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Effect of *S*-metolachlor and flumioxazin herbicides on sweetpotato treated with and without activated charcoal applied through transplant water

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Abstract

Flumioxazin and *S*-metolachlor are widely used in conventional sweetpotato production in North Carolina and other states; however, some growers have recently expressed concerns about potential effects of these herbicides on sweetpotato yield and quality. Previous research indicates that activated charcoal has the potential to reduce herbicide injury. Field studies were conducted in 2021 and 2022 to determine whether flumioxazin applied preplant and *S*-metolachlor applied before and after transplanting negatively affect sweetpotato yield and quality when activated charcoal is applied with transplant water. The studies evaluated five herbicide treatments and two activated charcoal treatments. Herbicide treatments included two flumioxazin rates, one *S*-metolachlor rate applied immediately before and immediately after transplanting, and no herbicide. Charcoal treatments consisted of activated charcoal applied at 9 kg ha^{-1}, and no charcoal. No visual injury from herbicides or charcoal was observed. Likewise, no effect of herbicide or charcoal treatment on no. 1, marketable (sum of no. 1 and jumbo grades), or total yield (sum of canner, no. 1, and jumbo grades) was observed. Additionally, shape analysis conducted on calculated length-to-width ratio (LWR) for no. 1 sweetpotato roots found no effect from flumioxazin at either rate on sweetpotato root shape. However, both *S*-metolachlor treatments resulted in lower LWR of no. 1 sweetpotato roots in 2021. Results are consistent with prior research and indicate that flumioxazin and *S*-metolachlor are safe for continued use on sweetpotato at registered rates.

Introduction

Sweetpotato is an economically important crop in North Carolina, and in 2021, North Carolina growers harvested 42,000 ha valued at $392 million (USDA-NASS 2022). Nationally over the same period, the United States harvested 62,000 ha of sweetpotato for a total production value of $680 million (USDA-NASS 2022). Sweetpotato is also produced in Arkansas, Florida, Louisiana, Mississippi, and other states throughout the southeastern United States (USDA-NASS 2022).

Weed competition can reduce marketable sweetpotato yield by as much as 86% (Barkley et al. 2016; Basinger et al. 2019; Meyers et al. 2010b; Smith et al. 2020). A limited number of herbicides are registered for preemergence control of weeds in sweetpotato crops, including *S*-metolachlor, flumioxazin, clomazone, DCPA, and fomesafen. Not all these herbicides are registered nationally; for example, *S*-metolachlor and fomesafen may be used in specific regions of the united States under authority of section 24(c) of the Federal Insecticide, Fungicide, and Rodenticide Act. In addition to herbicides, hand-weeding is a widely used and expensive method of weed control in sweetpotato; North Carolina growers have self-reported hand-weeding costs of up to $370 per hectare (S.C.Smith and L.D. Moore, personal communication).

Flumioxazin, which is used preplant on approximately 90% of conventional sweetpotato hectarage planted in North Carolina (K.M. Jennings, personal communication), delays weed emergence until later in the season and reduces the frequency of expensive hand-weeding. Previous research has indicated that sweetpotato injury and yield reduction from flumioxazin applied before transplantation is minimal (Coleman et al. 2016; Kelly et al. 2006; Meyers et al. 2010a). Although flumioxazin is widely used on sweetpotato, some growers have concerns that flumioxazin may reduce sweetpotato yield or negatively affect root shape. Because flumioxazin is a vital component of many conventional weed management strategies in sweetpotato crop fields, it is important to investigate grower concerns and determine whether flumioxazin is responsible for perceived yield and quality reduction. Likewise, growers have expressed similar concerns about potential injury from *S*-metolachlor applied to sweetpotato after it has been transplanted. Researchers have reported that *S*-metolachlor has the potential to injure sweetpotato at high rates and when rain occurs after application (Abukari et al. 2015; Meyers et al. 2012, 2013). *S*-metolachlor is a member of the chloroacetamide herbicide family. It is a soil-applied preemergence herbicide that inhibits seedling root and shoot growth by blocking the formation of long-chain fatty acids (Shaner 2014); this activity may explain the reduction in root length observed in previous research.

Charcoal and high-carbon soil additives can reduce herbicide efficacy and crop injury in field conditions (Singh et al. 2019; Soni et al. 2015). Previous research has also shown that dipping crop roots into activated charcoal can reduce herbicide injury in transplanted crops such as strawberry (*Fragaria* L.) and tobacco (*Nicotiana tabacum* L.) (Ahrens 1967; Yelverton et al. 1992). However, little information exists on the potential for charcoal to reduce or eliminate herbicide injury to sweetpotato. Thus, we conducted studies to determine the effect of flumioxazin (applied preplant) or *S*-metolachlor (applied preplant or after transplanting) on sweetpotato injury, storage root yield, and quality with and without activated charcoal applied in transplant water.

Materials and Methods

Field studies were conducted at the Horticultural Crops Research Station in Clinton, NC, in 2021 (35.023°N, 78.280°W) and 2022 (35.022°N, 78.280°W). Soil at the study sites was a Norfolk sandy loam (fine-loamy, kaolinitic, thermic Typic Kandiudults), pH 6.6, with 0.5% organic matter in 2021; and an Orangeburg loamy sand (fine-loamy, kaolinitic, thermic Typic Kandiudults), pH 6.0, with 0.5% organic matter in 2022. On July 8, 2021, and June 9, 2022, nonrooted 'Covington' sweetpotato cuttings were transplanted onto weed-free, bedded rows using a commercial mechanical transplanter (Checchi and Magli, Lehi, UT) with an in-row spacing of 30 cm. Plots consisted of two rows, each 1 m wide by 6.1 m long. The first row was a nontreated border row, while the second was used for data collection. All plots were maintained weed-free with between-row cultivation and hand removal of weeds as needed. The statistical design was a randomized complete block with four replications.

Treatments consisted of a factorial arrangement of five herbicide treatments: 1) no herbicide; 2) flumioxazin (Valor SX; Valent U.S.A. LLC, San Ramon, CA) applied pretransplant at 107 g ai ha^{-1}; 3) flumioxazin applied pretransplant at 214 g ai ha^{-1}; 4) *S*-metolachlor (Dual Magnum; Syngenta, CH) applied pretransplant at 1.6 kg ai ha^{-1}; and 5) *S*-metolachlor applied immediately after transplanting at 1.6 kg ai ha^{-1}. Also included were two activated charcoal treatments: 1) no activated charcoal was used; or 2) activated charcoal was used in transplant water at 9 kg ha^{-1}, which also included a nonionic surfactant (Induce; Helena Agri Enterprises LLC, Collierville, TN) at 5 ml L^{-1}. Transplant water was applied to each slip through the mechanical transplanter at a rate of 3,648 L ha^{-1} across all plots. An activated charcoal slurry was made before mixing with transplant water to improve mixing throughout the tank. The activated charcoal suspension was regularly agitated during transplanting to ensure a consistent application. Herbicides were applied with a CO_2-pressurized backpack sprayer calibrated to deliver 187 L ha^{-1} at 173 kPa with a two-nozzle boom equipped with TeeJet XR 8003-VS flat-fan nozzles (Spraying Systems Co., Wheaton, IL). Other production practices, including fertility, and insect and disease management, were conducted following recommendations by Kemble (2022).

Visual estimates of foliar sweetpotato injury were assessed on a scale of 0% (no crop injury) to 100% (crop death) at 1, 2, 4, and 8 wk after transplanting (Frans et al. 1986). Sweetpotato storage roots were harvested 110 d after transplanting with a commercial chain digger, hand-sorted into jumbo (≥8.9 cm in diam), no. 1 (≥4.4 cm but <8.9 cm), and canner (≥2.5 cm but <4.4 cm) (USDA-AMS 2005) grades, and weighed. Marketable yield was calculated as the sum of jumbo and no. 1 yields. Additionally, no. 1 sweetpotato storage root dimensions were assessed using a high-throughput optical grader (Exeter Engineering, Exeter, CA) to quantify treatment effects on storage root shape. Average length-width ratio (LWR) was calculated as the length divided by the diameter for each individual root and then averaged with other roots from the same plot. LWR is a metric that indicates overall sweetpotato root shape and has previously been used as a metric of herbicide injury (Meyers et al. 2010a); a smaller LWR value indicates a rounder sweetpotato root.

Residuals were plotted and visually examined to ensure homogeneity of variance. Yield data required a square root transformation to meet the assumptions of ANOVA. ANOVA was conducted with SAS software (version 9.4; SAS Institute Inc., Cary, NC) using the MIXED procedure. Least squared means were separated using Tukey's honestly significant difference test ($\alpha = 0.05$). Herbicide, charcoal, and year were treated as fixed effects, while replication nested within year was treated as a random effect.

Results and Discussion

Crop Injury

No visual injury was observed from flumioxazin applied preplant at rates as high as 214 g ai ha^{-1} (2× the registered rate) or *S*-metolachlor as high as 1.6 kg ai ha^{-1} (2× the recommended rate; Kemble 2022; data not shown). The lack of observed injury is consistent with previous research (Coleman et al. 2016; Kelly et al. 2006; Meyers et al. 2010a).

Sweetpotato Yield

Yield data were combined across years because no significant treatment-by-year interactions were observed ($P > 0.05$). No effect was observed from herbicide or charcoal treatment on no. 1, marketable, or total yield ($P > 0.05$). Results indicate that flumioxazin applied at the labeled rate does not reduce sweetpotato yield compared with the nontreated check (Table 1). Additionally, *S*-metolachlor applied at twice the recommended rate (Kemble 2022) did not reduce sweetpotato yield. Previous research indicates that *S*-metolachlor can reduce sweetpotato yield under certain environmental conditions (Abukari et al. 2015; Meyers et al. 2012), but yield reductions due to *S*-metolachlor application were not observed in this study. The addition of activated charcoal in the transplant water also resulted in no effect on sweetpotato yield. The results of this study confirm the conclusions of prior research and support the safety of applying flumioxazin preplant to sweetpotato when used at registered rates.

Table 1. Effect of flumioxazin and *S*-metolachlor with and without activated charcoal on sweetpotato storage root yield in Clinton, NC, in 2020 and 2021.[a]

Activated charcoal	Herbicide	Sweetpotato yield				
		Canner	No. 1	Jumbo	Marketable[b]	Total marketable[c]
		kg ha^{-1}				
No	None	4,320	22,630	5,650	28,280	32,600
Yes	None	4,980	22,510	7,220	29,730	34,710
No	Flumioxazin 107 g ai ha^{-1} preplant	3,910	20,220	6,960	27,180	31,080
Yes	Flumioxazin 107 g ai ha^{-1} preplant	4,270	21,060	6,730	27,680	31,910
No	Flumioxazin 214 g ai ha^{-1} preplant	4,070	17,090	8,670	25,640	29,670
Yes	Flumioxazin 214 g ai ha^{-1} preplant	4,380	20,690	4,910	25,600	29,980
No	*S*-metolachlor 1.6 kg ai ha^{-1} preplant	5,210	18,440	4,610	23,050	28,260
Yes	*S*-metolachlor 1.6 kg ai ha^{-1} preplant	5,040	19,850	6,030	25,880	30,910
No	*S*-metolachlor 1.6 kg ai ha^{-1} immediately after planting	5,150	19,260	7,250	26,510	31,660
Yes	*S*-metolachlor 1.6 kg ai ha^{-1} immediately after planting	4,270	20,940	5,900	26,840	31,110

[a]No significant treatment effects or interactions were present (P > 0.05). Least squared means with different letters are significantly different.
[b]Marketable yield is the sum of no. 1 and jumbo grades.
[c]Total marketable yield is the sum of canner, no. 1, and jumbo grades.

Table 2. Effect of flumioxazin and *S*-metolachlor with and without activated charcoal on length to width ratio of no. 1 sweetpotato storage roots in Clinton, NC, in 2020 and 2021.[a]

Herbicide	Length to width ratio	
	2021	2022
None	1.75a	2.05
Flumioxazin 107 g ai ha^{-1}	1.70a	2.05
Flumioxazin 214 g ai ha^{-1}	1.68ab	2.02
S-metolachlor 1.6 kg ai ha^{-1} before planting	1.55b	1.99
S-metolachlor 1.6 kg ai ha^{-1} after planting	1.56b	2.08

[a]Least squared means were separated by Tukey's honestly significant difference test at $\alpha = 0.05$. Means with different letters are significantly different.

Sweetpotato Storage Root Shape

There was a significant herbicide-by-tear interaction ($P = 0.0102$) for shape data; thus LWR was assessed by year. Charcoal had no effect on no. 1 LWR, and there were no interactions between charcoal and herbicide ($P > 0.05$). Herbicide affected LWR in 2021 ($P < 0.0001$) but not ($P = 0.3115$) in 2022 (Table 2). In 2021, the LWR was not different between flumioxazin applied at 107 or 214 g ai ha^{-1}, and the no-herbicide treatment. In 2021, *S*-metolachlor applied at 1.6 kg ai ha^{-1} before or after transplanting reduced LWR compared to no herbicide treatment, indicating that both *S*-metolachlor treatments resulted in rounder no. 1 sweetpotato roots. These results are consistent with previous research indicating that *S*-metolachlor applied directly after transplanting can reduce sweetpotato LWR under certain environmental conditions (Meyers et al. 2012). Limited information exists on the effect of *S*-metolachlor applications before transplanting on sweetpotato injury and yield; however, because *S*-metolachlor is registered for use on sweetpotato after transplantation only, the results of this study are consistent with the existing registration and do not suggest that *S*-metolachlor should be considered for application before transplanting. Flumioxazin did not affect root shape at either the 107 g ai ha^{-1} (1× registered use) or the 214 g ai ha^{-1} (2× registered use) rates, which is consistent with previous research (Meyers et al. 2010a).

Activated charcoal had no effect on sweetpotato yield or quality (grades, shape) across any treatment, indicating either that flumioxazin and *S*-metolachlor are not injurious enough at the tested rates for the charcoal to make a difference in yield and quality, or that activated charcoal is not an effective safener when mixed with transplant water. Additionally, the effects of *S*-metolachlor on sweetpotato root shape were not affected by charcoal. More research with additional herbicides is necessary to fully evaluate the potential of activated charcoal mixed with transplant water as a safener for preemergence herbicides on sweetpotato.

Neither flumioxazin nor *S*-metolachlor reduced sweetpotato yield in this study. The results of this study are consistent with those reported in prior research and indicate that flumioxazin and *S*-metolachlor are not detrimental to sweetpotato yield when used according to registered rates. Flumioxazin did not affect sweetpotato root shape in either year; however, *S*-metolachlor use resulted in rounder sweetpotato roots in 2021, indicating that *S*-metolachlor may affect sweetpotato root shape when applied at higher than registered rates under certain environmental conditions. Although root shape was affected by *S*-metolachlor in one year, *S*-metolachlor did not reduce the yield of no. 1 sweetpotato roots. These results are consistent with those found in prior research and indicate that flumioxazin and *S*-metolachlor are safe for continued use on sweetpotato.

Practical Implications

Because both flumioxazin and *S*-metolachlor are crucial to existing weed management programs in sweetpotato production in North Carolina, addressing grower concerns about these herbicides is critically important because herbicide options are limited for use on this crop. These studies were conducted in response to grower concerns about potential storage root yield and shape effects from flumioxazin and *S*-metolachlor, and they provide supporting evidence for their continued use as part of integrated weed management strategies for sweetpotato. This work should improve grower confidence in current recommendations and does not indicate the presence of detrimental yield or shape effects from these herbicides when used according to their respective herbicide label instructions.

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Competing Interests. The authors declare they have no competing interests.

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