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Response of cotton at different growth stages to imazapyr

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Abstract

A significant proportion of the forested production area in South Carolina is managed using aerial applications of imazapyr. Cotton injury from off-target movement of imazapyr has been observed in South Carolina. Field experiments were conducted twice at the Edisto Research and Education Center (EREC) in 2021 and 2022, and once at the Pee Dee Research and Education Center (PDREC) in 2022, to evaluate the response of cotton at two growth stages to imazapyr at 0.1×, 0.05×, 0.025×, 0.0125×, and 0.00625× of the normal use rate of 0.84 kg ae ha^{-1}. Injury to cotton at the vegetative stage was 86% and 74% at 0.1× and 0.05× imazapyr rates 28 d after application (DAA). Cotton height ranged from 23 to 93 cm at all three locations. Yield at the EREC location in 2021 was reduced by 79%, 48%, and 31% at the 0.1×, 0.05×, and 0.025× rates of imazapyr, respectively. Similar reductions from imazapyr were observed at both EREC and PDREC in 2022. Injury to cotton at the reproductive stage based on visual estimates at 28 DAA ranged from 95% to 64% for the 0.1× to 0.0125× rates, respectively. Cotton height at the reproductive stage was reduced to 59% of the untreated control 28 DAA when the 0.1× rate of imazapyr was applied. Seed cotton (which included both seed and lint) yield ranged from 0 to 2,880 kg ha^{-1} at the three locations in both years. Seed cotton yield was lowest when imazapyr was applied at the 0.1× to 0.025× rates. Cotton exposure to imazapyr at the vegetative and reproductive growth stages resulted in plant injury, height, and yield reductions, especially at the higher rates of imazapyr. The greatest reduction in cotton growth and yield was observed after exposure at the reproductive growth stage regardless of imazapyr rate. In summary, the magnitude of cotton response to imazapyr depends on crop growth stage and imazapyr concentration at the time of exposure with the greatest impact occurring at the reproductive growth stage.

Introduction

In South Carolina, 67% of the total land area, or 5.2 million ha, is forested (USDA-NRCS 2023). Softwoods such as longleaf pine (*Pinus palustris* L.) and loblolly pine (*Pinus taeda* L.), and hardwoods such as oaks (*Quercus* spp.) and sweetgum (*Liquidambar styraciflua* L.) represent most of the tree species in production (Brandeis et al. 2016). For example, loblolly pine and oak/hickory (*Carya* spp.) account for 44% and 22% of timberland in production, respectively, in South Carolina. In 2016, approximately 20 million cubic meters of loblolly pine was harvested (Brandeis et al. 2016). Commercial forestry contributes US$18.6 billion annually to the state economy (Anonymous 2023a).

In South Carolina, cotton, soybean [*Glycine max* (L.) Merr.], corn (*Zea mays* L.), and peanut (*Arachis hypogea* L.) were produced on 423,000 ha generating US$566 million in revenue in 2022 (USDA-NASS 2023a, 2023b). Of that total, cotton was grown on 38,000 ha, with US$53 million in revenue in 2022. Cotton fields in South Carolina are often located near or adjacent to private and commercial forestry production sites (Anonymous 2023b). In addition, other managed non-crop sites, including roadsides, power line rights-of-ways, and ditches are located near cotton production fields (M. Marshall, personal observations).

Imazapyr is used to manage undesirable vegetation in forestry and non-cropland sites (Addington et al. 2012; Anonymous 2015a; Cain 1991; Harrington et al. 1998; Lauer and Quicke 2022; Neary et al. 1990). For example, imazapyr provides control of several woody brush species including honeysuckle (*Lonicera* spp.), sweetgum, tree of heaven (*Ailanthus altissima* L.), and privet [*Ligustrum vulgare* L.] (Anonymous 2015a). Imazapyr was applied to 73% of the land area in commercial forestry production in the United States in 2015 (Anonymous 2015b). Management of undesirable plants in a commercial forest using imazapyr when the plants are actively growing can overlap the same time period (April through September) when cotton is normally produced in South Carolina (Anonymous 2015a). This overlap increases the likelihood of potential spray drift from aerial applications of herbicides from these forestry production sites to nearby sensitive crops, including cotton.

Table 1. Experiment paraments at EREC in 2021 and 2022 and PDREC in 2022.[a,b]

Location and year	Cotton variety[a]	Planting date	Soil parameters			Application dates		Harvest date
			Series[c]	Organic matter	pH	Vegetative stage	Reproductive stage	
				%				
EREC 2021	Deltapine 2038 B3XF	May 15, 2021	Fuquay sand	1.3	5.7	June 8, 2021	June 22, 2021	November 9, 2021
EREC 2022	Deltapine 2038 B3XF	May 17, 2022	Varina loamy sand	1.6	6.1	June 13, 2022	June 28, 2022	October 27, 2022
PDREC 2022	Deltapine 2038 B3XF	May 6, 2022	Noboco sandy loam	1.1	5.8	June 10, 2022	June 29, 2022	October 11, 2022

[a]Abbreviations: EREC, Edisto Research and Education Center; PDREC, Pee Dee Research and Education Center.
[b]Deltapine cotton varieties were supplied by Bayer CropScience, St. Louis, MO.
[c]Soil series were classified as Fuquay sand (loamy, siliceous, thermic Arenic Plinthic Paleudults); Varina loamy sand (clayey, kaolinitic, thermic Plinthic Paleudults); and Noboco sandy loam (Fine-loamy, siliceous, thermic Typic Paleudults).

Particle drift from aerial applications of herbicides to forestry sites has been observed in cotton, soybean, and corn production fields in South Carolina (M. Marshall, personal observations). Jefferies et al. (2014) reported a 32% and 36% reduction in cotton height and biomass, respectively, from simulated sulfometuron drift. In that same study, soybean height and biomass were also reduced by 29% and 28%, respectively. Previous studies have shown similar cotton injury from simulated drift from other herbicides including auxins (Everitt and Keeling 2009; Marple et al. 2007, 2008; Smith et al. 2017; Snipes et al. 1991), glyphosate (Ellis and Griffin 2002; Thomas et al. 2005), glufosinate (Ellis and Griffin 2002; Johnson et al. 2012), and sulfometuron (Jefferies et al. 2014). However, information is lacking on the effects of imazapyr on cotton growth, development, and yield. Therefore, the objective of this study was to evaluate the response of cotton at two different growth stages to various sublethal levels of imazapyr.

Materials and Methods

Field experiments were conducted at the Clemson University Edisto Research and Education Center (EREC) in Blackville, SC (33.36424°N 81.33155°W; 100 m above sea level) in 2021 and 2022; and in 2022 at the Pee Dee Research and Education Center (PDREC) in Florence, SC (34.28904°N 79.74037°W; 36 m above sea level). The experimental design was a three (location) by two (application timing) factorial arranged in a randomized complete block with four replications. Six herbicide treatments were applied at the vegetative stage (3- to 5-leaf) or the reproductive stage (first bloom or appearance of the first white flower). Cotton height at the time of herbicide application ranged from 21 cm to 30 cm, and from 59 cm to 65 cm for the vegetative and reproductive growth stages, respectively.

Cotton variety, planting date, soil parameters, herbicide application dates, and harvest dates are shown in Table 1. Study sites were fertilized with potassium (90 kg ha^{-1}) based on the soil test recommendations provided by the Soil Testing Laboratory at Clemson University 1 mo before trial initiation. Cotton was seeded in each site at 45,920 seeds ha^{-1} at a depth of 1.3 cm using a four-row John Deere 1700 planter (Deere and Co., Moline, IL). The plot dimensions were four rows of 12 m on 97-cm row spacing. Cotton production practices, including in-season nitrogen (37 kg ha^{-1} was applied in three equal increments during the growing season: at planting, at the first pin-head square, and at mid-bloom shortly before row closure); regulation of plant growth; disease and insect management; and defoliation/harvest procedures were carried out according to the guidelines published in the South Carolina Cotton Production Guide (Jones et al. 2021).

Imazapyr (Polaris®; Nufarm Americas, Alsip, IL) at 0.1×, 0.05×, 0.025×, 0.0125×, and 0.00625× of the normal use rate of 0.84 kg ae ha^{-1} was applied in water using a backpack sprayer calibrated to deliver 140 L ha^{-1} at a pressure of 276 kPa using a four-nozzle hand-held spray boom equipped with TeeJet XR8002 flat-fan nozzles (Spraying Systems Co., Glendale Heights, IL) on a spacing of 48 cm. The spray pattern from the four nozzles covered the middle two rows (two per row) of the plot with approximately 20-cm coverage on the outside row middles with no over-the-top contact on Rows 1 and 4. All treatments included a nonionic surfactant (Trademark®; Carolina Eastern, Denmark, SC) applied at 0.25% v/v. An untreated control (0 kg ae ha^{-1}) was included for each application timing (vegetative and reproductive) at each site location. In addition, Rows 1 and 4 were left as buffer rows to minimize potential spray movement between plots. Plots were maintained weed-free for the duration of the study using a combination of herbicides and/or hand removal.

Cotton injury was visibly assessed on a 0% to 100% scale with 0% being no injury and 100% being complete plant death. Visual injury relative to the untreated control in this study considered several factors including stunting, leaf chlorosis, stem reddening, and flower and fruit shedding. Visual injury ratings were collected at 14 and 28 d after herbicide application (DAA). Cotton plant heights from the soil surface to the uppermost growing point (node) of six plants in the middle two rows of each plot were measured at 28 DAA. At crop maturity, the center two rows were harvested using a John Deere 9986 spindle picker (Deere and Co.) equipped with a weighing system. Yield was reported as seed cotton, which included both seed and lint. Seed cotton yield was reported in this study because future research is planned to determine the effects of imazapyr exposure at various reproductive growth stages (i.e., pin-head square, first bloom, mid-bloom) on gin turnout and lint quality parameters.

Location and year (EREC 2021, EREC 2022, and PDREC 2022), application timing (vegetative or reproductive), and herbicide treatments were considered fixed effects, and block and block nested within location and timing were random effects in the model. Also, all fixed by random effects in the model were considered random. Cotton visual injury, height, and yield data were analyzed using the MIXED procedure with SAS software (version 9.3; SAS Institute, Cary, NC). Differences between treatment means were separated using the Tukey-Kramer method ($P < 0.05$).

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Table 2. Effects of sublethal rates of imazapyr applied to cotton at the vegetative growth stage on cotton injury, height, and seed cotton yield response in 2021 and 2022.[a]

Imazapyr[b]	Injury[c]		Height 28 DAA[d]			Yield[e]		
	14 DAA	28 DAA	EREC 2021	EREC 2022	PDREC 2022	EREC 2021	EREC 2022	PDREC 2022
	%		cm			$kg\ ha^{-1}$		
0.1×	73 a	86 a	23 d	28 e	23 d	410 d	260 e	60 d
0.05×	54 b	74 b	32 c	36 d	26 d	990 c	420 d	250 d
0.025×	23 c	18 c	62 b	49 c	27 d	1,310 b	950 c	680 c
0.0125×	10 d	3 d	69 b	78 b	43 c	1,790 a	1,590 b	1,820 b
0.00625×	1 e	0 e	76 a	86 a	60 b	2,120 a	1,990 a	2,000 ab
0	—	—	66 b	93 a	78 a	1,910 a	2,170 a	2,370 a
P-value					<0.001			

[a]Abbreviations: DAA, days after application; Pr > F, probability of a greater *F* value; EREC, Edisto Research and Education Center; PDREC, Pee Dee Research and Education Center.
[b]The normal use rate for imazapyr is 0.84 kg ae ha^{-1}.
[c]Visual determination of cotton injury on a 0% to 100% scale with 0% indicating no injury and 100% indicating complete plant death. The untreated control was not included in the means separation. Cotton visual injury at 14 and 28 DAA was combined across locations (P = 0.5781 and P = 0.9829, respectively).
[d]Cotton height (P < 0.0001) was separated by location. Cotton height at the time of treatment application (Table 1) ranged from 21 cm to 30 cm.
[e]Seed cotton yield was separated by locations (P < 0.0001).

Results and Discussion

Application timing (P < 0.0001), location (P < 0.0001), and application timing by location (P < 0.0001) were significant; therefore, data were separated by application timing (vegetative and reproductive stages) and location (EREC 2021, EREC 2022, and PDREC 2022).

Vegetative Cotton Response to Imazapyr

No differences in cotton injury at the vegetative growth stage between location and treatment were observed at 14 and 28 DAA (P = 0.5781 and P = 0.9829, respectively); therefore, data were pooled across locations. However, vegetative cotton height at 28 DAA was separated by location due to a signification interaction (P < 0.0001). Vegetative-stage seed cotton yields were pooled across locations (P = 0.0681); however, the main effect of herbicide treatment was significant for cotton injury at 14 (P < 0.0001) and 28 DAA (P < 0.0001), cotton height at 28 DAA (P < 0.0001), and seed cotton yield (P < 0.0001).

The application of imazapyr 14 DAA to cotton at the vegetative growth stage resulted in 73% and 54% injury when the herbicide was applied at the 0.1× and 0.05× rates, respectively (Table 2). At 28 DAA, visual injury increased by 13 and 20 percentage points, respectively. Cotton visual injury at the higher rates of imazapyr included stunting, leaf chlorosis, and stem reddening (Figure 1A). Visible injury was less apparent at the 0.025× rate of imazapyr (23% and 18% at 14 and 28 DAA, respectively). The visible injury symptoms observed from plants that had been treated with the 0.0125× and 0.00625× rates of imazapyr were 10% or less at 14 DAA. Injury to cotton at the vegetative stage decreased to less than 5% at 28 DAA. In a study comparing constant and variable carrier volumes, Smith et al. (2017) observed cotton injury at the 6-leaf growth stage of 19% and 47% at 14 d after treatment (DAT) with dicamba and 2,4-D simulated drift rates, respectively. However, Ellis and Griffin (2002) observed much lower cotton injury, from 0% to 9%, at 28 DAT from sublethal rates of glyphosate and glufosinate at the early growth stage (2- to 3-leaf). These differences were most likely attributed to higher cotton sensitivity to growth regulator herbicides, especially 2,4-D, compared to glyphosate or glufosinate (Marple et al. 2007, 2008).

Cotton height response to imazapyr was similar to the visible injury observations. Height ranged from 23 cm to 93 cm among the EREC 2021, EREC 2022, and PDREC 2022 sites. Cotton height was reduced by 56% to 71% at the 0.1× rate of imazapyr compared with the untreated control across locations (Table 2). At the 0.05× rate of imazapyr, height was 52%, 61%, and 67% of the untreated control at EREC 2021, EREC 2022, and PDREC 2022 sites, respectively. However, cotton height at EREC 2021 was either

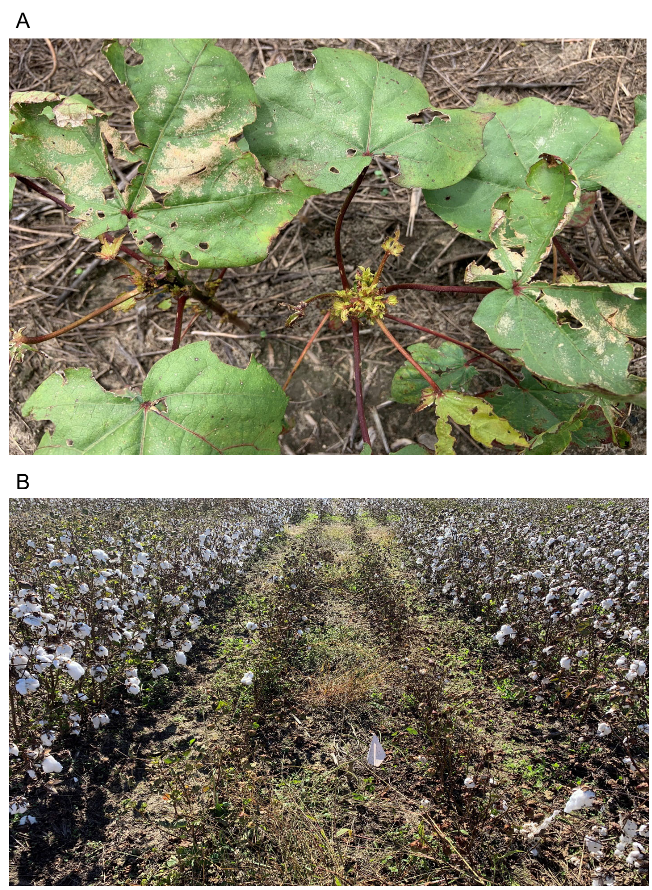

Figure 1. Vegetative cotton (at the 3- to 4-leaf growth stage) at (A) 28 d after application and (B) at harvest following postemergence applications of imazapyr at the 0.1× rate in Blackville, SC, in 2021. The normal use rate of imazapyr is 0.84 kg ae ha^{-1}.

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reduced by 4 cm when the 0.025× imazapyr rate was applied or the height exceeded that of the untreated control by 3 cm and 10 cm at 28 DAA at the 0.0125× and 0.00625× imazapyr rates, respectively. However, cotton height at EREC 2022 and PDREC 2022 was reduced by all rates of imazapyr compared with the height of the untreated control. No differences in height were observed between cotton treated with imazapyr at 0.00625× and the untreated control at EREC 2022. Cotton height was reduced by 70% to 47% at the 0.1× and 0.025× imazapyr rates, respectively. Cotton height at EREC 2022 was reduced by less than 20% following application of imazapyr at the 0.0125× and 0.00625× rates. At PDREC 2022, no difference in cotton height was observed when imazapyr was applied at the 0.1×, 0.05×, and 0.025× rates. Height was also reduced by 45% and 23% when the 0.0125× and 0.00625× rates of imazapyr, respectively, were applied. Cotton height was reduced by 12%, 20%, and 32% when low rates of dicamba, 2,4-D, and sulfometuron, respectively, were applied (Jeffries et al. 2014; Smith et al. 2017). Similarly, low rates of glyphosate and glufosinate applied to nontransgenic soybean and cotton at the early growth stage (2- to 3-leaf) reduced plant height by 11% at 28 DAT and by 20% at 14 DAT, respectively (Ellis and Griffin 2002).

Yield from cotton treated with imazapyr at the vegetative growth stage ranged from 60 to 2,370 kg ha^{-1} across locations. Visual inspection at harvest of cotton that had been treated with 0.1× and 0.05× imazapyr at the vegetative growth stage revealed very few harvestable bolls. Of these, most were small, immature, and failed to open after defoliation. Seed cotton yield at EREC 2021 was reduced by 79%, 48%, and 31% when the 0.1×, 0.05×, and 0.025× rates of imazapyr, respectively, were applied (Table 2). No differences in cotton yield were observed between the untreated control (1,910 kg ha^{-1}) and the 0.0125× (1,790 kg ha^{-1}) and 0.00625× (2,120 kg ha^{-1}) rates of imazapyr. In contrast, cotton yield at EREC 2022 was 260, 420, and 950 kg ha^{-1} (88%, 81%, and 56% yield reduction, respectively) when the 0.1×, 0.05×, and 0.025× rates of imazapyr were applied, respectively, relative to yield from the untreated control (2,170 kg ha^{-1}), which was lower than yield obtained from the EREC 2021 location (Table 2). In addition, a significant reduction in cotton yield occurred when the 0.0125× rate of imazapyr was applied. Cotton yield at the PDREC 2022 location followed a similar pattern to that of EREC 2022, where a reduction of 97%, 87%, 71%, and 23% of the untreated control (2,370 kg ha^{-1}) was observed when imazapyr was applied at the 0.1×, 0.05×, 0.025×, and 0.00125× rates, respectively. Across locations, the 0.00625× rate of imazapyr did not result in a significant yield reduction (Table 2). At the time of defoliation, cotton treated with sublethal rates of imazapyr (0.1×, 0.05×, and 0.025×) at the 3- to 5-leaf growth stage were still producing new leaves, flowers, and fruit on the mid to lower main stem and side branches (i.e., in the upper one-third of the plant where exposure to the herbicide was greatest, growth was very limited). Smith et al. (2017) also observed a 68% reduction in cotton yield with a low rate of 2,4-D applied at the 6-leaf growth stage. Exposure at the vegetative growth stage (3- to 5-leaf) to imazapyr at 5.25 g ha^{-1} (0.00625×) resulted in marginal impact on cotton yield; however, moderate to severe reductions in cotton yield were observed when imazapyr was applied at 10.5 g ha^{-1} (0.0125×) or higher (0.025× to 0.1×).

Reproductive Cotton Response to Imazapyr

No differences in cotton reproductive injury were observed between location and treatment at 14 and 28 DAA; therefore, visual injury data were pooled ($P = 0.9893$ and $P = 0.8525$, respectively). Cotton height at 28 DAA was also combined from all three locations due to a nonsignificant interaction ($P = 0.1202$). Cotton yield was separated by location due to herbicide treatment by location interaction ($P = 0.0003$). The main effect of herbicide treatment was also significant for cotton injury at 14 and 28 DAA ($P < 0.0001$ and $P < 0.0001$, respectively), cotton height at 28 DAA ($P < 0.0253$), and yield ($P < 0.0001$).

At 14 DAA, visual injury to cotton after application of imazapyr at the 0.1× and 0.05× rates was 87% and 69%, respectively (Table 3). Visual injury ranged from 48% to 0% at 14 DAA for the other imazapyr treatments. Smith et al. (2017) observed 19% and 26% cotton injury 14 DAT after exposure to 2,4-D at 18.7 and 37.4 g ae ha^{-1}, respectively, at the pinhead square growth stage. At 28 DAA, cotton injury based on visual ratings ranged from 95% to 64% when the 0.1×, 0.05×, and 0.025× rates of imazapyr rates were applied (an increase of 8% to 16%). Smith et al. (2017) also reported an increase in injury to cotton from 2,4-D of 10% to 12% at 28 DAT compared with injury at 14 DAT. Cotton injury at the reproductive growth stage, especially when the 0.1× to 0.025× rates of imazapyr were applied, included pronounced leaf chlorosis and vein and petiole reddening, especially the new growth in the terminal of the plant (Figure 2A). Older leaves on the main stem and side branches in the middle and lower portions of the plant remained green and healthy; however, new growth on the side branches mirrored the same injury symptoms observed in the terminal. In addition, there was visible shedding of squares and blooms on the ground at 28 DAA. We observed no visible injury when the 0.00625× rate of imazapyr was applied to cotton at the reproductive growth stage. Visible injury to cotton at the reproductive stage was 40% 28 DAA at the 0.0125× rate of imazapyr. However, no visual injury was noted at the lowest imazapyr rate (0.00625×).

Overall, the reduction in cotton height from imazapyr at the reproductive growth stage was less than when the herbicide was applied at the vegetative growth stage. Cotton stunting was greatest (42 cm less stunting than in the untreated control) when the 0.1× rate of imazapyr was applied (Table 3). When imazapyr was applied at the 0.05× and 0.025× rates, cotton height was 27 and 26 cm less, respectively, than the untreated control. Cotton height was not different from the control when imazapyr was applied at the 0.0125× and 0.00625× rates (Table 3). In contrast, cotton height was reduced by 30% and 29% after applications of aminocyclopyrachlor plus metsulfuron ($11 + 3.5$ g ha^{-1}) and clopyralid plus triclopyr (21 and 63 g ha^{-1}), respectively, at 70 DAT (Jeffries et al. 2014). Ellis and Griffin (2002) observed cotton height reductions of 5% to 8% at 28 DAT with simulated drift rates of glyphosate and glufosinate applied at the first bloom growth stage. Cotton height was reduced by 20% when treated with triclopyr at 60 g ha^{-1} at the early bloom growth stage (Snipes et al. 1991). Cotton sensitivity and relative growth stage at the time of herbicide application may explain the differences in observed height reductions relative to this study. Crop response could also depend on the mode of action of the herbicide. For example, cotton was more sensitive to drift rates of growth regulators (Marple et al. 2007, 2008) than to glufosinate or glyphosate (Ellis and Griffin 2002).

Seed cotton yield was reduced when imazapyr was applied at the early reproductive growth period. Yields ranged from 0 to 2,880 kg ha^{-1} across the three locations in 2021 and 2022. At EREC 2021, yield was reduced by 100%, 95%, and 84% when imazapyr was applied at the 0.1×, 0.05×, and 0.025× rates, respectively (Table 3). No differences were observed between seed cotton yields when

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Table 3. Effects of sublethal rates of imazapyr applied to cotton at the reproductive growth stage on cotton injury, height, and yield in 2021 and 2022.[a]

	Injury[c]		Height[d]	Yield[e]		
Imazapyr[b]	14 DAA	28 DAA	28 DAA	EREC 2021	EREC 2022	PDREC 2022
	%		cm	kg ha^{-1}		
0.1×	87 a	95 a	61 b	0 e	10 e	0 b
0.05×	69 b	78 b	76 b	150 d	40 de	80 b
0.025×	48 c	64 c	77 b	470 d	220 d	50 b
0.0125×	24 d	40 d	88 a	1,030 c	510 c	200 b
0.00625×	0 e	0 e	95 a	1,850 b	990 b	380 b
0	—	—	103 a	2,880 a	2,170 a	2,460 a
P-value	<0.0001		0.0317		<0.0001	

[a]Abbreviations: DAA, days after application; EREC, Edisto Research and Education Center; PDREC, Pee Dee Research and Education Center.
[b]The normal use rate of imazapyr is 0.84 kg ae ha^{-1}.
[c]Visual determination of cotton injury on a 0% to 100% scale with 0% indicating no injury and 100% indicating complete plant death. Cotton visual injury at 14 and 28 DAA was combined across locations (P = 0.9953 and P = 0.8734, respectively). The untreated control was not included in the means separation.
[d]Cotton height was combined across locations (P = 0.1935). Cotton height at the time of treatment application (Table 1) ranged from 59 cm to 65 cm.
[e]Seed cotton yield was separated by location (P < 0.0001).

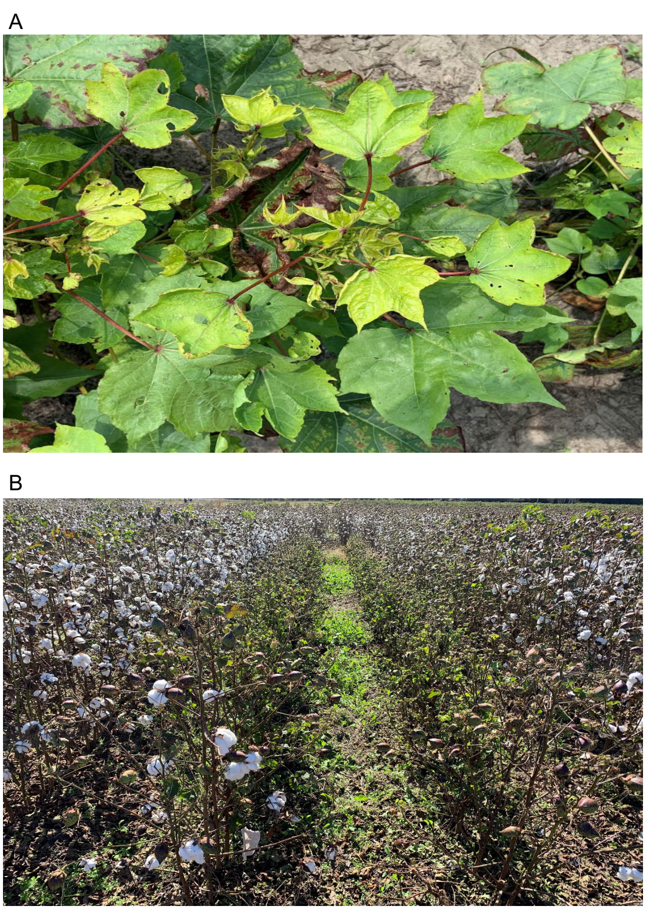

Figure 2. Reproductive cotton (the first bloom growth stage) at (A) 28 d after application and (B) at harvest following postemergence applications of imazapyr at the 0.1× rate in Blackville, SC, in 2021. The normal use rate of imazapyr is 0.84 kg ae ha^{-1}.

imazapyr was applied at the 0.05× and 0.025× rates. When imazapyr was applied at the 0.0125× and 0.00625× rates, seed cotton yield was 64% (1,030 kg ha^{-1}) and 36% (1,850 kg ha^{-1}) of that of the untreated control. The reduction in cotton seed yield was greater from EREC 2022 when imazapyr was applied at the 0.05× and 0.025× rates than from EREC 2021 (Table 3). A similar reduction was also observed when the 0.0125× and 0.00625× rates of imazapyr were applied at the EREC 2022 location. However, seed cotton yield reduction was greatest at the PDREC 2022 location (ranging from 0 to 380 kg ha^{-1}). In this study, the reproductive growth stage (first bloom) was the most impacted by imazapyr exposure. Previous research has shown varying levels of cotton yield reductions from different herbicides such as 2,4-D, dicamba, triclopyr, glufosinate, and glyphosate, when cotton was exposed during reproductive growth stages (Ellis and Griffin 2002; Marple et al. 2007, 2008; Smith et al. 2017; Snipes et al. 1991).

Cotton treated with imazapyr at the first bloom growth stage had few to no harvestable bolls at the end of the season (Figure 2B). This reduction in boll number was primarily due to square, flower, and immature boll shedding following imazapyr exposure and lack of initiation of new squares, flowers, or bolls (M. Marshall, personal observation). Following application of imazapyr at the 0.0125× and 0.00625× rates at first bloom, more harvestable (open) bolls were observed at harvest (data not shown), but cotton yield was still significantly lower than the untreated control. In cotton that was treated at the vegetative stage, few harvestable bolls were observed when imazapyr was applied at the 0.1× (Figure 1B), 0.05×, and 0.025× rates. In this study, all rates (0.1× to 0.00625×) of imazapyr applied to cotton at the reproductive stage resulted in substantial crop loss (Table 3). At harvest, plant growth was observed on cotton that had been treated with imazapyr at first bloom; however, these new leaves and stems exhibited chlorosis and reddening and other malformations (M. Marshall, personal observations). Smith et al. (2017) observed a similar reduction (89%) in cotton yield when 2,4-D was applied at the first square growth stage compared with a 68% reduction at the 6-leaf growth stage. In contrast, Marple et al. (2008) observed the opposite: cotton yield loss was lower when 2,4,-D was applied at later (8-node or larger) versus earlier (3- to 4-leaf) growth stages.

This study simulated cotton exposure to imazapyr using a carrier volume of 140 L ha^{-1}, which was similar to that used in other drift simulation studies (Ellis and Griffin 2002; Everitt and Keeling 2009; Johnson et al. 2012; Marple et al. 2007, 2008; Snipes et al. 1991). However, Smith et al. (2017) reported greater cotton injury and yield loss from applications of 2,4-D and dicamba when carrier volume was reduced from 140 to 4.7 or 9.4 L ha^{-1} while maintaining the same herbicide concentration. Cotton yield loss from 2,4-D at the ultra-low carrier volume was 97% and 81% when applied at the first square and 6-leaf growth stages, respectively, which represented 8% and 13% increases in yield reduction compared with the 140 L ha^{-1} carrier volume. Therefore, cotton injury, height, and yield reductions observed in this study from imazapyr exposure may have been higher if ultra-low carrier volumes were used instead of the 140 L ha^{-1} carrier volume (Smith et al. 2017).

This study demonstrated the potential impact of cotton exposure to low rates of imazapyr at the vegetative and reproductive growth stages. Early season exposure of cotton to imazapyr did result in visible injury and greater height and yield reductions, especially at the higher doses; however, these impacts became less apparent as the imazapyr rate was reduced in the spray mixture. In contrast, cotton at the reproductive growth stage treated with imazapyr exhibited substantial reductions in crop growth and yield at most of the rates used in the study. Therefore, cotton at the reproductive growth stage appears to be the most sensitive to low rates of imazapyr. In this study, precipitation and temperature at the study sites were at or near the 30-yr average (data not shown). Poor environmental conditions following imazapyr exposure may increase cotton response. In this study, the first-bloom reproductive growth stage was tested, and future research is needed to determine whether the effects of reduced imazapyr rates across other cotton reproductive growth stages are similar and to determine whether a low carrier volume would result in similar or higher cotton response to low rates of imazapyr.

Practical Implications

The use of imazapyr is important for managing vegetation in forestry, powerline rights-of-ways, industrial turf, and other non-cropland sites in the Virginia-Carolina region. In South Carolina, managed forestry sites are typically located near areas of cotton production. Aerial application of herbicides such as imazapyr is the economically preferred method for controlling weeds in forestry production. The proximity of cotton fields to managed forestry sites increases the potential for off-target movement of imazapyr. Growth stage at the time of exposure and the amount of the herbicide reaching the crop determines the degree of cotton response. This study demonstrated the potential effects of low levels of imazapyr on cotton growth, development, and yield. Of the two cotton growth stages examined in this study, the reproductive stage (i.e., first bloom) appeared to be the most sensitive, with severe crop injury and yield loss when exposed to reduced rates of imazapyr. This information will aid growers in determining the relative in-season response of cotton and potential yield loss that may occur from potential imazapyr exposure during the growing season. However, the limiting factor for growers in determining potential yield loss after exposure is not knowing the actual amount of imazapyr that contacted the crop. In addition, several factors, including wind speed and direction, can influence the magnitude of the exposure. Imazapyr exposure at the vegetative growth stage (3 to 5 leaves) at 5.25 g ha^{-1} (0.00625×) had little effect on cotton yield in this study; however, moderate to severe reductions were observed when imazapyr was applied at 10.5 g ha^{-1} (0.0125×) or higher (0.025×, 0.05×, and 0.1×). Yield impacts from imazapyr exposure at the reproductive growth stage (first bloom) were more pronounced at all rates. Therefore, cotton was more sensitive to imazapyr exposure at the reproductive growth stage and resulted in significant yield loss.

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