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Growth Regulation with Lactofen Does Not Affect Seed Yield of Irrigated Soybean

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ABSTRACT

Soybean [*Glycine max* (L.) Merr.] producers have considered the use of lactofen herbicide (2-ethoxy-1-methyl-2-oxoethyl 5-[2-chloro-4-(trifluoromethyl)phenoxy]-2-nitrobenzoate) as a growth regulator part of management systems for high-yielding soybean, believing that lactofen can reduce plant height and lodging or increase node number. Previous research on non-irrigated soybean was largely unable to show significant benefits for lactofen applied during early vegetative growth (V1–V4) as a growth regulator. However, it is unclear how early-season lactofen applications affect soybean growth and seed yield in high-yielding, irrigated soybean management systems common in the midsouthern United States. The purpose of this study was to investigate the effect of early-season lactofen application on soybean injury, stunting, plant height, node number, intercepted photosynthetically active radiation, lodging, and seed yield at multiple planting dates. Trials were established during the 2013 and 2014 growing season in Stoneville, MS. Soybean was planted at four planting dates: 15 April, 1 May, 15 May, and 1 June. Crop oil concentrate (COC) and lactofen plus COC were applied to soybean at the second trifoliate growth stage (V2). Lactofen plus COC application resulted in early-season injury and stunting, but did not affect intercepted photosynthetically active radiation, plant height at harvest, lodging, or seed yield while, planting date affected soybean plant height, but did not affect seed yield. The findings of this study suggest that the use of lactofen as a growth regulator for irrigated soybean production in the midsouthern United States is not necessary.

Core Ideas

- Early-season lactofen application results in temporary injury and stunting in high-yielding, irrigated soybean in the midsouthern United States.
- Early-season lactofen application does not affect soybean seed yield in high-yield irrigated midsouthern U.S. environments.
- Soybean planting date failed to affect soybean seed yield in growing seasons with above-average precipitation.

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Lactofen and other diphenyl ether herbicides such as fomesafen are used in soybean production in the midsouthern United States, for control of broadleaf weeds (Kapusta et al., 1986; Wichert and Talbert 1993), particularly glyphosate [N-(phosphonomethyl) glycine] and acetolactate synthase (ALS)-resistant Palmer amaranth (*Amaranthus palmeri* S. Wats) (Norsworthy et al., 2008). When lactofen is applied postemergence, the herbicide is absorbed into plant tissue where it inhibits protoporphyrinogen oxidase (PPO) enzymes resulting in breakdown of cell membranes causing loss of turgor pressure and cell death in susceptible plants (Graham, 2005). Although lactofen is labeled for use in soybean, application results in severe bronzing and necrosis on exposed soybean tissue which can persist for a number of weeks (Kapusta et al., 1986).

It has been hypothesized that the damaged caused by lactofen can have beneficial effects on high-yielding soybean. It has been hypothesized that the damage caused by lactofen stunts soybean resulting in decreased plant height. Decreasing plant height in vigorous, high-yielding soybean can reduce yield losses associated with lodging (Wilcox and Sediyama, 1981). It has also been hypothesized that the damage caused by lactofen can potentially damage or kill the apical meristem of the soybean plant, stimulating lateral branching and increasing soybean node number (Orlowski et al., 2016). Recent research in the upper midsouthern United States (Kentucky) reported that early-season (V1–V4) (Fehr and Caviness, 1977) lactofen application limited effects on soybean morphology and yield components and did not increase soybean seed yield (Gregg et al., 2015; Orlowski, 2015; Orlowski et al., 2016). However, soybean management in Kentucky is far more similar to non-irrigated midwestern U.S. production systems than the furrow-irrigated systems common in the lower midsouthern United States (Mississippi River Delta).

Aside from being furrow-irrigated, soybean in the midsouthern United States are planted much earlier than midwestern U.S. soybean, generally in early to mid-April to avoid harsh environmental conditions during reproductive growth (Heatherly and Spurlock, 1999). The early planting system coupled with supplemental irrigation results in seed yields (>5.3 Mg ha^{-1}) being achieved by producers well above the national average (3.1 Mg ha^{-1}). The purpose

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Abbreviations: COC, crop oil concentrate; DAT, days after treatment; IPAR, intercepted photosynthetically active radiation.

of this study was to (i) determine the effect of early-season lactofen application on soybean growth characteristics, including injury, stunting, intercepted photosynthetically active radiation (IPAR), node number, lodging, and seed yield for irrigated soybean in the midsouthern United States. Also, since soybean planting date can affect a number of the same soybean growth parameters as lactofen, such as plant height (Parker et al., 1981), node number (Anderson and Vasilas, 1985) and seed yield (Heatherly, 1988), we also wanted to (ii) determine if soybean growth and seed yield responses to lactofen varied by planting date.

MATERIALS AND METHODS

Field studies were conducted during the 2013 and 2014 growing seasons at the Mississippi State University Delta Research and Extension Center in Stoneville, MS (33°25′ N, 90°54′ W). The studies were established on a Bosket silt loam (fine-loamy, mixed, active, thermic Mollic Hapludalf). An indeterminate maturity group IV soybean cultivar, Progeny 4819LL (Progeny Ag. Products, Wynne, AR), was planted at 370,000 seed ha^{-1} with a John Deere 1730 small-plot vacuum planter (Deere and Company, Moline, IL). Individual plots consisted of four rows spaced 0.76 m apart and 18 m in length. The experimental sites were prepared by fall-disking, field cultivation, disk-hipping, and rolling. All plots were maintained weed free and furrow-irrigated as needed throughout the growing season.

The experimental design was a randomized complete block in a split-plot arrangement with four replications (blocks). Whole plots were planting dates and included targeted dates of 15 April, 1 May, 15 May, and 1 June. Soybean were planted within 2 d of the targeted dates each year. Subplots were postemergence treatments which included a nontreated control, crop-oil concentrate (COC) at 1% volume $volume^{-1}$, and lactofen at 220 g a.i. ha^{-1} mixed with COC at 1% volume $volume^{-1}$. Postemergence treatments were replicated four times within each planting date. Postemergence treatments were applied with a tractor-mounted sprayer calibrated to deliver 140 L ha^{-1} at 248 kPa with extended range flat-fan spray nozzles (TeeJet XR11002) (Spraying Systems Co.,Wheaton, IL) once soybean plants reached the second trifoliate (V2) growth stage.

Visual estimates of soybean injury were documented 7 and 14 days after treatment (DAT) and stunting at 21 and 28 DAT were recorded on a scale from 0 to 100%, with 0 representing no injury or stunting and 100 representing complete plant death. Growth reduction was visually estimated 21 and 28 DAT as a form of plant response to the COC only and lactofen plus COC treatments because injury and stunting were no longer observable at the 21 DAT evaluation. An AccuPar model LP-80 PAR/LAI Ceptometer sensor (Decagon Devices, Pullman, WA) was used to determine IPAR at 21 and 28 DAT. Ambient radiation conditions were measured in full sunlight between plots. The light sensor was then placed on the ground below the soybean canopy and the photosynthetically active radiation measured at three locations within each subplot. The ratio of below canopy to ambient radiation was subtracted from one and multiplied by 100 to determine the percentage of light intercepted by the soybean canopy. Plant height and total node number were measured on 10 randomly selected plants in each subplot 28 DAT and at harvest maturity (R8). Lodging was recorded before harvest on a scale from 1 to 10, where 1 represented a completely flat plant and 10 represented a completely erect plant. At harvest maturity (R8) the two center rows of each plot were harvested with a small-plot combine (Kincaid Manufacturing, Haven, KS), and soybean seed yield was adjusted to 130 g kg^{-1} moisture content.

Data were subjected to ANOVA using the PROCMIXED procedure in SAS (SAS Institute, Cary, NC). Year and replication(year) were considered random effects while treatment, planting date and the treatment × planting date interaction were considered fixed effects (Blouin et al., 2011). Type III statistics were used to test the fixed effects of treatment and planting date and the treatment × planting date interaction. Least square means were calculated and mean separation ($P \le 0.05$) was produced using PDMIX800 macro in SAS (Saxton, 1998).

RESULTS AND DISCUSSION

Growing conditions were very favorable for soybean growth in both 2013 and 2014 (Table 1). Soybean in 2013 received above average rainfall in April and May and near average precipitation in June. Although precipitation amounts in July and August were below the 30-yr average, mean temperature was ~2°C cooler than the 30-yr average which likely resulted in reduced heat stress and transpiration. Supplemental furrow irrigation also likely minimized the effects of reduced rainfall. Precipitation amounts were well above the 30-yr average for September and October, providing adequate soil moisture for pod set (R3–R4) and seed fill (R5–R6) across planting dates. Soybean in 2014 received above average precipitation every month from April through August. Precipitation levels were below average for September and October, but supplemental irrigation reduced the effects of the decreased precipitation. Similar to 2013, soybean in 2014 experienced ~ 2°C cooler temperatures in June compared to the 30-yr average.

Table 1. Monthly and 30-yr average precipitation (Precip.) and temperature (Temp.) for Stoneville, MS, for the 2013 and 2014 growing seasons.

	2013†				2014‡			
Month	Precip.	30 yr	Temp.	30 yr	Precip.	30 yr	Temp.	30 yr
	mm		°C		mm		°C	
April	168	122	16.4	17.8	249	126	17.3	17.9
May	145	120	21.1	22.7	158	117	22.3	22.8
June	93	94	25.7	26.6	145	92	26.9	26.6
July	46	93	25.9	27.8	135	97	25.6	27.7
August	51	67	27.6	27.5	80	68	26.8	27.5
September	130	90	25.6	23.9	35	89	25.1	24.0
October	181	112	18.8	18.0	21	112	19.9	18.1
Total/Avg.	814	698	23.0	23.5	823	701	23.4	23.5

† 30-yr average for 1983 to 2013.

‡ 30-yr average for 1984 to 2014.

Table 2. Significance of the ANOVA for the main effects of treatment and planting date and the treatment × planting date interaction for soybean injury, stunting, plant height, node number, intercepted photosynthetically active radiation, lodging, and yield for experiments at Stoneville, MS, during the 2013 and 2014 growing seasons.

Effects	Injury 7 DAT†	Injury 14 DAT	Stunting 21 DAT	Stunting 28 DAT	Plant height 28 DAT	Plant height R8	Node number 28 DAT	Node number R8	IPAR‡ 21 DAT	IPAR‡ 28 DAT	Lodging	Seed yield
	P values											
Treatment	0.001	0.10	0.001	0.001	0.0001	0.88	0.69	0.28	0.26	0.06	0.93	0.90
Planting date	0.33	0.68	0.24	0.07	0.03	0.11	0.47	0.0001	0.59	0.08	0.36	0.07
Treatment × planting date	0.30	0.77	0.24	0.03	0.07	0.60	0.57	0.04	0.45	0.28	0.89	0.91

† DAT, days after treatment.

‡ Intercepted photosynthetically active radiation.

Differences in injury were observed for the main effect of treatment (Table 2). Lactofen plus COC resulted in 35% visible soybean injury at 7 DAT compared to the nontreated and COC only treatment (Table 3); however, no visible injury was apparent by 14 DAT. Injury symptoms observed included yellowing, bronzing, and tissue necrosis. At 21 DAT lactofen plus COC treated plants were stunted by 19% compared to COC and nontreated plants. At 28 DAT, a treatment × planting date interaction was observed (Table 2). At 28 DAT, the 15 April planting date showed greater stunting from lactofen plus COC application than the 1 May and 15 May planting dates (Table 4). Krausz and Young (2001) reported 35% injury (necrosis) 7 DAT when lactofen was applied at 0.14 kg ha^{-1} at V4, but injury was not apparent at 28 DAT.

The main effect of treatment also influenced plant height 28 DAT (Table 2). Plant height was similar in nontreated and COC treated soybean at 28 DAT. Lactofen plus COC resulted in 11% shorter plants compared to nontreated and COC treated soybean, Plant height reductions in this study are slightly less that those reported by Krausz and Young (2001) who reported 20% reduction in soybean height 28 d following lactofen at 0.14 kg ha^{-1} applied at the V4 growth stage.

Table 3. Soybean injury, stunting, and plant height for postemergence treatments averaged across planting dates for studies in Stoneville, MS, during the 2013 and 2014 growing seasons.

Treatment†	Injury 7 DAT‡	Stunting 21 DAT	Plant height 28 DAT
Control	0b	0b	44a
COC§	1b	0b	45a
Lactofen + COC	35a	19a	40b

† Values within a column followed by the same letter are not statistically different at $P \leq 0.05$.

‡ DAT, days after treatment.

§ COC, crop oil concentrate.

Soybean planted 15 April, 1 May, and 15 May had similar plant height 28 DAT (Table 5). When averaged across treatments, plant height at 28 DAT for soybean planted 1 June were 32% greater than 15 April planted soybean (53 vs. 36 cm), 26% greater than 1 May planted soybean (53 vs. 39 cm), and 17% greater 15 May planted soybean (53 vs. 44 cm). However, differences in R8 plant height were not observed for either treatment or planting date. Orlowski (2015) did not observe reductions in plant height for soybean treated with lactofen. Previous studies have reported reduced plant heights for June-planted soybean compared to May-planted soybean (Anderson and Vasilas, 1985; Heatherly, 1988; Parvez et al., 1989) or increased plant heights associated with later planting dates (Parker et al., 1981; Board, 1985). Since significant lodging was not observed in this study (Table 2), differences in plant height likely did not affect seed yield.

Differences in IPAR were not observed for either treatment or planting date 21 or 28 DAT (Table 2). These results differ from those of Orlowski (2015), who observed decreased light interception for lactofen treated soybean compared to nontreated soybean at four study locations. Similarly, Gregg et al. (2015) observed decreased early-season light interception for lactofen treated compared to nontreated soybean across two different maturity

Table 5. Plant height at 28 d after treatment for four planting dates for experiments at Stoneville, MS, during the 2013 and 2014 growing seasons.

Planting date	Plant height 28 DAT†‡
	cm
15 April	36b
1 May	39b
15 May	44b
1 June	53a

† Values followed by the same letter are not statistically different at $P \leq 0.05$.

‡ DAT, days after treatment.

Table 4. Stunting and node number for the interaction of treatment and planting date for experiments in Stoneville, MS, during the 2013 and 2014 growing seasons.

Planting date†	Stunting 28 DAT‡ Control	Stunting 28 DAT‡ COC¶	Stunting 28 DAT‡ Lactofen + COC	R8§ Node number Control	R8§ Node number COC	R8§ Node number Lactofen + COC
	%			nodes plant^{-1}		
15 April	0c	0c	19a	18b	19ab	19ab
1 May	0c	0c	13b	18b	18b	19ab
15 May	0c	0c	13b	20a	20a	20a
1 June	0c	0c	15ab	20a	20a	19ab

† Values followed by the same letter, within a column, are not statistically different at $P \leq 0.05$.

‡ DAT, days after treatment.

§ R8, harvest maturity.

¶ COC, crop oil concentrate.

groups. Since injury was no longer apparent 14 DAT on lactofen plus COC-treated plants, the soybean likely recovered from the foliar injury caused by the lactofen, adding enough new leaf area to achieve similar IPAR to nontreated soybean by 21 and 28 DAT.

Treatment, planting date, or the treatment × planting date interaction did not affect node number 28 DAT, but a treatment × planting date interaction was observed for node number at harvest (Table 2). In general, the 15 May and 1 June planting dates had slightly more nodes (~2 nodes plant^{-1}) than the 1 May and 15 April planting dates, with small variation due to treatment (~ 1 node plant^{-1}) (Table 4). Neither Orlowski et al. (2016) nor Gregg et al. (2015) reported differences in node numbers for lactofen treated and nontreated soybean.

Despite differences in node number, neither treatment nor planting date affected seed yield (Table 2). When averaged across 4 (Orlowski, 2015) and 5 (Gregg et al., 2015) site-years, both studies conducted in Kentucky had overall seed yield averages of 5.1 Mg ha^{-1} under dryland conditions. In contrast, when averaged across both site-years, seed yield averaged 6.8 Mg ha^{-1} in this study. Despite the significantly greater seed yields achieved with furrow irrigation, lactofen application did not result in increased seed yield which fails to support the hypothesis growth regulation with lactofen is beneficial in high-yielding soybean. Moreover, it appears that lactofen application for growth regulation of soybean is not necessary regardless of yield level.

The lack of seed yield response to planting date is more surprising. In the midsouthern United States earlier planting dates consistently produce higher seed yields than later planting dates (Egli and Cornelius, 2009; Salmeron et al., 2014). This is because early-planted soybean complete reproductive growth before regular drought develops during late summer (Heatherly and Spurlock, 1999; Heatherly and Elmore, 2004). Similar soybean seed yield across planting dates can likely be attributed to ~2°C cooler average temperatures in July of both 2013 and 2014 and the availability of irrigation which limited stress during flowering and pod development across all planting dates (Table 1). Under more typical climatic conditions, decreased seed yield would likely be observed for later planted soybean in the midsouthern United States (Salmeron et al., 2014).

CONCLUSION

Early-season lactofen plus COC application caused necrosis, stunting, and decreased plant height early in the growing season. However, lactofen application did not affect photosynthetically active radiation and ultimately did not affect seed yield. The findings of this study are very similar to those conducted under non-irrigated conditions upper midsouthern United States that failed to observe increased seed yield for lactofen applied early in the growing season for growth regulation under-high yield management. Even under high-yielding, irrigated production, early-season lactofen application is of little value in increasing soybean seed yield and its use as a growth regulator should not be recommended for soybean producers in the midsouthern United States.

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