Soil and Residual Herbicide Affect Peanut Seedling Development

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ABSTRACT

Greenhouse experiments were conducted to determine the effect of soil type, residual herbicide, and herbicide rate on peanut seedling development. Diclosulam, flumioxazin, and sulfentrazone were evaluated at three rates in soils with different pH and mineral fractions from Georgia and Texas. Total peanut biomass (mg root plus shoot per seedling) in nontreated soil types were Faceville sandy clay loam > Duval sand > Pelham sandy loam > Brownfield loamy sand > Tremona sand > Tifton loamy sand. Averaged across all soils, total nontreated dry weight biomass was 722 mg plant^{-1}, with a range of 574 to 841 mg plant^{-1}, respectively. Averaged across soils, shoot length and shoot and root biomass were greatest in nontreated control > diclosulam > flumioxazin > sulfentrazone; and shoot lengths were greatest in nontreated control = flumioxazin = sulfentrazone > diclosulam. Herbicide rate did not affect peanut development. When soil pH was 7.8 (Tremona and Brownfield), peanut root biomass was significantly reduced to less than 74% of the nontreated control for sulfentrazone, diclosulam, and flumioxazin. For sulfentrazone and diclosulam, this was attributable to an increase in solubility with increasing soil pH that increased that specific herbicides availability for uptake. Soil organic matter and clay content potentially affected flumioxazin soil solution availability which resulted in variations in seedling growth.

Key Words: *Arachis hypogaea*, residual herbicide, soil.

The residual herbicides diclosulam, flumioxazin, and sulfentrazone are broad-spectrum herbicides used for weed control in many different crops. Diclosulam may be applied preplant incorporated or preemergence (PRE), while flumioxazin and sulfentrazone are PRE applied. Sulfentrazone (Dayan et al., 1996) and flumioxazin (Anderson et al., 1994; Yoshida et al., 1991) are protoporphyrinogen oxidase inhibitors while diclosulam inhibits acetolactate synthase (Vencill, 2002). Peanut is tolerant to these herbicides due to its ability to metabolize these herbicides, but injury in the form of necrosis and stunting has been observed. Sulfentrazone is no longer registered for peanut.

Sulfentrazone and diclosulam are weak acids with pKa values of 6.86 and 4.09, respectively (Vencill, 2002). As soil pH increases, these compounds become more ionic and greater amounts of sulfentrazone and diclosulam are desorbed from soil and found in solution (Vencill, 2002). Formation of the ionic species at a pH above the pKa increases water solubility for sulfentrazone and diclosulam (Hatzios, 1998). Flumioxazin does not disassociate (Kwon et al. 2004; Vencill, 2002). Dissociation of these herbicides into an ionic form will cause them to remain in solution.

Reports of seedling peanut injury for diclosulam (Bailey et al., 1999; Grey et al., 2001; Main et al., 2002; Murphree et al., 2003), flumioxazin (Askew et al., 1999; Burke et al., 2002; Grichar et al., 2004; Main et al., 2003; Price et al., 2004; Swann, 2002; Wilcut et al., 2001) and sulfentrazone (Grey et al., 2000; 2001; 2004; Grichar et al., 2006) have periodically occurred across the peanut belt. As with all crops, soil type and soil pH can vary significantly where peanut is grown. In 2004 Georgia and Texas led the US in peanut production with 246,000 and 95,000 hectares harvested, respectively (NASS, 2005).

The amount of herbicide active ingredient applied for weed control varies by soil type and pH, and these rate differences are often reflected via the manufactures registration. For example, diclosulam registration for peanut specifically states "when emergence of the planted crop is delayed due to unusually cool and/or wet conditions, factors such as pH, disease, and nutrient deficiencies can contribute to reduced crop tolerance to a soil-applied herbicide" (Anonymous, 2005a). Reports of none to transient injury have been reported with diclosulam in south Texas (Grichar et al., 1999), Georgia (Grey et al., 2001, 2003), Florida (Main et al., 2002; Teuton et al., 2004) and North Carolina (Bailey et al., 1999, 2000; Price et al., 2002). However, in west Texas, diclosulam has caused peanut stunting and reduction in yield (Grichar et

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al., 2001; Karnei et al., 2001, 2002; Murphree et al., 2003). Under weed-free conditions, diclosulam at 0.05 kg ai/ha caused 8 to 10% late-season peanut injury, while lower doses resulted in less than 3% injury (Karnei et al., 2001, 2002). Murphree et al. (2003) reported that diclosulam at 0.03 kg ai/ha PRE applied injured peanut 15 to 40% 14 d after treatment in 2001 but in 2002 injury was less than 8%. Peanut injury was less than 5% when evaluated late season with no yield loss.

The sulfentrazone registration (for all crops registered) specifically states "soil pH exerts a dramatic affect on sulfentrazone availability in the soil solution" (Anonymous, 2005b). Sulfentrazone PRE in peanut at 0.28 and 0.42 kg/ha caused significant injury and reduced peanut yield (Johnson and Mullinix, 1994). However, 0.14 kg/ha sulfentrazone applied PRE was similar to the nontreated control in terms of late-season injury, canopy width, vegetative and pod biomass, and yield. In Florida and Georgia studies, 16% and less visual injury was noted for runner peanut cultivars with sulfentrazone applied PRE up to 0.42 kg/ha (Grey et al., 2004). Sulfentrazone registration prohibits use on sandy soils that have less than 1% organic matter due to injury concerns. It has been determined that sulfentrazone availability in soil varies with soil pH (Grey et al., 1997; Grey et al., 2000) and soil type (Ohmes et al., 2000). Thus, variations in peanut injury for these studies (Johnson and Mullinix, 1994; Grey et al., 2004) may be indicative of soil type differences and organic matter quantity (Grey et al., 2005). The main mechanism for peanut tolerance to sulfentrazone is through metabolism (Thomas et al., 2005).

Flumioxazin peanut registration states that "crop injury may occur from applications made to poorly drained soils and or applications made under cool, wet conditions" (Anonymous, 2005c). Main et al. (2003) noted 25% visual peanut injury from flumioxazin in Florida studies and associated this injury with cool and extremely wet growing conditions. In North Carolina, peanut exhibited 15 to 25% visual injury from flumioxazin PRE. The cultivar VC-1 had 45% injury (Wilcut et al., 2001). Differences in the soil availability and dissipation of flumioxazin have been attributed to hydrolysis and photolysis of the parent with changes in soil pH (Kwon et al., 2004) and adsorption kinetics associated with organic matter and clay mineral content (Ferrell et al., 2005).

Explanations for peanut injury in the form of stunting and necrosis have not been fully investigated with respect to diclosulam, flumioxazin, and sulfentrazone rates and soil type. Thus, the objective of this research was to evaluate peanut seedling development in the presence of diclosulam, flumioxazin, and sulfentrazone at different rates, in three soils from Georgia and three soils from Texas.

Materials and Methods

Greenhouse experiments were conducted in 2001 and 2002 in Griffin, GA, with average day/night temperatures of 30 (±5)/25 (±3) C. A 16-h photoperiod was maintained by natural and supplemental halide lighting. Soils were collected from areas herbicide-free for at least two years, to a depth of 15 to 20 cm. Soil descriptions are presented in Table 1. Soil analysis and organic matter content were determined by the University of Georgia Soil Test laboratory.

Standard circular pots, 24 cm tall by 14 cm wide, were filled with soil from each location to

Table 1. Soil types, origin, and physical characteristics of each soil used to test the effect of residual herbicides on peanut seedling growth.

Soil type	Taxonomy	Origin		pH[a]	Sand	Silt	Clay	C[b]	CEC
		County	State		———	%	———		meq 100^{-1}
Faceville sandy clay loam	Clayey, kaolinitic, thermic, Typic Kandiudults	Sumter	GA	6.1	53	24	23	1.2	11.9
Tifton loamy sand	Fine-loamy, kaolinitic, thermic Plinthic Kandiudults	Tift	GA	5.6	83	12	5	2.3	3.9
Pelham sandy loam	Loamy, kaolinitic, thermic Arenic Kandiudults	Decatur	GA	5.7	67	23	10	1.3	9.4
Duval sand	Loamy, fine sand mixed hyperthermic Aridic Haplustalfs	Frio	TX	5.8	90	6	4	0.9	2.5
Tremona sand	Loamy, fine sand, thermic Aquic Arenic Paleustalfs	Yoakum	TX	7.8	90	8	2	0.4	3.0
Brownfield loamy sand	Loamy, mixed, superactive, thermic Arenic Aridic Paleustalfs	Gaines	TX	7.8	80	18	2	0.7	2.8

[a] Soil pH was determined by the 1:1 (wt/v) soil-water method.
[b] Organic matter.

within three cm of the top. Two seed of Georgia Green peanut were hand-planted approximately two cm deep in each pot. Herbicide treatments included diclosulam at 0.018, 0.026, and 0.039 kg ai/ha, flumioxazin at 0.07, 0.11, 0.16 kg ai/ha, and sulfentrazone at 0.17, 0.28, 0.4 kg ai/ha. A nontreated control for each soil was included. Pots were sprayed using a moving belt sprayer calibrated to deliver 187 L/ha at 210 kPa. Pots were surface irrigated with 1.0 cm of water to activate the herbicides, fertilized weekly after peanut emergence, and sub-irrigated as needed based on observations.

Twenty one days after emergence when peanut was in the three to five leaf stage, peanut emergence via stand counts were recorded, and then plants were carefully washed to remove all soil. Shoot and root length of individual plants were measured. Plants were divided into shoot and root portions, oven dried for 48 hrs at 50 C, and biomass was measured.

The experiment was a completely randomized design with five replications and was repeated twice over time. Data for root and shoot biomass and length were converted to a percentage of the nontreated control to facilitate comparisons among soils. Data were subjected to analysis of variance and treatment means were separated using Fisher's Protected LSD test at the 0.05 level of probability.

Results and Discussion

Statistical Analysis.

Due to lack of treatment by repetition of study interaction, data for experiments were combined for analysis (Table 2). The two-way interactions between soil and herbicide were significant for root biomass and root and shoot length; therefore, data for the main effects for soil by herbicide are presented for all variables. For all measurements, the interaction between herbicide and rate was not significant. Thus, data for individual herbicides were combined across rate.

Soil Properties.

Soil properties varied by location (Table 1). The cation exchange capacity was 2.5 to 11.9 meq 100/g while organic matter ranged from 0.4 to 2.3%. These data indicate variation in adsorptive capability among the soils examined. The pH for Faceville, Tifton, Pelham, and Duval were acidic ranging from 5.6 to 6.1, while Tremona and Brownfield pH were alkaline with pH 7.8. The Tifton soil organic matter content of 2.3% was due to its origin from an area that had not been disturbed for over 20 years.

Peanut Emergence.

Peanut emergence was not affected by soil type, herbicide, rate, or their interactions (data not shown). In growth chamber studies, Grichar et al. (2001) reported diclosulam rate was a factor in reduced peanut germination. In that study, there was an inverse relation between peanut germination and diclosulam rate. However, poor seed quality was considered to have contributed to reduced peanut seed germination in combination with diclosulam (Grichar et al. 2001). Flumioxazin did not influence peanut germination across a thermogradient (Price et al., 2004), indicating that it does not affect initial seed germination upon absorption.

Biomass.

Total peanut biomass (root plus shoot) in nontreated soil was different across soil type (Faceville > Duval > Pelham > Brownfield > Tremona > Tifton). Averaged across all soils, total nontreated biomass was 722 mg/plant, with a minimum and maximum of 574 and 841 mg/plant, respectively (data not shown). Nontreated control

Table 2. Analysis of variance for root and shoot biomass and length for experiment soil, herbicide, and rate effects.

		Root		Shoot	
Treatment	Degrees of freedom	Biomass	Length	Biomass	Length
Experiment (Exp)	2	NS	NS	NS	NS
Replication (Rep)	4				
Error (Exp × Rep)	8				
Soil	5	***[a]	***	***	***
Herbicide (Herb)	3	***	***	***	***
Herbicide rate (Rate)	2	NS	NS	NS	NS
Herb × Rate	6	NS	NS	NS	NS
Soil × Herb	15	***	***	NS	***
Error	489				
Coefficient of variation (%)	—	50.6	36.5	37.7	31.5

[a] *,**,*** = levels of probability at $P \leq 0.05$, 0.01, and 0.001, respectively.

peanut root biomass varied by soil ranging from 104 to 210 mg/plant.

Sulfentrazone. There were significant differences in peanut response to sulfentrazone among soil types (Table 2). For sulfentrazone, root biomass was 64 to 79% of the nontreated control for Faceville, Pelham, Duval, Tremona, and Brownfield (Table 3). Previous studies indicated that the concentration of sulfentrazone in peanut root decreases over time as it moves to the shoot and that tolerance is due to metabolism (Thomas et al., 2005). Dayan et al. (1996) attributed sicklepod tolerance to sulfentrazone as a matter of differential metabolism and indicated that it is not active in the plant until it reaches tissues that are exposed to light. Thus, reduced root growth could be attributed to the plants emphasis on shifting energy for metabolism of sulfentrazone possibly leading to reduced root growth. Field trials indicated that foliar peanut injury in the form of chlorosis from sulfentrazone was transient (Grey et al., 2000, 2004). Root biomass from sulfentrazone in the Tifton soil was 147% of the nontreated control. This could be attributed to the 2.3% organic matter content for this soil. Organic matter sorption of sulfentrazone has been associated with reduced activity (Ohmes et al. 2000). Root length, as percentage of the nontreated control, was affected less by sulfentrazone than root biomass. Faceville, Tifton, Duval, Tremona, and Brownfield soils were similar to or exceeded (92 to 128%) the nontreated control (Table 2). Pelham root length was 70% of the nontreated control and reflected the reduction in root biomass for this soil-herbicide combination.

Reductions of shoot biomass and length as compared to the nontreated control for sulfentrazone mirrored root biomass reductions for each soil (Tables 3 and 4). The uptake and translocation of sulfentrazone to the shoot (Thomas et al.,2005) with subsequent injury, contributed to reductions in plant growth, resulting in decreased root biomass production.

Diclosulam. Differences in peanut growth in response to diclosulam were detected among soil types. Root biomass was 73 and 54% of the nontreated control for Tremona and Brownfield (Table 3). The pH of these soils was 7.8. In contrast, Faceville, Tifton, Pelham, and Duval root biomass was 97 to 154% of the nontreated check. The pH of these soils was 5.6 to 6.1. As previously noted, as pH increases diclosulam becomes more ionic, and greater amounts remain in solution (Vencill 2002). Degradation of diclosulam is biphasic with initial rapid dissipation and adsorption by soil colloids (Zabik et al. 2001). It is theorized that soil with pH of 7.8 resulted in higher diclosulam concentration in the soil solution due to increased solubility, which increased availability for root absorption, causing root injury and reducing growth. When the pH was less than 6.1, diclosulam was not as available for uptake, therefore minimizing crop injury (Zabik et al., 2001). Organic matter sorption of diclosulam has as also been associated with reduced activity (Vencill, 2002).

Root length as a percentage of the nontreated control for Faceville, Tifton, and Pelham exceeded the nontreated (120%) and were similar to root biomass responses for diclosulam (Table 3). Duval root length was 89% of the nontreated control. Tremona and Brownfield root length were 60 and 55% of the nontreated and mirrored root biomass

Table 3. Residual herbicide effect on Georgia Green peanut root length and biomass in GA and TX soils 21 d after treatment[a].

	Root biomass				Root length			
Soil type	Nontreated control	Sulfentrazone[b]	Diclosulam	Flumioxazin	Nontreated control	Sulfentrazone	Diclosulam	Flumioxazin
	mg plant^{-1}	% of nontreated			cm plant^{-1}	% of nontreated		
Faceville	210	79 b[c]	97 b	101 bc	16.2	128 a	120 a	122 a
Tifton	104	147 a	154 a	139 a	11.9	116 ab	120 a	121 a
Pelham	168	66 b	110 b	116 b	18.8	70 d	120 a	121 a
Duval	164	64 b	99 b	68 d	15.2	98 bc	89 b	86 b
Tremona	171	73 b	73 c	51 d	11.4	101 bc	60 c	74 b
Brownfield	104	74 b	54 c	70 cd	7.1	92 c	55 c	85 b

[a] Soils were irrigated immediately after treatment to water holding capacity to activate the herbicides.

[b] Analysis indicated that rate was not significant for any individual herbicide, therefore rate data was combined across individual herbicide for presentation. Rates were: sulfentrazone 0.17, 0.28, and 0.40 kg ai/ha; diclosulam 0.018, 0.026, and 0.039 kg ai/ha; and flumioxazin 0.07, 0.11, and 0.16 kg ai/ha.

[c] Means within a variable for year followed by the same letter are not significant according to Fisher's protected LSD test at $P \leq 0.05$.

Table 4. Residual herbicide effect on Georgia Green peanut shoot length and biomass in GA and TX soils 21 d after treatment[a].

	Shoot biomass				Shoot length			
Soil type	Nontreated control	Sulfentrazone[b]	Diclosulam	Flumioxazin	Nontreated control	Sulfentrazone	Diclosulam	Flumioxazin
	mg $plant^{-1}$	% of nontreated			cm $plant^{-1}$	% of nontreated		
Faceville	618	94 a[c]	96 b	112 a	5.9	101 a	107 ab	130 a
Tifton	485	93 a	114 a	95 a	6.3	90 b	79 c	77 c
Pelham	602	73 b	104 ab	106 a	7.1	71 d	98 bc	101 b
Duval	632	71 b	93 b	88 a	6.4	78 cd	120 a	101 b
Tremona	495	83 ab	97 b	97 a	5.1	77 cd	94 bc	103 b
Brownfield	586	88 ab	89 b	78 a	5.4	82 bc	83 c	101 b

[a] Soils were irrigated immediately after treatment to water holding capacity to activate the herbicides.

[b] Analysis indicated that rate was not significant for any individual herbicide, therefore rate data was combined across individual herbicide for presentation. Rates were: sulfentrazone 0.17, 0.28, and 0.40 kg ai/ha; diclosulam 0.018, 0.026, and 0.039 kg ai/ha; and flumioxazin 0.07, 0.11, and 0.16 kg ai/ha.

[c] Means within a variable for year followed by the same letter are not significant according to Fisher's protected LSD test at $P \leq 0.05$.

reductions. No previous information about root length as affected by diclosulam was found in review of the literature.

Peanut shoot biomass and length, as a percentage of the nontreated control, were at least 89 and 83%, respectively when treated with diclosulam. These two variables were consistent with the reductions in root biomass for Tremona and Brownfield. One unexplainable anomaly did occur, in that Tifton shoot biomass was 114% of the nontreated check but the shoot length was 79%.

Flumioxazin. Differences for flumioxazin root biomass segregated by state (Table 3). Peanut root biomass of plants treated with flumioxazin in Georgia soils (Faceville, Tifton, and Pelham) was greater than their nontreated controls. In contrast, Texas soils (Duval, Tremona, and Brownfield) treated with flumioxazin had peanut root biomass that was 70% and less than their nontreated controls. One difference between the soils of these two states was that Texas soil had organic matter contents of 0.9% and less while the Georgia soils were 1.2% and greater. Previous research by Ferrell et al. (2005) indicated that flumioxazin adsorption was highly correlated to soil organic matter ($r^2 = 0.95$, $P < 0.001$) and clay content ($r^2 = 0.70$, $P < 0.05$), but negatively correlated to soil pH ($r^2 = -0.17$, $P < 0.71$). Flumioxazin peanut registration states under *Soil Characteristics* that "application of Valor to soils with high organic matter and/or high clay content may require higher dosages than soils with low organic matter and/or low clay content" (Anonymous, 2005c). From this statement, it can be inferred that as organic matter and clay contents decreased, the availability of flumioxazin in soil solution increased. The amount of clay for the Georgia soils was at least 5%, while the Texas soils were 4% and less (Table 1). Therefore, the combination of low organic matter and clay mineral content for the Texas soils resulted in greater fluimoxazin availability, which translated into peanut injury. Reduced peanut root biomass and root lengths (Table 3) supports this hypothesis when comparing Georgia to Texas soils (Table 1). Since peanut production typically occurs in soils characterized by low organic matter and clay content, the potential for injury as a result of this combination explains the injury associated with flumioxazin (Burke et al., 2002; Grey et al., 2002; Main et al., 2003; Wilcut et al., 2001). Peanut injury occurred on Norfolk loamy sand with 1.1% or less organic matter (Burke et al. 2002; Wilcut et al. 2001), Chipola loamy sand with 1.0% organic matter and Arredondo fine sand with 0.5% organic matter (Main et al., 2003), and Tifton loamy sand and Dothan loamy sand with 0.5% organic matter (Grey et al., 2002).

Conclusion

With respect to seedling peanut growth, these data indicate soil type and pH influenced sulfentrazone and diclosulam availability when used PRE. For soils with pH of 7.8 (Tremona and Brownfield), solubility of these two herbicides increased, which increased herbicide availability, resulting in decreased root and shoot biomass and lengths. In contrast, soil organic matter and clay content potentially affected flumioxazin soil solution availability (Ferrell et al., 2005) which resulted in variations of the seedling growth parameters. In general, for each of these herbicides, peanut root biomass was affected more than shoot biomass.

Thus, peanut injury caused by these herbicides could result in delayed early season development and delayed maturity. Main et al. (2003) noted slower canopy development for flumioxazin injured peanut but did not elaborate on delay of maturity. Future research should investigate if differences exist between peanut cultivars for these herbicide and soil combinations.

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