Published July 11, 2016

Early-Season Lactofen Application Fails to Increase Soybean Yield under Weed-Free Conditions

John M. Orlowski,* Gary L. Gregg, Chad D. Lee, and William R. Serson

ABSTRACT

In an effort to increase soybean [*Glycine max* (L.) Merr.] yield, growers may consider non-traditional use of crop inputs. One non-traditional input use is the application of lactofen {2-ethoxy-1-methyl-2-oxoethyl 5-[2-chloro-4-(trifluoromethyl)phenoxy]-2-nitrobenzoate} herbicide to early-vegetative soybean to promote increased branch development and ultimately increase seed yield. The purpose of this study was to evaluate the effect of early-season lactofen application and simulated herbicide injury on stands, plant height, light interception, and seed yield. The experiments were conducted at two locations in Kentucky during the 2013 and 2014 growing seasons. Treatments included lactofen herbicide applied at 240 g a.i. ha^{-1} and fomesafen {5-[2-chloro-4-(trifluoromethyl) phenoxy]-N-methylsulfonyl-2-nitrobenzamide} herbicide applied at 600 g a.i. ha^{-1}. A meristem removal treatment was included, where the apical meristem of each soybean was physically removed, and a leaf removal treatment was also performed. All treatments were applied to soybean at V1, V2, V3, and V4 growth stages. The herbicide application timing had no effect on any of the above mentioned agronomic measurements. The apical meristem removal reduced plant stands and plant height in 2 site-years while lactofen and leaf removal decreased early-light interception in all site-years. Meristem removal and leaf removal reduced seed yield in 1 site-year, while lactofen, leaf removal, and meristem removal reduced seed yield in another site-year. None of the treatments increased seed yield compared with the untreated control. Despite a limited number of trials, this study suggests that application of lactofen to soybean for non-weed control purposes is not a viable strategy to increase soybean yield.

Core Ideas

- Leaf removal and lactofen application decrease early-season light interception in soybean.
- Destroying the soybean apical meristem either decreases or does not affect soybean yield.
- Lactofen application to early vegetative soybean does not increase yield under weed free conditions.

Published in Agron. J. 108:1552–1560 (2016)
doi:10.2134/agronj2015.0589
Received 10 Dec. 2015
Accepted 2 Apr. 2016

The recent interest in maximizing soybean yield prompted many producers to consider non-traditional uses of various inputs. One non-traditional input use is application of lactofen herbicide to soybean for non-weed control purposes. Lactofen is a diphenyl ether class herbicide which also includes the herbicides fomesafen and acifluorfen {5-[2-chloro-4-(trifluoromethyl)phenoxy]-2-nitrobenzoic acid}. These herbicides are registered for use in soybean for post-emergence control of several broadleaf weeds (Graham, 2005). While these herbicides are registered for soybean use, this class of herbicides can cause varying degrees of chlorosis and necrosis of soybean tissues (Kapusta et al., 1986; Wichert and Talbert, 1993). For example, Harris et al. (1991) reported severe soybean injury when lactofen was applied to soybean in early-vegetative growth stages, but reported only slight injury when fomesafen was applied to soybean at the same growth stages. Furthermore, the injury to soybean caused by these herbicides can vary depending on the growth stage of the plant when treated. Kapusta et al. (1986) found that the acifluorfen caused more visible injury to soybean when applied at the V3 growth stage as compared with the V5 growth stage. Other studies have also shown that visible soybean injury is greater when either acifluorfen (Hart et al., 1997; Young et al., 2003) or lactofen (Wichert and Talbert, 1993) is applied to earlier growth stages compared to later growth stages.

Recently, soybean producers have considered applying lactofen to soybean during early-vegetative growth stages to damage or destroy the apical meristem, thus stimulating lateral branching and subsequently increasing node, pod, and seed numbers and ultimately seed yield (Orlowski et al., 2016). However, we found no published research that evaluated the use of lactofen or other diphenyl ether herbicides in this manner. Previous research on the effect of lactofen on soybean seed yield have focused on the use of lactofen for weed control. Nelson and Renner (2001) found herbicide mixtures that contained lactofen reduced soybean yield when compared to weed-free untreated soybean. Similarly, Young et al. (2003) found acifluorfen reduced soybean yields by 1.5% compared to untreated weed-free soybean. Other studies have shown no decrease in yield with the application of lactofen for weed control purposes (Kapusta et al., 1986; Harris et al., 1991; Wichert

J.M. Orlowski, Delta Research and Extension Center, Mississippi State University, Stoneville, MS 38776; G.L. Gregg, C.D. Lee, and W.R. Serson, Department of Plant and Soil Sciences, University of Kentucky, Lexington, KY 405046. *Corresponding author (john.orlowski@msstate.edu).

Abbreviations: UTC, untreated control; DAE, days after emergence; MG, maturity group.

and Talbert, 1993). Therefore, the objective of this study was to quantify the effects of early-season lactofen application, specifically for yield component manipulation and yield enhancement on soybean stands, plant heights, light interception, and seed yield.

MATERIALS AND METHODS

Field studies were established at two locations in Kentucky during 2013 and 2014. One site was located at the Spindletop Research Farm in Lexington, KY (38.12 N, 84.49124 W). The soil type at this location was a Loradale silt loam (fine, mixed, active, mesic Typic Argiudoll). The other site was located on a private farm near Hodgenville, KY (37.567839 N, –85.82642 W) which contained predominately Elk silt loam soil (fine-silty, mixed, active, mesic Ultic Hapludalf). The preceding crop was corn (*Zea mays* L.) at both locations in both years. Planting occurred in mid-May in 2013 and late May to early June in 2014 (Table 1). All plots were seeded in 0.38 m row spacing at a seeding rate of 432,000 seeds ha^{-1}. Plot size at Lexington and Hodgenville measured 2.3 by 7.0 m. Glyphosate [*N*-(phosphomethyl)glycine]-resistant soybean cultivar AG 4130 (Monsanto Co, St. Louis, MO) was planted in 2013 and, due to seed availability issues, a similar cultivar, AG 4135, was planted in 2014. Plots were maintained weed free for the entire growing season.

The trials were arranged in a randomized complete block design with four replications. Treatments consisted of an untreated control (UTC), lactofen applied at a rate of 240 g a.i. ha^{-1} and fomesafen applied at 600 g a.i. ha^{-1}. The herbicide treatments were applied using a CO_2 backpack sprayer calibrated to deliver a spray volume of 187 L ha^{-1} at a pressure of 0.2 MPa and an application speed of 4.8 km h^{-1}. Crop oil concentrate was also added to the spray mix at a rate of 1.87 L ha^{-1} crop oil concentrate (1% volume volume^{-1} ratio) as a spray adjuvant. The study also included a defoliation treatment where all leaflets of each plant in the plot were physically removed with hand clippers, and a meristem removal treatment where the apical meristem of each plant in the plot was manually removed by pinching between the thumb and forefinger. Each treatment was performed at the first (V1), second (V2), third (V3), and fourth (V4) trifoliate stage of soybean development (Fehr and Caviness, 1977) in both years. However, the V3 treatments in Hodgenville in 2013 were not completed due to excessive rainfall preventing access to the plots (Table 1).

Plant stands were determined at harvest (R8) by counting the total number of plants in a 1.5 m^2 (four 0.38 m rows 1 m long) area in each plot. Light interception measurements were initiated at the V1 growth stage and conducted weekly or bi-weekly until physiological maturity in 2013 or the soybean

Table 1. Planting date, treatment application timings, and date of application for studies conducted in Lexington and Hodgenville, KY, for the 2013 and 2014 growing seasons.

	2013		2014	
Growth stage	Lexington	Hodgenville†	Lexington	Hodgenville
Planting	16 May	28 May	20 May	4 June
V1	5 June	18 June	9 June	18 June
V2	12 June	21 June	13 June	24 June
V3	17 June	–	19 June	29 June
V4	20 June	28 June	23 June	3 July

† V3 treatments were not applied due to field inaccessibility.

Table 2. Monthly and 30-yr average temperature (Temp.) and precipitation (Precip.) for Lexington and Hodgenville, KY, for the 2013 and 2014 growing seasons.

	Lexington				Hodgenville			
Year/month	Precip.	30 yr	Temp.	30 yr	Precip.	30 yr	Temp.	30 yr
	——— mm ———		——— °C ———		——— mm ———		——— °C ———	
2013†								
May	143	130	18.1	18.0	152	135	18.7	19.5
June	166	117	22.4	22.8	121	97	22.3	24.2
July	233	127	22.9	24.7	147	107	22.8	26.2
August	181	86	23.1	24.1	103	84	23.2	25.6
September	36	84	20.3	20.2	62	84	20.7	21.6
October	102	82	13.8	13.8	86	86	14.2	15.1
Total	861	626	20.1	20.6	671	593	20.3	22.0
2014‡								
May	108	132	18.4	64.5	124	135	19.2	19.6
June	116	119	22.9	22.8	86	94	23.2	24.2
July	68	124	22.3	24.6	78	107	22.2	26.4
August	164	91	23.3	24.0	135	86	23.7	25.7
September	89	84	19.9	20.2	17	84	20.2	21.6
October	116	81	13.3	13.8	114	86	14.1	15.1
Total	661	631	20.1	20.6	554	592	20.4	22.0

† 30-yr average for 1983 to 2013.
‡ 30-yr average for 1984 to 2014.

reached the R4 or R5 developmental stages in 2014. Canopy light interception was determined using the digital imagery method described by Purcell (2000). Canopy images analyzed with Sigma Scan Pro 5.0 (Systat Inc, Richmond, CA) using a macro that automated the analysis process for a large number of images (Karcher and Richardson, 2005). The software was used to quantify the fraction of green pixel to total pixels in an image which was assumed to have a one-to-one relationship with the percentage of light intercepted by the soybean canopy (Edwards et al., 2005b). Prior to harvest, plant height measurements were taken at three locations within each plot. Plant height measurements were taken from ground level to the top of the terminal mainstem node for the lactofen, fomesafen, leaf removal, and UTC treatments. However, meristem removal resulted in plants without a mainstem, so plant height measurements were taken from ground level to the terminal node of the tallest branch. The four middle rows (1.5 m) of each plot were harvested with a Wintersteiger Delta plot combine (Wintersteiger AG, Reid, Austria) and the yield and moisture recorded with a HarvestMaster System (Juniper Systems, Logan, UT). For analysis, all seed yield values were adjusted assuming a seed moisture content of 130 g kg^{-1}.

Statistical analyses were performed in SAS Version 9.3 (SAS Institute Inc., Cary, NC) using PROC MIXED. The Shapiro–Wilk test indicated normality for all data. The Bartlett test indicated that the variances for most measurements were not homogeneous across years or locations, so each site-year was analyzed separately. For plant stands, plant height, and seed yield, the main effects of stress and timing and the timing × stress interaction were considered fixed effects while replication was considered a random effect. An LSD comparison was used to separate means, if significant, at a critical level of P £ 0.05. Light interception data was analyzed using a repeated measures ANOVA with PROC MIXED and the REPEATED statement. The main effects of timing and stress, and the timing × stress interaction were considered fixed effects while replication was considered a random effect.

Table 3. Plant stands at harvest (R8), plant height, and seed yield values for early-season stress treatments at four timings for a study in Hodgenville, KY, in 2013.

	Stress					
Timing	UTC	Lactofen	Fomesafen	Leaf removal	Meristem removal	Avg.
			plants m^{-2}			
Plant stands						
V1	61.7	60.7	61.7	59.8	61.0	60.9
V2	67.5	68.3	63.5	56.8	68.0	64.8
V3	–	–	–	–	–	–
V4	67.4	55.8	67.0	74.0	57.0	64.2
Avg.	65.5	61.6	64.1	63.5	62.0	
LSD†	11.7					
			cm			
Plant height						
V1	98.7	99.6	98.6	94.5	93.8	97.0
V2	99.0	99.5	100.3	89.5	98.8	97.4
V3	–	–	–	–	–	–
V4	94.5	103.0	100.8	100.5	94.3	98.6
Avg.	97.4	100.7	99.9	94.8	95.6	
LSD	ns‡					
			Mg ha^{-1}			
Seed yield						
V1	3.77	3.71.	3.88	3.55	3.98	3.78
V2	3.87	3.93	4.01	3.61	4.06	3.89
V3	–	–	–	–	–	–
V4	3.83	3.87	3.72	3.67	3.79	3.78
Avg.	3.82	3.83	3.87	3.61	3.95	
LSD	ns					
	Plant stands	Plant height	Seed yield			
Significance (P values)						
Stress	0.79	0.07	0.08			
Timing	0.31	0.69	0.35			
Timing × stress	0.03	0.26	0.89			

† LSD, least significant difference for the main effect of stress.

‡ ns, not significant ($P \le 0.05$).

Table 4. Plant stands at harvest (R8), plant height, and seed yield values for early-season stress treatments at four timings for a study in Lexington, KY, in 2013.

	Stress					
Timing	UTC	Lactofen	Fomesafen	Leaf removal	Meristem removal	Avg.
	plants m^{-2}					
Plant stands						
V1	50.8	42.0	37.8	44.3	35.5	42.1
V2	30.8	40.8	38.3	46.3	42.3	39.7
V3	43.5	36.0	32.5	42.3	39.0	38.7
V4	40.8	40.8	44.3	36.3	51.0	42.6
Avg.	41.4	39.9	38.2	42.3	41.9	
LSD†	ns‡					
	cm					
Plant height						
V1	97.3	91.8	90.8	90.5	93.3	92.7
V2	91.5	96.3	96.0	93.3	92.3	93.8
V3	96.5	93.5	91.5	92.5	87.8	92.4
V4	95.8	90.8	93.3	88.8	91.5	92.0
Avg.	95.3	93.1	92.9	91.3	91.2	
LSD	2.6					
	Mg ha^{-1}					
Seed yield						
V1	5.57	5.21	5.59	4.82	4.70	5.18
V2	5.21	5.06	5.25	5.19	4.97	5.14
V3	5.41	5.03	5.03	4.89	5.02	5.08
V4	5.52	5.56	5.35	4.42	5.03	5.18
Avg.	5.43	5.21	5.31	4.83	4.93	
LSD	0.40					
	Plant stands	Plant height	Seed yield			
Significance (*P* values)						
Stress	0.83	0.02	0.02			
Timing	0.63	0.42	0.94			
Timing × stress	0.33	0.06	0.66			

† LSD, least significant difference for the main effect of stress.
‡ ns, not significant ($P \leq 0.05$).

RESULTS

While monthly temperature patterns were very consistent between growing seasons, precipitation patterns differed markedly (Table 2). Plots were planted timely in 2013 and both locations received substantial amounts of precipitation through the end of August, resulting in very good yields, especially at Lexington (5.56 Mg ha^{-1}). Although conditions became dry in September (35–62 mm), adequate levels of soil moisture were available to the crop and no drought stress was observed at either locations. May of 2014 was slightly drier however, timing of the rainfall events delayed planting at both locations. Lexington experienced dry conditions in July (68 mm), but rainfall during flowering and pod development in August (164 mm) allowed for excellent yields (5.29 Mg ha^{-1}). Hodgenville experienced rather dry conditions in June and July but received substantial rainfall in August (135 mm) resulting in exceptional yields (5.95 Mg ha^{-1}). Wet spring weather delayed planting at Hodgenville in 2013, but the plots were planted into a good seedbed and experienced very favorable early season environmental conditions.

At Hodgenville in 2013, timing × stress interactions were observed for plant stands (Table 3). Stands for the leaf removal treatment at V4 were greater than all stress treatments at V1. The leaf removal treatment at V4 had greater stand density than the leaf removal treatment at V2 (74.0 vs. 56.8 plants m^{-2}). The leaf removal treatment at V4 also had greater stands than the lactofen and meristem removal treatments at V4 (74.0 vs. 55.8 and 57.0 plants m^{-2}). Plant stands did not respond to timing or stress at Lexington in 2013 (Table 4). At Hodgenville in 2014, plant stands responded to the main effect of stress (Table 5). The meristem removal treatment decreased harvest stands compared to the other stress treatments (~9% lower). Similarly, stands for the meristem removal treatment were reduced compared to all other stress treatments (~14%) at Lexington in 2014 (Table 6).

Plant height responses to stress were observed in two out of four environments. At Hodgenville in 2014, meristem removal decreased plant height by 8% compared to the UTC (91.8 vs. 99.4 cm) (Table 5). Similarly, at Lexington in 2013, meristem

Table 5. Plant stands at harvest (R8), plant height, and seed yield values for early-season stress treatments at four timings for a study in Hodgenville, KY, in 2014.

Timing	Stress					
	UTC	Lactofen	Fomesafen	Leaf removal	Meristem removal	Avg.
	plants m^{-2}					
Plant stands						
V1	58.8	58.0	56.0	56.0	51.3	56.0
V2	55.9	54.8	56.3	55.0	51.6	54.7
V3	57.1	59.3	54.3	58.5	52.4	56.3
V4	56.3	52.5	53.4	55.5	50.8	53.7
Avg.	57.0	56.1	55.0	56.3	51.5	
LSD†	3.0					
	cm					
Plant height						
V1	98.3	101.0	97.8	106.5	94.3	99.6
V2	102.0	102.3	99.8	98.5	94.7	99.4
V3	97.8	95.8	103.8	101.8	91.8	98.2
V4	99.5	103.5	98.7	96.8	86.5	97.0
Avg.	99.4	100.6	100.0	100.9	91.8	
LSD	3.8					
	Mg ha^{-1}					
Seed yield						
V1	6.47	5.95	6.21	5.94	6.13	6.14
V2	6.12	5.58	6.00	6.10	5.58	5.88
V3	6.17	5.64	6.15	6.02	5.62	5.99
V4	6.23	5.94	5.79	5.57	5.95	5.83
Avg.	6.25	5.78	6.04	5.91	5.82	
LSD	0.29					
	Plant stands	Plant height	Seed yield			
Significance (*P* values)						
Stress	0.0038	<0.0001	0.02			
Timing	0.19	0.41	0.09			
Timing × stress	0.90	0.09	0.66			

† LSD, least significant difference for the main effect of stress.

removal decreased plant height by 4% compared to the UTC (91.2 vs. 95.3 cm) (Table 4). At Lexington in 2013, leaf removal also decreased plant height by 4% compared to the UTC (91.3 vs. 95.3 cm).

The main effect of stress affected light interception in all environments (Table 7). Light interception patterns varied by environment but in general, the lactofen and leaf removal treatments decreased early-season light interception. At Hodgenville in 2013, leaf removal decreased light interception by 6% compared to the UTC (11 vs. 17%) at 18 d after emergence (DAE) (Fig. 1). At 40 DAE, lactofen and leaf removal resulted in decreased light interception compared to the UTC (84 and 70% vs. 94%, respectively). Despite lactofen and leaf removal affecting early-season light interception, all treatments reached canopy closure (>95% light interception) by ~50 d after emergence. At Lexington in 2013, differences in light interception were not observed until late June. Lactofen and leaf removal intercepted less light between 25 and 58 DAE compared to the UTC (Fig. 2). At 36 DAE, untreated plants intercepted 56% of the available light while lactofen-treated plants intercepted 28% and leaf removal plants intercepted only 21% of available light. Similarly, at 43 DAE, untreated soybean intercepted 85% of the available light while lactofen-treated plants intercepted 64% of available light and leaf removal plants intercepted 52% of available light. Meristem removal and fomesafen had similar levels of light interception to the UTC throughout the growing season. At the beginning of reproductive growth (R1), the lactofen and leaf removal treatments still lagged behind the UTC and other stress treatments. However, all stress treatments achieved >95% light interception by 58 DAE, coinciding with the beginning of pod development (R3). Early in the 2014 growing season (15 DAE) at the Hodgenville location, the leaf removal treatment intercepted less light than the UTC (32 vs. 39%) (Fig. 3). At 26 DAE, lactofen (66 vs. 87%) and leaf removal (54 vs. 87%) intercepted less light than the UTC. The lactofen-treated plants eventually intercepted a similar amount of light as the untreated plants on 33 DAE, but the leaf removal treatment intercepted less light than the UTC (80 vs. 90%). Interestingly, all treatments achieved canopy closure (>95%

Table 6. Plant stands at harvest (R8), plant height, and seed yield values for early-season stress treatments at four timings for a study in Lexington, KY, in 2014.

Timing	Stress					
	UTC	Lactofen	Fomesafen	Leaf removal	Meristem removal	Avg.
	plants m^{-2}					
Plant stands						
V1	48.3	52.8	50.0	47.3	39.0	47.5
V2	47.0	48.0	49.0	50.3	41.8	47.2
V3	48.9	49.8	46.5	49.5	42.3	47.4
V4	47.5	49.3	50.5	49.8	46.0	48.6
Avg.	47.9	49.9	49.0	49.2	42.3	
LSD†	4.0					
	cm					
Plant height						
V1	75.3	79.0	73.3	76.8	71.5	75.2
V2	74.6	78.5	73.0	103.8	72.3	80.4
V3	72.4	80.8	76.0	77.3	69.8	75.2
V4	74.8	79.0	75.3	76.8	70.3	75.2
Avg.	74.3	79.3	74.4	83.6	70.9	
LSD	ns‡					
	Mg ha^{-1}					
Seed yield						
V1	5.08	5.37	5.26	5.15	5.70	5.31
V2	5.23	5.37	5.21	5.35	5.19	5.27
V3	4.86	5.27	5.55	5.17	5.31	5.23
V4	5.23	5.49	5.33	5.15	5.52	5.37
Avg.	5.11	5.37	5.33	5.24	5.43	
LSD	ns					
	Plant stands	Plant height	Seed yield			
Significance (*P* values)						
Stress	0.001	0.07	0.12			
Timing	0.84	0.54	0.55			
Timing × stress	0.88	0.57	0.35			

† LSD, least significant difference for the main effect of stress.

‡ ns, not significant ($P \le 0.05$).

light interception) before flowering (R1), with the exception of the UTC which only achieved a maximum of 90% light interception throughout the growing season. Lexington in 2014 had somewhat different pattern of light interception than the other environments. Similar to the other environments, lactofen and leaf removal soybean intercepted less light than the UTC prior to flowering (Fig. 4). However, unlike the other environments, differences in light interception between treatments persisted for a number of days after R1. Dry conditions during the month of July delayed canopy closure for all stress treatments. At 56 DAE, only the meristem removal treatment achieved 95% light interception which was greater than the UTC (87%). Canopy closure was eventually achieved by all treatments, but occurred well after the beginning of flowering and pod development.

The main effect of stress affected seed yield in two of the four study environments. At Lexington in 2013, the yield of the leaf removal treatment was decreased by 12% compared to the UTC (4.83 vs. 5.43 Mg ha^{-1}) while the yield of the meristem removal treatment was reduced by 9% as compared to the UTC (4.93 vs. 5.43 Mg ha^{-1}) (Table 4). The yield of lactofen and fomesafen treatments were similar to the yield of the UTC. At Hodgenville in 2014, seed yield responded to the main effect of stress but not to the main effect of timing and there was no timing × stress interaction (Table 5). The only treatment that yielded similarly to the UTC was the fomesafen treatment. Lactofen treatment decreased yield by 8% (5.78 vs. 6.25 Mg ha^{-1}), while the leaf removal treatment reduced yield

Table 7. P values associated with the repeated measures ANOVA for light interception for studies in Lexington and Hodgenville, KY, during the 2013 and 2014 growing seasons.

Timing	2013		2014	
	Lexington	Hodgenville	Lexington	Hodgenville
	P values			
Timing	0.19	0.26	0.61	0.65
Stress	<0.0001	0.03	0.003	0.001
Timing × stress	0.07	0.16	0.53	0.35

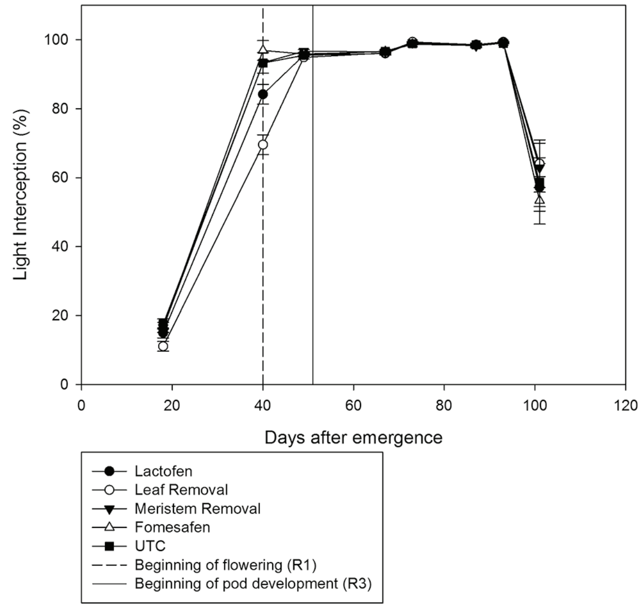

Fig. 1. Percent light interception of soybean exposed to five stress treatments averaged across four timings for a study in Hodgenville, KY, in 2013. Vertical bars represent standard error of the mean.

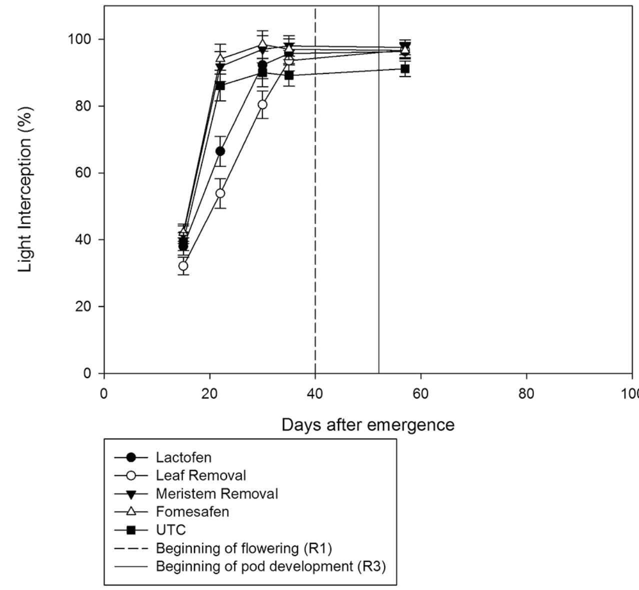

Fig. 3. Percent light interception of soybean exposed to five stress treatments averaged across four timings for a study in Hodgenville, KY, in 2014. Vertical bars represent standard error of the mean.

by 6% compared to the UTC (5.91 vs. 6.25 Mg ha^{-1}). The meristem removal treatment decreased yield by 7% compared to the UTC (5.82 vs. 6.25 Mg ha^{-1}).

DISCUSSION

The differences in harvest stands at Hodgenville in 2013, while statistically significant, are likely not due to actual treatment effects. There is no apparent agronomic reason that leaf removal at V4 would result in greater stands than untreated plants. The likely reason for the stand variability in this environment is the planter type that was used. Hodgenville in 2013 was seeded with a small-plot research grain drill. Seeding soybean with a grain drill often results in more variable stands than seeding with a row crop planter, likely explaining differences in stand establishment at this location (Bertram and Pedersen, 2004; Epler and Staggenborg, 2008). However, in 2014 plots at both locations were seeded with precision row-crop planter which resulted in far more consistent stands (Tables 5 and 6). At both locations in 2014, meristem removal decreased soybean stands. There are two main hypotheses to explain the reduced stand densities observed for the meristem removal treatment. One hypothesis is that the physical damage to the plant caused by the removal of the meristem killed some plants in the plot, resulting in decreased stands. Previous studies have shown stand reductions for soybean that are damaged

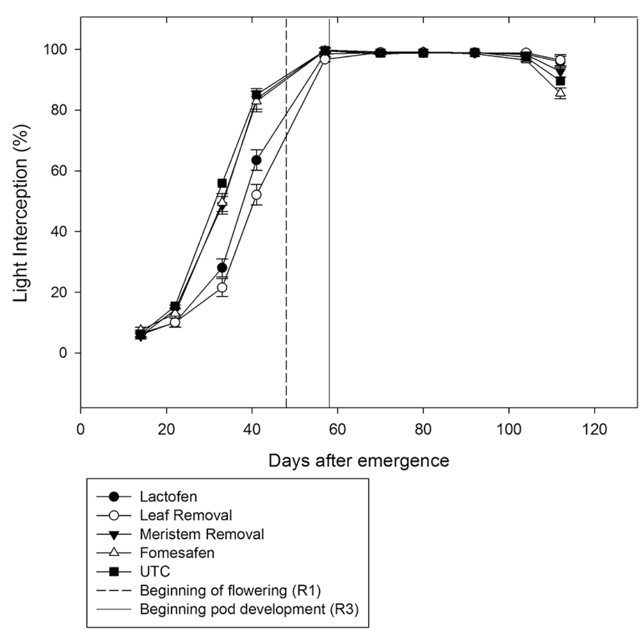

Fig. 2. Percent light interception of soybean exposed to five stress treatments averaged across four timings for a study in Lexington, KY, in 2013. Vertical bars represent standard error of the mean.

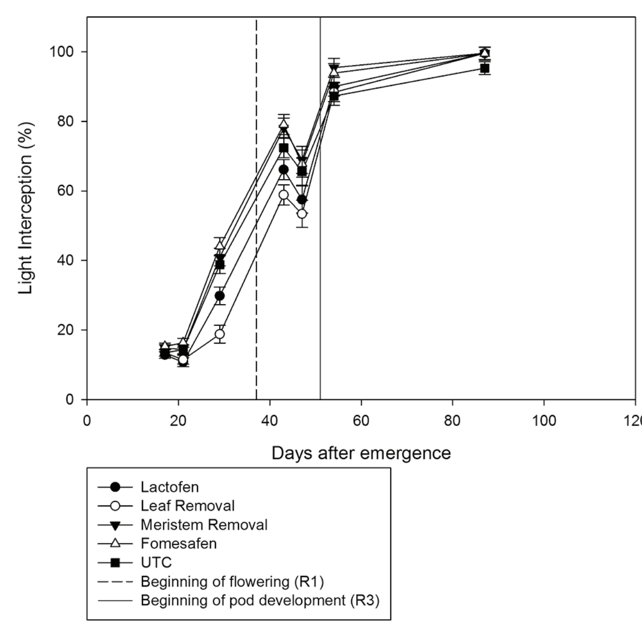

Fig. 4. Percent light interception of soybean exposed to five stress treatments averaged across four timings for a study in Lexington, KY, in 2014. Vertical bars represent standard error of the mean.

during early vegetative growth from environmental factors such as hail (Kalton et al., 1949; Weber, 1955). However, if plant damage was the cause of the reduced stands for the meristem removal treatment, then decreased stand densities at R8 would be expected for other stress treatments, particularly the leaf removal treatment. Another explanation for the reduction in harvest stands is increased branching observed on meristem removal plants, which likely resulted in increased intra-row competition. Previous studies have shown decreased establishment for soybean with increased intra-row competition, such as soybean grown in wide (>76 cm) rows (Elmore, 1998; Oplinger and Philbrook, 1992; De Bruin and Pedersen, 2008). Despite variable stands in 2013 and reduced stands for meristem removal in 2014, densities were well above stand densities previously reported to be necessary for attainment of maximum yields (Oplinger and Philbrook, 1992; Lee et al., 2008).

Although meristem removal decreased plant height in two environments, height reductions were minor, indicating that loss of the apical meristem does not dramatically stunt soybean under full-season growth in high-yielding environments. Young et al. (2003) reported an average 2.4% height reduction for late-maturity group (MG) 2 soybean treated with acifluorfen at multiple timings for studies in Iowa and Illinois. A study in Michigan showed season-long soybean height reductions for herbicide treatments containing both acifluorfen and lactofen in MG 1 soybean, but only temporary plant height reduction in MG 2 soybean (Nelson and Renner, 2001). Plant height reductions were not observed for either lactofen or fomesafen application to the MG 4 soybean used in this study, suggesting that later-maturing varieties with longer growth cycles are less sensitive to reductions in plant height than early-maturing varieties.

Previous studies have shown that soybean yield is maximized when light interception approaches 90% at R1 (beginning of flowering) and 95% at R5 (beginning of seed filling) (Board and Harville, 1994; Board, 2004; Lee et al., 2008). In all four environments, lactofen and leaf removal decreased early season light interception compared to untreated soybean, however, the effect of decreased light interception on seed yield varied by environment. At Hodgenville in 2013, leaf removal and lactofen treatments did not reach 90% light interception at R1. However, all treatments reached >95% light interception by R3 resulting in similar yields across all treatments. At Lexington in 2014, >95% light interception was not reached for any treatment until after R3, indicating that yields were not maximized at this location. Although lactofen and leaf removal intercepted less light at R1 than the UTC, light interception was similar to the other stress treatments at R3 which resulted in similar yields across treatments. Lexington in 2013 exhibited a similar pattern of light interception. Lactofen and leaf removal failed to achieve >90% light interception by R1. At R1, lactofen treated soybean intercepted >80% of available light, while the leaf removal soybean intercepted only 63% of available light. Although both treatments achieved >95% light interception by R3, yield decrease was observed for the leaf removal treatment. Apparently in this environment, light interception at R1 was necessary to maximize yield. Interestingly at Hodgenville in 2014, all stress treatments, except for the UTC, reached >95% light interception before R1. However, yield decreases for lactofen and leaf removal treatments were still observed. Nelson and Renner (2001) observed decreases in soybean leaf area index (calculated from light interception measurements) and seed yield across multiple years for herbicide treatments containing lactofen. A study in Arkansas also observed decreased canopy closure (light interception) for soybean treated with lactofen during early-vegetative growth for MG 0 and MG 2 soybean, but yields were unaffected (Edwards and Purcell, 2005a).

Light interception patterns were similar between meristem removal and UTC soybean in all environments, however, meristem removal decreased yield at Lexington in 2013 and Hodgenville in 2014. A likely explanation for the decreased seed yield for the meristem removal treatment is increased harvest loss. Meristem removal resulted in the development of three to five large branches originating from the remaining mainstem nodes. Branches were visibly thinner and likely more fragile than the mainstem, making them more likely to detach the mainstem, especially with a substantial pod load attached. The soybean at this location were harvested late due to large amounts of rainfall during October (Table 2), which exposed the standing plants to harsh fall weather conditions. A study in Wisconsin showed that losses due to stem breakage accounted for between 22 and 27% of harvest loses and that stem loss increases linearly with harvest delay (Philbrook and Oplinger, 1989). Physical damage to the standing plants caused by the combine harvester may have caused brittle branches to break off and remain in the field instead of being threshed by the combine harvester.

CONCLUSION

While this study is one of the first to examine the use of lactofen specifically to manipulate yield components and increase seed yield, the results of this study are similar to previous studies that evaluated lactofen and other diphenyl ether herbicides for weed control purposes. Soybean seed yield remained unchanged or decreased due to early-season lactofen application. It is unlikely that either lactofen or fomesafen was able to damage or destroy the apical meristem and our results show there is no agronomic or yield advantage to removing the apical meristem. These data indicate that soybean producers should not apply lactofen to early-vegetative soybean solely to increase yield. Furthermore, decreases in light interception and yield for lactofen, but not fomesafen, suggest that when diphenyl ether herbicides are necessary for post-emergence weed control, soybean producers should strongly consider using fomesafen over lactofen.

REFERENCES

Bertram, M.G., and P. Pedersen. 2004. Adjusting management practices using glyphosate resistant soybean cultivars. Agron. J. 96:462–468. doi:10.2134/agronj2004.0462

Board, J.E. 2004. Soybean variety differences in light lnterception and leaf area index during seed fill. Agron. J. 96:305–310. doi:10.2134/agronj2004.0305

Board, J.E., and B.G. Harville. 1994. A criterion for acceptance of narrow-row culture in soybean. Agron. J. 86:1103–1106.

De Bruin, J.L., and P. Pedersen. 2008. Effect of row spacing and seeding rate on soybean yield. Agron. J. 100:704–710. doi:10.2134/agronj2007.0106

Edwards, J.T., and L.C. Purcell. 2005a. Light interception and yield response of ultra-short-season soybean to diphenylether herbicieds in midsouthern United States. Weed Technol. 19:168–175. doi:10.1614/WT-04-085R

Edwards, J.E., L.C. Purcell, and D.E. Karcher. 2005b. Soybean yield and biomass responses to increasing plant populations among diverse maturity groups: II. Light interception and utilization. Crop Sci. 45:1778–1785. doi:10.2135/cropsci2004.0570

Elmore, R.W. 1998. Soybean cultivar responses to row spacing and seeding rates in rainfed and irrigated environments. J. Prod. Agric. 11:326–331. doi:10.2134/jpa1998.0326

Epler, M., and S. Staggenborg. 2008. Soybean yield and yield component responses to plant density in narrow row systems. www.plantmanagementnetwork.org/pub/cm/. Crop Manage. doi:10.1094/CM-2008-0925-01-RS. Plant Management Network, St. Paul, MN.

Fehr, W.R., and C.E. Caviness. 1977. Stages of soybean development. Coop. Ext. Serv., Agric. and Home Economics Exp. Stn., Iowa State Univ., Ames.

Graham, M.Y. 2005. The diphenyl ether herbicide lactofen induces cell death and expression of defense-related genes in soybean. Plant Physiol. 139:1784–1794. doi:10.1104/pp.105.068676

Harris, J.R., B.J. Gossett, T.R. Murphy, and J.E. Toler. 1991. Response of broadleaf weeds and soybeans to diphenyl ether herbicides. J. Prod. Agric. 4:407–411. doi:10.2134/jpa1991.0407

Hart, S.E., L.M. Wax, and A.G. Hager. 1997. Comparison of total postemergence weed control programs in soybean. J. Prod. Agric. 10:136–141. doi:10.2134/jpa1997.0136

Kalton, R.R., C.R. Weber, and J.C. Elderedge. 1949. The effect of injury simulating hail damage to soybeans. Res. Bull. 359. U.S. Regional Soybean Lab., Ames, IA.

Kapusta, G., L.A. Jackson, and D.S. Mason. 1986. Yield response of weed-free soybeans (*Glycine max*) to injury from postemergence broadleaf herbicides. Weed Sci. 34:304–307.

Karcher, D.E., and M.D. Richardson. 2005. Batch analysis of digital images to evaluate turfgrass characteristics. Crop Sci. 45:1536–1539. doi:10.2135/cropsci2004.0562

Lee, C.D., D.B. Egli, and D.M. TeKrony. 2008. Soybean response to plant population at early and late planting dates in the Mid-South. Agron. J. 100:971–976. doi:10.2134/agronj2007.0210

Nelson, K.A., and K.A. Renner. 2001. Soybean growth and development as affected by phyphosate and postemergence herbicide tank mixtures. Agron. J. 93:428–434. doi:10.2134/agronj2001.932428x

Oplinger, E.S., and B.D. Philbrook. 1992. Soybean planting date, row width, and seeding rate response in three tillage systems. J. Prod. Agric. 5:94–99. doi:10.2134/jpa1992.0094

Orlowski, J.M., G.L. Gregg, and C.D. Lee. 2016. Early-season lactofen application has limited effect on soybean branch and mainstem yield components. Crop Sci. 56:432–438. doi:10.2135/cropsci2015.08.0482

Philbrook, B.D., and E.S. Oplinger. 1989. Soybean field losses as influenced by harvest delays. Agron. J. 81:251–258. doi:10.2134/agronj1989.00021962008100020023x

Purcell, L.C. 2000. Soybean canopy coverage and light interception measurements using digital imagery. Crop Sci. 40:834–837. doi:10.2135/cropsci2000.403834x

Weber, C.R. 1955. Effects of defoliation and topping simulating hail injury to soybeans. Agron. J. 47:262–266. doi:10.2134/agronj1955.00021962004700060007x

Wichert, R.A., and R.E. Talbert. 1993. Soybean [*Glycine max* (L.)] response to lactofen. Weed Sci. 41:23–27.

Young, B.G., J.M. Young, J.L. Matthews, D.K. Owen, I.A. Zelaya, R.G. Hartzler et al. 2003. Soybean development and yield as affected by three postemergence herbicides. Agron. J. 95:1152–1156. doi:10.2134/agronj2003.1152