Peanut Cultivar Response to *S*-metolachlor and Paraquat Alone and in Combination

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ABSTRACT

Field experiments were conducted at Yoakum in south Texas and at Lamesa in the Texas High Plains area in 2007 and 2008 to evaluate peanut variety tolerance to *S*-metolachlor or paraquat alone or in combination applied postemergence 7 to 28 d after peanut emergence. Runner market-type peanut were evaluated at Yoakum (Tamrun OL02, York, and Florida 07) while runner (Flavorrunner 458) and Virginia market-types (NC-7 and Gregory) were evaluated at Lamesa. Peanut stunting with paraquat alone or *S*-metolachlor + pararquat combinations varied from 0 to 15% and increased as application timing was delayed. Runner market type yields were variable while Virginia market type yields were not affected by paraquat or any combinations. Peanut grade (% SMK + SS) of runner or Virgina market types were not affected by paraquat applications.

Key Words: *Arachis hypogaea* L., groundnut, herbicide injury, peanut tolerance, postemergence, visible injury, peanut yield.

Paraquat is one of the most frequently used postemergence (POST) herbicides in Southeastern US peanut (*Arachis hypogaea* L.) production systems but is seldom used in the Southwestern US production region, because crop injury may occur, reducing yield and grade characteristics (Knauft *et al.*, 1990; Wilcut and Swann, 1990). The addition of bentazon to paraquat is a common practice to reduce peanut injury, although it may be either antagonistic or synergistic in its effect on weed control depending on the weed species and herbicide rate (Wehtje *et al.*, 1992) and often does not improve peanut yield despite the reduction in crop injury (Wehtje *et al.*, 1986, 1992; Wilcut *et al.*, 1989). Due to the low price of paraquat, growers in the southwest continue to express an interest in its use (authors' personal observations). However, concerns have been expressed about peanut cultivar response to paraquat applications. Evaluations of cultivar response to herbicide treatments containing paraquat have been studied (Knauft *et al.*, 1990; Wehtje *et al.*, 1991; Wilcut and Swann, 1990). However, most of the cultivars that have been evaluated are no longer grown in the U.S.

Metolachlor is commonly used in peanut for control of small-seeded broadleaf weeds, some annual grasses, and yellow nutsedge (Grichar *et al.*, 1996). *S*-metolachlor is labeled for either PPI, POST-plant incorporated, PRE, POST, or lay-by in peanut (Anonymous, 2004). Peanut cultivars commonly used in the Southwest production area have not been evaluated with respect to response to *S*-metolachlor, paraquat, or combinations of the two. Therefore, the objective of this research was to evaluate the effect of *S*-metolachlor, paraquat, or a combination of the two herbicides applied at several timings POST on peanut stunting, yield, and grade of four runner and two Virginia market-type peanut cultivars.

Materials and Methods

Peanut tolerance studies under weed-free conditions were conducted at Yoakum and near Lamesa with runner and Virginia market-types during the 2007 and 2008 growing seasons. The soils at Yoakum were a Denhawken sandy clay loam (fine, smectitic, hyperthermic, Vertic Haplustepts, 1.6% organic matter, pH 7.6) and at Lamesa the soils were a Amarillo fine sandy loam (fine-loamy, mixed, superactive, thermic Aridic Paleustalf, 0.4% organic matter, pH 7.8). Planting date, application dates, and other variables for each study are given in Table 1.

At Yoakum, treatments consisted of a factorial arrangement of three runner market-type peanut varieties, 'Tamrun OL02' (Simpson *et al.* 2006) in both years, 'York' (Gorbet and Tillman, 2011) in 2007 and 'Florida 07' (Gorbet and Tillman, 2009) in 2008, three herbicide treatments (*S*-metolachlor at 1.6 kg ai/ha, paraquat at 0.14 kg ai/ha, or a combination of the two herbicides at the represented rate), and four application timings [7, 14, 21, or 28 days after peanut cracking (DAC)]. The peanut cultivar York was not used in 2008 due to lack of availability. At Lamesa, the treatments consisted of a factorial arrangement of three herbicide treatments by four application timings.

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Table 1. Planting and application dates, peanut cultivars, and time of application for various studies in south Texas and the High Plains of Texas.[a]

	South Texas		High Plains			
	Runner		Runner		Virginia	
Variable	2007	2008	2007	2008	2007	2008
Planting date	June 13	June 17	April 23	April 30	Apr 23	April 30
Application dates:						
7 DAC	June 28	July 1	May 14	May 20	May 14	May 20
14 DAC	July 6	July 8	May 21	May 27	May 21	May 27
21 DAC	July 1	July15	May 29	June 3	May 29	June 3
28 DAC	July 19	July 22	June 5	June 10	June 5	June 10
Peanut varieties	TamOL02 York	TamOL02 Florida 07	FL 458	FL 458	NC-7	Gregory

[a]Abbreviations: DAC, days after ground cracking; FL, Flavorrunner; Tam, Tamrun.

The runner market-type used in each year was Flavorrunner (FL) 458 (Beasley and Baldwin, 2009) while NC-7 (Wynne et al., 1979) and Gregory (Isleib et al., 1999) were the Virginia market-types used in 2007 and 2008, respectively. An untreated check was included in each study at both locations. Each study was replicated three times. Paraquat only treatments include Induce (Helena Chemical Company, 225 Schilling Boulevard, Suite 300, Collierville, TN 38017) at 0.25% v/v. Individual plot size was 1.9 by 7.6 m at Yoakum and 2.1 by 9.5 m at Lamesa. Seasonal rainfall at Yoakum (June through Oct) was 61.8 cm in 2007 and 20.2 cm in 2008 while at Lamesa seasonal rainfall (May through Oct) was 37.3 cm in 2007 and 30.7 cm in 2008. Supplemental irrigation was supplied as needed at both locations. Traditional production practices were used to maximize peanut growth, development, and yield. All plots received a dinitroaniline herbicide applied preplant incorporated and were cultivated and hand-weeded throughout the growing season to maintain weed-free conditions. Clethodim at 0.18 kg ai/ha was applied POST to control annual grass escapes at Yoakum. No insecticides were needed at any location in any year.

Herbicides were applied using water as a carrier with a CO_2-pressurized backpack sprayer using Teejet 11002 DG flat fan nozzles (Teejet Spraying Systems Co., P.O. Box 7900, Wheaton, IL 60188) that delivered 190 L/ha at 180 kPa at Yoakum or Teejet 80015 flat fan nozzles that delivered 140 L/ha at 207 kPa at Lamesa. Peanut stunting was evaluated approximately 60 d after peanut planting with the runner peanuts cultivars at Yoakum and Lamesa, while the Virginia cultivars were rated prior to peanut digging. Peanut stunting were based on a scale of 0 (no peanut stunting) to 100% (peanut death). Peanut yield was determined by digging the pods based on maturity of untreated control plots determined by mesocarp pod color (Williams and Drexler, 1981), air-drying in the field for 6 to 10 d, and harvesting individual plots with a combine. Yield samples were cleaned and adjusted to 10% moisture. For grades, a 200-g pod sample from each plot was obtained and grades determined following procedures described by the Federal-State Inspection Service (USDA, 1993).

Data for percentage of peanut injury and 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 SAS PROC MIXED (SAS, 2002). Treatment means were separated using Fisher's Protected LSD at $P \leq 0.05$. The untreated check was used for peanut yield and grade calculation comparison and a visual comparison for peanut injury and was only included in yield and grade analysis.

Results and Discussion

Runner market type response

Yoakum

Early season injury from paraquat alone or in combination consisted of leaf bronzing as is normally seen with paraquat (Wilcut *et al.* 1995) (data not shown). No attempt was made to combine data over years since neither York or Florida 07 were not used in both years. Analysis of variance indicated no herbicide treatment by peanut cultivar interaction for peanut stunting; therefore, that data were combined over cultivars. There was a herbicide, application timing, and cultivar interaction for peanut yield and grade; therefore, that data were presented as an interaction of the three parameters at $P \leq 0.05$.

Table 2. Peanut stunting in south Texas to *S*-metolachlor and paraquat alone and in combination when applied 7, 14, 21, and 28 days after ground cracking.[a,b]

Herbicide	2007				2008			
	7	14	21	28	7	14	21	28
	%							
S-metolachlor	7	3	2	1	0	3	1	3
Paraquat	4	5	6	1	3	2	11	10
S-metolachlor + paraquat	2	8	6	3	10	3	12	13
LSD (0.05)	6				4			

[a]Peanut stunting ratings taken approximately 60 d after peanut planting.
[b]S-metolachlor rate, 1.6 kg ai/ha; paraquat rate, 0.14 kg ai/ha. Paraquat only treatments included Induce® at 0.25% v/v.

Peanut stunting. In 2007, peanut stunting was no greater than 8% with any herbicide treatment or application timing (Table 2). *S*-metolachlor plus paraquat caused the greatest stunting (8%) when applied 14 DAC while *S*-metolachlor alone caused peanut stunting (7%) when applied 7 DAC. Many growers have reported peanut stunting when soil applications of metolachlor have been followed by rain (Grichar *et al.*, 1996). Combinations of factors, such as herbicide rate, moisture conditions at planting, soil organic matter, and pH may affect peanut injury by chloroacetamide herbicides such as *S*-metolachlor (Cardina and Swann, 1988; Wehtje *et al.*, 1988; Osborne *et al.*, 1995; Mueller *et al.*, 1999). Cardina and Swann (1988) reported that metolachlor often delayed peanut emergence and reduced peanut growth when irrigation followed planting. However, yield loss was observed only when metolachlor was applied at a 3X rate. Metolachlor applied POST followed by irrigation within 24 h was effective for yellow nutsedge control and reduced the chance of peanut injury from preplant incorporated or preemergence applications of metolachlor (Grichar *et al.*, 1996).

In 2008, *S*-metolachlor alone did not cause any peanut stunting at any application timing while paraquat alone caused at least 10% stunting when applied 21 and 28 DAC (Table 2). *S*-metolachlor plus paraquat caused at least 10% stunting with all application timings with the exception of 14 DAC timing application.

Peanut tolerance to paraquat was first noted in the late 1970's (Wilcut *et al.*, 1995). Wehtje *et al.* (1986) reported that paraquat controlled Texas panicum (*Panicum texanum* Buckl.) when applied sequentially, and Johnson *et al.* (1993) noted differences in cultivar tolerance. Paraquat is often tank-mixed with bentazon and can be applied up to 28 d after peanut emergence (Senseman, 2007; Wilcut *et al.*, 1995). Bentazon increases control of paraquat-tolerant species such as bristly starbur (*Acanthospermum hispidum* DC.), coffee senna (*Cassia occidentalis* L.), prickly sida (*Sida spinosa* L.), and smallflower morningglory [*Jacquemontia tamnifolia* (L.) Griseb.] (Wehtje *et al.*, 1992) and reduces paraquat-induced injury to peanut (Wehtje *et al.*, 1992). Although paraquat is a standard herbicide in southeastern U. S. peanut weed management (Wehtje *et al.*, 1992; Grey *et al.*, 2003), it lacks residual activity and has a narrow window of application (Wilcut *et al.*, 1995).

Peanut yield. In 2007 with the cultivar York, only paraquat alone applied 21 DAC reduced yield when compared with the untreated control (Table 3). However, paraquat alone applied 7 DAC did produce a greater yield than the untreated check or *S*-metolachlor plus paraquat applied 14 or 21 DAC. None of the herbicide treatments affected Tamrun OL02 yields when compared with the untreated control. However, paraquat alone applied 28 DAC produced the greatest yield, higher than all herbicide treatments with the exception of the untreated check, *S*-metolachlor alone at 14 DAC, and *S*-metolachlor plus paraquat applied 7 and 28 DAC.

In 2008 with the cultivar Florida 07, no response to herbicide treatment was noted when compared with the untreated check (Table 3). *S*-metolachlor alone applied 7 DAC produced the greatest yield and this was greater than *S*-metolachlor alone applied 14 DAC, paraquat alone applied 7 and 14 DAC, or *S*-metolachlor plus paraquat applied 7, 21, and 28 DAC. With Tamrun OL02, no yield differences were noted between the untreated control and any herbicide treatments (Table 3). Paraquat alone applied 14 DAC produced the highest yield and this was greater than paraquat alone applied 28 DAC or *S*-metolachlor plus paraquat applied 28 DAC.

Other studies have not reported any yield reductions with the use of paraquat (Carley *et al.*, 2009; Johnson *et al.*, 1993; Wehtje *et al.*, 1991). Brecke (1989) reported that the peanut cultivars

Table 3. Peanut yield in south Texas as influenced by herbicide, application timing, and cultivar.[a,b]

Treatment	Application timing	Yield 2007 York	Yield 2007 Tam OL02	Yield 2008 Florida07	Yield 2008 TamOL02
	Kg/ha				
Untreated	2720	3143	3053	3050	
S-metolachlor	7 DAC	3151	2957	3580	2935
	14 DAC	3024	3100	2581	2667
	21 DAC	3286	2841	3487	2821
	28 DAC	3229	2928	3223	2774
Paraquat	7 DAC	3390	2958	2867	2718
	14 DAC	3218	2870	2790	3271
	21 DAC	2067	2913	2976	2821
	28 DAC	2970	3473	3431	2620
S-metolachlor + paraquat	7 DAC	3109	3303	2851	2744
	14 DAC	2486	2853	3110	2718
	21 DAC	2701	2841	2790	2667
	28 DAC	3143	3534	2862	2588
LSD (0.05)		455		620	

[a]Abbreviations: DAC, days after peanut cracking; Tam, Tamrun.
[b]*S*-metolachlor rate, 1.6 kg ai/ha; paraquat rate, 0.14 kg ai/ha. Paraquat only treatments included Induce® at 0.25% v/v.

Early Bunch and Southern Runner exhibited yield suppression from a treatment that included two applications of paraquat at 0.3 kg/ha per application. However, this is twice the normal use rate of paraquat (Wehtje *et al.*, 1991). Wehtje *et al.* (1991) noted that paraquat can be used on different peanut cultivars without a detrimental cultivar response. However, they concluded that adverse environmental conditions, such as drought stress, or other growth limiting factors could result in a cultivar-by-paraquat interaction.

Peanut grade. With the cultivar York, grades were low (<70%) for all treatments (Table 4). No reduction in grade from the untreated control was noted with any herbicide treatments and this may be due to its extremely low grade for the untreated control (63.2%). However, several herbicide treatments including *S*-metolachlor alone applied 21 and 28 DAC, paraquat alone applied 7 and 28 DAC, and *S*-metolachlor plus paraquat applied 28 DAC improved peanut grade over the untreated control. Tamrun OL02 grades with any herbicide treatments were not different from the untreated control. However, *S*-metolachlor alone applied 28 DAC, paraquat alone applied 14 DAC, and *S*-metolachlor plus paraquat applied 7 DAC produced greater grades than *S*-metolachlor alone applied 14 DAC.

With the cultivar Florida 07 in 2008, no differences from the untreated control were noted with any herbicide treatments although *S*-metolachlor alone applied 7, 14, and 28 DAC and *S*-metolachlor plus paraquat applied 28 DAC produced higher grades than *S*-metolachlor plus paraquat applied 21 DAC (Table 4). Previous research suggested that paraquat may affect peanut grade (especially Virginia types) by increasing the proportion of other kernels (Knauft *et al.*, 1990), which may indicate that the herbicide affected grade by delaying maturity (Carley *et al.*, 2009).

Lamesa

There was a herbicide treatment by timing by year interaction for peanut stunting; therefore, that data are presented as a herbicide treatment by timing interaction for each year. There was a herbicide effect for peanut yield in each year; therefore, that data are presented for herbicide for each year, while there was no effect of herbicide or timing on peanut grade (data not presented).

Peanut stunting. In 2007, *S*-metolachlor alone caused stunting when applied 7 DAC but no stunting was observed at any other application timing with this herbicide (Table 5). Stunting from paraquat alone was greatest when applied 14 DAC or later. The combination of *S*-metolachlor plus paraquat caused peanut stunting at all application timings. In 2008, no stunting was noted with any *S*-metolachlor alone application timing. Similar trends as seen in 2007 were noted with paraquat alone and combination treatments of *S*-metolachlor plus paraquat (Table 5).

Peanut yield. In 2007, the untreated control produced the lowest yield when compared with *S*-metolachlor while paraquat and *S*-metolachlor plus

Table 4. Peanut grade in south Texas as influenced by herbicide, application timing, and cultivar.[a,b,c]

Treatment	Application timing	Grade 2007 York	Grade 2007 Tam OL02	Grade 2008 Florida07	Grade 2008 TamOL02
		%			
Untreated	-	63.2	69.7	72.7	72.5
S-metolachlor	7 DAC	62.8	70.2	73.8	67.2
	14 DAC	62.8	67.8	77.2	74.3
	21 DAC	68.0	69.0	72.0	73.3
	28 DAC	67.3	71.2	73.8	69.5
Paraquat	7 DAC	69.5	69.2	71.5	74.5
	14 DAC	64.7	70.7	71.7	73.3
	21 DAC	64.0	68.5	73.0	67.7
	28 DAC	67.8	69.8	72.7	73.3
S-metolachlor + paraquat	7 DAC	65.2	71.7	69.5	69.7
	14 DAC	62.2	69.3	69.2	68.7
	21 DAC	64.2	70.5	68.5	70.5
	28 DAC	69.0	69.8	74.2	72.8
LSD (0.05)		2.9		5.2	

[a]Abbreviations: DAC, days after peanut cracking; Tam, Tamrun.
[b]Grade, sound mature kernels (SMK) + sound splits (SS).
[c]S-metolachlor rate, 1.6 kg ai/ha; paraquat rate, 0.14 kg ai/ha. Paraquat only treatments included Induce® at 0.25% v/v.

paraquat were intermediate in yield (Table 6). In 2008, *S*-metolachlor plus paraquat reduced peanut yield when compared with the untreated control and *S*-metolachlor and paraquat alone. No response with respect to yield was noted with application timing in either year (Table 6). The indeterminate growth habit of peanut often allows compensation from early season stress (such as herbicide injury), and if given sufficient recovery time and good growing conditions, peanut yields and grade may not be compromised (Carley *et al.*, 2009; Mozingo *et al.*, 1991).

Peanut grade. No peanut response to either herbicide or application timing were noted in either year (data not shown). Wehtje *et al.* (1991) reported no effect on peanut yield when using paraquat at 0.14 or 0.28 kg/ha; however, these treatments were applied only once, 4 d after crop emergence.

Virginia market type response

No attempt was made to combine data over years due to different cultivars being used in each year of study. For peanut stunting, there was a herbicide treatment by application timing interaction; therefore, that data are presented separately by herbicide treatment and application timing for each year. Analysis of variance indicated no significant interaction for peanut yield; therefore, that data are presented as main effects by year.

Peanut stunting. In 2007, *S*-metolachlor alone applied 7 DAC caused peanut stunting; however, no stunting was noted with any other application of *S*-metolachlor alone when rated prior to peanut

Table 5. Stunting of runner peanut in Texas High Plains to *S*-metolachlor and paraquat alone and in combination when applied 7, 14, 21, and 28 days after ground cracking.[a,b]

Herbicide [c]	2007 7	2007 14	2007 21	2007 28	2008 7	2008 14	2008 21	2008 28
	%							
S-metolachlor	6	0	2	0	1	0	0	0
Paraquat	3	10	9	11	0	8	7	10
S-metolachlor + paraquat	10	8	11	15	5	5	9	7
LSD (0.05)	4				3			

[a]Peanut stunting ratings taken prior to peanut digging.
[b]*S*-metolachlor rate, 1.6 kg ai/ha; paraquat rate, 0.14 kg ai/ha. Paraquat only treatments included Induce® at 0.25% v/v.

Table 6. Yield of runner peanut (Flavorrunner 458) in Texas High Plains as influenced by *S*-metolachlor and paraquat alone and in combination and timing of application.[a,b]

Herbicide treatment	Yield 2007	Yield 2008	Application timing	Yield 2007	Yield 2008
	Kg/ha			Kg/ha	
Untreated	6110	6398	7 DAC	6759	5998
S-metolachlor	6972	6228	14 DAC	6813	6201
Paraquat	6939	6322	21 DAC	7118	6132
S-metolcahlor + paraquat	6699	5769	28 DAC	7191	6093
LSD (0.05)	835	258		NS	NS

[a]Abbreviation: DAC, days after peanut cracking; NS, not significant at the 5% level of probability.
[b]*S*-metolachlor rate, 1.6 kg ai/ha; paraquat rate, 0.14 kg ai/ha. Paraquat only treatments included Induce® at 0.25% v/v.

digging (Table 7). Paraquat alone or the combination of *S*-metolachlor plus paraquat applied at 7, 14, 21, or 28 DAC resulted in stunting when compared with *S*-metolachlor alone applied 21 and 28 DAC. In 2008, *S*-metolachlor alone applied 7 or 21 DAC, paraquat alone at all application timings, and *S*-metolachlor plus paraquat applied 21 and 28 DAC resulted in peanut stunting when compared with S-metolachlor plus paraquat applied 7 DAC (Table 7). Carley *et al.* (2009) reported when using the cultivar Gregory, that in one year, paraquat alone at 0.14 kg/ha was more injurious than paraquat plus bentazon at 0.28 kg/ha applied with diclosulam at 0.027 kg/ha, dimethenamid at 0.84 kg/ha, or *S*-metolachlor at 1.1 kg/ha when rated 3 weeks after treatment.

Peanut yield. No yield differences were noted with herbicide treatment or application timing in either year (Table 8). Although Carley *et al.* (2009) noted early season injury to Gregory with paraquat alone or in combination with bentazon, diclosulam, dimethenamid, or *S*-metolachlor no yield difference were noted.

Peanut grade. No grade differences were noted with herbicide treatment or application timing in either year (data not shown). Carley *et al.* (2009) reported that paraquat applied to Virginia peanut reduced extra-large kernels (ELK) from 45% (non-treated peanut) to 41% in one year but did not affect percentage ELK in another.

The results from these studies demonstrated although runner peanut cultivars were stunted by paraquat or *S*-metolachlor plus paraquat combination treatments, peanut yield and grade response was variable and no consistent trend could be determined. In laboratory studies, Wehtje *et al.* (1991) reported the absorption and translocation of paraquat did not vary significantly between peanut cultivars. They concluded that paraquat could be used on different peanut cultivars without a detrimental cultivar response. They also felt that adverse environmental conditions, such as drought stress, or other growth limiting factors may result in a cultivar-by paraquat interaction. With respect to Virginia market type, although peanut stunting was noted, no negative yield or grade response were noted. Under growing conditions at Lamesa where the growing season can be shortened by cold weather, the use of paraquat did not delay peanut maturity as has been noted in other peanut growing regions (Carley *et al.*, 2008; Mozingo *et al.*, 1991).

Table 7. Stunting of Virginia peanut in Texas High Plains to *S*-metolachlor and paraquat alone and in combination when applied 7, 14, 21, and 28 days after ground cracking.[a,b]

Herbicide	2007 7	2007 14	2007 21	2007 28	2008 7	2008 14	2008 21	2008 28
	%							
S-metolachlor	5	1	0	0	7	2	5	2
Paraquat	3	6	3	5	5	8	5	7
S-metolachlor + paraquat	5	6	10	5	0	2	6	7
LSD (0.05)	3				4			

[a]Peanut stunting ratings taken prior to peanut digging.
[b]Peanut cultivars: 2007, NC-7; 2008, Gregory.
[c]S-metolachlor rate, 1.6 kg ai/ha; paraquat rate, 0.14 kg ai/ha. Paraquat only treatments included Induce® at 0.25% v/v.

Table 8. Virginia peanut yield as influenced by *S*-metolachlor and paraquat alone and in combination and timing of application.[a,b,c]

Herbicide treatment	Yield 2007	Yield 2008	Application timing	Yield 2007	Yield 2008
	Kg/ha			Kg/ha	
Untreated	5303	5823	7 DAC	5334	5752
S-metolachlor	5213	6013	14 DAC	5073	6075
Paraquat	5245	5792	21 DAC	5323	6090
S-metolcahlor + paraquat	5202	6159	28 DAC	5149	6035
LSD (0.05)	NS	NS		NS	NS

[a]NC-7 planted in 2007 and Gregory planted in 2008.
[b]Abbreviations: DAC, days after peanut cracking; NS, not significant at the 5%level of probability.
[c]*S*-metolachlor rate, 1.6 kg ai/ha; paraquat rate, 0.14 kg ai/ha. Paraquat only treatments included Induce® at 0.25% v/v.

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