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Author for Correspondence: Mark W. Shankle, North Mississippi Research and Extension Center- Pontotoc Ridge–Flatwoods Branch Experiment Station, Mississippi State University, Pontotoc, MS 38863
Email: mark.shankle@msstate.edu

Sweetpotato response to reduced rates of dicamba

Mark W. Shankle[1], Lorin M. Harvey[2], Stephen L. Meyers[3] and Callie J. Morris[4]

[1]Research Professor, North Mississippi Research and Extension Center- Pontotoc Ridge–Flatwoods Branch Experiment Station, Mississippi State University, Pontotoc, MS, USA; [2]Assistant Professor, North Mississippi Research and Extension Center- Pontotoc Ridge–Flatwoods Branch Experiment Station, Mississippi State University, Pontotoc, MS, USA; [3]Assistant Professor, Department of Horticulture and Landscape Architecture, Purdue University, West Lafayette, IN, USA and [4]Research Associate, North Mississippi Research and Extension Center- Pontotoc Ridge–Flatwoods Branch Experiment Station, Mississippi State University, Pontotoc, MS, USA

Abstract

A field study was conducted in Mississippi to determine the effect of reduced dicamba rates on sweetpotato crop tolerance and storage root yield, simulating off-target movement or sprayer tank contamination. Treatments included a nontreated control and four rates of dicamba [70 g ae ha^{-1} (1/8×), 35 g ae ha^{-1} (1/16×), 8.65 g ae ha^{-1} (1/64×), and 1.09 g ae ha^{-1} (1/512×)] applied either 3 d before transplanting (DBP) or 1, 3, 5, or 7 wk after transplanting (WAP). An additional treatment consisted of 560 g ae ha^{-1} (1×) dicamba applied 3 DBP. Crop injury ratings were taken 1, 2, 3, and 4 wk after treatment (WAT). Across application timings, predicted sweetpotato plant injury 1, 2, 3, and 4 WAT increased from 3T to 22%, 3% to 32%, 2% to 58%, and 1% to 64% as dicamba rate increased from 0 to 70 g ha^{-1} (1/8×), respectively. As dicamba rate increased from 1/512× to 1/8×, predicted No. 1 yield decreased from 127% to 55%, 103% to 69%, 124% to 31%, and 124% to 41% of the nontreated control for applications made 1, 3, 5, and 7 WAP, respectively. Similarly, as dicamba rate increased from 1/512× to 1/8×, predicted marketable yield decreased from 123% to 57%, 107% to 77%, 121% to 44%, and 110% to 53% of the nontreated control for applications made 1, 3, 5, and 7 WAP, respectively. Dicamba residue (5.3 to 14.3 parts per billion) was detected in roots treated with 1/16× or 1/8× dicamba applied 5 or 7 WAP and 1/64× dicamba applied 7 WAP with the highest residue detected in roots harvested from sweetpotato plants treated at 7 WAP. Collectively, care should be taken to avoid sweetpotato exposure to dicamba especially at 1/8× and 1/16× rates during the growing season.

Introduction

In the mid-1990s, genetically enhanced Roundup Ready® crops tolerant to the herbicide glyphosate were introduced and subsequently revolutionized weed control. The Roundup Ready® crop system became the foundation for weed management in cotton, corn, and soybean production in the United States for more than a decade, prior to the onset of glyphosate-resistant weeds. Today there are more than 50 species of glyphosate-resistant weeds worldwide (Heap 2021) and in response, additional herbicide tolerance traits have been developed in major row crops.

The Roundup Ready® Xtend System was approved by the U.S. Environmental Protection Agency (EPA) in 2016 for over-the-top use of dicamba in cotton and soybean to control glyphosate-resistant broadleaf weeds (EPA 2020). Initially in 2020, four dicamba products, XtendiMax®, Engenia®, FeXapan®, and Tavium® were labeled for use in dicamba-tolerant cotton and soybean. Registrations of three dicamba herbicides, XtendiMax®, Engenia®, and FeXapan® were vacated on June 3, 2020, by the U.S. Court of Appeals for the Ninth Circuit. However, on October 27, 2020, new registrations for over-the-top dicamba products XtendiMax®, Engenia®, and Tavium® were approved for use through 2025. These new registrations include additional requirements intended to mitigate off-target movement (Ambrose and Scott 2019).

Dicamba is a synthetic herbicide that mimics the plant growth hormone auxin. Auxin and other plant hormones influence growth through a balance of concentrations. Synthetic auxin herbicides are thought to induce cell elongation by reducing apoplastic pH and subsequently increasing enzyme activity responsible for cell wall loosening (Shaner 2014). At low concentrations, these compounds stimulate RNA polymerase, which in turn, results in increased RNA, DNA, and protein biosynthesis (Shaner 2014). The result is uncontrolled cell division and the destruction of vascular tissues. Conversely, at high concentrations, synthetic auxins inhibit cell division and stimulate ethylene production, which leads to the characteristic epinastic growth often associated with exposure to this class of herbicide (Shaner 2014).

In 2019, U.S. producers harvested 59,367 ha of sweetpotato with a farm value of more than US$588 million (USDA-NASS 2020). The southeastern states of Louisiana, Mississippi, and North Carolina as well as California make up the majority of sweetpotato production in the United States. During the 2017 growing season suspected off-target movement of dicamba to sweetpotato was reported on limited plantings in Arkansas (Francis 2018) and on an estimated 600 ha in Mississippi (Meyers 2018). Damage to sweetpotato plants due to dicamba drift consists of foliar twisting and curling, stem swelling, and leaf cupping (Clark et al. 2013). Sensitivity of sweetpotato to dicamba at 11 g ha^{-1} (1/10×) and 106 g ha^{-1} (1/100×) was documented by Schroeder et al. (2018). Batts et al. (2020) and Miller et al. (2020) also reported that reduced rates of dicamba alone or with glyphosate reduced sweetpotato yield. However, previous studies were limited to applications made 10 and 30 d after transplanting (DAP), which leaves uncertainty regarding dicamba effects at other exposure timings on sweetpotato crop injury and yield. Therefore, the purpose of this study was to investigate the effects of dicamba rate and application timing on sweetpotato injury and yield.

Materials and Methods

Field trials were conducted at the Pontotoc Ridge-Flatwoods Branch Experiment Station in Pontotoc, MS (34.1331°N, 89.0063°W) from 2018 to 2020. 'Beauregard' sweetpotato slips were transplanted on June 11, 2018; June 17, 2019; and June 30, 2020; into a Falkner silt loam (fine-silty, siliceous, thermic Aquic Paleudalfs) soil with pH 6.3 and 1.3% organic matter. The B-14 mericlone of 'Beauregard' was used because it represents the predominant rose-skinned, orange-fleshed, table-stock cultivar commonly grown in Mississippi (Shankle 2020). Plots consisted of two rows, each 9.14 m long, and 1.0 m apart with an in-row plant spacing of 30 cm. One row was treated, and the other row served as a nontreated buffer.

Treatments consisted of five rates of diglycoamine salt of dicamba with VaporGrip technology (XtendiMax®; Bayer CropScience, Monheim am Rhein Germany): 560 g ae ha^{-1} (1×), 70 g ae ha^{-1} (1/8×), 35 g ae ha^{-1} (1/16×), 8.65 g ae ha^{-1} (1/64×), and 1.09 g ae ha^{-1} (1/512×), and a nontreated control. All dicamba rates were applied 3 d before transplanting (DBP) or 1, 3, 5, or 7 wk after transplanting (WAP) with the exception of the 1× rate, which was applied only 3 DBP. Dicamba was applied with a tractor-mounted, CO_2-pressurized sprayer fitted with two 8002 TTI nozzles (Teejet Technologies, Springfield, IL) and calibrated to deliver 140 L/ha^{-1} carrier volume at 159 kPa. The experiment design was a randomized complete block with five replications in 2018 and four replications in 2019 and 2020.

Visual crop injury was rated on a scale of 0% (no injury) to 100% (crop death; Frans et al. 1986) at 1, 2, 3, and 4 wk after treatment (WAT). Sweetpotatoes were harvested 141, 114, and 111 DAP in 2018, 2019, and 2020, respectively, with a platform digger and separated using a Kerian L-30 Speed Sizer (Kerian Machines Inc., Grafton ND) into canner (>2.5 to 4.4 cm diam), No. 1 (>4.4 to 8.9 cm), and jumbo (>8.9 cm) grades. Misshapen roots of No. 1 size or greater were separated and classified as culls. The sum of jumbo, No.1, and canner grades represents total marketable yield.

Storage root samples were analyzed for the presence of dicamba and its metabolites. In 2019, only roots from plots treated with 1/8× dicamba and the nontreated control were analyzed. In 2020, roots from all plots were analyzed. A single No. 1 root per plot was delivered immediately following harvest to the Mississippi State Chemical Laboratory in Starkville, MS. Roots were washed, peeled, subsampled, homogenized, and stored at −20 C. Dicamba and metabolite detection was determined using liquid chromatography with two mass spectrometry detectors (LS-MS/MS).

Statistical Analysis

All data were subjected to ANOVA using JMP Pro software (JMP® version 15.2.1; SAS Institute Inc., Cary, NC). To determine whether there was a significant ($P \leq 0.05$) treatment-by-year interaction for the data collected, the Fit Model approach was used with treatment as a fixed effect, and year, replication within year and the interaction between treatment and year as random effects. A second ANOVA was conducted using the Fit Model approach, with the main effects of rate and application timing as fixed effects and replication as a random effect. Mean injury and yield data were subjected to regression analysis using the nonlinear curve-fitting function in JMP Pro and fit to the following models:

Linear (Equation 1):

$$Y = A + BX \quad [1]$$

where Y is the predicted value, A is the y-intercept, B is the slope of the line, and X is dicamba rate in g ae ha^{-1}.

Two-parameter exponential (Equation 2):

$$Y = A[exp(BX)] \quad [2]$$

where Y is the predicted value, A is the scale, B is the growth rate, and X is dicamba rate in g ae ha^{-1}.

Three-parameter exponential (Equation 3):

$$Y = A + B[exp(CX)] \quad [3]$$

where Y is the predicted value, A is the asymptote as dicamba rate approaches infinity, B is the scale, C is the growth rate and X is dicamba rate in g ae ha^{-1}.

Results and Discussion

Sweetpotato Injury

Due to a lack of significant treatment-by-year interaction, injury data were analyzed across all 3 yr. Because of a lack of significant dicamba application timing-by-rate interaction, the effect of dicamba rate on sweetpotato plant injury was pooled across application times. Preplant applications of dicamba did not result in discernable crop injury (data not shown). This observation is consistent with that reported by Price et al. (2020) who found no significant injury to cotton (*Gossypium hirsutum* L.) following a preplant application of dicamba. However, in soybean, which is more sensitive to dicamba than cotton, a preplant application of dicamba was found to cause significant injury (Thompson et al. 2007). Therefore, it is possible that sweetpotato sensitivity to dicamba may fall somewhere between that of cotton and soybean. Typically, symptoms of dicamba injury occur in regions of new plant growth first and will appear as twisted stems, cupped leaves, leaf pigment loss (yellow to white), and overall stunted growth.

Pooled across application timings of 1, 3, 5, and 7 WAP, predicted sweetpotato plant injury 1, 2, 3, and 4 WAT increased from 3% to 22%, 3% to 32%, 2% to 58%, and 1% to 64% as dicamba rate increased from 0 to 70 g ha^{-1} (1/8×), respectively (Figure 1). Miller

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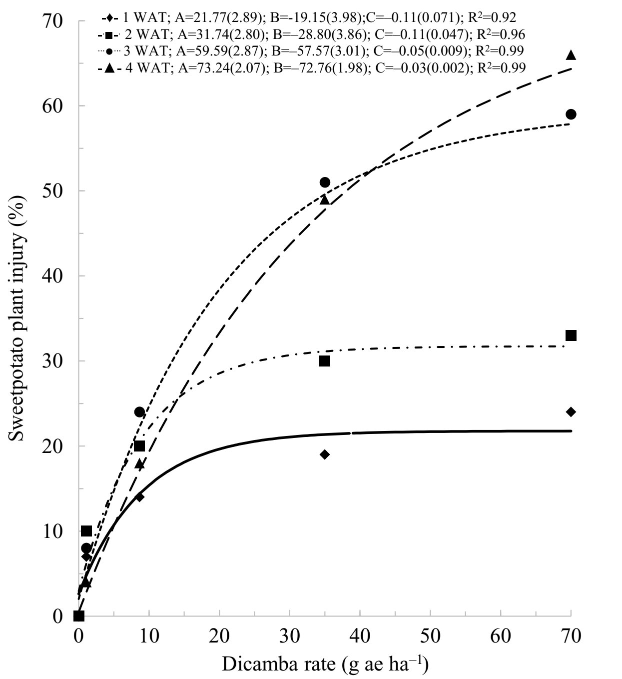

Figure 1. Effect of dicamba rate on sweetpotato plant injury pooled across application timings and 2018, 2019, and 2020 at Pontotoc, MS. Points represent observed mean data. Lines represent predicted values from Equation 3 (three-parameter exponential). Parameter estimates are followed by SE values in parentheses. WAT, weeks after treatment.

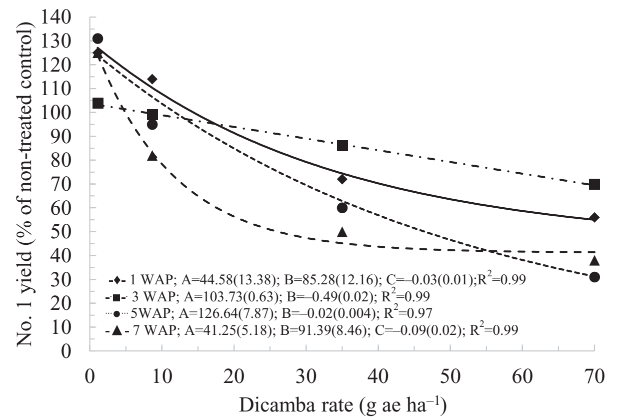

Figure 2. Effect of dicamba rate on No. 1 sweetpotato yield as a percent of the non-treated control by application timing and pooled across 2018, 2019, and 2020 at Pontotoc, MS. Points represent observed mean data. Lines represent predicted values from Equation 1 (linear: 3 WAP), Equation 2 (two-parameter exponential: 5 WAP), and Equation 3 (three-parameter exponential: 1 and 7 WAP). Parameter estimates are followed by SE values in parentheses. WAP, weeks after transplanting.

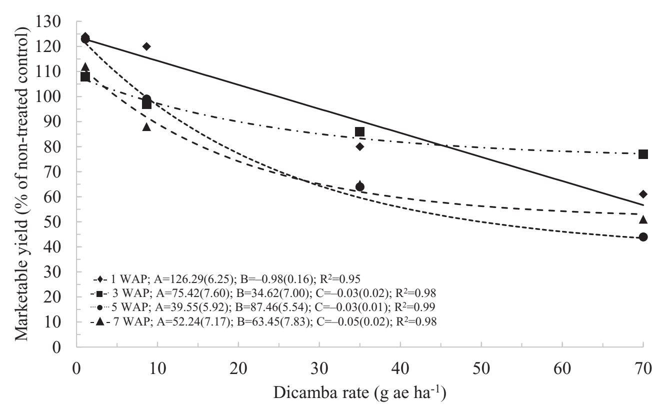

Figure 3. Effect of dicamba rate on marketable sweetpotato yield as a percent of the non-treated control by application timing and pooled across 2018, 2019, and 2020 at Pontotoc, MS. Points represent observed mean data. Lines represent predicted values from Equation 1 (linear: 1 WAP) and Equation 3 (three-parameter exponential: 3, 5, and 7 WAP). Parameter estimates are followed by SE values in parentheses. WAP, weeks after transplanting.

et al. (2020) reported similar results in 'Beauregard' sweetpotatoes treated 10 and 30 DAP with reduced rates possibly encountered in tank contamination and drift events of glyphosate plus dicamba. As glyphosate/dicamba increased from 11.2/5.6 g ae ha^{-1} to 112/56 g ha^{-1}, visual injury increased from 19% to 38%, 26% to 64%, and 17% to 43% at 1, 2, and 4 WAT, respectively. In general, as dicamba rate in the present study increased, injury severity increased from 1 to 3 WAT, and started to decrease by 4 WAT. Similarly, Miller et al. (2020) reported greatest visual injury symptoms 2 WAT, after which point injury remained consistent or decreased slightly through 5 WAT. Batts et al. (2020), who applied 0.56 to 56 g ae ha^{-1} dicamba to 'Beauregard' sweetpotato 10 or 30 DAP, also observed that injury from the highest dicamba rate increased between 7 and 14 DAT and then either decreased or remained the same between 14 and 28 DAT.

Sweetpotato Yield

Due to a lack of significant treatment-by-year interaction, sweetpotato yield data were analyzed across all 3 yr. Due to a significant dicamba application timing-by-rate interaction, the effect of dicamba rate was analyzed separately by dicamba application time. Across years, jumbo, No. 1, canner, and total marketable yield of the nontreated control were 992, 12,778, 4,555, and 18,325 kg ha^{-1}, respectively. There was no effect of treatment on either jumbo or canner yield grades (data not shown). Dicamba applied at 3 DBP did not reduce sweetpotato yield compared with the nontreated control (data not shown). As dicamba rate increased from 1.09 to 70 g ha^{-1}, predicted No. 1 yield decreased from 127% to 55%, 103% to 69%, 124% to 31%, and 124% to 41% of the nontreated control for applications made 1, 3, 5, and 7 WAP, respectively (Figure 2). Similarly, as dicamba rate increased from 1.09 to 70 g ha^{-1}, predicted marketable yield decreased from 126% to 61%, 110% to 77%, 125% to 45%, and 114% to 52% of the non-treated control for applications made 1, 3, 5, and 7 WAP, respectively (Figure 3). At higher dicamba rates (35 and 70 g ha^{-1}), applied at 1 or 3 WAP resulted in more No. 1 and total marketable sweetpotato than applications made 5 or 7 WAP. This suggests that sweetpotato plants encountering off-target movement of dicamba during early stages of growth may have time to recover from exposure. Plants that intercept dicamba, specifically at higher concentrations during later growth stages, do not have enough time to recover leading to reduced yield potential. In addition, a sweetpotato plant has at least 10× more leaves at 7 WAP compared with 1 WAP, resulting in the potential for increased interception of dicamba. Once dicamba enters the plant it is capable of moving from leaves (source) to storage roots (sink), thereby impeding storage root development (sizing-up), and hence reduced yield. These results agree with those reported by Miller et al. (2020) who found that 1/10× and 1/33× rates of glyphosate plus dicamba or 2,4-D reduced No. 1 and total sweetpotato yield more when applied at 30 DAP compared with 10 DAP.

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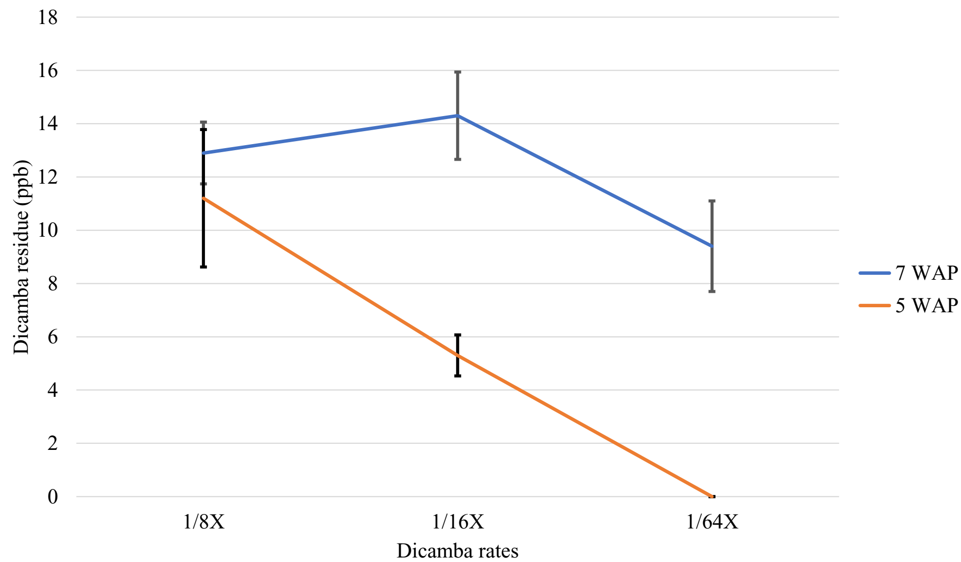

Figure 4. Amount of dicamba residue detected in 2020 sweetpotato storage roots from applications at 5 and 7 WAP at Pontotoc, MS. 1× = 560 g ae ha^{-1}. ppb, parts per billion; WAP, weeks after transplanting.

Our research demonstrates that very low sublethal rates of dicamba may increase No. 1 and total marketable sweetpotato yield (Figures 2 and 3) compared with a nontreated control, but this response can differ relative to application time. Based on predictive models, dicamba at rates less than 26, 19, 24, and 5 g ha^{-1} applied 1, 3, 5, and 7 WAP, respectively, resulted in a higher No. 1 sweetpotato yield than the nontreated control. Similarly, dicamba at rates less than 27, 10, 10, and 5 g ha^{-1} applied at 1, 3, 5, and 7 WAP, respectively, resulted in a higher total marketable sweetpotato yield than the nontreated control. In a review about the role of auxin on tuber and storage root initiation, Kondhare et al. (2021) reported that endogenous auxin levels are high during very early stages of belowground storage organ initiation, but levels drop in later stages. The authors suggest that the increased abundance of auxin during storage root initiation promotes cell division. Kondhare et al. (2021) further summarized that the expression of *SRD1*, a MADS box gene, is correlated with auxin content and that the overexpression of *SRD1* can lead to enhanced sweetpotato yield due to induced proliferation of metaxylem and cambium cells. However, little is understood about the role of exogenous synthetic auxin on these processes. Further research is needed to determine whether very low sublethal rates of dicamba might increase storage root production.

Dicamba Residue in Storage Roots

In 2019 and 2020, dicamba and metabolites 3,6-dichlorosalicylic acid and 5-hyrdoxy-dicamba were not detected in storage roots from the nontreated control. In addition, the two metabolites were not detected in any roots from plots treated with dicamba. Dicamba residue was detected in roots with 1/8× dicamba applied 5 or 7 WAP in both 2019 and 2020, as well as 1/16× dicamba applied 5 or 7 WAP and 1/64× dicamba applied 7 WAP, which were submitted for analysis only in 2020 (Figure 4). The amount of dicamba residue detected ranged from 5.3 to 14.3 parts per billion (ppb). The highest amount of dicamba was detected in roots with treatments applied closest to harvest at 7 WAP. Also, levels of detected dicamba decreased as dicamba application rate decreased from 1/8× to 1/64×. To our knowledge, this is the first documentation of simulated dicamba drift resulting in detectable dicamba residue in harvested sweetpotato storage roots. Similar results have been reported in watermelon. Culpepper et al. (2018) applied dicamba at 7.5 g ha^{-1}(1/75×) and 2.24 (1/250×) to watermelon at 20, 40, and 60 DAP and reported that applications of 1/75× resulted in 10 to 30 ppb of dicamba residue at harvest. In addition, dicamba at 1/250× applied 40 or 60 DAP resulted in detectable dicamba residue (10 ppb) in one of two years. This is of concern because the EPA has a zero tolerance for dicamba in sweetpotato storage roots. EPA guidelines 40 CFR 180.5 states that if no tolerable level of chemical residue has been set for a crop, then there is a zero tolerance for the presence of that chemical (EPA 2021). Therefore, the detection of any amount of dicamba in sweetpotato storage roots will render them unmarketable. With this knowledge, extra precautions should be taken to limit sweetpotato crop exposure to dicamba, specifically closer to harvest.

Conclusions

Dicamba applied at reduced rates to simulate off-target movement onto sweetpotato does have the potential to reduce yield, specifically at the 1/8× rate when compared with a nontreated control. In this study, storage root yield with dicamba applied earlier in the growing season at 1 and 3 WAP was higher compared with treatments applied at 5 and 7 WAP despite similar visual crop injury. This suggests that off-target interception of dicamba by sweetpotato plants during early stages of growth might not result in complete crop loss. In fact, yield with the lowest rate of dicamba applied 1 WAP was not different than that of the nontreated control. Therefore, future investigation is warranted to determine whether a potential positive yield effect exists with very low sublethal rates of a synthetic auxin applied during the storage root initiation stage. Lastly, precautions should be taken to avoid sweetpotato crop exposure to dicamba throughout the growing season, especially near harvest, because it is unlikely that storage roots will have adequate time to completely metabolize dicamba molecules, rendering the storage roots unmarketable due to EPA pesticide residue guidelines. Special consideration should be given to sweetpotato production fields in close proximity to other crops that are

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genetically tolerant to dicamba because certain environmental conditions combined with close proximity can culminate in catastrophic yield loss events. It is important to consider all management options to properly steward herbicide applications and minimize off-target movement of dicamba to sensitive crops. Future studies should also validate these findings in other commercially grown sweetpotato varieties and growing environments as herbicide tolerance may vary due to genetics, environment, and the combination of interactions thereof.

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