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Sweetpotato tolerance and Palmer amaranth control with indaziflam

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Research Article

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Abstract

Field studies were conducted in North Carolina in 2018 and 2019 to determine sweetpotato tolerance to indaziflam and its effectiveness in controlling Palmer amaranth in sweetpotato. Treatments included indaziflam pre-transplant; 7 d after transplanting (DATr) or 14 DATr at 29, 44, 58, or 73 g ai ha^{-1}; and checks (weedy and weed-free). Indaziflam applied postemergence caused transient foliar injury to sweetpotato. Indaziflam pretransplant caused less injury to sweetpotato than other application timings regardless of rate. Palmer amaranth control was greatest when indaziflam was applied pretransplant or 7 DATr. In a weed-free environment, sweetpotato marketable yield decreased as indaziflam application was delayed. No differences in storage root length to width ratio were observed.

Introduction

Sweetpotato is a decumbent, vining crop typically produced on 106- to 122-cm-wide rows (Kemble 2021). Its prostrate growth habit makes it susceptible to competition for light by upright-growing weeds (Meyers et al. 2010b). The crop's lack of competitiveness and wide row spacing require a long critical weed-free period, from 2 to 6 wk after transplanting (WATr) (Seem et al. 2003; Smith et al. 2020). Of the weeds found in sweetpotato, Palmer amaranth is the most troublesome in the southeastern United States (Webster 2010). Season-long interference of sweetpotato by Palmer amaranth can result in 79% to 95% marketable yield loss (Basinger et al. 2019; Meyers et al. 2010b; Smith et al. 2020).

Palmer amaranth control in sweetpotato is difficult due to limited herbicide options (Kemble 2021). Growers rely on a combination of herbicides, cultivation, and hand removal for control of this weed. However, cultivation is often only possible in the first 4 WATr, and hand removal can cost $500 to $1,000 ha^{-1} (K. M. Jennings, personal communication, March 1, 2021). Sweetpotato growers are limited to three herbicide modes of action to control Palmer amaranth: photosystem I inhibition (paraquat), protoporphyrinogen oxidase (PPO) inhibition (flumioxazin and fomesafen) (Barkley et al. 2016; Meyers et al. 2010a), and long-chain fatty acid inhibition (*S*-metolachlor) (Meyers et al. 2010a, 2012). Paraquat can be used only as a nonselective pretransplant application (Anonymous 2019). Growers are reluctant to use *S*-metolachlor because of the potential for crop injury if application is made too soon after transplanting or if it is followed by heavy rainfall (Meyers et al. 2012, 2013; Monks et al. 2013). Furthermore, PPO inhibitor–resistant Palmer amaranth has been confirmed in Arkansas (Salas et al. 2016), Illinois (Heap 2020), North Carolina (W. J. Everman, personal communication, March 29, 2021), and Tennessee (Giacomini et al. 2017). Thus sweetpotato growers have a critical need for new herbicide modes of action.

Indaziflam is a cellulose biosynthesis-inhibiting, alkylazine herbicide (Brabham et al. 2014) that to date has been registered for preemergence use in turf, noncropland, and perennial fruit and nut crops. To date, there are no known cases of indaziflam-resistant populations (Heap 2020). In orchard crops, it is used to control many of the same weeds found in sweetpotato, including common purslane [*Portulaca oleracea* (L.)], *Amaranthus* spp., common ragweed (*Ambrosia artemisiifolia* L.), large crabgrass [*Digitaria sanguinalis* (L.) Scop.], and goosegrass [*Eleusine indica* (L.) Gaertn.] (Anonymous 2019). Thus, if safe to sweetpotato, indaziflam would represent a unique mode of action for sweetpotato production systems.

Because sweetpotato is produced from nonrooted cuttings rather than seeds, indaziflam may have potential for use in current sweetpotato production systems; however, sweetpotato tolerance to indaziflam has not been reported. Furthermore, no research has reported on the use of indaziflam in an annual cropping system. Therefore studies were conducted to determine

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Table 1. Indaziflam studies with 'Covington' sweetpotato conducted in North Carolina in 2018 and 2019.[a]

Study	Location	Year	Planting date	1 DBTr application date	7 DATr application date	14 DATr application date	Harvest (DATr)
							DATr
Weed control efficacy	Clinton, NC	2018	8 Jun 2018	7 Jun 2018	15 Jun 2018	22 Jun 2018	115
		2019	3 Jul 2019	2 Jul 2019	10 Jul 2019	17 Jul 2019	118
Sweetpotato tolerance	Clinton, NC	2018	8 Jun 2018	7 Jun 2018	15 Jun 2018	22 Jun 2018	115
		2019	27 Jun 2019	26 Jun 2019	3 Jul 2019	11 Jul 2019	110
	Rocky Mount, NC	2018	26 Jun 2018	25 Jun 2018	3 Jul 2018	10 Jul 2019	117

[a]Abbreviations: DBTr, days before transplanting; DATr, days after transplanting.

sweetpotato tolerance to indaziflam and the herbicide's effectiveness in controlling Palmer amaranth in a sweetpotato production system.

Materials and Methods

Field studies were conducted at two sites to evaluate Palmer amaranth control by indaziflam and at three sites to evaluate sweetpotato tolerance to indaziflam (Table 1). Studies were conducted on a grower field near Rocky Mount, NC (35.93°N, 77.75°W), in 2018 and at the Horticultural Crops Research Station near Clinton, NC (35.02°N, 78.28°W), in 2018 and 2019. Both locations are in the sweetpotato production area of North Carolina. Soils were a Norfolk (fine-loamy, kaolinitic, thermic Typic Kandiudults) loamy sand in Rocky Mount, an Orangeburg (fine-loamy, kaolinitic, thermic Typic Kandiudults) loamy sand in Clinton in 2018, and a Goldsboro (fine-loamy, siliceous, subactive, thermic Aquic Paleudults) loamy sand in Clinton in 2019. Soil organic matter content was <1%, and pH ranged from 6 to 6.5 at each study site.

Nonrooted 'Covington' cuttings were transplanted onto weed-free, bedded rows using a commercial mechanical transplanter (Checchi and Magli, Lehi, UT) in June or early July (Table 1). Plots were one row, each 1 m wide by 6.1 m long. There was a nontreated border row between each treated plot. The experimental design was a randomized complete block with four replications. Treatments were arranged in a factorial arrangement of three application timings (1 d before transplanting [DBTr], 7 DATr, or 14 DATr) by four rates (29, 44, 58, or 73 g ai ha^{-1}) of indaziflam. Palmer amaranth control studies also included a nontreated weedy and weed-free check. Sweetpotato tolerance studies included a weed-free check. Herbicide treatments were applied using a CO_2-pressurized backpack sprayer with 8003VS nozzle tips (TeeJet® Technologies, Springfield, IL, USA) calibrated to deliver 187 L ha^{-1} spray solution at 165 kPa. Both studies received 0.05 kg ai ha^{-1} clethodim (Select Max®, Valent USA Corp., Walnut Creek, CA, USA) at 4 WATr to control grasses and cultivation as needed to incorporate fertilizer and insecticide. In addition, sweetpotato tolerance studies received 0.1 kg ai ha^{-1} flumioxazin (Valor® SX, Valent USA Corp.) 1 DBTr and weekly hand removal of weeds to maintain a weed-free environment.

Visual estimates of Palmer amaranth control and sweetpotato injury ratings were determined at 4, 6, and 8 WATr using a scale of 0 (no control or no injury) to 100% (complete control or crop death) (Frans et al. 1986). Foliar chlorosis and necrosis, crop stunting, and loss of stand were considered when making the visual estimates. Sweetpotato storage roots were harvested 115 ± 5 DATr using a tractor-mounted commercial sweetpotato chain digger or disk turning plow and then sorted by hand into jumbo (≥8.9 cm in diameter), no. 1 (≥4.4 cm but <8.9 cm), and canner (≥2.5 cm but <4.4 cm) grades (USDA 2005) and then weighed. Total yield was calculated as the sum of jumbo, no. 1, and canner grades. Marketable yield was calculated as the sum of jumbo and no. 1 grades. Sweetpotato storage roots from the crop tolerance studies were also graded using a high-throughput optical grader (Exeter Engineering, Exeter, CA) to quantify herbicide effects on storage root shape. After grading, ten no. 1 roots per plot were randomly selected to test for internal necrosis (Jiang et al. 2015). Internal necrosis incidence was determined by cutting roots into approximately 3-mm slices beginning on the proximal end and ending halfway to the distal end and then making visual observations (Beam et al. 2017).

Data for the weed control and crop tolerance studies were analyzed separately to characterize the effect of indaziflam on storage root yield and to assess the benefit of indaziflam application for weed control. Homogeneity of variance and normality were determined prior to analysis of variance (ANOVA) by plotting residuals against predicted estimates. Crop stunting in the crop tolerance study and marketable and total yield in the weed control study were subjected to square root transformation. Back-transformed data were presented in figures and tables for interpretability. Transformed data were subjected to ANOVA using PROC MIXED in SAS, version 9.4 (SAS Institute Inc., Cary, NC, USA). Indaziflam rate, application timing, and their interaction were treated as fixed effects, while trial and replication within trial were treated as random effects where data were combined for both years and locations. When appropriate, means were separated using Fisher's protected least significant difference (LSD) ($\alpha = 0.05$). Least-squares means for crop stunting and marketable yield were subjected to linear regression using PROC REG in SAS.

Results and Discussion

Palmer Amaranth Control Studies

The interaction of indaziflam rate and application timing as well as the main effect of indaziflam rate were not significant ($P < 0.05$) for Palmer amaranth control; therefore rates were combined across application timings. Evaluations at 4, 6, and 8 WATr; indaziflam applications at 1 DBTr; and 7-DATr treatments provided greater control of Palmer amaranth than the 14-DATr treatments (Table 2). The poor weed control observed by the 14-DATr treatments was due to emergence of Palmer amaranth in the first 2 wk of the growing season, prior to indaziflam application. Few Palmer amaranth plants emerged after indaziflam application regardless of

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Table 2. Main effect of indaziflam application timing on Palmer amaranth control in 'Covington' sweetpotato.[a,b]

Application timing	Palmer amaranth control		
	4 WATr	6 WATr	8 WATr
	%		
1 DBTr	93 a	86 a	73 a
7 DATr	80 a	80 a	75 a
14 DATr	49 b	43 b	42 b

[a]Means within a column followed by the same letter are not different according to Fisher's LSD test of $P \leq 0.05$.
[b]Abbreviations: DATr, days after transplanting; DBTr, days before transplanting; WATr, weeks after transplanting.

Table 3. Main effect of indaziflam application timing on 'Covington' sweetpotato yield in Palmer amaranth control studies.[a,b]

Application timing	Storage root yield				
	Total	Marketable[c]	No. 1	Jumbo	Canner
	% of weed-free check				
1 DBTr	45 a	48 a	33 a	84 a	45 a
7 DATr	37 a	31 b	37 a	16 b	49 a
14 DATr	25 b	19 c	23 a	7 bc	46 a
Weedy check	12 c	3 d	4 a	0 c	49 a

[a]Means within a column followed by the same letter are not different according to Fisher's LSD test of $P \leq 0.05$.
[b]Abbreviations: DATr, days after transplanting; DBTr, days before transplanting.
[c]Marketable yield was No. 1 plus jumbo.

application timing. Indaziflam provided good control (93% at 4 WATr) of Palmer amaranth if applied prior to weed emergence.

Interaction of Indaziflam and Weed Interference on Sweetpotato Yield and Quality

In the Palmer amaranth control studies, the interaction of application timing and herbicide rate as well as the main effect of indaziflam rate were not significant for total, marketable, no. 1, jumbo, or canner yield; therefore rates were combined across application timings. Yield for the nontreated weed-free check was 3,100, 8,300, and 4,400 kg ha^{-1} for canner, no. 1, and jumbo grade, respectively. No differences were observed in the effect of application timing on no. 1 or canner yield, which ranged from 4% to 37% and 45% to 49% of the nontreated weed-free check, respectively (Table 3). Jumbo yield was affected by application timing, with 1-DBTr treatments yielding higher than 7-DATr and 14-DATr treatments. Indaziflam 1 DBTr resulted in 84% of the weed-free check jumbo yield, while the weedy check resulted in no jumbo roots. Marketable storage root yield showed similar trends, with 1-DBTr treatments yielding higher than either DATr treatments, which yielded greater than the weedy check. Total yield was similar for 1-DBTr and 7-DATr timings. The differences in total and marketable yield were likely due to better control of Palmer amaranth observed in the 1-DBTr treatment than the other treatments.

Sweetpotato Tolerance Studies

Sweetpotato Injury

Minimal and transient leaf chlorosis and necrosis were observed soon after application of indaziflam at both DATr treatments (data not presented). However, indaziflam injury to sweetpotato appeared as stunting relative to the weed-free check.

Table 4. Main effect of indaziflam application timing on 'Covington' sweetpotato yield as a percentage of the weed-free check in sweetpotato tolerance studies conducted weed-free.[a,b]

Application timing	Storage root yield			
	Total	No. 1	Jumbo	Canner
	% of weed-free check			
1 DBTr	90 a	79 a	149 a	71 a
7 DATr	77 b	77 a	100 b	57 b
14 DATr	71 b	74 a	87 b	58 b

[a]Means within a column followed by the same letter are not different according to Fisher's LSD test of $P \leq 0.05$.
[b]Abbreviations: DATr, days after transplanting; DBTr, days before transplanting.

The interaction of application timing and herbicide rate was significant ($P < 0.05$) for visual stunting ratings; thus visual ratings were analyzed by application timing. Minimal stunting (≤7%) was observed at all rating times when indaziflam was applied 1 DBTr, regardless of indaziflam rate (data not presented). At 4 WATr, indaziflam at 29 g ai ha^{-1} resulted in the lowest levels of stunting for 7-DATr (24%) and 14-DATr (30%) treatments, with sweetpotato stunting increasing 5.7% and 6.2% for each additional 10 g ha^{-1}, respectively (Figure 1 A). Similarly, at 6 WATr, the 29-g ha^{-1} indaziflam treatments resulted in the lowest levels of sweetpotato stunting for the 7-DATr (11%) and 14-DATr (26%) applications, with stunting increasing 5.4% and 7.6% for each additional 10 g ha^{-1}, respectively (Figure 1 B). By 8 wk after planting, ≤13% stunting was observed regardless of indaziflam application timing or rate (data not presented).

Effect of Indaziflam on Storage Root Yield

No differences were observed in sweetpotato storage root length to width ratio or internal necrosis incidence, regardless of application timing or rate of indaziflam (data not presented).

In the crop tolerance studies, the interaction of application timing and herbicide rate was significant for marketable yield; therefore analyses were conducted by application timing. Yield for the nontreated check was 3,300, 8,100, and 3,700 kg ha^{-1} for canner, no. 1, and jumbo grade, respectively. No rate effect was observed for marketable yield with 1-DBTr or 7-DATr treatments, which averaged 100% and 87% of the weed-free check, respectively (data not presented). Marketable yield for 14-DATr treatments decreased linearly, as indaziflam rate increased by 1.43 g ha^{-1} indaziflam, there was a 1% reduction in marketable yield relative to the nontreated check (Figure 2). The interaction of application timing and herbicide rate as well as the main effect of indaziflam rate were not significant for jumbo, no. 1, canner, or total yield; therefore rates were combined across application timings. No. 1 yields for the three indaziflam timings were similar, ranging from 74% to 79% of the nontreated weed-free check (Table 4). Indaziflam applications 1 DBTr resulted in greater jumbo, canner, and total sweetpotato yields than 7-DATr or 14-DATr treatments. Sweetpotato receiving the 7-DATr and 14-DATr treatments had similar jumbo, canner, and total yields.

These results suggest that indaziflam has potential for use in sweetpotato. Indaziflam provided good control of Palmer amaranth in the sweetpotato production system. However, Palmer amaranth control was not high enough for indaziflam to be used as a stand-alone herbicide. Because indaziflam has residual activity only, it must be applied before weed emergence or prior to or in combination with a POST herbicide or cultivation. To achieve

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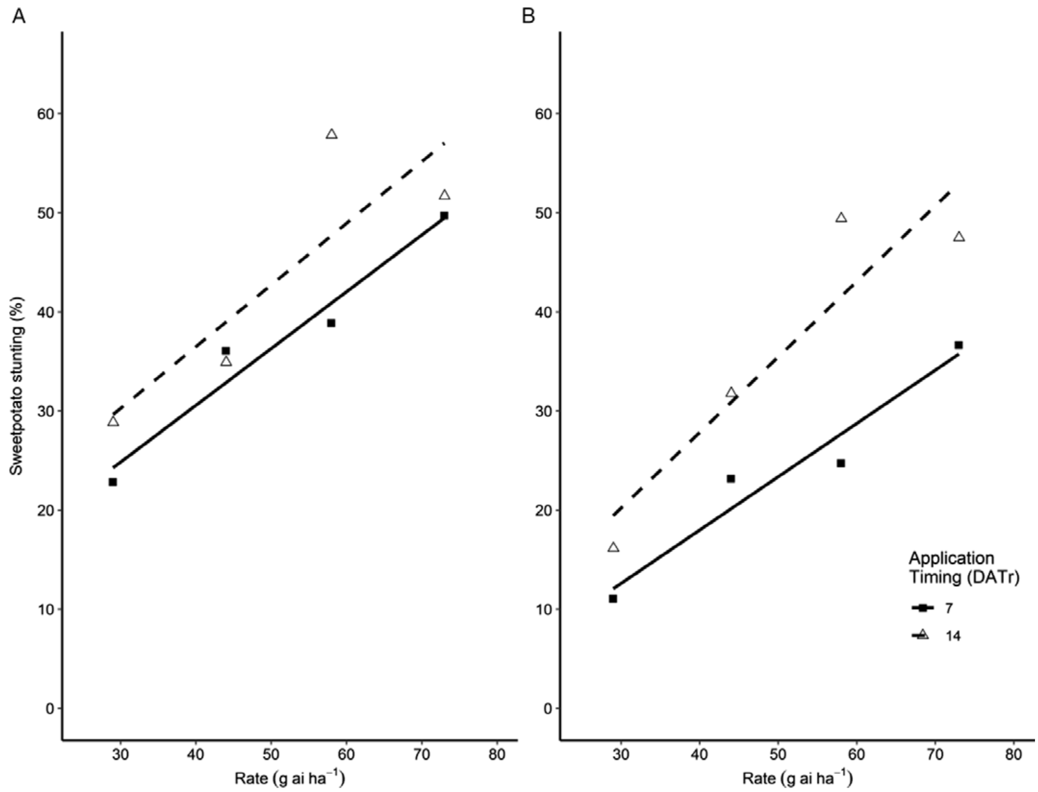

Figure 1. The effect of indaziflam application rate and timing on ‘Covington’ sweetpotato stunting in sweetpotato tolerance studies. Ratings were collected at 4 (A) and 6 (B) wk after transplanting (DATr). For (A), linear equations, application 7 DATr, $y = 0.57x + 7.64$ (root mean square error = 2.88; modeling efficiency coefficient = 0.95); application 14 DATr, $y = 0.62x + 11.59$ (root mean square error = 8.63; modeling efficiency coefficient = 0.74). For (B), linear equations, application 7 DATr, $y = 0.54x - 3.54$ (root mean square error = 3.15; modeling efficiency coefficient = 0.93); application 14 DATr, $y = 0.76x - 2.67$ (root mean square error = 7.21; modeling efficiency coefficient = 0.86).

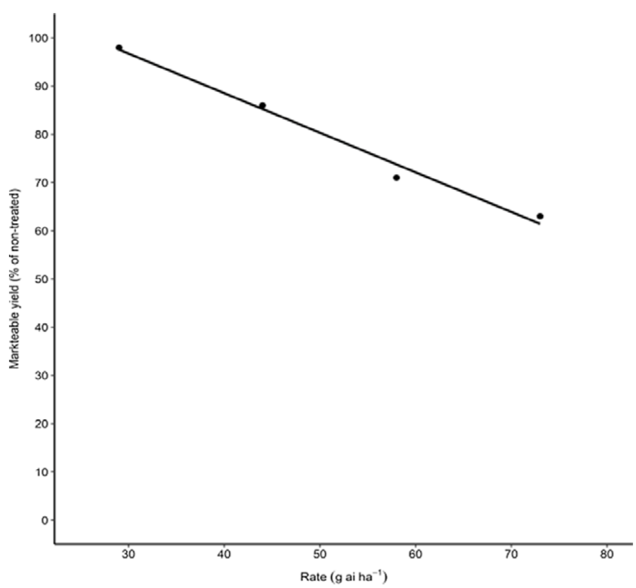

Figure 2. Effect of indaziflam application rate applied 14 d after transplanting on ‘Covington’ sweetpotato marketable yield as a percentage of the weed-free check in sweetpotato tolerance studies. Marketable yield included No. 1 and jumbos. Linear equation: $y = mx + b$, where m is –0.7 (standard error = 0.29) and b is 115 (standard error = 15.7). Root mean square error = 9.59; modeling efficiency coefficient = 0.73.

optimum weed control, indaziflam would need to be utilized in a weed management program that includes additional methods (i.e., herbicides, cultivation, hand removal) for weed control. Furthermore, these results suggest that sweetpotato has tolerance to indaziflam herbicide particularly when applied prior to transplanting. Future research should evaluate adjusting application timings to optimize activity and crop safety from indaziflam.

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