant in 2014 (P < 0.0001) (Table 3). Main effect of rate (P < 0.0001) was significant for 2012. Peanut injury was higher when pyraflufen-ethyl was applied at 3.6 g/ha compared with to lower rate of 1.8 g/ha (Table 3). In 2014 at Lewiston-Woodville, pyraflufen-ethyl applied at 1.8 g/ha caused no more than 11% injury at both application timings. As was noted when comparing injury at the two timings, pyraflufen-ethyl at 3.6 g/ha injured peanut 33% at 2 WBD compared with only 8% at 1 WBD (data not shown in tables). At 2 WAT, the main effect of pyraflufen-ethyl rate was significant in 2012 (P $\leq$ 0.0367) and 2014 (P = 0.0002), with the higher application rate of 3.6 g/ha causing more peanut injury compared with the rate of 1.8 g/ha (Table 4).

Peanut yield following carfentrazone-ethyl and pyraflufen-ethyl was not influenced by the main effect of herbicide rate or application timing and their interaction alone or with experiment. Peanut yield was similar to non-treated peanut regardless of herbicide rate or timing of application (Tables 1 and 3). Dotray *et al.* (2010) reported that carfentrazone-ethyl and pyraflufen-ethyl applied late POST 93 to 121 d after planting reduced peanut yield reduction at only at 1 of 6 locations. Peanut in our experiments was in the R8 stage of growth with 60-70% of pods in orange, brown, and black pod mesocarp classifications (Boote, 1982). It is postulated that herbicide phytotoxicity to foliage at this stage of growth and development did not affect foliage adequately to cause pod shed or the pod and seed maturation process.

Peanut response to carfentrazone-ethyl and pyraflufen-ethyl compared with diclosulam, lactofen, and 2,4-DB. The main effect of herbicide and the interaction of experiment $\times$ herbicide were significant for visible injury (P $\leq$ 0.0001). Although

Table 3. Peanut injury 1 week after treatment and pod yield as influenced by experiment and pyraflufen-ethyl rate and timing of application.

Main effect	Treatment	Peanut injury			Pod yield
		2012	2013	2014	
		%			kg/ha
Pyraflufen-ethyl (g/ha)	Non-treated	-	-	-	5250 a
	1.8	19 b[b]	12 a	11 b	5360 a
	3.6	38 a	13 a	21 a	5200 a
Application time (WBD)[a]	Non-treated	-	-	-	5250 a
	1	28 a	13 a	9 b	5360 a
	2	29 a	12 a	23 a	5200 a
Rate $\times$ Time (P > F)		0.9999	0.6059	<0.0001	0.4305

[a]Abbreviations: Weeks before digging peanut pods and inverting vines, WBD.
[b]Means within columns for main effects (rate or application timing) followed by the same letter are not significantly different according to Fisher's Protected LSD Test at P $\leq$ 0.05.

Table 4. Peanut injury 2 week after POST application of pyraflufen-ethyl.[a]

Herbicide	Rate	Peanut injury 1 week before digging		
		2012	2013	2014
	g/ha		—%—	
Pyraflufen-ethyl	1.8	30 b	8 a	14 b
	3.6	40 a	8 a	31 a
P > F		0.0367	0.9677	0.0002

[a]Means within a year followed by the same letter are not significantly different according to Fisher's Protected LSD Test at P ≤ 0.05. Pyraflufen-ethyl applied 2 weeks before digging peanut pods and inverting vines.

the main effect of herbicide was significant for pod yield, the interaction of experiment × herbicide was not significant (P = 0.3805). Therefore, data are combined over experiments for this interaction. The interaction of experiment × herbicide for visible injury was caused by lower peanut injury at Whiteville following carfentrazone-ethyl compared with pyraflufen-ethyl, and due to lack of differences in injury caused by lactofen and 2,4-DB compared with different results at Lewiston-Woodville (Table 5). At Lewiston-Woodville in both fields, no difference in injury was observed when comparing carfentrazone-ethyl and pyraflufen-ethyl. Visible injury at this location caused by lactofen exceeded that of diclosulam and 2,4-DB. Pod yield was 9% to 10% lower when carfentrazone-ethyl and pyraflufen-ethyl were applied compared with non-treated peanut (Table 5). Diclosulam, lactofen, and 2,4-DB did not negatively affect pod yield when compared with non-treated peanut. Other research (Lancaster et al., 2007) demonstrated no detrimental effect of diclosulam applied POST to peanut 7 to 35 d after planting prior to the R1 stage

of growth (Boote, 1982). Diclosulam can be applied up to 30 d after planting with minimal concern for negative impact on peanut (Anonymous, 2004; Prostko, 2004). Although Baughman et al. (2002) reported no adverse impact of 2,4-DB on peanut yield when applied 30 to 120 d after planting which corresponds to pre-flowering to pod maturity, other research has shown that lactofen can negatively affect yield in some but not all instances (Ferrell et al., 2013; Grichar, 1997; Jordan et al., 1993). Results from these experiments indicate that the injury caused by carfentrazone-ethyl and pyraflufen-ethyl observed 4 WBD is more deleterious to peanut growth and development and subsequent yield than the same level of injury within 2 WBD.

Conclusions

Overall, these results demonstrate that variation in peanut injury can occur depending on rate of carfentrazone-ethyl and pyraflufen-ethyl and application timing. However, when applied within 2 weeks of digging, these herbicides will not reduce peanut yield and may have potential to minimize weed interference with digging and vine inversion.

Acknowledgments

Table 5. Peanut injury 2 weeks after treatment and pod yield as influenced by carfentrazone-ethyl, pyraflufen-ethyl, diclosulam, lactofen, and 2,4-DB applied 4 weeks before digging peanut.[a]

Herbicide	Herbicide rate	Visible peanut injury			Pod yield
		Whiteville, 2014	Lewiston-Woodville, 2015		
			Field 1	Field 2	
	g/ha		—%—		kg/ha
Carfentrazone-ethyl	17.5	13 b	39 a	30 a	5,000 cd
Pyraflufen-ethyl	1.8	25 a	34 a	34 a	4,920 d
Lactofen	220	5 c	14 b	10 b	5,240 bc
Diclosulam	30	0 c	5 c	1 c	5,620 a
2,4-DB	280	5 c	0 c	1 c	5,410 ab
Non-treated control	-	-	-	-	5,470 ab

[a]Means within a column followed by the same letter are not significantly different according to Fisher's Protected LSD Test at P < 0.05. Data for pod yield are combined over experiments.

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