Weed Control and Soybean (Glycine max) Response to Mixtures of a Blended Foliar Fertilizer and Postemergence Herbicides

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Abstract: Growers commonly mix foliar fertilizers with postemergence (POST) herbicides to reduce application costs and/or to decrease soybean injury. Field studies conducted in 2015 and 2016 in Stoneville, MS, evaluated the impact on weed control and soybean (Glycine max (L.) Merr) injury, growth, and yield when combining a blended foliar fertilizer with POST herbicide applications. Herbicide treatments included no herbicide and glyphosate alone and in combination with S-metolachlor, fomesafen, or lactofen. The blended foliar fertilizer was applied at 0, 0.39, and 0.78 kg a.i. ha\(^{-1}\). In the Weed Control Study, 14 antagonistic effects at various evaluations were detected on Palmer amaranth (Amaranthus palmeri (S.) Wats) and barnyardgrass (Echinochloa crus-galli (L.) P. Beauv.) control 7, 14, and 21 d after treatment (DAT) when a blended foliar fertilizer at 0.39 or 0.78 kg a.i. ha\(^{-1}\) was mixed with glyphosate alone or combined with S-metolachlor, fomesafen, or lactofen. Of the 14 total effects, nine were detected with foliar fertilizer at the higher rate of 0.78 kg a.i. ha\(^{-1}\). Seven antagonistic effects were detected for both weed species regardless of herbicide treatment or foliar fertilizer rate. The only treatment combination in which an antagonistic effect was not detected was glyphosate plus lactofen plus foliar fertilizer at 0.78 kg a.i. ha\(^{-1}\). Blended foliar fertilizer did not influence soybean injury. In the Agronomic Study, blended foliar fertilizer did not impact soybean injury, height, dry wt., nutrient conc., or yield. Foliar fertilizer in combination with POST soybean herbicides did not reduce soybean injury and produced inconsistent effects on weed control across herbicide treatments and between weed species.

Keywords: agronomic performance; antagonism; herbicide interactions; foliar fertilizer rate; plant health management; synergism

1. Introduction

Amaranthus ssp., known collectively as pigweeds, belong to the family Amaranthaceae and have ranked among the top ten most troublesome weeds in southern U.S. soybean (Glycine max (L.) Merr) since the early 1970s [1–3]. Among eight southern U.S. states surveyed in 2013, Palmer amaranth was ranked as the most troublesome weed of cotton Gossypium hirsutum (L.) and soybean in seven and three states, respectively [4]. Palmer amaranth Amaranthus palmeri (S.) Watts is one of thirteen weed species in Mississippi to exhibit herbicide resistance [5]. In 2008, Palmer amaranth was confirmed resistant to glyphosate and acetolactate synthase (ALS) inhibitors in Mississippi [6].

With timely applications, glyphosate-resistant (GR) Palmer amaranth can be managed in soybean with herbicides other than glyphosate and ALS inhibitors [7]. Protoporphyrinogen oxidase (PPO)
inhibitors have become staple herbicides for PRE and POST weed control in soybean. Fomesafen is a member of the diphenylether family of PPO inhibitors labeled in soybean, and it controls common cocklebur (Xanthium strumarium L.), prickly sida (Sida spinosa L.), and Palmer amaranth [8]. Soybean yield was greater when fomesafen was applied POST to Palmer amaranth [7].

Barnyardgrass (Echinochloa crus-galli (L.) P. Beauv.) is one of the more problematic weeds in U.S. soybean production [9]. Mississippi and Arkansas ranked barnyardgrass as the fourth and eighth most troublesome weed in soybean production systems in 2013, respectively [4]. In addition, barnyardgrass is a troublesome weed around the world with resistance reported to 11 herbicide modes of action (MOA) [10]. Recently, Tennessee became the first state to confirm GR barnyardgrass [11]. A barnyardgrass population in Mississippi has developed resistance to four MOA [10,12]. Glyphosate has been a principal herbicide for barnyardgrass control [13–15]. Research has reported, 82, 97, and 98% reduction in barnyardgrass density, dry wt., and seed production, respectively, 84 d after an application of glyphosate at 0.450 kg a.e. ha$^{-1}$ in GR corn (Zea mays L.) [14].

Plant health management is the practice of understanding and overcoming several factors limiting plants from achieving their full genetic potential [16]. This concept can be applied to crops, trees, or any other plant [16]. The full genetic potential of a plant is a known or approximated capacity of a plant to grow, develop, and reproduce without limiting factors [16]. Breeding has increased the genetic potential of plants; however, plant health management focuses on improving upon the preexisting potential and not the modifications developed through breeding and genetic engineering [16].

Foliar fertilizers are routinely applied in a variety of crops to aid in plant health management [17–20]. Research has shown inconsistent soybean and cotton responses to foliar fertilizers [19,21,22]. Soybean yield increases attributed to foliar fertilizer applications have been small and infrequent [21]. Soybean yield increase has been reported with a 10-1-3-0.5 liquid nitrogen-phosphorous-potassium-sulfur (N-P-K-S) fertilizer applied at the R5 to R6 growth stages [18]. Greater soybean yields compared with the nontreated following various rates of 3-8-15 (N-P-K) fertilizers applied at the V5 growth stage [23]. Most research suggests no soybean yield increase with foliar S or micronutrients applied at reproductive stages [17,20]. The addition of micronutrients boron (B), iron (Fe), and zinc (Zn) to an N-P-K-S (10-4-8-1) fertilizer failed to improve soybean yields [19]. Other research reported reduction in soybean yield following foliar fertilization with observed reduction attributed to leaf injury from the application [21].

The option to mix different herbicide MOA provides the potential for increased weed control and a reduction in application costs [24]. However, some components of herbicide mixtures can synergize or antagonize others. Synergism is the simultaneous action of two or more components in which the total response of the combination is greater than the sum of the individual components [25]. Antagonism is reported when the total response is less than the sum of the individual components [25]. Interactions between components (water, foliar fertilizers, and other herbicides) of herbicide mixtures have been documented throughout the literature [25–31].

Tests for synergistic, antagonistic, and additive responses have evolved over time. Synergistic effects on wild oat Avena fatua (L.) and wild mustard Sinapis arvensis (L.) control utilizing Colby’s method [32,33]. The nonlinear model developed by [34] was utilized by [35] to evaluate a safening interaction on rice Oryza sativa (L.) treated with clomazone mixed with bensulfuron or halosulfuron. In 2010, [36] expanded on the nonlinear model creating the augmented mixed-model methodology providing a more versatile model than [34]. The augmented mixed-model methodology has been utilized by [37] to determine synergistic and antagonistic effects on red rice Oryza sativa (L.) and barnyardgrass control when applying mixtures of propanil and imazamox.

Results of herbicide-by-herbicide interactions are abundant throughout the literature. Synergism on red rice control was reported with propanil and imazamox mixtures; however, the same mixtures antagonized barnyardgrass control [37]. Antagonism on barnyardgrass control when the ACCase inhibitors quizalofop or sethoxydim were combined with the PPO inhibitor lactofen [38]. Starke and Oliver (1998) reported antagonism when fomesafen was combined with glyphosate on
entireleaf morningglory *Ipomoea hederacea* var. *integriuscula* (Gray) but not on pitted morningglory *Ipomoea lacunosa* (L.).

Fomesafen and lactofen are common treatments for Palmer amaranth control in soybean, but soybean injury is often observed following POST applications [5,39,40]. In an effort to reduce the number of applications and decrease soybean injury, growers commonly mix foliar fertilizers with POST herbicides [41,42]. Due to limited research on the interaction between herbicides and foliar fertilizers, field studies were conducted detailing the impact of mixing a blended foliar fertilizer with POST soybean herbicides. The objectives were to (1) evaluate the influence of a blended foliar fertilizer on soybean injury and weed control with POST herbicides and (2) to characterize soybean growth and yield following POST applications of mixtures of herbicides and a blended foliar fertilizer.

2. Materials and Methods

2.1. Weed Control Study

A field study was conducted at the Mississippi State University Delta Research and Extension Center in Stoneville (MS, USA) in 2015 and 2016 to evaluate weed control when a blended foliar fertilizer was mixed with POST herbicides in soybean. The study was performed at two sites in 2015 (2015—A and 2015—B) and 2016 (2016—A and 2016—B). Coordinates, soil series, description, pH, and organic matter (OM) for each siteyear are presented in Table 1.

| Siteyear | Coordinates            | Soil Series               | Description                                      | pH | OM 1:2(v:v) |
|----------|------------------------|---------------------------|--------------------------------------------------|----|------|
|          |                        |                           |                                                  |    | %    |
| Weed Control Study |                 |                           |                                                  |    |      |
| 2015-A   | 33°26’29.18” N, 90°5′41.92” W | Dundee very fine sandy loam | Fine-silty, mixed, active, thermic Typic Endoaqualfs | 6.1 | 1.2 |
| 2015-B   | 33°24’21.94” N, 90°55’31.27” W | Newellton silty clay     | Clayey over loamy, smectitic over mixed, superactive, nonacid, thermic Fluvaquentic Epiaquepts | 6.9 | 1.6 |
| 2016-A   | 33°26’28.33” N, 90°54’23.67” W | Commerce sandy clay loam | Fine-silty, superactive, nonacid, thermic Fluvaquentic Endoaquents | 6.8 | 1.6 |
| 2016-B   | 33°24’21.94” N, 90°55’31.27” W | Newellton silty clay     | Clayey over loamy, smectitic over mixed, superactive, nonacid, thermic Fluvaquentic Epiaquepts | 6.9 | 1.6 |

Agronomic Study

| Siteyear | Coordinates            | Soil Series               | Description                                      | pH | OM 1:2(v:v) |
|----------|------------------------|---------------------------|--------------------------------------------------|----|------|
| 2015-A   | 33°25’6.68” N, 90°54’3.44” W | Dundee very fine sandy loam | Fine-silty, mixed, active, thermic Typic Endoaqualfs | 6.1 | 1.3 |
| 2015-B   | 33°24’54.02” N, 90°54’3.44” W | Dundee very fine sandy loam | Fine-silty, mixed, active, thermic Typic Endoaqualfs | 6.2 | 1.2 |
| 2016-A   | 33°25’6.68” N, 90°54’3.44” W | Dundee very fine sandy loam | Fine-silty, mixed, active, thermic Typic Endoaqualfs | 6.1 | 1.3 |
| 2016-B   | 33°26’0.99” N, 90°54’31.52” W | Commerce sandy clay loam | Fine-silty, mixed, superactive, nonacid, thermic Fluvaquentic Endoaquents | 6.9 | 0.6 |

The experimental sites were known to be infested with barnyardgrass and Palmer amaranth. Each site was conventionally tilled prior to planting to stimulate weed germination and ensure uniform emergence. ‘Asgrow 4632’ (Monsanto Company, St. Louis, MO, USA) mid maturity group IV soybean was utilized in all siteyears and planted with a John Deere small-plot air planter (John Deere 1730, Deer and Company, Moline, IL, USA).

The study was designed as a two-factor factorial within a randomized complete block with four replications. Factor A was herbicide treatment and included no herbicide, glyphosate...
N-(phosphonomethyl)glycine) at 1.36 kg a.e. ha\(^{-1}\) alone and in combination with S-metolachlor (2-chloro-N-(2-ethyl-6-methylphenyl)-N-(1S)-2-methoxy-1-methylethyl acetamide) at 1.42 kg a.i. ha\(^{-1}\), fomesafen (5-2-chloro-4-(trifluoromethyl)phenoxy-N-(methylsulfonyl)-2-nitrobenzamide) at 0.375 kg ha\(^{-1}\), or lactofen (2-ethoxy-1-methyl-2-oxoethyl 5-2-chloro-4-(trifluoromethyl) phenoxy-2-nitrobenzoate) at 0.128 kg a.i. ha\(^{-1}\). Factor B was liquid foliar fertilizer rate and consisted of a blended foliar fertilizer with a 4-0-0-3-3-3-0.25%, N-P-K-S-Mn-Zn-B guaranteed analysis (Brandt SmartTrio, foliar fertilizer, Brandt Consolidated, Inc., Springfield, IL, USA) applied at 0, 0.39, and 0.78 kg a.i. ha\(^{-1}\). Liquid foliar fertilizer rates were based on product label [43] and unpublished fertility research from Mississippi. Treatments were applied with a tractor-mounted sprayer calibrated to deliver 140 L ha\(^{-1}\) at 248 kPa, fitted with extended range flat-fan nozzles (XR10002 Teejet® Wheaton, IL, USA), at the V3 soybean growth stage.

Visible estimates of soybean injury and weed control were recorded on a scale from 0 to 100% with 0 representing no injury or control and 100 representing soybean death or complete weed control [44]. Soybean injury was evaluated 3, 7, 14, 21, and 28 d after treatment (DAT) and control of Palmer amaranth and barnyardgrass was evaluated 7, 14, 21, and 28 DAT. Heights of five soybean plants in each plot were measured from the ground to the uppermost node 14 DAT and at maturity. Soybean were harvested using a small-plot combine (Kincaid Equipment, 210 West First St., P.O. Box 400; Haven, KS 67543, USA) on 25 Sept. 2015 and 5 Oct. 2015 and 16 Sept. 2016 and 12 Oct. 2016. Yield data were adjusted to 130 g kg\(^{-1}\) moisture content.

Square roots of visible injury and control estimates were arcsine transformed. The transformation did not improve the homogeneity of the variance based on visual inspection of the plotted residuals; therefore, nontransformed data were utilized in all analyses. Soybean injury and weed control data were analyzed utilizing the augmented mixed-model methodology described by Blouin et al. [36]. Data for soybean height and yield were subjected to ANOVA using the PROC MIXED procedure in SAS 9.4 (SAS Institute Inc., Cary, NC, USA) with siteyear, replication (nested within siteyear), and treatment-by-rep interactions listed as random variable parameters [45]. Type III Statistics were utilized to test the fixed effects of herbicide and foliar fertilizer for soybean height and yield. Least square means were calculated and mean separation (\(p \leq 0.05\)) was produced using PDMIX800 in SAS v. 9.3 (SAS Institute Inc. 100 SAS Campus Drive Cary, NC 27513-2414, USA), which is a macro for converting mean separation output to letter groupings [46]. When injury and weed control data did not return a significant synergistic or antagonistic effect [36], data were analyzed as described for soybean height and yield.

### 2.2. Agronomic Study

A field study was conducted at the Mississippi State University Delta Research and Extension Center at Stoneville in 2015 and 2016 to evaluate soybean response when mixing a blended foliar fertilizer with POST herbicides. The study was performed at two sites in 2015 (2015—1 and 2015—2) and 2016 (2016—1 and 2016—2). Global position system (GPS) coordinates, series, description, pH, and organic matter (OM) for each siteyear are presented in Table 1. Each site was conventionally tilled, then planted with a John Deere small-plot air planter. ‘Pioneer 48T53’ (Pioneer Hi-Bred P.O. Johnston, IA, USA) and Asgrow 4632 were planted in 2015 and 2016, respectively.

The treatment structure and experimental design for the Agronomic Study was identical to the Weed Control Study. However, the Agronomic Study was maintained weed-free each siteyear to prevent weed interference with soybean agronomic performance. Plots were hand-weeded or treated with labeled POST and residual herbicides applied with an in-row hooded sprayer (Willmar Fabrication, Benson, MN, USA) to prevent foliar soybean injury.

Visible estimates of soybean injury were recorded 3, 7, 14, 21, and 28 DAT on the previously described scale. Soybean height was recorded 14 DAT and at maturity as previously described. Soybean biomass was collected from 1 m sections of rows 1 and 4 in each plot 14 DAT. Soybean biomass samples were dried at 60 °C for 1 wk and weight converted to g m\(^{-2}\). Ten trifoliate leaves were
collected from the uppermost fully mature nodes of plants in rows 2 and 3 of each plot 14 DAT for tissue analysis. Tissue samples were air-dried in a greenhouse for analysis. Tissue samples were digested with concentrated nitric acid (HNO$_3$) and 30% hydrogen peroxide (H$_2$O$_2$) and analyzed by inductively coupled plasma atomic emission spectroscopy (ICP-AES) for nutrient conc. Soybean were harvested using a small-plot combine on Oct. 5, 2015, and Sept. 27 and Oct. 3, 2016. Yield data were adjusted to 13% moisture content. Data analyses were identical to the Weed Control Study.

3. Results

3.1. Weed Control Study

No synergistic or antagonistic effects were detected for soybean injury across all evaluation intervals. A main effect of herbicide treatment was detected for soybean injury at 3, 7, and 14 DAT (Table 2). Pooled across foliar fertilizer rates, glyphosate plus lactofen injured soybean more than other herbicide treatments 3 and 14 DAT. Glyphosate plus S-metolachlor injured soybean more than glyphosate alone, but not as severely as glyphosate plus fomesafen. Differences among treatments for soybean injury 7 DAT were similar as for 3 and 14 DAT (data not presented). Bronzing and necrosis of plant tissue due to lactofen and fomesafen is well-documented [5,40]. By 21 and 28 DAT, no soybean injury was observed (data not presented).

Palmer amaranth control 7 DAT with glyphosate alone was antagonized with 7% reduction by the addition of foliar fertilizer at 0.39 kg a.i. ha$^{-1}$ and 11 and 13% reduction at 14 and 21 DAT, respectively, with foliar fertilizer at 0.78 kg a.i. ha$^{-1}$ (Table 3). Control with glyphosate plus S-metolachlor was antagonized ≥11% by adding foliar fertilizer at 0.39 or 0.78 kg a.i. ha$^{-1}$ at 7 and 14 DAT (Table 3). Antagonism on velvetleaf Abutilon theophrasti (Medik) control has been reported when glyphosate at 0.28 kg a.i. ha$^{-1}$ was combined with different formulations of manganese (Mn); however, some of the antagonistic effects were overcome by adding ammonium sulfate at 20 g L$^{-1}$ [42]. Palmer amaranth in the current research was controlled 66% 7 DAT, with reduction attributed to the population contained some glyphosate-susceptible and -resistant individuals.

A herbicide main effect influenced Palmer amaranth control 28 DAT (Table 2). Pooled over foliar fertilizer rates, Palmer amaranth control with glyphosate plus fomesafen was at least 7% greater than with F all other herbicide treatments. Palmer amaranth control with fomesafen is well-documented; however, published research detailing control with glyphosate plus fomesafen is limited [7,47–49]. Miller and Norsworthy (2016) reported 93% Palmer amaranth control with glyphosate plus fomesafen and 2,4-D 14 DAT [48]. Barkley et al. (2016) documented ≥90% control of Palmer amaranth with varying rates of fomesafen alone 28 d after transplanting sweet potato (Ipomoea batatas (L.) Lam.) [47].

Palmer amaranth control with glyphosate alone was 56% and less than that with all other herbicide treatments 28 DAT (Table 2). Since glyphosate is a POST herbicide lacking residual control, it should be expected that the residual activity from fomesafen and S-metolachlor would control more Palmer amaranth than glyphosate alone 28 DAT [5,50,51]. Similar to glyphosate, there is minimal residual control expected with lactofen; however, glyphosate plus lactofen increased control of Palmer amaranth 18 and 21% compared with glyphosate alone 7 and 14 DAT, respectively (data not presented). Palmer amaranth control with glyphosate alone and glyphosate plus S-metolachlor was similar regardless of evaluation interval prior to 28 DAT (data not presented).

Barnyardgrass control was antagonized when foliar fertilizer at 0.78 kg a.i. ha$^{-1}$ was mixed with glyphosate alone 7 and 21 DAT, glyphosate plus fomesafen 14 and 21 DAT, and glyphosate plus S-metolachlor 14 DAT (Table 4). Differences between the observed and expected levels of control ranged from 6 to 10%. Antagonism for barnyardgrass control was also detected when foliar fertilizer at 0.39 kg a.i. ha$^{-1}$ was mixed with glyphosate plus fomesafen 14 DAT and glyphosate plus lactofen 21 DAT, and differences between the observed and expected levels of control were 9 and 6% for mixtures of glyphosate plus fomesafen or lactofen, respectively (Table 4).
Table 2. Soybean injury 3, and 14 d after treatment (DAT), Palmer amaranth (*Amaranthus palmeri* (S.) Wats) and barnyardgrass (*Echinochloa crus-galli* (L.) P. Beauv.) control 28 DAT, soybean height 14 DAT, and soybean yield following application of mixtures of POST soybean herbicides and a blended foliar fertilizer applied at the V3 growth stage in the Weed Control Study at Stoneville, MS, in 2015 and 2016 †.

| Herbicide Treatment          | Rate (kg ae or ai ha\(^{-1}\)) | Soybean Injury | Palmer Amaranth Control | Barnyardgrass Control | Soybean Height | Yield (kg ha\(^{-1}\)) |
|------------------------------|---------------------------------|----------------|-------------------------|-----------------------|----------------|------------------------|
| No herbicide                 | -                               | 0 d            | 0 d                     | 0 d                   | 38 b           | 2660 c                 |
| Glyphosate                   | 1.37                            | 1 d            | 0 d                     | 56 c                  | 77 bc          | 37 b                   | 3420 a                 |
| Glyphosate plus fomesafen    | 1.37 + 0.395                    | 12 b           | 4 b                     | 78 a                  | 74 c           | 36 ab                  | 3560 a                 |
| Glyphosate plus lactofen     | 1.37 + 0.218                    | 22 a           | 7 a                     | 71 b                  | 77 bc          | 33 a                   | 3380 ab                |
| Glyphosate plus S-metolachlor| 1.37 + 1.42                     | 6 c            | 2 c                     | 67 b                  | 82 a           | 36 ab                  | 3330 ab                |

† Data are pooled over four siteyears and three foliar fertilizer rates. Means followed by the same letter for each parameter and/or evaluation interval are not different at \( p \leq 0.05 \).
Table 3. Antagonistic effects for Palmer amaranth (*Amaranthus palmeri* (S.) Wats) control 7, 14 and 21 d after treatment (DAT) with mixtures of POST soybean herbicides and a blended foliar fertilizer applied at the V3 growth stage in the Weed Control Study at Stoneville, MS, in 2015 and 2016.

| Herbicide Treatment † | Rate (kg ae or ai ha⁻¹) | Foliar Fertilizer Rate(kg a.i. ha⁻¹) | 0.39 | 0.78 |
|----------------------|--------------------------|--------------------------------------|------|------|
|                      |                          | Expected (%) ‡ | Observed (%) †† | p-Value ‡‡ | Expected (%) ‡ | Observed (%) †† | p-Value ‡‡ |
| 7 DAT                |                          | Expected (%) ‡ | Observed (%) †† | p-Value ‡‡ | Expected (%) ‡ | Observed (%) †† | p-Value ‡‡ |
| Glyphosate           | 1.37                     | 66 | 59 * | 0.0453 | 66 | 61 | 0.1185 |
| Glyphosate plus fomesafen | 1.37 + 0.395     | 83 | 79 | 0.2651 | 83 | 77 | 0.1025 |
| Glyphosate plus lactofen | 1.37 + 0.218         | 82 | 80 | 0.6387 | 82 | 77 | 0.1831 |
| **Glyphosate plus**  |                          |                      |                 |              |                      |                   |                |
| S-metolachlor       | 1.37 + 1.42              | 73 | 62 * | 0.0142 | 73 | 62 * | 0.0088 |
| 14 DAT               |                          | Expected (%) ‡ | Observed (%) †† | p-Value ‡‡ | Expected (%) ‡ | Observed (%) †† | p-Value ‡‡ |
| Glyphosate           | 1.37                     | 66 | 57 | 0.0718 | 66 | 55 * | 0.0294 |
| Glyphosate plus fomesafen | 1.37 + 0.395     | 81 | 77 | 0.3447 | 81 | 74 | 0.1200 |
| Glyphosate plus lactofen | 1.37 + 0.218         | 83 | 80 | 0.5289 | 83 | 78 | 0.2437 |
| **Glyphosate plus**  |                          |                      |                 |              |                      |                   |                |
| S-metolachlor       | 1.37 + 1.42              | 74 | 60 * | 0.0247 | 74 | 60 * | 0.0200 |
| 21 DAT               |                          | Expected (%) ‡ | Observed (%) †† | p-Value ‡‡ | Expected (%) ‡ | Observed (%) †† | p-Value ‡‡ |
| Glyphosate           | 1.37                     | 66 | 58 | 0.0819 | 66 | 53 * | 0.0099 |
| Glyphosate plus fomesafen | 1.37 + 0.395     | 79 | 78 | 0.6772 | 79 | 72 | 0.0886 |
| Glyphosate plus lactofen | 1.37 + 0.218         | 76 | 74 | 0.7159 | 76 | 71 | 0.2770 |
| **Glyphosate plus**  |                          |                      |                 |              |                      |                   |                |
| S-metolachlor       | 1.37 + 1.42              | 69 | 63 | 0.1451 | 69 | 60 | 0.0502 |

† Evaluation interval and respective herbicide treatment. ‡ Expected values for each rate of foliar fertilizer at each evaluation interval are the same due to a lack of herbicidal activity from the foliar fertilizer; therefore, values are visual estimates of weed control for each herbicide treatment when foliar fertilizer rate was 0 kg ha⁻¹. †† Asterisks within each evaluation interval denote antagonistic effects between herbicide treatment and foliar fertilizer rate when p ≤ 0.05. ‡‡ The p-value nested within each foliar fertilizer rate for each evaluation interval denotes significant differences between observed and expected values within the corresponding rate of foliar fertilizer. Boldness is for ease of identification significant p values.
Table 4. Antagonistic effects for barnyardgrass (*Echinochloa crus-galli* (L.) P. Beauv.) control 7, 14, and 21 d after treatment (DAT) with mixtures of POST soybean herbicides and a blended foliar fertilizer applied at the V3 growth stage in the Weed Control Study at Stoneville, MS, in 2015 and 2016.

| Herbicide Treatment † | Rate (kg ae or ai ha⁻¹) | Foliar Fertilizer Rate (kg a.i. ha⁻¹) | 0.39 | 0.78 |
|----------------------|------------------------|--------------------------------------|------|------|
|                      | Expected (%) ‡ | Observed (%) †† | p-Value ‡‡ | Expected (%) ‡ | Observed (%) †† | p-Value ‡‡ |
| 7 DAT                |                      |                                      |      |      |
| Glyphosate           | 1.37                  | 88                                   | 84   | 0.1354 | 88 | 81 * | 0.0274 |
| Glyphosate plus fomesafen | 1.37 + 0.395  | 83                                   | 79   | 0.1810 | 83 | 78   | 0.1082 |
| Glyphosate plus lactofen     | 1.37 + 0.218 | 85                                   | 80   | 0.0964 | 85 | 82   | 0.2646 |
| Glyphosate plus S-metolachlor | 1.37 + 1.42 | 82                                   | 82   | 0.8546 | 82 | 80   | 0.6181 |
| 14 DAT               |                      |                                      |      |      |
| Glyphosate           | 1.37                  | 87                                   | 88   | 0.7292 | 87 | 82   | 0.0818 |
| Glyphosate plus fomesafen | 1.37 + 0.395  | 84                                   | 75 * | 0.0174 | 83 | 74 * | 0.0087 |
| Glyphosate plus lactofen     | 1.37 + 0.218 | 85                                   | 81   | 0.2404 | 85 | 81   | 0.2942 |
| Glyphosate plus S-metolachlor | 1.37 + 1.42 | 86                                   | 83   | 0.2163 | 86 | 79 * | 0.0437 |
| 21 DAT               |                      |                                      |      |      |
| Glyphosate           | 1.37                  | 85                                   | 80   | 0.0697 | 85 | 79 * | 0.0397 |
| Glyphosate plus fomesafen | 1.37 + 0.395  | 82                                   | 79   | 0.3155 | 82 | 72 * | 0.0046 |
| Glyphosate plus lactofen     | 1.37 + 0.218 | 83                                   | 77 * | 0.0465 | 83 | 79   | 0.1877 |
| Glyphosate plus S-metolachlor | 1.37 + 1.42 | 86                                   | 82   | 0.1971 | 86 | 82   | 0.1166 |

† Evaluation interval and respective herbicide treatment. ‡ Expected values for each rate of foliar fertilizer at each evaluation interval are the same due to a lack of herbicidal activity from the foliar fertilizer; therefore, values are visual estimates of weed control for each herbicide treatment when foliar fertilizer rate was 0 kg ha⁻¹. †† Asterisks within each evaluation interval denote antagonistic effects between herbicide treatment and foliar fertilizer rate when p ≤ 0.05. ‡‡ The p-value nested within each foliar fertilizer rate for each evaluation interval denotes significant differences between observed and expected values within the corresponding rate of foliar fertilizer. Boldness is for ease of identification significant p values.
A main effect of herbicide treatment was detected for barnyardgrass control 28 DAT (Table 2). Barnyardgrass control 28 DAT was 82% with glyphosate plus S-metolachlor due to its residual activity on small-seeded broadleaf and grass species [51]. Other research reported 88% residual control of barnyardgrass 56 DAT with glyphosate plus S-metolachlor in cotton [52]. Residual control with fomesafen primarily targets broadleaf weeds [52] and barnyardgrass control 28 DAT with glyphosate plus fomesafen in the current study was comparable to glyphosate alone or mixed with lactofen (Table 2). A main effect of foliar fertilizer was detected for barnyardgrass control 28 DAT, and the addition of foliar fertilizer at 0.39 or 0.78 kg a.i. ha\(^{-1}\) reduced barnyardgrass control ≥4% regardless of herbicide treatment (Table 5).

Table 5. Barnyardgrass (Echinochloa crus-galli (L.) P. Beauv.) control 28 d after treatment (DAT) with mixtures of POST soybean herbicides and a blended foliar fertilizer applied at the V3 growth stage in the Weed Control Study at Stoneville, MS, in 2015 and 2016 †.

| Foliar Fertilizer Rate (kg a.i. ha\(^{-1}\)) | Control (%) |
|-----------------------------------------|-------------|
| 0                                       | 65 a        |
| 0.39                                    | 61 b        |
| 0.78                                    | 60 b        |

† Data are pooled over four siteyears and five herbicide treatments. Means followed by the same letter are not different at \(p \leq 0.05\).

Pooled across foliar fertilizer rates, glyphosate plus lactofen reduced soybean height 14 DAT 5 and 4 cm compared with the no herbicide and glyphosate alone treatments, respectively (Table 2). Similar results have been reported, where lactofen at 0.22 kg a.i. ha\(^{-1}\) alone or mixed with crop oil concentrate (COC) reduced soybean height 4 and 5 cm, respectively, compared with a control and COC alone [40]. Soybean height at maturity was not affected by foliar fertilizer rate and/or herbicide treatment (data not presented). Pooled across foliar fertilizer rates, soybean yield in plots receiving herbicide were similar and greater than yield in the no herbicide treatment (Table 2).

### 3.2. Agronomic Study

A main effect of herbicide treatment was detected for soybean injury 3, 7, and 14 DAT, soybean dry wt. 14 DAT, and soybean height 14 DAT (Table 6). Glyphosate plus lactofen resulted in the greatest soybean injury followed by glyphosate plus fomesafen. Soybean injury was less with glyphosate plus S-metolachlor compared with glyphosate plus fomesafen, but greater than glyphosate alone at all evaluation intervals.

Treatments containing a PPO inhibitor reduced soybean dry wt. ≥9% and soybean height 14 DAT ≥7.5% compared with the no herbicide treatment. Soybean dry wt. and height 14 DAT with glyphosate plus S-metolachlor were similar to plots receiving no herbicide or glyphosate alone. Foliar fertilizer rate did not affect the measured parameters. Minor differences in tissue nutrient conc. were detected; however, no explanation for these differences was apparent and all values from the analysis were within the nutrient sufficiency range (data not presented; [53]).
Table 6. Soybean *Glycine max* (L.) Merr injury 3, 7, and 14 d after treatment (DAT), soybean dry wt. 14 DAT, and soybean height 14 DAT following application of mixtures of POST soybean herbicides and a blended foliar fertilizer applied at the V3 growth stage in the Agronomic Study at Stoneville, MS, in 2015 and 2016 †.

| Herbicide Treatment | Rate (kg a.e. or a.i. ha⁻¹) | Injury 3 DAT | Injury 7 DAT | Injury 14 DAT | Dry wt. 14 DAT (g m⁻²) | Height 14 DAT (cm) |
|---------------------|-----------------------------|--------------|--------------|---------------|------------------------|-------------------|
| No herbicide        | -                           | 0 d          | 0 d          | 0 d           | 253 a                  | 40 a              |
| Glyphosate          | 1.37                        | 1 d          | 1 d          | 0 d           | 254 a                  | 39 a              |
| Glyphosate plus fomesafen | 1.37 + 0.395     | 17 b         | 12 b         | 4 b           | 230 b                  | 37 b              |
| Glyphosate plus lactofen | 1.37 + 0.218   | 29 a         | 22 a         | 9 a           | 201 c                  | 35 c              |
| Glyphosate plus S-metolachlor | 1.37 + 1.42  | 6 c          | 4 c          | 2 c           | 245 ab                 | 39 a              |

† Data are pooled over four siteyears and three foliar fertilizer rates. Means followed by the same letter for each parameter and/or evaluation interval are not different at *p* ≤ 0.05.
4. Discussion

The injury caused by POST soybean herbicide treatments evaluated in this research was not influenced by the addition of a blended foliar fertilizer; therefore, the blended foliar fertilizer (4-0-0-3-3-3-0.25%; N-P-K-S-Mn-Zn-B) evaluated herein should not be mixed with POST soybean herbicides with the intent to reduce injury.

Mixing the blended foliar fertilizer with POST soybean herbicides influenced weed control. Palmer amaranth and barnyardgrass control were antagonized 7, 14, and 21 DAT by one or more of the herbicide treatments and blended foliar fertilizer rate combinations. Across species and evaluation intervals, 14 total antagonistic effects were detected. Antagonism of glyphosate from foliar fertilizer at 0.78 kg a.i. ha\(^{-1}\) was the most common antagonistic effect across both weed species and all evaluation intervals with four detected effects. Antagonism of glyphosate plus S-metolachlor from foliar fertilizer at 0.78 kg a.i. ha\(^{-1}\) was detected three times. Of the 14 total antagonistic effects, nine were detected with foliar fertilizer at the higher rate of 0.78 kg a.i. ha\(^{-1}\). Seven antagonistic effects were detected for both weed species regardless of herbicide treatment or foliar fertilizer rate. The only treatment combination in which an antagonistic effect was not detected was glyphosate plus lactofen plus foliar fertilizer at 0.78 kg a.i. ha\(^{-1}\). A grower with the intention of applying the blended foliar fertilizer (4-0-0-3-3-3-0.25%; N-P-K-S-Mn-Zn-B) at 0.78 kg a.i. ha\(^{-1}\) with a POST soybean herbicide should expect antagonism.

Soybean agronomic performance was not improved by mixing a blended foliar fertilizer with POST herbicide treatments. Since the blended foliar fertilizer (4-0-0-3-3-3-0.25%; N-P-K-S-Mn-Zn-B) did not affect soybean injury, height, dry wt., nutrient conc., or yield, the addition of this blended foliar fertilizer would not be economically beneficial to soybean and would represent an added expense to the grower. Even when the blended foliar fertilizer was applied with no herbicide, the agronomic performance of soybean was not improved.

5. Conclusions

Foliar fertilizer in combination with POST soybean herbicides did not reduce soybean injury and produced inconsistent effects on weed control across herbicide treatments and between weed species. Foliar fertilizers also did not improve agronomic performance of soybean. Since this research evaluated only one blended foliar fertilizer, growers should be cautious of other foliar fertilizers applied with POST herbicides in soybean. If a soybean herbicide treatment includes glyphosate, no foliar fertilizer should be added.

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