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ARTICLE

Peanut Variety Response to Carfentrazone plus Pyroxasulfone in Texas and Oklahoma

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ABSTRACT

Field studies were conducted in south Texas near Yoakum, the Texas High Plains near Lubbock, and in southwestern Oklahoma near Ft. Cobb during the 2017 through 2018 growing seasons to evaluate the runner peanut cultivars (Georgia-09B, Georgia 13-M) and the Virginia cultivar (Florida Fancy) tolerance to the pre-mix of carfentrazone + pyroxasulfone (C + P) at 0.005 + 0.07 and 0.009 + 0.13 kg ai/ha applied preemergence (PRE), peanut cracking (CRACK), or early postemergence (EPOST). Leaf necrosis (15-20%) with the EPOST application of C + P was noted at all locations. No peanut stunting (Georgia 09B, Georgia 13-M) was observed with C + P rate or application timing at Yoakum but was seen at Lubbock (Georgia 09B) and Ft. Cobb (Florida Fancy). Carfentrazone + pyroxasulfone affected yield at Lubbock in 2017. The nontreated check yielded higher than C + P at 0.009 + 0.13 kg/ha applied at CRACK. Peanut grade was influenced by C + P rate and application timing at Yoakum in 2017; however, no differences were noted in Yoakum in 2018 or Ft. Cobb. C + P increased the percent sound mature kernels (SMK) + sound splits (SS) and reduced the percent other kernels (OK) over the nontreated check. Using C + P in Texas and Oklahoma will result in some early-season necrosis but only in isolated instances will C + P have a negative effect on yield.

INTRODUCTION

Peanut (*Arachis hypogaea* L.) is a crop with challenging weed management issues. First, most peanut cultivars grown in the U.S. require a 140 to 160 d growing season depending on cultivar and geographical region (Henning *et al.*, 1982; Wilcut *et al.*, 1995; Leon *et al.*, 2025). Soil-applied herbicides may not provide season-long weed control and this can result in mid- to late-season weed problems. Secondly, peanut has a shorter growth habit, a shallow canopy, and depending on weather conditions, may be slow to shade row middles allowing weeds to grow and become more competitive (Wilcut *et al.*, 1995). Additionally, peanut fruit develops underground on pegs that originate from stems and grow along the soil surface. The shorter growth habit and pattern of fruit development limits cultivation to an early season control option (Brecke and Colvin, 1991; Wilcut *et al.*, 1995;).

The repeated use of herbicides with the same or similar modes of action has led to herbicide resistance in weeds, most specifically *Amaranthus* species (Culpepper *et al.*, 2006; Peterson, 1999; Van Gessel, 2001). This species, especially Palmer amaranth (*Amaranthus palmeri* S. Wats), is the most common and most troublesome weed in seven of the nine major peanut producing states in the U.S. (Van Wychen, 2022). *Amaranthus* species are very sensitive to resistance of ALS-inhibiting herbicides and possess characteristics such as high genetic variability, prolific seed production, and efficient pollen and seed distribution that predispose them to have herbicide resistant biotypes (Lovell *et al.*, 1996). To reduce the risk and rate of development of herbicide-resistant weed populations, the use of soil-applied and POST herbicides with alternative sites of action is necessary (Shanner *et al.*, 1997).

The premix of carfentrazone + pyroxasulfone (C + P) was labelled for use on peanut in the U.S. as Anthem Flex ® by the FMC Corporation (Anonymous, 2020a) in time for the 2020 growing season and adds another herbicide combination to the peanut weed control arsenal. It is labelled in peanut for early postemergence (EPOST) or postemergence (POST) use only. This premix will control ALS- (HRAC Group 2 herbicide) and glyphosate- (HRAC Group 9 herbicide) resistant Palmer amaranth, which is becoming more widespread across southwestern peanut producing areas (Anonymous, 2020b). Control of annual grasses such as Texas millet (*Urochloa texana* (Buckl.) R. Webster) is limited and full–season control of this annual grass in peanut typically requires the postemergence use of clethodim® (WSSA Group 1 herbicide) or other grass-inhibiting herbicides (Anonymous, 2020b).

Carfentrazone is an aryl triazolinone herbicide (Theodoridis *et al.*, 1992) and the mode of action is the inhibition of protoporphyrinogen oxidase (Protox) (Dayan *et al.*, 1997a; Dayan *et al.*, 1997b) in the chlorophyll biosynthesis pathway that results in the accumulation of protoporphyrin IX (PPIX) in the cytosol (site of action Group 14) (Becerril *et al.*, 1989; Sherman *et al.*, 1991). PPIX is photoactive and involved in the light-dependent formation of singlet oxygen, which is responsible for plant death via membrane oxidation (Devine *et al.*, 1993). It is a rapid-acting contact herbicide with little or no residual activity (Anonymous, 2017a) and susceptible weeds begin to desiccate within hours of treatment followed by necrosis and plant death within days.

Peanut injury from carfentrazone is typically expressed as leaf necrosis (burn) and this injury can be visible for 7 to 21 days after a carfentrazone application. Any new growth that appears after this time period is void of any type of injury. This leaf necrosis has been noted in other studies in Texas with carfentrazone (Dotray *et al.*, 2010; Grichar *et al.*, 2010).

Pyroxasulfone is a very long-chain fatty-acid biosynthesis inhibitor (Group 15), similar to chloroacetamide, oxyacetamide, and tetrazolinone herbicides and can be applied either preplant (PP), preplant incorporated (PPI), preemergence (PRE), or EPOST in corn (*Zea mays* L.), cotton (*Gossypium hirsutum* L.), peanut, soybean (*Glycine max* (L.) Merr.), and wheat (*Triticum aestivum* L.) (Hardwick, 2013; King and Garcia, 2008; Knezevic *et al.*, 2009; Mangin *et al.*, 2017; Tanetani *et al.*, 2009; Tanetani *et al.,* 2011). Application timing is crop specific. In peanut, pyroxasulfone may be applied from ground cracking (CRACK) through beginning of the pod development stage (Anonymous, 2017b). It provides good to excellent control of many weeds in peanut including *Amaranthus* spp., *Lolium* spp, *Urochloa* spp., goosegrass (*Eleusine indica* L.), crowfootgrass (*Dactyloctenium aegyptium* L.), and *Digitaria* spp. (Cahoon *et al.*, 2012; Koger *et al.*, 2008; Nurse *et al.*, 2011; Odero and Wright, 2013). Pyroxasulfone has low water solubility (3.49 mg/L at 20 C), and there is a strong correlation between soil binding, reduced herbicide dissipation, and increased soil organic matter content (Westra *et al.*, 2014). Although pyroxasulfone has a similar weed control spectrum as *S*-metolachlor and dimethenamid-P, it has a higher specific activity allowing for use rates approximately eight times lower than dimethenamid-P (Curran and Lingenfelter, 2016).

Research has reported no injury from pyroxasulfone in corn (Mueller and Steckel, 2011) and Sikkema et al. (2008) reported that pyroxasulfone was safe on several sweet corn hybrids. In other crops pyroxasulfone was reported to injure pinto and small red Mexican beans (*Phaseolus vulgaris* L.) when applied PPI (Soltani *et al.*, 2008). Cotton was less tolerant to pyroxasulfone PRE or POST than other chloroacetimde herbicides (Cahoon *et al.*, 2015). In peanut, pyroxasulfone has good crop tolerance; however, pyroxasulfone applied PRE to peanut has been documented to cause early-season stunting but no yield loss (Eure et al., 2015).

To further understand peanut tolerance to carfentrazone + pyroxasulfone (C + P) and the potential for injury, field studies were conducted at two rates and three application timings in south Texas, the High Plains of Texas, and in the southwestern Oklahoma peanut growing regions to determine peanut variety response. The Anthem Flex® label (Anonymous, 2020a) states that this herbicide combination can be applied POST to peanuts from CRACK at the 1st leaf stage through the beginning of pod development. While PRE applications are currently not labled, this timing was included for information and future reference.

MATERIALS AND METHODS

Peanut tolerance studies were conducted during the 2017 and 2018 growing seasons at the Texas A&M AgriLife Research site in south Texas near Yoakum, in 2017 near Lubbock at the Texas Tech Fiber and Biopolymer Research Institute (FBRI) and in 2018 at the Texas A&M AgriLife Research and Extension Center (TAMAREC). In Oklahoma, studies were conducted at the Oklahoma State University Caddo Research Station near Ft. Cobb in southwestern Oklahoma. Soils (Table 1) at Yoakum were a Tremona loamy fine sand (clayey. mixed, active, hyperthermic, Aquic Arenic Paleustalfs). Soils at the Lubbock location were a Amarillo fine sandy loam (fine-loamy, mixed, superactive, thermic Aridic Paleustalfs) at FBRI and a Pullman sandy clay loam (fine, mixed, superactive, thermic Torrertic Paleustolls) at TAMAREC. At Ft. Cobb, soils were a Binger fine sandy loam (fine-loamy, mixed, active, thermic Udic Rhodustalfs).

Treatments consisted of a factorial arrangement of two C + P rates (0.005 + 0.07 and 0.009 + 0.13 kg ai/ha) and three application timings, PRE, CRACK, and EPOST. The PRE applications were applied immediately after planting or up to 5 days after planting (DAP), the CRACK applications were made up to 21 DAP, and EPOST applications were made up to 34 DAP depending on location. Herbicides were applied using water as a carrier with a CO_2-pressurized backpack sprayer. An untreated check was included in each study and each treatment was replicated three to four times depending on location. Other specifics of each study can be found in Table 1.

Table 1. Variables associated with the study at each location.

Variables	Location					
	Yoakum		Lubbock		Ft. Cobb	
	2017	2018	2017	2018	2017	2018
Coordinates	29.1634° N; 97.0725° W	29.1634° N; 97.0725° W	33.5887° N; 101.7856° W	33.6939° N; 101.8192° W	35.0911° N 98.2745° W	35.0911° N 98.2745° W
Soil name	Tremona	Tremona	Amarillo	Pullman	Binger	Binger
Soil type	Loamy fine sand	Loamy fine sand	Fine sandy loam	Sandy clay loam	Fine sandy loam	Fine sandy loam
Sand (%)	65	65	57	60	73	73
Silt (%)	35	35	18	14	18	18
Clay (%)	10	10	25	26	9	9
pH	7.4	7.5	7.5	7.6	7.4	7.4
OM (%)	0.7	0.7	1.0	1.0	0.9	0.9
CEC	31	31	29	27	7	7
Variety	Georgia 09B	Georgia 13-M	Georgia 09B	Georgia 09B	Florida Fancy	Florida Fancy
Planting date	June 14	June 26	April 26	April 26	May 5	May 8
Harvest date	Nov 20	Dec 4	Oct 9	Nov 13	Nov 3	Oct 23
Application						
PRE	June 15	July 1	April 28	April 26	May 5	May 8
CRACK	June 28	July 8	May 12	May 8	May 26	May 17
EPOST	July 17	July 27	May 26	May 24	June 8	May 30
Sprayer	CO_2 backpack					
Operating pressure (kPa)	207	207	220	220	131	193
Spray volume (L ha^{-1})	187	187	112	140	94	112
Spray nozzles	DG 11002	DG 11002	TT 11002	TT 11002	TT 110015XRAI	TT 110015XRAI

Peanut cultivars evaluated were those commonly grown in each production area. In south Texas Georgia-09B (Branch, 2010) was grown in 2017 while Georgia 13-M (Branch, 2014) was grown in 2018. At the Texas High Plains locations Georgia-09B was grown in both years while in Oklahoma the Virginia type peanut, Florida Fancy (Anonymous, 2008) was grown. Georgia-09B and Georgia 13-M have been grown in Texas for a number of years and are high-oleic and low-linoleic fatty acid composition with partial resistance to the Tomato Spotted Wilt Virus (TSWV) (Anomymous, 2024). Florida Fancy has a high-oleic fatty acid composition and has demonstrated very good yield potential and has among the best resistance to TSWV available in a Virginia markettype peanut (Tillman *et al*., 2015).

Each plot consisted of two rows spaced 97 cm apart and 7.6 m long at Yoakum. At both Lubbock locations plot size was 4 rows spaced 102 cm apart and 9.1 m long while at Ft. Cobb plots consisted of 4 rows spaced 76 cm apart and 7.6 m long. Traditional production practices were used to maximize peanut growth, development, and yield. Plots were maintained weed-free with the use of POST herbicides including clethodim for annual grasses and 2,4-DB for broadleaf weeds or hand-weeding.

For irrigation purposes, at Yoakum, lateral hand moved irrigation lines were used. At the FBRI location and the Ft. Cobb location, center pivot irrigation systems were used while at Texas A&M Research and Extension Center at Lubbock a furrow irrigation system was used. Irrigation was applied as needed throughout the growing season at all locations.

Peanut injury and stunting were based on visual subjective estimates using a scale of 0 to 100 (0 = no peanut injury/stunting) to 100 (peanut death) (Frans, et al., 1986). Peanut yield was determined by digging the pods based on maturity of non-treated control plots, air-drying in the field for 6 to 10 d, and harvesting with a 2-row combine. Yield samples were cleaned and adjusted to 10% moisture. Pod, shell, and peanut kernel weight were determined from each sample. Grades [percent sound mature kernels (SMK) plus sound splits (SS)] were determined for a 200-g pod sample from each plot following procedures described by the Federal-State Inspection Service (Anonymous, 2019). Grade data was collected both years at Yoakum and in 2017 at Ft. Cobb.

Data for peanut stunting were transformed to the arcsine square root prior to analysis; however, nontransformed 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) and treatment means were separated using Fisher's Protected LSD at P < 0.05.

RESULTS AND DISCUSSION

Injury

Injury was estimated visually throughout the growing season; however, only the 28 to 35 and 90 days after planting (DAP) evaluations are presented. Peanut injury with C + P applied PRE or CRACK manifested itself as plant stunting while POST injury consisted of leaf burn and chlorosis. This stunting can be attributed to the pyroxasulfone in the mixture while the leaf burn can be attributed to the carfentrazone in the premix (Anonymous, 2017). Typically, the peripheral leaves that were burned are replaced by new leaves that are void of any type of injury. This leaf burn also has been noted in other studies with either carfentrazone or C + P (Dotray *et al.*, 2010; Grichar *et al.*, 2010, Grichar et al, 2021, Grichar et al. 2024).

No stunting was seen at Yoakum with any PRE or CRACK application of C + P. Also, leaf burn (<15%) was visible for 7 to 21 d after all the C + P POST applications and this burn was consistent across C + P rates (data not shown). These results are similar to that seen in previous studies with pyroxasulfone where no stunting was observed (Grichar *et al.*, 2019).

At the Lubbock location in 2017, when evaluated early-season, 30 days after planting (DAP), peanut stunting was not evident with C + P at 0.05 + 0.07 kg/ha while C + P at 0.009 + 0.13 kg/ha resulted in stunting and/or leaf burn regardless of application timings (Table 2). At the 90 DAP evaluation, peanut stunting was only evident with C + P at 0.009 + 0.13 kg/ha applied CRACK. In 2018, when evaluated 28 DAP, stunting was evident with C + P at 0.009 + 0.13 kg/ha applied CRACK. No other injury was noted with C + P rate or application timing. No late-season injury was seen with any application. In a previous study in the Texas High Plains, pyroxasulfone applied PRE at 0.09 or 0.18 kg/ha resulted in some peanut stunting but it was not consistent over years (Dotray *et al.*, 2018).

At Ft. Cobb in 2017, C + P applied PRE and CRACK at both rates resulted in peanut stunting; however, no leaf burn/chlorosis was noted following the POST application (Table 2). In 2018, only C + P applied PRE resulted in any stunting. In previous work with pyroxasulfone in Oklahoma, peanut stunting was observed with PPI and PRE treatments with injury ranging from 4 to 13% (Baughman *et al.*, 2018).

Peanut stunting has been noted when using either carfentrazone or pyroxasulfone alone but no documented reports could be found when used in combination. Carfentrazone stunting has been noted with POST applications 35 to 36 DAP (Grichar *et al.*, 2010). This stunting ranged from 7 to 10% when evaluated 60 to 65 days after application across 3 runner cultivars. In Georgia, Eure *et al.* (2015) reported that peanut stunting during two years of testing with pyroxasulfone applied PRE ranged from 3 to 11% in one year and 38 to 55% in another, depending on peanut cultivar. They reported several factors played a role in the differences observed between the two years. More rainfall occurred during peanut CRACK in the year with greater injury than in the year with lesser injury (50.8 mm vs. 25.4 mm). Prostko *et al.* (2013) documented transient peanut stunting at one of two locations following pyroxasulfone applied PRE. Also, enhanced peanut stunting has been observed following the application of PRE herbicides under cool, wet conditions (Grichar *et al.*, 2004).

In other crops, pyroxasulfone has shown greater crop injury when applied PRE on course-textured soils than on fine-textured or organic soils (Cahoon *et al.*, 2012; Eure, 2013; Koger *et al.*, 2008; Nurse *et al.*, 2011; Odero and Wright, 2013). Sweet corn injury has been documented to be greater than 10% following pyroxasulfone at 0.25 kg/ha on soil with 82% sand (Nurse *et al.*, 2011) while no injury has been observed on soils high in organic matter (Odero and Wright, 2013). In cotton, Koger *et al.* (2008) reported only transient injury on a silt loam soil following pyroxasulfone applied PRE.

Table 2. Peanut injury with carfentrazone plus pyroxasulfone (C + P) applied at three different timings during the growing season.[a,b]

C + P rate	Application timing[c]	Lubbock			Ft. Cobb	
		Georgia 09B			Florida Fancy	
		2017		2018	2017	2018
kg ai/ha		Days after planting (DAP)				
		30	90	28	34	35
0		0	0	0	0	0
0.005 + 0.07	PRE	3	0	0	8	4
0.009 + 0.13		19	5	0	9	4
0.005 + 0.07	CRACK	0	0	0	6	3
0.009 + 0.13		5	0	8	6	1
0.005 + 0.07	POST	1	0	0	0	3
0.009 + 0.13		13	0	0	0	3
LSD (0.05)		4	2	2	5	4

[a] Injury consisted of plant stunting with the PRE and CRACK application timings while leaf burn and chlorosis was present with the POST applications.

[b] No visible injury was noted late-season at Lubbock in 2018 or either year at Ft. Cobb.

[c] Abbreviations: PRE, preemergence; CRACK, peanut ground cracking; POST, postemergence.

Yield

No attempt was made to combine yield data over years at Yoakum since different varieties were used in each year. Yield differences were seen between years at the High Plains locations while data were combined over years at Ft. Cobb due to a lack of treatment by year interaction. (Table 3).

No differences in yield between any C + P rates or application timings were noted at Yoakum when evaluated either on Georgia 09B or Georgia 13-M (Table 3). At Lubbock in 2017 there was a C + P rate by timing interaction as C + P at 0.009 + 0.13 kg/ha applied CRACK and C + P at 0.005 + 0.07 kg/ha applied POST reduced peanut yield when compared with the untreated check (Table 3). There was no effect on yield in 2018 at Lubbock with C + P rate or application timing. At Ft. Cobb, C + P rate or application timing had no effect on Florida Fancy yield.

No documented evidence could be found on the effect of C + P on peanut yield; however, studies on the effect of carfentrazone or pyroxasulfone alone on peanut yield have been reported (Baughman *et al.*, 2018; Chaudhari *et al.*, 2017; Dotray *et al.*, 2010; Grichar *et al.*, 2010). Dotray *et al.* (2010) reported that carfentrazone at 0.04 kg/ha applied 28 to 51 DAP reduced yield at 2 of 6 locations while the same rate applied 93 to 121 DAP reduced yield at 1 of 6 locations. Grichar *et al.* (2010) in a two-yr study reported that carfentrazone at 0.03 or 0.04 kg/ha applied 35 to 36 DAP in south Texas reduced peanut yield both years while the same rate applied 51 to 56 DAP in the Texas High Plains reduced yield in one of two years. Chaudhari *et al.* (2017) found that carfentrazone at 0.017 or 0.035 kg/ha applied 4 wks before digging (WBD) reduced peanut yield 10% but did not reduce yield when applied 1 to 2 WBD.

Baughman *et al.*, (2018) in a 2 yr study reported at one location there was no difference in yield between the untreated check and any pyroxasulfone treatment and the authors attributed this to the lack of adequate *U. texana* control with any herbicide treatment while at the other location all herbicide systems yielded more than the untreated check. The herbicide system that included pyroxasulfone at 0.06 kg/ha applied PRE and late postemergence (LPOST) provided the greatest yield. Eure *et al.* (2015) reported that treatments that included pyroxasulfone at 0.12 kg/ha yielded similar to treatments without pyroxasulfone; however, pyroxasulfone applied at 0.24 kg/ha reduced peanut yield 6%. Prostko *et al.* (2013) did not observe a yield loss following pyroxasulfone applied PRE.

Studies in other crops have reported some yield reductions when using pyroxasulfone and results can vary by crop (Boydston *et al.*, 2012; Hulting *et al.*, 2012; Soltani *et al.*, 2012; Mahoney *et al.*, 2014; McNaughton *et al.*, 2014; Tidemann *et al.*, 2014). Winter wheat showed minimal injury or yield reductions at doses up to 0.15 kg/ha (Hulting *et al.*, 2012). Potato (*Solanum tuberosum* L.) also showed tolerance to pyroxasulfone at rates up to 0.15 kg/ha with minor yield reduction and quality losses (Boydston *et al.*, 2012). Pyroxasulfone at 0.125 kg/ha caused unacceptable yield losses in barley (*Hordeum vulgare* L.) as well as durum wheat and oats

(*Avena sativa* L.) (Soltani *et al.*, 2012). Sunflower (*Helianthus annus* L.) also has shown acceptable tolerance to pyroxasulfone up to 0.33 kg/ha although injury (but not yield loss) did occur at locations with heavy precipitation events shortly after application (Olsen *et al.*, 2011).

Table 3. Peanut yield response to carfentrazone plus pyroxasulfone (C + P) applied at three different timings during the growing season.

		Yoakum		Lubbock		Ft Cobb[b]
C + P Rate	Application timing[a]	Georgia 09B	Georgia 13-M	Georgia 09B		Florida Fancy
		2017	2018	2017	2018	
kg ai/ha		--------------------------------kg/ha		----------------------------------		
0		3343	3952	2479	2032	6069
0.005 + 0.07	PRE	4113	4200	2461	2570	5789
0.009 + 0.13		3497	4048	2442	2056	5723
0.005 + 0.07	CRACK	3857	4228	2181	2240	6009
0.009 + 0.13		3909	4009	1858	2240	6121
0.005 + 0.07	POST	3465	4024	1919	2117	6123
0.009 + 0.13		3459	3838	2212	2152	5831
LSD (0.05)		NS	NS	560	NS	NS

[a] Abbreviations: PRE, preemergence; CRACK, peanut ground cracking; POST, postemergence.

[b] Yield combined over years due to a lack variety by year interaction.

Table 4. Peanut grade response to carfentrazone plus pyroxasulfone (C + P) applied at three different timings during the growing season.

		Grade					
		Yoakum				Ft Cobb	
		2017		2018		2017	
C + P Rate	Application timing[a]	SMK +SS	OK	SMK + SS	OK	SMK + SS	DK
kg ai/ha		----------------------------- % -----------------------------					
0		68	7	67	10	73	1
0.005 + 0.07	PRE	70	5	69	8	74	0
0.009 + 0.13		70	5	67	9	73	1
0.005 + 0.07	CRACK	71	6	70	8	71	1
0.009 + 0.13		70	6	69	8	74	1
0.005 + 0.07	POST	71	6	69	9	72	1
0.009 + 0.13		72	5	68	9	74	0
LSD (0.05)		2	1	NS	NS	NS	NS

[a] Abbreviations: PRE, preemergence; CRACK, peanut ground cracking; POST, postemergence; SMK, sound mature kernels; SS, sound splits; OK, other kernels; DK, damaged kernels.

Grade

Peanut grade was influenced by C + P rate and application timing at Yoakum in 2017; however, no differences were noted in 2018 at Yoakum or Ft. Cobb in 2017 (Table 4). In fact, C + P increased the percent sound mature kernels (SMK) + sound splits (SS) and reduced the percent other kernels (OK) over the untreated check. No other research could be found reporting on peanut grade response when using C + P.

The results of these studies indicate that C + P is safe to use on peanut in Texas and Oklahoma with only occasional issues with rate and/or application timing. Therefore, more research is needed on the conditions that are responsible for peanut injury which may be seen in certain areas of the southwestern U.S. peanut production area.

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