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ARTICLE

Peanut Tolerance and Weed Control following Norflurazon in Texas and Oklahoma

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ABSTRACT

Field experiments were conducted in south Texas and the Texas High Plains region during the 2019 and 2020 growing seasons and in Oklahoma in 2020 to evaluate peanut tolerance to norflurazon at 0.56 and 1.12 kg ai/ha applied preemergence (PRE) or early postemergence (EPOST). Weed control with norflurazon applied either preplant incorporated (PPI) or PRE was evaluated in south Texas. Norflurazon at 1.12 kg ai/ha caused more injury than norflurazon at 0.56 kg ai/ha in both years in south Texas, in 2019 in the High Plains region, and in Oklahoma. The EPOST application was more injurious in south Texas but not at the other locations. Peanut yield was only affected in the High Plains in 2020. Norflurazon at 1.12 kg ai/ha applied PRE caused a 25% yield reduction compared to the untreated check. Preplant incorporated applications of norflurazon alone provided 89 to 94% early-season control of Texas millet [*Urochloa texana* (Buckl.)] and 96 to 100% control of both Palmer amaranth (*Amaranthus palmeri* L.) and smellmelon (*Cucumis melo* L.). Norflurazon applied PRE controlled Texas millet 73 to 98%, Palmer amaranth 91 to 98%, and smellmelon 88 to 98% early-season. Late-season weed control was erratic and required the addition of either pendimethalin or ethalfluralin for more consistent weed control. There may be opportunities to utilize norflurazon in peanut in Texas or Oklahoma. However, norflurazon is not a stand-alone herbicide and there is potential for crop injury and yield reductions under certain environments.

INTRODUCTION

Control of many broadleaf and annual grass weeds in peanut (*Arachis hypogaea* L.) can be challenging and requires the use of a preplant application of a dinitroaniline herbicide such as trifluralin (Treflan®), pendimethalin (Prowl® or Prowl H₂0®), or ethalfluralin (Sonalan®) (Wilcut *et al.*, 1995). Weeds such as Texas millet [*Urochloa texana* (Buckl.)], Palmer amaranth (*Amaranthus palmeri* S. Wats), pitted morningglory (*Ipomoea lacunosa* L.), yellow nutsedge (*Cyperus esculentus* L.), purple nutsedge (*Cyperus rotundus* L.), and smellmelon (*Cucumis melo* L.) are a continuing problem in peanut growing areas of the southwestern U.S. (Grichar and Dotray, 2013; Baughman *et al.*, 2018; Dotray *et al.*, 2018; Grichar *et al.*, 2019). These weeds can escape control due to extremely high weed populations, improper soil incorporation, large seed size, and/or an inadequate herbicide rate (Grichar and Colburn, 1996). Also, the dinitroaniline herbicides alone do not adequately control any of these weeds season-long (Wilcut *et al.*, 1995; Grichar *et al.*, 1999; Grichar and Dotray, 2013; Baughman *et al.*, 2018; Dotray *et al.*, 2018; Grichar *et al.*, 2019).

Norflurazon [4-chloro-5-(methylamino)-2-(3-trifluoromethyl) phenyl-3-(2H)-pyridazinone] is registered for use on peanut only in Alabama, Florida, Georgia, Mississippi, North Carolina, New Mexico, Oklahoma, South Carolina, Texas, and Virginia (Anonymous, 2015a). Norflurazon is not registered for use on Spanish peanuts and is only available for use on certain runner or Virginia-type peanut cultivars including 'Florunner', 'GK-7', 'GA Runner', 'Southern Runner', 'NC 7', 'VA 93B', 'NC 9', 'NC-V11', 'VA-C 92R', 'AgraTech VC-1', and 'NC 10C' (Anonymous, 2015a). Most if not all of these cultivars are no longer commercially available for production.

Norflurazon is a phytoene desaturase inhibitor which catalyzes a rate-limiting step in carotenoid biosynthesis (Manaa *et al.*, 2019). Carotenoid deficiency causes oxidative stress due to significant increase in reactive oxygen species (ROS) formation (Jung *et al.*, 2000). Therefore, carotenoids are not only accessory pigments in the photosynthesis process, they also act as photoprotective agents by absorbing excess energy of triplet excited states of chlorophyll and detoxifying of singlet oxygen (Shaner, 2014). Norflurazon also inhibits the unsaturation of chloroplast lipids (Abrous-Belbachir *et al.*, 2009). Other modes of action ascribed to norflurazon are: a) inhibition of the Hill reaction (Eder, 1979), b) alteration of the ratio of linolenic/linoleic acid (St. John 1976; St. John and Hilton, 1976; Eder, 1979), and c) influence on the chloroplast ribosomes (Eder, 1979). Lack of translocation and the presence of lysigenous or pigment glands are two major factors responsible for its selectivity in cotton (*Gossypium hirsutum* L.) (Strang and Rogers, 1974; 1975).

Norflurazon controls broadleaf weeds including prickly sida (*Sida spinosa* L.), spurred anoda [*Anoda cristata* (L.) Schlecht.], tropic croton (*Croton glandulosus* var. septentrionalis Muell.-Arg.], common ragweed (*Ambrosia artemissiifolia* L.), and common lambsquarters (*Chenopodium album* L.) and some annual grasses such as barnyardgrass (*Echinochloa crus-galli* L.), crowfootgrass (*Dactyloctenium aegyptium*), crabgrass (*Digitaria* spp.), fall panicum (*Panicum* spp.), and Texas millet [*Urochloa texana* (Buckl.)] (Anonymous, 2015a). Norflurazon also can suppress nutsedge (*Cyperus* spp.) (Wilcut *et al.*, 1995; Jordan *et al.*, 1998).

Currently, many peanut growers in Texas and Oklahoma apply pendimethalin in combination with either *S*-metolachlor or flumioxazin preemegence (PRE) and follow that with postemergence (POST) applications of a graminicide or broadleaf herbicide to control any weed escapes (authors' personal observations). Imazapic has been used to control broadleaf and nutsedge weed issues in peanut for the last thirty years (Grichar, 2008); however, some weed resistant issues have developed (possibly *Amranthus palmeri*) and growers are concerned about the lack of available herbicides for control of problem weeds. Norflurazon would provide Texas and Oklahoma growers with another tool to combat these weed issues. Little research could be found on norflurazon use in the Texas or Oklahoma on peanut. Also, since the peanut varieties cleared for use with norflurazon are either no longer available or commercially limited (Anonymous, 2015a), it was decided to evaluate the newer released peanut cultivars for tolerance to norflurazon in the Texas and Oklahoma peanut growing areas.

MATERIALS AND METHODS

Norflurazon tolerance studies were conducted at the Texas A&M AgriLife Research site in south Texas near Yoakum (29.0369° N, 97.2616° W) during the 2019 and 2020 growing seasons, in the Texas High Plains during the 2019 and 2020 season in a producer's field in Gaines County near Seminole (32.7429° N, 102.8253° W). The study in Oklahoma was conducted only in 2020 at the Oklahoma State University Caddo Research Station near Ft. Cobb (35.091° N, 98.275°W). Weed efficacy studies were also conducted during the 2019 and 2020 growing season at the Texas A&M AgriLife Research site near Yoakum.

The soils at Yoakum were a Denhawken sandy clay loam (fine, smectitic, hyperthermic, Vertic Haplustepts) with less than 1.0 % organic matter and pH 7.6 while near Seminole the soils were a Patricia loamy fine sand (fine-loamy, mixed, superactive, thermic Aridic Paleustalfs) with 1.4% organic matter and a pH 7.9. Soils at Ft. Cobb were a Cobb fine sandy loam (fine-loamy, mixed, active, thermic Typic Haplustalfs) with less than 1% organic matter and a pH 7.3.

Treatments in the peanut tolerance study consisted of a factorial arrangement of two norflurazon rates (0.56 or 1.12 kg/ha) and two application timings [preemergence (PRE) or early postemergence (EPOST). The PRE applications were made within two days of peanut planting while the EPOST applications were applied 7 to 13 d after planting depending on location (V1 to V3) (Boote, 1982). Treatments in the weed efficacy trials included norflurazon alone at 0.56 and 1.12 kg ai/ha applied either preplant incorporated (PPI) or PRE after peanuts were planted, pendimethalin at 1.06 kg ai/ha plus norflurazon at either 0.56 or 1.12 kg ai/ha applied PRE, and ethalfluralin at 0.84 kg ai/ha applied PPI followed by (fb) norflurazon at either 0.56 or 1.12 kg ai/ha applied PRE. Pendimethalin at 1.06 kg ai/ha plus *S*-metolachlor at 1.42 kg ai/ha applied PRE was included as a standard. An untreated check was included in each study and each study was replicated three to four times depending on location. The PPI treatments were incorporated with a tractor-driven power tiller approximately 5 cm deep immediately after herbicide application. The PPI treatments were not included in the tolerance study since currently, very few, if any growers mechanically incorporate soil-applied herbicides (authors' personal observations).

Herbicides were applied using water as a carrier with a CO_2-pressurized backpack sprayer. Trial variables for each location are listed in Table 1. Georgia 09-B (Branch, 2010) was planted in all Texas trials. The Spanish cultivar OLe´ (Anonymous, 2015b) was planted at Ft. Cobb.

For studies at Yoakum, each plot consisted of two rows spaced 97 cm apart and 7.6 m long while at the High Plains locations plot size was 4 rows spaced 102 cm apart and 9.1 m long. The Oklahoma location consisted of 2 rows spaced 91 cm apart and 7.6 m long. Traditional production practices were used to maximize peanut growth, development, and yield. Plots in the peanut tolerance studies received either ethalfluralin or pendimethalin applied PPI to control early season weeds. In south Texas, clethodim and 2,4-DB were applied postemergence (POST) to control any late- season weed infestations. Hand-weeding as needed was used exclusively in Oklahoma and the High Plains locations. Insecticides were not needed at any location in any year.

Table 1. Variables associated with norflurazon study in Oklahoma and Texas.

	South Texas						
Variable	Tolerance studies		Efficacy studies		Texas High Plains		Oklahoma
Year	2019	2020	2019	2020	2019	2020	2020
Location	Yoakum	Yoakum	Yoakum	Yoakum	Seminole	Seminole	Ft. Cobb
Coordinates	29.2671°N 97.0541°W	29.2671°N 97.0541°W	29.2770°N 97.1245°W	29.2765 °N 97.1240 °W	32.7324 °N 102.8767 °W	32.7521°N 102.7872 ° W	35.0910 °N 98.2745 °W
Planting date	June 24	June 17	June 24	June 15	April 30	April 28	May 6
Variety	Georgia-09B	Georgia-09B	Georgia-09B	Georgia-09B	Georgia-09B	Georgia-09B	OLe′
Sprayer type	CO2 backpack	CO2 backpack	CO2 backpack	CO2 backpack	CO2 backpack	CO2 backpack	CO2 backpack
Spray pressure (kPa)	180	180	180	180	198	198	168
Nozzle type	Flat fan	Flat fan	Flat fan	Flat fan	Flat fan	Flat fan	Flat fan
Nozzles tips	DG 11002	DG 11002	DG 11002	Teejet 11002	Teejet 11002	Teejet 11002	TTI 110015
Spray volume (L ha-1)	187	187	187	187	140	140	112
Application[a]							
PPI	-	-	June 24	June 15	-	-	-
PRE	June 26	June 19	June 24	June 15	May 1	April 28	May 6
EPOST	July 1	June 30	-	-	May 13	May 6	May 19

[a]Abbreviations: PPI, preplant incorporated; PRE, preemergence; EPOST, early postemergence.

In the weed efficacy trials at Yoakum no irrigation was applied while in the peanut tolerance trials supplemental irrigation was used at all locations. At Yoakum, lateral hand-moved irrigation lines were used and irrigation was applied as needed throughout the growing season. Center pivot systems were used to apply irrigation as needed at Seminole and Ft. Cobb.

Peanut emergence was obtained 30 d after planting (DAP) at Seminole and 13 DAP at Ft. Cobb by counting emerged peanut plants in 2 m of row. Emergence data were not obtained at Yoakum. Peanut injury and weed control were estimated visually on a scale of 0 to 100 (0 indicating no control or plant death and 100 indicating complete control or plant death) relative to the untreated check (Frans *et al.* 1986). Weed control was evaluated throughout the growing season but only the 2 and 12 wks after planting (WAP) evaluations are presented.

Peanut yield was obtained by digging the pods based on maturity of control plots, air-drying in the field for 6 to 10 d, and harvesting individual plots with a small-plot thresher. Yield samples were cleaned and adjusted to 10% moisture prior to weighing.

Data for percentage of peanut injury and weed control were transformed to the arcsine square root prior to analysis; however, non-transformed means are presented because arscine transformation did not affect interpretation of the data. Data were subjected to ANOVA and analyzed using the SAS PROC MIXED procedure 23 (SAS, 2019). Treatment means were separated using Fisher's Protected LSD at $P < 0.05$.

RESULTS AND DISCUSSION

Peanut tolerance studies.

Injury from norflurazon consisted of foliar chlorosis and bleaching and was present for approximately 3 wks after peanut emergence. No injury was observed later in the growing season.

South Texas (Yoakum).

There was a norflurazon rate by application timing interaction at the Yoakum location for the 7 d after emergence (DAE) evaluation for both years (Table 2). In 2019 norflurazon at both rates resulted in greater injury than the untreated check while in 2020 only norflurazon at 1.12 kg ai/ha resulted in greater injury. The PRE application of norflurazon had no effect on peanut when evaluated 7 DAE in either year while the EPOST application resulted in 17 and 18% injury in 2019 and 2020, respectively (Table 2).

Yields were combined over years since there was no treatment by year interaction (Table 3). No differences in yield were noted between norflurazon rate or application timing and the untreated check.

Table 2. Early-season peanut injury with norflurazon.[a,b]

			Yoakum		Seminole	Ft. Cobb
			7 DAE		14 DAE	21 DAE
Treatment	Rate	Application timing[c]	2019	2020	2019	2020
	kg ai/ha		---------------------------	%	--------------------------------	
Untreated			0	0	0	0
Norflurazon	0.56		3	2	4	1
Norflurazon	1.12		15	16	16	5
LSD (0.05)			2	5	4	2
Norflurazon		PRE	1	0	11	3
Norflurazon		EPOST	17	18	8	3
LSD (0.05)			3	5	4	NS

[a] The peanut cultivar at Yoakum and Seminole was Georgia-09B while at Ft. Cobb the cultivar was OLe'.

[b] Injury consisted of foliar chlorosis and bleaching.

[c] Application timing: PRE, preemergence; EPOST, early postemergence.

Table 3. Peanut yield when using norflurazon.[a]

				Seminole		Ft. Cobb
Treatment	Rate	Application timing[b]	Yoakum[c]	2019	2020	2020
	kg ai/ha		-------------------------------	kg/ha	----------------------------------	
Untreated	-	-	3831	7648	4636	7226
Norflurazon	0.56	PRE	3516	7801	3844	7389
Norflurazon	1.12	PRE	3664	7618	3477	7535
Norflurazon	0.56	EPOST	3413	8107	4271	7161
Norflurazon	1.12	EPOST	3664	7312	4331	7096
LSD (0.05)			NS	NS	804	NS

[a] The peanut cultivar at Yoakum and Seminole was Georgia-09B while at Ft. Cobb the cultivar was OLe'.

[b] Abbreviation: PRE, preemergence; EPOST, early postemergence.

[c] Data pooled over years due to a lack of treatment by year interaction.

High Plains (Seminole)

Plant stands were not affected by any treatment in either year (data not shown). There was a norflurazon rate by application timing interaction for peanut injury in 2019 (Table 2). When evaluated 14 DAE, norflurazon at 1.12 kg ai/ha resulted in 16% peanut injury compared with 4% injury for norflurazon at 0.56 kg ai/ha. No differences were noted in peanut injury when norflurazon was applied either PRE or EPOST. No peanut injury (22 DAE) was observed in 2020 with norflurazon (data not shown).

Norflurazon did not affect peanut yield in 2019 while in 2020 norflurazon at 1.12 kg ai/ha applied PRE reduced yield 25% compared to the untreated check (Table 3). Manaa *et al.* (2019) reported that peanut plants grown in norflurazon-contaminated soil were impaired in their photosynthesis and displayed a reduction in growth. This reduction in photosynthesis may be linked to a decrease in chlorophyll content in depigmented leaves of peanut (Dankov *et al.*, 2009) and may have contributed to the yield reduction.

Oklahoma (Ft. Cobb)

No reduction in stand was observed with any norflurazon treatment (data not shown). When evaluated 21 DAE there was a norflurazon rate effect but not an application timing effect (Table 2). Norflurazon at 0.56 kg ai/ha resulted in peanut injury similar to the untreated check while norflurazon at 1.12 kg ai/ha resulted in 5% injury. There was no difference in yield between the untreated check and any norflurazon rate or application timing (Table 3).

Weed efficacy studies

Texas Millet Control

Data are presented separately since there was a treatment by year interaction for both the 2 and 12 WAP evaluations (Table 4). At the 2 WAP evaluation in 2019, herbicide treatments which included either pendimethalin or ethalfluralin provided 99 to 100% control while norflurazon alone applied PPI controlled 88 to 89% and norflurazon alone applied PRE provided 94 to 98% control. In 2020, pendimethalin or ethalfluralin treatments provided 89 to 98% control while norflurazon alone at either 0.56 or 1.12 kg ai/ha applied PPI and norflurazon at 1.12 kg ai/ha applied PRE controlled Texas millet at least 93%. Norflurazon at 0.56 kg ai/ha applied PRE only provided 73% control (Table 4). In 2019, 12.2 mm of rainfall was received within 7 d of herbicide application while in 2020, 34.5 mm of rainfall was received within 7 d of herbicide application.

Table 4. Texas millet control in peanut with norflurazon.

			Weeks after planting			
			2		12	
Treatment	Rate	Application timing[a]	2019	2020	2019	2020
	kg ai/ha		-------------------	%	--------------------------	
Untreated	-	-	0	0	0	0
Norflurazon	0.56	PPI	89	94	63	30
Norflurazon	1.12	PPI	88	93	43	17
Norflurazon	0.56	PRE	94	73	65	20
Norflurazon	1.12	PRE	98	95	88	33
Pendimethalin + norflurazon	1.06 + 0.56	PRE	100	89	90	33
Pendimethalin + norflurazon	1.06 + 1.12	PRE	99	94	84	32
Ethalfluralin Norflurazon	0.84 0.56	PPI PRE	100	96	96	80
Ethalfluralin Norflurazon	0.84 1.12	PPI PRE	100	97	80	87
Pendimethalin + S-metolachlor	1.06 + 1.42	PRE	100	98	86	62
LSD (0.05)			11	11	18	42

[a] Abbreviations: PPI, preplant incorporated; PRE, preemergence.

In 2019 when evaluated 12 WAP, either pendimethalin or ethalfluralin in combination with norflurazon at 0.56 kg ai/ha controlled Texas millet 90 to 96% while combinations with norflurazon at 1.12 kg ai/ha controlled this weed 80 to 84%. Norflurazon alone applied PPI and norflurazon alone at 0.56 kg ai/ha applied PRE controlled Texas millet < 65% while norflurazon at 1.12 kg ai/ha applied PRE provided 88% control (Table 4). In 2020 at the 12 WAP evaluation, only the ethalfluralin applied PPI followed by (fb) norflurazon applied PRE treatments provided > 80% control. No other herbicide treatments provided acceptable control of Texas millet.

Little information is available on norflurazon control of annual grasses. However, Wilcut *et al.* (1995) mentions that it will control some annual grasses. The Solicam® DF label states that norflurazon at 0.56 to 2.8 kg ai/ha will control Texas millet (Anonymous, 2015a).

Palmer Amaranth Control

The 2 WAP evaluation was combined over years since there was no treatment by year interaction; however, the 12 WAP evaluations are presented separately by year due a treatment by year interaction. All herbicide treatments provided > 91% control 2 WAP (Table 5). In 2019 at the 12 WAP evaluation, all herbicide treatments with the exception of norflurazon alone applied PRE controlled Palmer amaranth > 90%. In 2020, only ethalfluralin applied PPI fb norflurazon at 1.12 kg ai/ha applied PRE and pendimethalin plus *S*-metolachlor applied PRE controlled Palmer amaranth > 82%. No other herbicide treatment provided > 74% control.

Table 5. Broadleaf weed control in peanut with norflurazon.[a]

Treatment	Rate	Application timing[b]	Palmer amaranth			Smellmelon		
			Weeks after planting					
			2	12		2	12	
				2019	2020		2019	2020
	kg ai/ha		-------------------			%	-------------------	
Untreated	-	-	0	0	0	0	0	0
Norflurazon	0.56	PPI	100	98	60	100	87	89
Norflurazon	1.12	PPI	96	90	47	96	75	82
Norflurazon	0.56	PRE	91	40	33	88	76	75
Norflurazon	1.12	PRE	98	67	30	98	89	83
Pendimethalin + norflurazon	1.06 + 0.56	PRE	100	99	53	97	76	74
Penndimethalin + norflurazon	1.06 + 1.12	PRE	99	98	40	97	100	83
Ethalfluralin Norflurazon	0.84 0.56	PPI PRE	100	99	74	95	91	63
Ethalfluralin Norflurazon	0.84 1.12	PPI PRE	100	97	82	98	92	82
Pendimethalin + S-metolachlor	1.06 + 1.42	PRE	100	99	99	100	100	76
LSD (0.05)				30	32	12	28	24

[a] No treatment by year interaction for the 2 weeks after planting (WAP) evaluation; however, there was a treatment by year interaction for the 12 WAP evaluation.

[b] Abbreviations: PPI, preplant incorporated; PRE, preemergence.

Gossett *et al.* (1992) reported that norflurazon at 0.84 and 1.68 kg ai/ha controlled susceptible and dinitroaniline resistant Palmer amaranth equally (> 97%). Preemergence applications of norflurazon have been reported to control other broadleaf weeds such as spurred anoda at least 93% 4 WAP (Solano *et al.*, 1976).

Smellmelon Control.

As with the Palmer amaranth evaluation, the 2 WAP evaluation was combined over years since there was no treatment by year interaction; however, the 12 WAP evaluations are presented separately by year due a treatment by year interaction. At the 2 WAP evaluation, all herbicide treatments, with the exception of norflurazon alone at 0.56 kg ai/ha applied PRE controlled smellmelon at least 95% (Table 5). In 2019 at the 12 WAP evaluation, all herbicide treatments provided >75% control. Pendimethalin plus norflurazon at 1.12 kg ai/ha applied PRE and the standard treatment of pendimethalin plus *S*-metolachlor provided perfect control. In 2020 norflurazon alone at 0.56 kg ai/ha applied PPI provided the most effective control. Adding either pendimethalin or ethalfluralin to norflurazon did not improve smellmelon control over norflurazon alone.

Henedina *et al.*, (2012) reported that in greenhouse studies norflurazon at 2.64 kg/ha controlled citron melon [*Citrullus lanatus* (Thunb.) Matsum and Nalai] 55% 7 d after treatment (DAT) and this increased to 91% control 21 DAT. Lo and Merkle (1984) reported that grain sorghum [*Sorghum bicolor* (L.) Moench.], wheat (*Triticum aestivum* L.), and sicklepod (*Cassia obtusufolia* L.) was some of the most susceptible plants to norflurazon while cotton was one of the most tolerant.

Peanut injury at all locations was rate dependent. Jordan et al. (1998) reported that norflurazon reduced peanut yield and gross returns in two of four experiments regardless of cultivar and suggested that norflurazon use on Virginia-type peanut should be avoided except for the control of specific problem weeds. Weed control with norflurazon was erratic when applied alone but was greatly improved with tank-mixes of either pendimethalin or ethalfluralin. Season-long control of both annual grasses and broadleaf weeds requires the use of both PRE and POST herbicides to provide effective season-long grass control. Although norflurazon caused early-season chlorosis and bleaching, this injury was transient and resulted in a reduction in yield at only one of five locations. Peanut injury was more severe in south Texas with the EPOST application but in the Texas High Plains and Oklahoma no differences in injury was noted between the PRE and EPOST applications.

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