

Research Article

Effect of Irrigation Regime and Fertilization on Recovery of Dicamba Injured Soybean

Wesley France ¹, Jason Norsworthy,¹ Trent Roberts,¹ Jeremy Ross ², Tom Barber,² and Edward Gbur³

¹Crop, Soil, and Environmental Sciences Department. University of Arkansas 1354 W. Altheimer Dr. Fayetteville AR 72704 USA

²University of Arkansas Systems Division of Agriculture Lonoke Extension Center 2001 Hwy. 70 E Lonoke AR 72086 USA

³Agriculture Statistics Laboratory University of Arkansas Fayetteville AR 72701 USA

Correspondence should be addressed to Wesley France; owfrance@uark.edu

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With the release of the dicamba-resistant crop technology and subsequent increase in dicamba off-target movement to non-dicamba-resistant crops, discovering means of mitigating yield loss through studying dicamba injury to soybean and interactions with factors such as irrigation regime and fertilization would prove beneficial. Field experiments were conducted in 2019 in Fayetteville and Colt, Arkansas, to evaluate the effect of irrigation regime to non-dicamba-resistant soybean that was injured by dicamba at a low dose at multiple timings. Another experiment was conducted in Fayetteville in 2019 and 2020 evaluating the impact of nitrogen (N) and potassium (K) fertilization on soybean recovery following injury by dicamba at multiple reproductive stages. Visible injury in both experiments was affected by application timing. Soybean yield components were impacted by dicamba applications within the irrigation regime experiment, and yields were decreased by dicamba applications; however, soybean yield was higher from branches than from the mainstem in dicamba-treated compared to nontreated plants. In the fertilization experiment, soybean treated with a low dose of dicamba that received N fertilization tended to have reduced biomass compared to treatments receiving no fertilizer or K alone, with greatest biomass reduction tending to occur among treatments receiving both N and K. Total grain yield was not affected by either irrigation regime or fertilization. While an increase in yield due to neither irrigation nor fertilization was observed, these results may help improve understanding of the effect of low-dose dicamba on soybean and aid producers making management decisions.

1. Introduction

The mid-southern US agricultural region has unique characteristics allowing for high potential soybean yields, such as a wide planting window, which in turn allows for wide cultivar and maturity group (MG) selection, and manipulation of yield-affecting factors to optimize yield [1]. Understanding the interaction between manipulatable factors that affect soybean growth and yield, such as the impact of planting date, irrigation, or additional fertilization on herbicide injury sustained by soybean, may allow producers

to augment recovery and safeguard yields when faced with stressors such as off-target herbicide injury.

Irrigation is a practice proven to increase yields over nonirrigated cropland. Recent USDA-NASS [2] data reports that, for Arkansas in 2018, average nonirrigated soybean yield for the state was 2448 kg·ha⁻¹, whereas the average irrigated soybean yield was 3618 kg·ha⁻¹. The difference in yield is due to a common seasonal moisture deficit for traditional soybean production (planted in May and later), occurring when soybean is in its reproductive stages and when moisture deficit is most detrimental [3]. For MG IV, V,

and VI soybean planted in April and May, yields for irrigated and nonirrigated were substantially different, with nonirrigated fields yielding 42% lower.

Along with yield impact, the effect of irrigation on soil moisture can also influence herbicide activity. An experiment evaluating the impact of soil moisture on glyphosate efficacy on junglerice (*Echinochloa colona* L.) across four different soil moisture contents found that, regardless of rate, junglerice seedlings treated at 100% field capacity all died earlier than seedlings receiving glyphosate at lower field capacities [4]. At 29% field capacity, seedlings receiving a higher glyphosate rate died earlier than those receiving a lower rate, and all seedlings at 29% field capacity died later than those applied at 100% field capacity, suggesting that glyphosate is more easily translocated within the plant when there is adequate soil moisture [4]. In addition, Miller and Norsworthy [5] found that soils with higher moisture content increased efficacy of a synthetic auxin herbicide, floryrauxifen-benzyl, on the weed species barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv.], yellow nutsedge (*Cyperus esculentus* L.), and hemp sesbania (*Sesbania herbacea* Mill.) by increasing absorption, translocation, and metabolism within each weed species. Also, Weidenhamer et al. [6] noted that in a year with greater drought-stress a dicamba rate as low as 0.4 g-ae-ha^{-1} caused a 10% yield reduction in non-dicamba-resistant soybean, whereas in a year with adequate rainfall, dicamba at 15 g-ae-ha^{-1} was needed to obtain a similar level of yield loss.

Aside from soybean grain yield, yield components can also be affected by drought and herbicide stress. Seed yield of the soybean mainstem is usually unaffected when the stressor is drought alone; however, yield of branches can be greatly reduced, accounting for most of the yield reduction of soybean under droughty conditions [7, 8]. Furthermore, dicamba at sufficient rates can restrict plant height [6, 9–11]. Height restriction results from dicamba injury to or termination of the soybean apical meristem, which restricts seed yield of the mainstem and forces the plant to rely on seed production from axillary nodes or branches [10]. In addition, Robinson et al. [10] postulated that drought stress may inhibit detoxification of dicamba within soybean due to reduced translocation. The compounding stress of drought and dicamba injury potentially leads to even greater yield loss as yield components are affected. Some commonly considered soybean yield components include pod and seed number [9, 10, 12].

The impact of fertilization on plant response to a herbicide is a little-studied topic; however, it may be important to understand to safeguard soybean yields as well as furthering the current understanding of plant processes. For example, it was found that N applied to rice before flood favors plant recovery from an injurious application of bentazon, whereas N applied after flood delays recovery from bentazon injury [13]. The opposite behavior was found in the case of bispyribac-sodium, which caused greater injury to rice when all N was applied before flood, indicating that the interaction between herbicide injury and fertilization may be different depending on the herbicide site of action. Cathcart and Chandler [14] noted that, under low N

fertility conditions, herbicide efficacy would likely be reduced on weeds. Similarly, a study evaluating the efficacy of mesotrione as influenced by various N fertilization factors, crabgrass (*Digitaria sanguinalis* L.) with high aboveground N concentrations experienced greater herbicide injury/weed control versus crabgrass with lower N concentrations, indicating injury decreased as days between N application and mesotrione application increased [15]. The higher N concentrations were believed to allow an increase of mesotrione translocation and, therefore, activity [15].

Specific to soybean, several researchers have explored how the interaction of herbicide injury and fertilization affects multiple factors that can impact final yield. For example, soybean injury from synthetic auxins can reduce legume nodulation, decreasing N fixation, which may partially account for yield reduction [16]. Van de Stroet et al. [17] determined that the application of foliar and broadcast N in addition to synthetic auxins applied at low rates impacted soybean rhizobia nodulation, therefore decreasing biomass. Following dicamba application and foliar-applied N, a significant decrease in yield was noted but not when soil-applied broadcast N was used [17]. At one location soybean nodulation was not affected while, at another location, nodulation was decreased by 35% for plants treated at V3 and R1 with dicamba [17]. At 1 g-ae-ha^{-1} of dicamba applied at R1 alone and V3 + R1 to soybean, biomass was reduced as much as 25% when applied with foliar N7 days following the R1 dicamba application; biomass reduction was only 10% when treated with foliar N 20 days following the R1 application of dicamba [17]. For soybean not treated with N, biomass reduction averaged 20% [17]. Addition of N to dicamba injured soybean does not allow for dicamba recovery; however, weekly irrigation of dicamba injured soybean can result in appreciable soybean recovery in terms of injury level, height, and yield [18]. Specific fungicide applications, plant-growth hormone treatments, and micronutrient treatments were also ineffective at allowing soybean recovery in the same experiment [18]. These experiments demonstrate how multiple events or management decisions can compound to affect distinct crop responses. Converse to research investigating relations between herbicide use and N fertilization, little research has been conducted concerning the effect of herbicide use and K fertilization on plants.

The results of crop response to fertilizers following herbicide injury are largely due to the role of nutrients in the crop. N, absorbed as nitrate (NO_3^-) and ammonium (NH_4^+) by plants, plays a role in the creation of amino acids and proteins, chlorophyll formation, energy transfer, and overall increased vegetative growth [19]. K absorbed as a positive ion (K^+) by plants is responsible for cell water and transpiration rate regulation, carbohydrate transfer, and amino acid synthesis and is also known to aid rhizobium activity in legumes and improve plant drought resistance [19]. Considering the recent introduction of dicamba-resistant technology and increase in off-target movement of dicamba to sensitive soybean, this research was conducted to estimate the interaction of dicamba influence to soybean crop at low doses and the interaction of subsequent injury with either irrigation regime or application of fertilizers.

2. Materials and Methods

Separate field experiments were conducted in 2019 at Fayetteville, AR, and near Colt, AR, to evaluate the effect of irrigation regime on soybean recovery following injury by drift rates of dicamba. In 2019 and 2020, field experiments were conducted in Fayetteville to develop an understanding of the impact of nitrogen (N) and potassium (K) fertilization after a low-dose dicamba exposure on recovery of soybean.

2.1. General Methodology. Experiments were initiated on a tilled and bedded bare-ground field, and herbicide treatments were applied using a CO₂-pressurized backpack sprayer calibrated to deliver 140 L·ha⁻¹ at 276 kPa using TTI 110015 spray tips. The trial was kept weed-free with herbicides labeled for conventional soybean as well as through use of row cultivation and hand weeding as needed. Visual estimates of percentage injury to soybean were recorded at 14, 21, and 28 days after each application (DAA) on a scale of 0 to 100%, with 0 representing no injury and 100 representing plant death. Soybean grain was harvested at maturity, and grain moisture was measured and corrected to 13% moisture. Relative yield was calculated for each plot by comparing yield of treated plots to the nontreated plots (treated yield/nontreated yield * 100). All injury data were analyzed as a beta distribution in a repeated measures analysis using the first order autoregressive (AR [1]) covariance structure.

2.2. Irrigation Experiment. A field experiment was conducted in 2019 at the Milo J. Shult Arkansas Agricultural Research and Extension Center in Fayetteville and at the Pine Tree Research Station near Colt, AR, to determine the impact of irrigation regime to soybean injured with a low-dose rate of dicamba. The soil series at the Fayetteville site was a leaf silt-loam soil (fine, mixed, active, thermic Typic Albaqualts) with 25% sand, 64% silt, and 11% clay, 1.67% organic matter (OM), and a pH of 6.0. The soil series in the trial near Colt was a Calloway silt-loam soil (fine-silty, mixed, active, thermic Aquic Flaglossudalfs). Rainfall events and irrigation were recorded at each trial location. The section of the trial receiving irrigation for each location was furrow irrigated as needed if at least 2.5 cm of rainfall did not occur over a seven-day period, with irrigation occurring on August 14th and 18th and September 7th, 10th, and 12th in Fayetteville. At the Colt site, irrigation occurred on August 6th, 14th, and 20th and on September 3rd, 9th, and 16th. The glufosinate-resistant soybean cultivar “Credenz CZ 4819LL” was planted at 346,000 seed ha⁻¹ in 4-row plots of 7.6 m in length and row width of 91 cm at Fayetteville and 76 cm at Colt. This trial was planted on May 27, 2019, for the Fayetteville location and on June 18, 2019, for the location near Colt. The two sites are separated by approximately 315 km.

The trial design was a randomized complete block design with treatments set up in a split-plot arrangement with the whole-plot factor as irrigation regime and split-plot factor as growth stage at exposure with dicamba. The irrigation regime consisted of nonirrigated versus furrow-irrigated plots and growth stages at dicamba application being V5 and R1

separately as well as a sequential application at V5 and R1. The application rate of dicamba was 2.2 g·ae·ha⁻¹ or a 1/256x rate, with a 1x rate for over-the-top use in dicamba-resistant crops being 560 g·ae·ha⁻¹ (Xtendimax™ herbicide, Bayer Crop Science). In addition to injury ratings and relative yield data, yield component data, including number of branches per plant, pods per plant, pods on the main plant stem, pods on plant branches, and seed weight per plot, were taken as an extra data measurement in Fayetteville by removing 10 plants from each plot and counting by hand.

Replication was analyzed within location and made random while the effects of irrigation regime, growth stage at application, and the interaction of each main effect were analyzed as fixed effects within the analysis. A beta distribution was used to analyze injury data and a gamma distribution for relative yield, seed weight, number of branches, and pods per plant data. Injury, relative yield, and yield component data were subjected to analysis of variance using PROC GLIMMIX in SAS 9.4 [20].

2.3. Fertilization Experiment. This experiment follows the methods of France et al. [21]. A field experiment was conducted in 2019 and 2020 at the Milo J. Schult Agricultural Research and Extension Center in Fayetteville, AR, to determine the impact of broadcasting fertilizers following the manifestation of dicamba symptomatology on soybean. A glufosinate-resistant soybean cultivar “CZ 4820LL” was planted at 346,000 seed ha⁻¹ in 4-row plots of 6.1 m in length and row width of 91 cm. The trial was planted on May 16 in 2019 and on May 22 in 2020. The experiment was furrow irrigated if at least 2.5 cm of rainfall did not occur over a 7-day period. The experimental design was a randomized complete block with a two-factor factorial of dicamba (Xtendimax™ herbicide, Bayer Crop Science) application timing as factor A (R1, R3, R1 fb R3) and factor B as fertilizer applied following dicamba application (none, N only, K only, N + K). Nitrogen was applied as urea (46% N) at 50 kg·ha⁻¹ and K as potassium chloride (50% K) at 67 kg·ha⁻¹. Dicamba was applied at 3.73 g·ae·ha⁻¹ or a 1/150x rate, with a 1x rate for over-the-top use in dicamba-resistant crops being 560 g·ae·ha⁻¹ (Xtendimax™ herbicide, Bayer Crop Science). Row cultivation and hand weeding were used if necessary. All dicamba treatments were applied to the two middle rows of each four-row plot. During application, shields were used to prevent physical drift onto the outside rows of each four-row plot. Fertilizer rates were calculated for entire plot area and all fertilizer treatments were hand-spread over the entire four-row plot 1 week after the R1 dicamba application. The V5 dicamba and fertilizer treatments were made on June 24 and July 2, respectively, in 2019, and on July 13 and July 20, respectively, in 2020. Soybean biomass was collected when soybean reached the R6 growth stage from 1 m of row in each dicamba-treated plot and the adjacent nontreated row; this allowed the biomass of each treatment to be made relative to biomass of the nontreated within the same plot. Collected biomass was dried for at least 7 d at 55°C, weighed, and reported as relative biomass compared to the nontreated adjacent row.

Injury data were subjected to analysis of variance and analyzed as repeated measures as first-order autoregressive data within SAS using the PROC GLIMMIX statement. Biomass, seed weight, nutrient analysis data from tissue samples, and relative yield were subjected to analysis of variance using PROC GLIMMIX in SAS 9.4. Replication nested within year as a random effect while the effects of fertilizer type, growth stage at application, and the interaction of each were analyzed as fixed effects within the analysis. A beta distribution was used to analyze injury and seed weight data, and a gamma distribution was used for relative yield and relative biomass data.

3. Results and Discussion

3.1. Irrigation Experiment. The summer of 2019 was characterized by above-average rainfall. According to the National Weather Service (2020), Fayetteville received a total of 99 cm of rainfall from April through September in 2019, with the average rainfall of the past 30 years being 67 cm for the same months combined. A total of 27.8 cm of rainfall occurred within the first 4 weeks after planting at the Fayetteville location and 18.0 cm of rainfall within the 4 weeks following planting at the Colt location (Figure 1). In addition, for the 4 weeks following the V5 application, precipitation totaled 12.5 and 13.2 cm for Fayetteville and Colt, respectively, and a total of 10.1 and 8.6 cm at Fayetteville and Colt, respectively, for the 4 weeks following the R1 application (data not shown). In Fayetteville, irrigation was needed 28 days after the R1 application (August 14, 2019), in addition to other irrigation timings (refer to Section 2.2). At the Colt site, the trial was irrigated at 20 days after the R1 application (August 6, 2019), in addition to later irrigation timings.

3.1.1. Injury. Among injury evaluations, there was a significant interaction between application timing and rating date (Table 1), but with no effect of irrigation regime. For the V5 application timing, injury peaked at 21 DAT with 48% injury (Figure 2). Injury, averaging 60% or more, was greatest at 21 and 28 DAT following sequential dicamba applications at the V5 and R1 growth stages (Figure 2). Overall, less injury within a rating date was observed following dicamba applied at R1 than at the V5 growth stage, which is similar to findings of others [11]. Plant growth lessens as soybean enters reproductive development; thus less herbicide symptomology caused by dicamba is generally observed when exposure occurs during reproductive stages rather than vegetative stages. Decreased visible injury to soybean exposed to dicamba during reproductive development may also be attributed to decreased translocation of the herbicide to vegetative portions of the plant. Because irrigation was not needed until late in the growing season, with trials irrigated at mid-August through early September for both locations, no significant effect of irrigation to visible soybean injury occurred.

3.1.2. Yield Components. Analysis of yield component data illustrates the compounding effects of both irrigation and herbicide injury to soybean. For both pod and seed data

from the mainstem, there was a significant interaction of irrigation regime and application timing, whereas data for branches were impacted only by main effects (Table 2). The significance of irrigation regime to yield component data is due to the timing of data collection. Yield component data were collected at harvest, after irrigation events occurred. Alternatively, injury data, which was not affected by irrigation regime, was collected before irrigation was needed as a result of the early season rainfall.

Pod and seed number of mainstems were two of the most sensitive soybean yield components impacted by dicamba. Soybean plants receiving dicamba at the V5 timing had a significant reduction in pods present on the mainstem, with the reduction ranging from 51 to 90% relative to nontreated plants (Table 3). Similarly, three of the four dicamba applications at the V5 and V5 and R1 growth stages significantly reduced seeds on mainstems, with as much as a 91% reduction observed under nonirrigated conditions. Due to a high degree of variability among individual plants, a significant reduction in seed or pod numbers following the R1 application of dicamba was not detected, albeit there were 35% fewer pods on mainstems and 35 to 47% fewer seeds on mainstems relative to nontreated plants (Table 3). These findings suggest that low-dose dicamba injury to reproductive soybean had less effect on mainstem yield components than vegetative exposure. Based on the extent of the reduction in pod and seed number on mainstems, it appears that irrigated soybean had greater potential for recovery from the V5 exposure of dicamba than did nonirrigated plants. These differences are largely a result of the late-season irrigation events, albeit it is unknown whether there were fewer flowers on the mainstem or whether pods failed to form. Nonirrigated soybean had greater yield loss on the mainstem likely because of reduced detoxification or sequestration of dicamba even if less visible injury is present as reported elsewhere [10].

Dicamba exposure to soybean tended to cause the soybean plants to increase in branching (Table 3). Applications of the low dose of dicamba to V5 soybean resulted in more than a 2-fold increase in branches on plants. Conversely, the R1 application timing did not significantly increase branching in either irrigation regime, likely because of minimal new branches forming after the R1 stage of soybean as resources begin to shift toward reproductive development. Soybean plants receiving the sequential application of dicamba had more branches than nontreated plants within each irrigation regime (5.8 average branches irrigated and 7.1 average branches nonirrigated) (Table 3). The greater branching of nonirrigated soybean was likely due to the reduced translocation of dicamba and therefore reduced detoxification of the soybean plant resulting in greater injury to the apical meristem. The greater axillary node growth compensated for the greater apical meristem injury, as postulated by Robinson et al. [10] in a similar experiment. Under both irrigated and nonirrigated conditions, soybean compensated for a single exposure to dicamba at the V5 growth stage by increasing pod and seed numbers on branches. In regard to seed weight, it was only affected by application timing, with lower seed weight following sequential dicamba exposure at the V5 and R1 stages (Table 3).

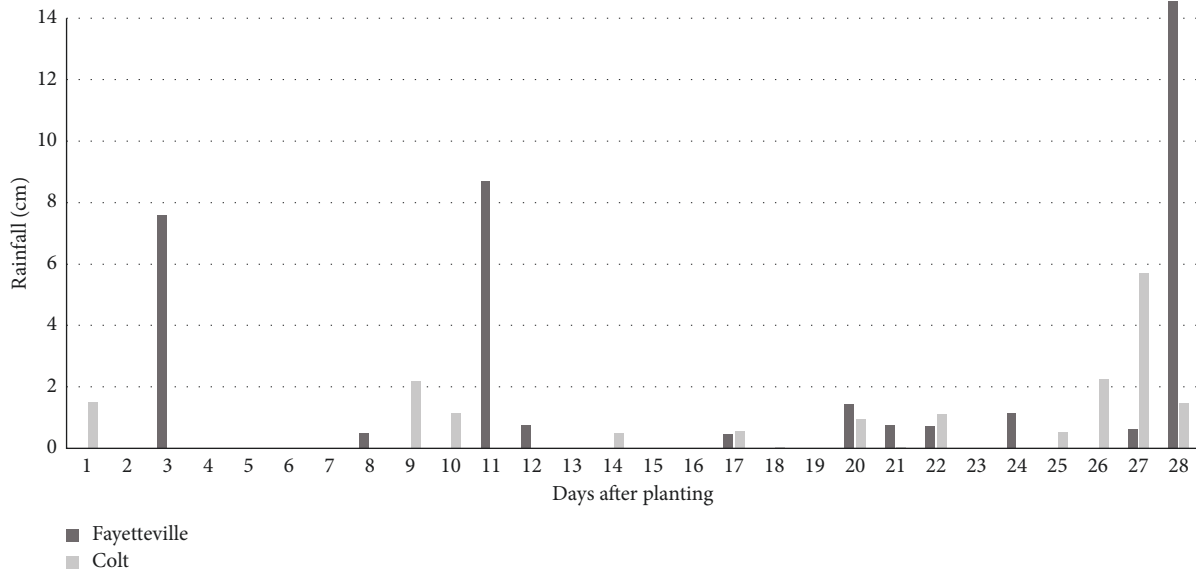


FIGURE 1: Precipitation history 28 days following planting of irrigation experiment conducted at Fayetteville and Colt, AR, in 2019.

TABLE 1: Effects of irrigation regime, application timing, and rating date to injury analyzed as a repeated measures analysis for the irrigation experiments conducted in Fayetteville and Colt, AR, in 2019.

Factors	Injury
	<i>p</i> -values
Irrigation regime	0.0696
Application timing	<0.0001 ^a
Irrigation regime * application timing	0.4765
Rating date	<0.0001
Irrigation * rating date	0.0864
Application timing * rating date	0.0003
Irrigation regime * application timing * rating date	0.5209

^a*p*-values at or smaller than 0.05 level considered significant.

3.1.3. Relative Yield. A significant effect of application timing occurred for grain yield ($\text{kg}\cdot\text{ha}^{-1}$) where nontreated plots had significantly greater yield than the V5 and V5 followed by R1 application timings (data not shown), but no effect of irrigation regime occurred (Table 2). Among treatments not receiving dicamba, yield was $3925 \text{ kg}\cdot\text{ha}^{-1}$ for irrigated plots and $2631 \text{ kg}\cdot\text{ha}^{-1}$ for non-irrigated plots (Table 3), supporting the research of Heatherly and Spurlock [3] that irrigated soybean yields often exceed those of nonirrigated soybean. Final grain yields of all treatments receiving dicamba were not different (data not shown), indicating that dicamba applications reduced yield regardless of irrigation events or application timings used for this experiment and despite initial differences in injury between application timings and differences in irrigation and application timing among yield component data.

3.2. Fertilization Experiment

3.2.1. Injury. All fertilizer applications were made 1 week following the R1 dicamba application. The main effect or interactions involving fertilizer were never significant for

soybean injury, indicating that the fertilizer treatments did not hasten recovery of soybean symptoms caused by dicamba (Table 4). There was an interaction between dicamba application timing and rating dates for soybean injury when the latter factor was analyzed as a repeated measure (Table 4). For ratings dates of 14, 21, and 28 DAT, injury was greatest following sequential exposure to dicamba at R1 and R3 stages than a single exposure at either of these stages (Figure 3). Exposure to dicamba at the R1 and R3 stages caused 65% injury to soybean by 14 DAT of the later exposure, with the level of injury increasing further by 21 DAT.

3.2.2. Biomass, 100-Seed Weight, and Relative Yield.

Soybean biomass production was affected by the interaction of fertilizer applied and dicamba application timing (Table 5). In the absence of dicamba, neither N, K, nor the combination of the two nutrients positively or negatively affected biomass production (Figure 4). There was no treatment of N, K, or the combination of the two nutrients that improved soybean biomass production over a dicamba application timing in the absence of additional nutrient fertilization. Surprisingly, N plus K applied to soybean sequentially exposed to dicamba at the R1 followed by R3 stages and the R1 stage alone had less biomass than when dicamba was applied in the absence of additional nutrients. The cause of the biomass reduction beyond that in the absence of the nutrients is unknown. Van de Stroet et al. [17] observed a biomass reduction following a foliar application of N to soybean and determined reduced rhizobia nodulation as the cause of biomass reduction. In addition, Dintelmann et al. [18] observed a reduction in height among soybeans treated with a low dose of dicamba followed by hand-spread urea fertilizer compared to soybeans treated only with a low dose of dicamba at the R2 growth stage. Foliar necrosis following urea applications is cited as a possible cause of height reduction to dicamba-treated

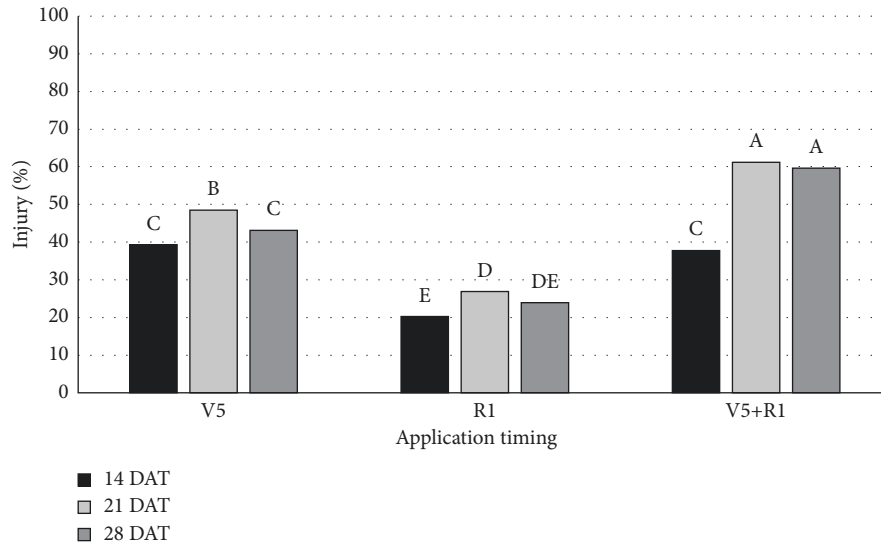


FIGURE 2: Injury of soybean according to the interaction of application timing and rating date in days after treatment (DAT) for the irrigation experiments conducted in Fayetteville and near Colt, AR, in 2019. Treatments with the same uppercase letter are not significantly different according to Fisher’s protected least significant difference $\alpha = 0.05$.

TABLE 2: Effects of dicamba, irrigation regime, and application timing and the interaction of these effects on yield components and grain yield associated with soybean for the irrigation experiments conducted in Fayetteville and near Colt, AR, in 2019.

Factors	Data collected						
	Pods on mainstem	Seeds on mainstem	Total branches	Pods on branches	Seed on branches	100-seed weight ^a	Grain yield
	----- <i>p</i> -values-----						
Irrigation regime	<0.0001	0.0007	0.0460	0.0734	0.0175	0.2163 ^a	0.4168
Application timing	<0.0001	<0.0001	<0.0001	0.0009	0.0061	0.0142	0.0282
Application timing * irrigation regime	0.0042	0.0014	0.9452	0.3439	0.7249	0.4962	0.3893

^a*p*-values at or smaller than 0.05 level considered significant as shown in bold.

TABLE 3: Effects of irrigation regime and application timing on yield components and grain yield collected for evaluation in the irrigation experiments conducted in Fayetteville and Colt, AR, in 2019.

Yield components	Pods/main ^{ab}		Seeds/main ^b		Total branches ^{bd}	Pods/branches ^{bd}	Seeds/branches ^{bd}	Seed weight ^{cd}	Yield ^d	
								<i>g</i>	kg·ha ⁻¹	
Irrigated	V5	16.2	abc	28.7	abc	4.5	23.3	43.4	15.4	2059
	R1	20.7	abc	34.5	abc	3.1	15.1	26.1	15.3	2618
	V5 + R1	11.6	cd	21.0	cd	5.8	18.1	30.7	12.9	2019
	None	31.8	a	53.4	a	2.2	14.1	25.4	15.4	3925
Nonirrigated	V5	2.3	e	4.6	e	5.5	37.1	68.0	15.5	2350
	R1	14.8	bcd	27.5	bcd	3.7	20.6	42.3	15.5	2376
	V5 + R1	7.1	d	15.0	d	7.1	23.2	39.7	14.5	2018
	None	22.6	ab	52.1	ab	2.6	12.3	28.6	15.6	2631

^aMeans within a column followed by the same lowercase letter are not different according to Fisher’s protected LSD ($\alpha = 0.05$). ^bYield component data other than seed weight taken as actual counted amounts averaged within each treatment. ^cSeed weight data collected as grams (*g*) per 100 seeds per plot averaged within each treatment. ^dThese data are included for informational purposes. Only some main effects are significant. Discussion of main effects are included in the text.

TABLE 4: Effects of application timing, fertilizer applied, and rating date to soybean injury of fertilizer experiment conducted in Fayetteville, AR, in 2019 and 2020.

Effects	<i>p</i> -values ^a
Application timing	0.0138
Fertilizer applied	0.1473
Rating date	0.0197
Application timing * fertilizer applied	0.3331
Application timing * rating date	0.0477
Fertilizer applied * rating date	0.3236
Application timing * fertilizer applied * rating date	0.1718

^a*p*-values at or smaller than 0.05 level considered significant.

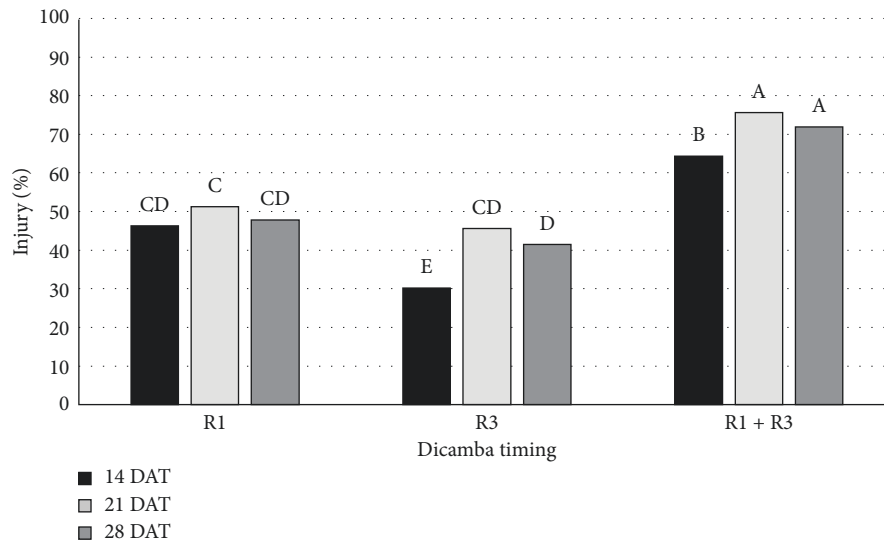


FIGURE 3: Injury of soybean according to the interaction of application timing and rating date in days after treatment (DAT) for the fertilizer experiment conducted in Fayetteville, AR, in 2019 and 2020. Treatments with the same uppercase letter are not significantly different according to Fisher’s protected least significant difference $\alpha = 0.05$.

TABLE 5: The effects of application timing, fertilizer type applied, and the interaction of these effects on injury, relative biomass, seed weight, and relative yield for the experiment conducted in Fayetteville, AR in 2019 and 2020.

Factors	Data collected		
	Relative biomass ^a	100-seed weight	Relative yield
		<i>p</i> -values	
Application timing	<0.0001	0.0012	<0.0001
Fertilizer applied	0.0002	0.7403	0.7097
Application timing * fertilizer applied	0.0031	0.9266	0.8969

^a*p*-values at or smaller than 0.05 level considered significant as shown in bold.

soybean [18]; however, no necrosis was noted among soybeans in this study.

Weight of 100 seeds was affected only by herbicide application timing with the treatments applied at R1 alone (15.8 g) and R3 alone (14.9 g) not different from the nontreated (14.9 g) (Figure 5). However, treatments applied at both R1 followed by R3 had reduced seed weight (12.9 g), likely due to increased stress at reproductive timings that prevented soybean plants from compensatory growth.

Similar to seed weight, relative yield was significantly affected by application timing, with all timings significantly different, except for treatments receiving dicamba at R1 alone (94% relative yield), which were not different from the

nontreated plots (Figure 6). Soybean plants treated at R1 had a relative yield of 69% and treatments receiving dicamba at both R1 and R3 stages yielded only 24% of the nontreated (Figure 6). Differences in injury between application timings partially mirrored yield as the greatest injury was seen among treatments receiving both application timings of dicamba (Figure 3); however, fertilizer treatments did not translate to yield differences.

3.3. Practical Implications. Under ideal growing conditions *ceteris paribus*, irrigated soybean will often yield higher than nonirrigated, and nutrient-stressed soybean will respond to

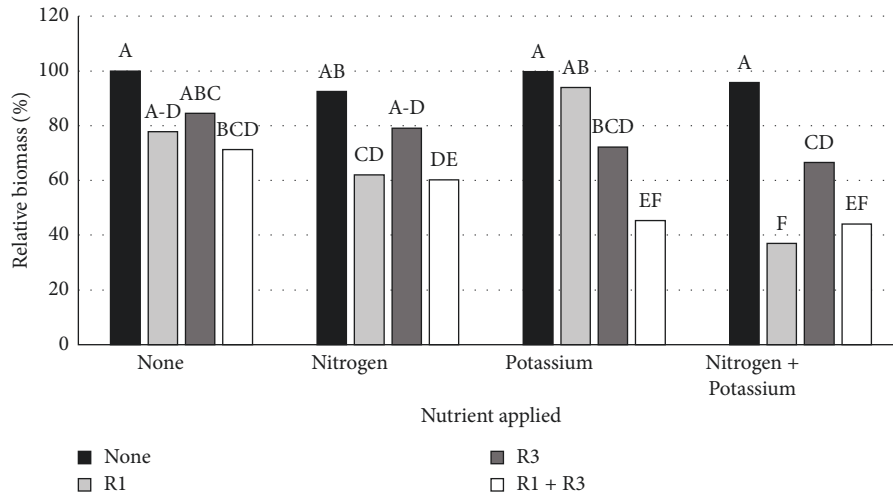


FIGURE 4: Relative biomass of soybean according to the interaction of application timing and fertilizer type for the experiment conducted in Fayetteville, AR, in 2019 and 2020. Treatments with the same uppercase letter are not significantly different according to Fisher’s protected least significant difference $\alpha = 0.05$.

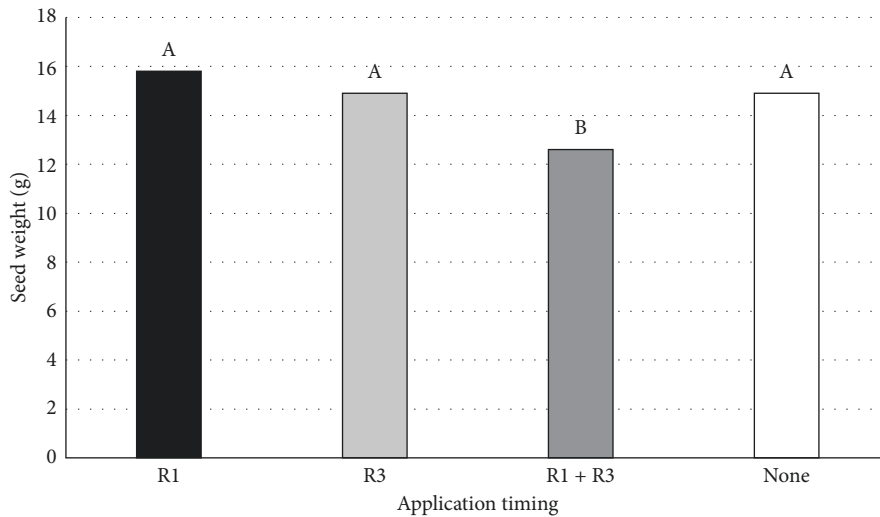


FIGURE 5: 100-seed weight of harvested soybean according to the main effect of application timing for the fertilizer experiment conducted in Fayetteville, AR, in 2019 and 2020. Treatments with the same uppercase letter are not significantly different according to Fisher’s protected least significant difference $\alpha = 0.05$.

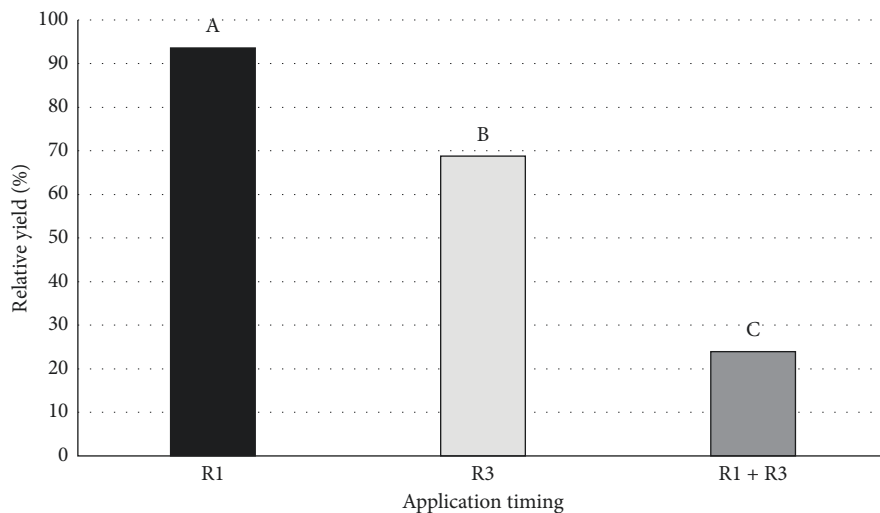


FIGURE 6: Relative yield of soybean according to the main effect of application timing for the fertilizer experiment conducted in Fayetteville, AR, in 2019 and 2020. Treatments with the same uppercase letter are not significantly different according to Fisher’s protected least significant difference $\alpha = 0.05$.

fertilization with higher yields. According to these experiments, final yields of soybean injured by dicamba at the late vegetative and early reproductive stages prevent sufficient recovery and yield improvement of the crop regardless of irrigation or fertilization following dicamba injury. In the irrigation regime experiment, above-average rainfall early in the season may have played a role in diminishing the differences observed between irrigated and nonirrigated treatments in regard to extent of injury and the failure to detect an interaction between dicamba application timing and use of irrigation. In the fertilization trial, the impact of N and K addition to dicamba-injured soybean generally caused reductions in biomass and significant, albeit biologically small, differences in injury. However, soybean yields following dicamba were not improved with a subsequent application of N or K. Dicamba exposure(s) during reproductive development may have contributed to the inability of soybean to recoup yield loss due to the shortened period of injury manifestation until maturity.

Typical dicamba injury to soybean includes damaged or killed apical meristems [6, 9–11], and while in the vegetative growth stages, soybean will attempt to compensate for injury with greater axillary stem growth [10]. In addition, soybean with mainstem nodes removed was best able to recover when injury occurred at early vegetative stages, such as V2 [22]; therefore, evaluation of an early vegetative application stage could provide different results. Regardless, according to this research, neither irrigation nor N or K aided in soybean recovery from dicamba injury under the conditions present in these field trials when injured at late vegetative and early reproductive growth stages.

Data Availability

Supplementary data can be obtained from the corresponding author upon request.

Conflicts of Interest

The authors declares that there are no conflicts of interest.

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