ABSTRACT

LINDLEY, JENNIFER JEAN. Bicyclopyrone as a Possible Flumioxazin Herbicide Alternative in Sweetpotato. (Under the direction of Dr. Katherine M Jennings).

North Carolina's sweetpotato is annually worth over $350 million. Growers have reported that a critical need exists for management options to limit sweetpotato yield loss caused by weeds. However, growers have few herbicide options available to them and several weeds species have developed resistance to traditionally applied herbicides, such as PPO- and ALS-inhibitors. Greenhouse studies were conducted in 2018 and field studies were conducted in 2016, 2017 and 2018 to examine sweetpotato tolerance to bicyclopyrone.

Greenhouse studies were conducted in 2018 to determine sweetpotato tolerance to bicyclopyrone treatments applied to 'Covington' and NC04-531 varieties. Herbicide treatments included PREPLANT (immediately before transplanting in soil) and POST (4 hours after planting) applications of bicyclopyrone (at 25, 50, 100 and 150 g ai ha^{-1}). A nontreated weed-free check was included in all studies for comparison. Sweetpotato plant height, chlorosis and dry weight were all negatively affected by bicyclopyrone treatments with plant height and dry weight decreasing with increasing rate of bicyclopyrone. Sweetpotato chlorosis increased with increasing rate of bicyclopyrone.

Field experiments were conducted in 2016, 2017 and 2018 to determine the tolerance of "Beauregard" and "Covington" sweetpotato to bicyclopyrone PREPLANT or POST-directed compared to traditionally applied herbicides. Treatments included bicyclopyrone 50 g ha^{-1}, flumioxazin 107 g ha^{-1}, bicyclopyrone 50 and 100 g ha^{-1} followed by *S*-metolachlor 800 g ha^{-1}, flumioxazin 107 g ha^{-1} followed by *S*-metolachlor 800 g ha^{-1}, flumioxazin 107 g ha^{-1} followed by *S*-metolachlor 800 g ha^{-1} followed by bicyclopyrone 50 g ha^{-1} and clomazone 420 g ha^{-1}followed by *S*-metolachlor 800 g ha^{-1}. Nontreated weedy and weed-free checks were included for comparison. The weed-free control plots were maintained weed-free during the studies and plant vigor was evaluated on test plots after the treatments were initiated. Visual injury, consisting of chlorosis and necrosis of leaves, and stunting were evaluated, with most treatments recovering by harvest. Marketable yield and quality of sweetpotato storage roots were reduced for increased rates of bicyclopyrone.

Bicyclopyrone as a Possible Flumioxazin Herbicide Alternative in Sweetpotato

by
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DEDICATION

To my husband Richard and daughter Gillian who gave me the time and support I needed throughout this journey back to school.

BIOGRAPHY

Jennifer Lindley grew up in Lexington NC. She completed a B.S. in Chemistry in 2001. After a career change in 2011, she had the opportunity to learn about the agrochemical industry and agricultural practices while working for Syngenta Crop Protection. Her experiences led her to pursue a Master of Science degree in the Department of Horticultural Science.

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North Carolina's sweetpotato is worth annually over $350 million (USDA-NASS 2017). The grower advisory committee for the US Sweetpotato Council recently have reported that the lack of pesticides, including herbicides, is a critical issue for growers as growers have few herbicide options available to them and several weeds species have developed resistance to traditionally applied herbicides, such as PPO- and ALS-inhibitors. Growers have reported that a critical need exists for management options to limit sweetpotato yield loss caused by weeds. Thus, greenhouse studies were conducted at the Syngenta Greenhouse complex, Greensboro NC in 2018 and field studies were conducted at the Horticultural Crops Research Station, Clinton NC in 2016, 2017 and 2018 to examine tolerance to bicyclopyrone applications.

Greenhouse studies were conducted in 2018 to determine application tolerance of Covington and NC04-531 sweetpotato clones to bicyclopyrone treatments. Herbicide treatments included PREPLANT (immediately before transplanting in soil) and POST (4 hours after planting) applications of bicyclopyrone (at 25, 50, 100 and 150 g ai ha^{-1}). A nontreated weed-free check was included in all studies for comparison. Sweetpotato vigor was evaluated after treatments were initiated. Sweetpotato plant height, plant height, chlorosis and dry weight were all negatively affected by bicyclopyrone treatments with plant height and dry weight decreasing with increasing rate of bicyclopyrone. Likewise, sweetpotato chlorosis increased with increasing rate of bicyclopyrone.

Field experiments were conducted in 2016, 2017 and 2018 on Beauregard and Covington varieties to determine the tolerance of the sweetpotato plants and storage roots to applications of bicyclopyrone PREPLANT or POST-directed when compared to traditional herbicide

management plans. Treatments included applications of bicyclopyrone 50 g ha^{-1}, flumioxazin 107 g ha^{-1}, bicyclopyrone 50 and 100 g ha^{-1} followed by *S*-metolachlor 800 g ha^{-1}, flumioxazin 107 g ha^{-1} followed by *S*-metolachlor 800 g ha^{-1}, flumioxazin 107 g ha^{-1} followed by *S*-metolachlor 800 g ha^{-1} followed by bicyclopyrone 50 g ha^{-1} and clomazone 420 g ha^{-1} followed by *S*-metolachlor 800 g ha^{-1}. Nontreated weedy and weed-free checks were included for comparison. The weed-free control plots were maintained weed-free during the studies and plant vigor was evaluated on test plots after the treatments were initiated. Visual injury, consisting of chlorosis and necrosis of leaves, and stunting were evaluated. Stunting and chlorosis of the sweetpotato plants were seen as soon as 8 days after application of PREPLANT bicyclopyrone, but most plants were able to recover vigor by 7 weeks after planting with treatment yields similar to weed-free control yields. Marketable yield and quality of sweetpotato storage roots were reduced for increased rates of bicyclopyrone.

Key words: sweetpotato, greenhouse, weed control, control, interference.

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With an increasing global population driving the need for food security and a continuous demand for high nutrition value crops, sweetpotato is a significant contributor to the diet of the world's population (Ofori et al. 2005). High in levels of vitamin A, vitamin C, iron, potassium, fiber and beta-carotene, yet relatively easy to grow in suboptimum soils, sweetpotato can both improve food security in developing countries and help to reduce malnutrition. In frost free regions, sweetpotato can be harvested sequentially, ensuring constant food availability and access to the high nutrition value crop (Smith et al. 2009, Ofori et al. 2005). Due to their ability to adapt to varying environments, drought tolerance and shorter maturity time of three to five mo, sweetpotato are highly important to smallholder cropping systems worldwide (Mosta et al. 2015).

In the US, North Carolina ranks as the top producing state for sweetpotato, with production primarily occurring from the coastal plain to the Sandhills region of the state (Anonymous 2017c, Schultheis et al. 1999). In terms of crop production value, sweetpotato ranks fourth for the state, surpassed only by tobacco, corn and soybean, and is an integral part of the North Carolina farming system in which these crops are grown in rotation. In North Carolina there were over 36,000 hectares of sweetpotato harvested in 2017, with a value of $346 M (USDA-NASS 2017). With similar root size, storage capacity and high yields, Beauregard and Covington are important commercial clones grown in the state (Yencho et al. 2008, Smith et al. 2009, Schultheis 2017).

Many factors can lead to crop loss including drought, weeds, insects and disease. One of the largest contributors to worldwide crop losses is weeds, currently estimated at 34%, which highlights the need for development and use of effective weed management practices (Sarangi and Jhala, 2016). With sweetpotato production representing a large portion of crop land in use for commercial farming in North Carolina, the need for effective weed management practices is a concern for many farmers (Alan Thornton, NC State University Extension Agent, personal communication). Sweetpotato is primarily a field production crop and maintaining a weed-free field through row closure is key to a successful crop yield (Monks and Schultheis 1998, Weaver et al. 1992). Weed management is typically managed through a variety of weed management strategies, including combinations of preplant tillage, PRE and POST herbicide applications, row middle cultivation and hand removal of remaining weeds (Schultheis et al. 1999, Egel et al. 2017). A significant number of weeds found in sweetpotato cropping systems can be managed by use of traditional herbicide applications. However, contributing to the difficulty in managing weeds in US sweetpotato, is the limited number of registered herbicides for sweetpotato (Kemble 2019, Neal et.al. 2016). Compounding the issue is repeated removal, via regulatory processes, of herbicides that have previously been registered in the US and Canada and increased restrictions on the legal approved use of a product (Fennimore and Doohan 2008).

A growing concern to farmers in sweetpotato fields is the increasing emergence of herbicide-resistant weeds. Sweetpotato, and many other traditionally grown agriculture row crops, rely on herbicides with similar modes of actions, such as protoporophyrinogen oxidase enzyme (PPO) inhibitors or acetyl CoA carboxylase (ACCase) inhibitors, which can encourage and allow weeds to develop resistance. Globally, there are over 250 reported weed species that show resistance to more than 160 different herbicides, highlighting the need for continual development of herbicides with alternate modes of action that can provide similar residual weed control (Sarangi and Jhala 2016). PPO-resistant weeds, including Palmer amaranth (*Amaranthus palmeri*), have been confirmed in North Carolina and PPO-resistant goosegrass, common ragweed, tall waterhemp and Palmer amaranth have been reported throughout the United States

(Heap 2019), leading to the need for additional herbicides with alternative modes of action for control of resistant weeds (Jennings and Hopper 2017).

A primary weed of concern for North Carolina farmers, Palmer amaranth can significantly reduce crop yield and lead to lost profits. The presence of Palmer amaranth in a sweetpotato field can negatively affect the yield to such an extent that researchers developed and established a recommended threshold. To successfully limit marketable sweetpotato yield losses to less than 10%, researchers recommended growers maintain their field with less than one Palmer amaranth plant per 11m row (Meyers et al. 2010b). There is also a limited time window for control of Palmer amaranth in sweetpotato to limit yield loss. Between 2 to 6 weeks after transplanting (WAT) the fields need to be maintained weed-free to maximize yield and limit loss due to weed presence (Meyers et al. 2010a). For these reasons, a significant amount of research has been done and continues to be centered on new and alternative MOA herbicides, both registered and non-registered, that exhibit potential for incorporation into a weed management plan that can control Palmer amaranth (Meyers et al. 2013a).

In order to successfully control Palmer amaranth in sweetpotato, the current recommendation schedule includes an application of Valor® (Valent U.S.A. Corporation, Walnut Creek, CA), which contains flumioxazin, preplant at 210 g ha^{-1} followed by application of Dual Magnum® (Syngenta Crop Protection LLC., Greensboro, NC), which contains *S*-metolachlor, at 7-14 days after transplanting at a rate of 840 g ha^{-1} (Meyers et al. 2010a, Jennings and Hopper 2017, Anonymous 2010). Application of these herbicides in series provides for initial control and season long residual weed management, with >90% control of troublesome weeds, including Palmer amaranth, when applied prior to emergence (Coleman et al. 2016). This herbicide rotation allows the fields to be maintained weed-free between weeks 2 to 6 WAT in order to maximize yield and limit loss due to competition (Meyers et al. 2010a). While there has been some concern reported related to root damage from *S*-metolachlor usage, application of *S*-metolachlor remains part of the recommended management plan, with application at the suggested 2 WAT greatly improving performance (Meyers et al. 2012, Meyers et al. 2013b). *S*-metolachlor does not provide postemergent weed control, so it must be applied before weeds appear to be effective (Meyers et al. 2010a, Anonymous 2014). However, Dual Magnum should not be applied immediately after transplanting as it can lead to decreased yield and injury (Meyers et al. 2012, Meyers et al., 2013b). In a recent survey, growers reported that approximately 98% of hectarage used for sweetpotato is treated with flumioxazin (Jennings and Hopper, 2017). With the extensive use of flumioxazin in sweetpotato, a need exists for an alternative preemergence herbicide in the weed management program for sweetpotato. One alternative herbicide to flumioxazin that offers potential to be utilized in sweetpotato cropping systems is bicyclopyrone, a member of the HPPD (*p*-hydroxyphenylpyruvate dioxygenase) inhibiting herbicide family (Dunne 2012).

Bicyclopyrone is a WSSA group 27 selective herbicide that has both PRE- and POST activity on broadleaf weeds and annual grasses (Anonymous 2017a). Currently sold as part of a premix, tradename Acuron® (Syngenta Crop Protection, Greensboro, NC), for use on field corn, seed corn, silage corn, yellow popcorn and sweet corn, bicyclopyrone represents a new class of herbicides that could aid in reducing selection pressures (Anonymous 2015, Walden 2015, Anonymous 2017a). With the ability to be applied PRE and taken up by the weeds through water in the soil or applied POST allowing for foliar uptake, bicyclopyrone has the potential to provide season long control through varying application timings (APVMA 2017).

Residual control of weeds with herbicides can be affected by many factors, including pesticide half-life and mobility in the soil. Many pesticides have been found to adsorb to soil particles, especially soils with high clay and organic matter, causing them to become immobile. In contrast, soils with high sand content are typically more permeable, which allows water, and pesticides, to move quickly through the soil profile. Bicyclopyrone has been found to be highly mobile in most soils due to a low soil adsorption coefficient, which leads bicyclopyrone to be capable of movement through soil after irrigation or rainfall events (APVMA 2017). Application of a pesticide followed by irrigation or rainfall event can lead to incorporation of the pesticide into the desired soil region and away from direct contact with the plant or it can lead to movement of the pesticide into a region where it would become ineffective, outside of the root zone. While bicyclopyrone can be transported away from the surface following irrigation or rainfall, research has shown that bicyclopyrone is also capable of returning to the soil surface in as little as 2 days under field conditions due to the upward and downward movement of water in the soil profile. This bidirectional movement indicates that bicyclopyrone is capable of movement away from and back into the root zone depending on soil moisture levels (Hand et al. 2015).

The use of bicyclopyrone for control of broadleaf weeds has previously been examined in several vegetable crops (Accinelli et al. 2015, Gage 2016, Chen 2017, Felix and Ishida 2015). Vegetable crops including onion, dill, radish and carrot have shown selective herbicide tolerance to bicyclopyrone when applied PRE, POST-directed and POST. Onion, dill, radish and carrot were found to be tolerant to PRE and POST-directed applications but bicyclopyrone POST caused severe crop injury. Bicyclopyrone POST controlled both hairy galinsoga (*Galinsoga quadriradiata* Cav.) and common purslane (*Portulaca oleracea* L.) >80% but provided limited control (45-80% injury) when applied PRE depending on soil types. However, PRE and POST applications of bicyclopyrone provided no control of prostrate pigweed (*Amaranthus blitoides* S. Wats.) (Chen 2017). Bicyclopyrone PRE reduced direct seeded onion stand ~65% and caused severe injury (65 to 80% chlorosis and stunting). However, bicyclopyrone POST at the 2-leaf stage provided good weed control, with limited crop injury and yields similar to nontreated controls. The weeds controlled by bicyclopyrone POST included common lambsquarters, redroot pigweed, hairy nightshade, kochia, spotted ladysthumb and grass weeds (Felix and Ishida, 2015).

With the lack of herbicides registered in sweetpotato and the need for alternative herbicides in sweetpotato, studies were conducted to determine the tolerance of sweetpotato to bicyclopyrone PREPLANT, POST and POST-directed.

Materials and Methods

Greenhouse Studies. Studies were conducted at the Syngenta Crop Protection greenhouse (36.07°N, -79.91°W) in Greensboro, NC in 2018. Covington and NC04-531 sweetpotato non-rooted cuttings (10 cm in height with 1 to 3 lf) were planted into 20-cm wide by 20-cm deep polyethylene pots (Nursery Supplies Inc., Chambersberg, PA) containing nontreated Orangeburg sandy loam (fine-loamy, kaolinitic, thermic, typic Kandiudults) with pH 6.2, CEC 2.8 meq per 100g and 0.6 % organic matter from the Horticultural Crops Research Station near Clinton, NC. The sweetpotato plants were grown in a greenhouse with natural sunlight during summer months with temperatures being controlled from 20 to 30 C.

A total of twenty treatments, consisting of combinations of two application timings, five herbicide rates and two sweetpotato clones, were evaluated in the greenhouse study. Treatments consisted of bicyclopyrone PREPLANT and POST at 0 (nontreated check), 25, 50, 100 and 150 g ha^{-1} arranged in a randomized complete block design with 4 replications. The study was conducted twice, with two runs separated temporally. PREPLANT and POST applications were applied to run 1 and run 2 on June 18, 2018 and July 6, 2018, respectively. PREPLANT treatments were applied to the soil surface and plants were planted immediately after application. POST herbicides were applied immediately after plants were transplanted. Treatments were applied in a spray chamber with a CO_2- pressurized sprayer calibrated to deliver 187 L ha^{-1} with a single XR 1102VS nozzle tip (TeeJet Technologies, Springfield, IL) at 280 kPa. Following the PREPLANT application, pots were watered lightly to incorporate the herbicides but not so much as to allow leaching through the pots. After 72 h pots were watered as needed. Sweetpotato plants were not watered for 72 h after POST applications to avoid potentially washing herbicide from leaves, after which time pots were watered as needed.

Each pot was treated as a single experimental unit. Data recorded included percent visual injury (chlorosis, necrosis and leaf deformation) and stunting rated visually on a 0 to 100% scale (0 = no injury to 100% = plant death) determined weekly for 8 or 9 wk (Frans et al 1986). Sweetpotato height was measured weekly by measuring from the soil surface to the node of the last fully expanded true leaf. Destructive harvest of sweetpotato plants were conducted 64±2 d after POST application. Shoots were cut at the soil surface then placed in paper bags and air-dried at 25 to 45 C for 30 d before determining dry weight.

Sweetpotato plant dry weight, plant height, injury and stunting data were subjected to analysis of variance (ANOVA) using PROC MIXED (SAS 9.4, SAS Institute, Inc. Cary, NC) with a separate analysis performed for each rating date. Clone, application timing, application rate and the interactions of these effects were considered fixed effects and replication, replication within run and run by treatment interactions were considered random. All data were checked for variance homogeneity and normality before statistical analysis by plotting residuals and the arcsine transformation was used to improve normality and homogeneity of error variances for stunting, dry weight and injury. Due to a lack of significant interaction for rate by application timing and rate by clone, data were averaged across application timings and clone, with the exception of dry weight where differences between the clones was determined to be significant. When ANOVA indicated a significant rate effect, data were subjected to regression analysis against rate by SAS PROC MIXED to determine best-fit models. Least squares means were used to estimate coefficients for logistic and Gompertz models via SAS PROC GLM.

The three-parameter logistic model was used to describe the relationship between application rate and each plant height and plant dry weight: $Y = A / (1 + k * \exp(- c * R))$, where Y is sweetpotato plant height or dry weight, A is the upper asymptote, k and c are constants and R is bicyclopyrone application rate in g ai ha^{-1}.

The three-parameter Gompertz equation was used to describe the relationship between application rate for plant stunting and injury: $Y = A * \exp(-k * \exp(- c * R))$ where Y is percentage sweetpotato stunting or injury, A is the upper asymptote for injury or stunting, k and c are constants and R represents the application rate of bicyclopyrone in g ai/ ha^{-1} (Knezevic et al. 2002).

Field Studies. Studies were conducted in 2016, 2017 and 2018 at the Horticultural Crops Research Station in Clinton, NC (35.0232°N, 78.2804°W). Field-grown slips (non-rooted cuttings) were cut from a field propagation bed in 2016 (Beauregard), 2017 (Covington) and 2018 (Covington). Slips were mechanically transplanted onto raised beds 10-cm deep and 30-cm apart using a tractor pulled commercial mechanical transplanter, with a between row spacing of 1 m. Soil type was a Norfolk sandy loam (fine-loamy, kaolinitic, thermic Typic Kandiudults) with pH 6.0 and CEC 2.8 meq per 100g, and pH 6.2 and 1.2 % organic matter in 2016 and 2017 respectively. In 2018, the soil type was an Orangeburg sandy loam (fine-loamy, kaolinitic, thermic Typic Kandiudults) with pH 6.2, CEC 2.3 meq per 100g and 0.8 % organic matter. Plots were two rows, each 1 m wide by 6.1 m long. The first row of each plot was a nontreated border row and the second row was treated.

Nine total herbicide treatments with varying application rates were evaluated in three field studies between 2016 and 2018. Within each study, the treatments were assigned randomly to locations within each of the replications, following a randomized complete block design. Treatments consisted of PREPLANT, POST and POST-directed (Table 1) herbicide treatments along with nontreated weedy and weed-free checks. Bicyclopyrone POST-directed in 2016 and 2018 also contained a nonionic surfactant (NIS) at a rate of 0.25%v/v. Four replications were used in 2016 and 2018, and three replications in 2017. PREPLANT applications were made 1 d prior to transplanting. All PREPLANT herbicide applications were made with a CO_2-pressurized backpack sprayer calibrated to deliver 187 L ha^{-1} through a 2-nozzle applicator boom equipped with TeeJet XR 8003VS nozzles. Subsequent POST and POST-directed herbicide applications were made with a CO_2-pressurized backpack sprayer calibrated to deliver 187 L ha^{-1} through a 1 or 2-nozzle boom equipped with TeeJet XR 8003VS nozzles, with a TeeJet Turbo TT11003 nozzle used for POST-directed applications in 2018.

Studies were maintained weed-free throughout the season by hand removal and cultivation. Sethoxydim (Poast®, 0.18 kg ai L^{-1}, BASF Corp., Research Triangle Park, NC) at 0.34 kg ai ha^{-1} plus 1% v/v crop oil (Agri-Dex, Helena Chemical Co., Collierville, TN) was applied as needed to control goosegrass [*Eleusine indica* (L.) Gaertn.] and large crabgrass [*Digitaria sanguinalis* (L.) Scop.] (Table 2).

Sweetpotato injury (chlorosis, necrosis and leaf deformation, and stunting) was estimated visually, on a scale from 0 (no injury) to 100% (crop death) at 2, 3, 4 and 8 WAT. Palmer amaranth control was estimated visually on a scale from 0 (no control) to 100% (complete control) at 4 and 8 WAT. Sweetpotato storage roots were harvested 113 ±5 DAP, using a tractor mounted chain digger and hand-graded into jumbo (≥8.9-cm diam), no. 1 (≥4.4 cm but <8.9 cm), and canner (≥2.5 cm but <4.4 cm) grades (USDA 2005). Total marketable yield was calculated as the sum of no. 1, jumbo, and canner grades.

Data were subjected to ANOVA using SAS (SAS 9.3, SAS Institute Inc., Cary, NC) PROC MIXED with the fixed effect of herbicide treatments and random effect of replication. Data were analyzed separately for each year because of the limitation of the experimental design; that is, one additional treatment included in 2017 and one treatment was missing in each 2016 and 2018. Along with this reason, all data was presented by year because a significant year by treatment interaction reported when analyzed using the treatments that were repeated during all three years. Data were checked for homogeneity of variance by plotting residuals. Weedy and weed-free check plots were included in the analysis for sweetpotato yield. Due to a lack of variance however, these treatments were not included in the ANOVA analysis of sweetpotato injury and Palmer amaranth control. Data for sweetpotato injury and Palmer amaranth control were subjected to arcsine transformation to improve normality and homogeneity of error variances; however, back-transformed means are presented. Means were separated using Fisher's least significant difference (LSD) test at the 0.05 significance level.

Results and Discussion

Greenhouse Studies. Due to a lack of treatment by replication and run interaction, the data were combined across each run and replicate. Additional statistical analysis indicated that the interaction between application timing and clone was not significant ($p<0.05$) for all measured variables except for dry weight. Therefore, the results are presented with respect to significance of main effects or their interactions.

*Sweetpotato Injury***.** Injury, including chlorosis, necrosis and leaf deformation, were observed in the growing tips as early as 1 WAT on sweetpotato treated with bicyclopyrone (data not shown). A linear trend of increasing sweetpotato injury (%) as bicyclopyrone rate increased was observed at 3, 5 and 8 WAT (Figure 1). Sweetpotato injury was less than 12% for all bicyclopyrone rates at 3 WAT, however by 8 WAT injury ranged from 15 to 39% for low to high application rates. Plant clone (Covington or NC04-531) only appeared as significant at 1 WAT and 9 WAT (end of the study). Application timing (PREPLANT or POST) was not a significant factor for plant injury.

*Sweetpotato Stunting***.** (Figure 2). Stunting of the sweetpotato followed a similar linear trend as injury, with stunting increasing as bicyclopyrone rate increased. Bicyclopyrone application timing (PREPLANT or POST) was not a significant factor for plant stunting. Plant clone (Covington or NC04-531) only appears as significant toward the end of the study, at 8 and 9 WAT near the end of the study. Nontreated controls were not included in the analysis of stunting because crop injury was always 0% within this treatment.

Sweetpotato Dry Weight. The transformed ANOVA data revealed a significant interaction between plant clone and bicyclopyrone application rate for sweetpotato dry weight. This interaction likely resulted because NC04-531 had larger dry biomass when compared to

Covington at the 0 rate (nontreated control). The difference in biomass with respect to clone are likely due to the inherent differences in clone biomass accumulation (La Bonte et al. 1999, Harrison and Jackson 2011). Dry weight of the sweetpotato clones decreased with increasing application rates (Figure 3).

*Sweetpotato Plant Height***.** Starting at 4 WAT, the rate of bicyclopyrone applied became significant relative to plant height (data not shown). The clone of sweetpotato, Covington or NC04-531, significantly affects plant height towards the end of the study, starting at 6 WAT (data not shown). The significantly greater plant height for NC04-531 clone compared to Covington at later dates may reflect a difference between clones in the response to application of bicyclopyrone. It may, however, also be attributed to some extent to different growth characteristics for the clones, which is observed in the growth of the control checks. For both clones, there is a significant decrease in the plant height corresponding to the increase of the application rates (Figure 4). At all timings, the clone by rate interaction is not significant. Application timing, PREPLANT or POST, with a couple of exceptions, were not significant to the sweetpotato plant height.

Field Studies.

2016. Sweetpotato injury caused by bicyclopyrone was observed in the form of bleaching, chlorosis, necrosis of plant tissues and overall crop stunting. At 3 WAT, injury of the sweetpotato was 23% for bicyclopyrone fb *S*-metolachlor, 14% for bicyclopyrone alone and less than 2% injury for all other treatments (Table 3). By 5 WAT, sweetpotato had recovered sufficiently as injury was 0 to 9% and was similar for all treatments. At 8 WAT, sweetpotato injury was 0 to 5% for all treatments except flumioxazin fb *S*-metolachlor fb bicyclopyrone which was 28%. At 3 WAT, sweetpotato stunting was 0 to 5% with no differences in stunting among herbicide treatments. Plant stunting at 5 WAT was 33% for 100 g bicyclopyrone fb *S*-metolachlor, 7% for 50g bicyclopyrone alone and 0% for all other treatments.

Although minor differences occurred among treatments for Palmer amaranth control, all of the treatments provided 95% or greater control at 4 WAT (Table 4). At 8 WAT, no differences in Palmer amaranth control were observed among the other treatments with control ranging between 67 and 95%.

No statistical differences were observed for canner yield (Table 3). No. 1 and jumbo yield were greatest for the weed-free check, 50 g bicyclopyrone, 50 g bicyclopyrone fb *S*-metolachlor and flumioxazin fb *S*-metolachlor. In addition, 100 g bicyclopyrone fb *S*-metolachlor had similar jumbo yield as these treatments. The lowest No. 1 and jumbo yield was from the nontreated weedy check and flumioxazin fb *S*-metolachlor fb bicyclopyrone. In addition to these treatments, flumioxazin alone and 100 g bicyclopyrone fb *S*-metolachlor had no. 1 yields lower than the weed-free check. The greatest marketable yield was observed in the weed-free check, 50 g bicyclopyrone fb *S*-metolachlor and flumioxazin fb *S*-metolachlor treatments. The lowest marketable yield was observed in the weedy check and the flumioxazin fb *S*-metolachlor fb bicyclopyrone application, likely due to lack of Palmer amaranth control and crop injury respectively. All other treatments were lower in marketable yields than the weed-free check but higher than the weedy check and flumioxazin fb *S*-metolachlor fb bicyclopyrone, likely due to herbicide injury or less than desirable Palmer amaranth control.

2017. Injury, in the form of chlorosis, necrosis and leaf deformation, was observed for all treatments of bicyclopyrone PREPLANT at 2, 4 and 8 WAT (Table 5). Injury was 1% or less for all other herbicide treatments between 2 and 8 WAT. At 8 WAT, injury was 88 to 96% for all bicyclopyrone PREPLANT treatments. Likewise, plant stunting at 4 WAT from bicyclopyrone

PREPLANT treatments was 72 to 89% while no stunting was observed in the other herbicide treatments. The day after sweetpotato transplanting, the study received 3.1 cm of rain and a total of 4.7 cm within the first wk. Bicyclopyrone is highly mobile in soil and high levels of rain immediately after application and transplanting moved the bicyclopyrone into the sweetpotato root zone, causing injury and stunting for all bicyclopyrone PREPLANT treatments.

Grower standard sweetpotato cultivation practices were not followed due to high amounts of rainfall in the first 30 d of the study, leading to higher weed densities than typically expected. Overall weed control was lower than usually seen with the standard Palmer amaranth control program of flumioxazin and *S*-metolachlor, with Palmer amaranth reaching sizes that were too large to control with cultivation. At 4 WAT control from bicyclopyrone PREPLANT fb or not fb *S*-metolachlor was 59% (Table 4). Control of Palmer amaranth was 9% at 4 WAT with clomazone fb *S*-metolachlor. Flumioxazin PREPLANT alone or fb *S*-metolachlor or *S*-metolachlor fb bicyclopyrone controlled Palmer amaranth at 98% at the 4 WAT. By 8 WAT, Palmer amaranth control had decreased for all treatments that included bicyclopyrone PREPLANT, with control at 10% for bicyclopyrone alone and bicyclopyrone (50g) fb *S*-metolachlor and 35% for bicyclopyrone (100g) fb *S*-metolachlor, Palmer amaranth control was 67, 95 and 92% by flumioxazin alone, flumioxazin followed by *S*-metolachlor and flumioxazin followed by *S*-metolachlor fb bicyclopyrone, respectively.

No. 1 yield was similar between flumioxazin fb *S*-metolachlor and the weed-free check (Table 5). Yield of canners, no. 1 roots, jumbos and total marketable yield were similar between all PREPLANT applications of bicyclopyrone, clomazone fb *S*-metolachlor and the nontreated weedy check. Flumioxazin alone, flumioxazin fb *S*-metolachlor and flumioxazin fb *S*-metolachlor fb bicyclopyrone had similar no. 1 yields. Flumioxazin alone and flumioxazin fb *S*-

metolachlor fb bicyclopyrone had similar jumbo yield to the weed-free check. All PREPLANT bicyclopyrone applications had less no. 1, jumbo and marketable yield than flumioxazin alone or followed by *S*-metolachlor. Total marketable yields were similar for the weed-free check and all treatments that included flumioxazin PREPLANT. Yields for treatments of bicyclopyrone (50g) fb *S*-metolachlor and bicyclopyrone (100g) fb *S*-metolachlor were not statistically different. No statistically significant differences were observed for canner yield between the weed-free and nontreated check, all applications of flumioxazin PREPLANT or clomazone fb *S*-metolachlor. All treatments yielded similar canner weights as the weed-free check with the exception of the 100g bicyclopyrone fb *S*-metolachlor and 50 g bicyclopyrone treatments, which were lower in yield.

2018. At 2 and 4 WAT, injury (10 to 12%) was similar for bicyclopyrone alone and bicyclopyrone fb *S*-metolachlor Ttable 6). All other herbicide treatments were ≤1% at 2 WAT, while 4 WAT, injury levels remained ≤4%. At 2 and 4 WAT, stunting was 8% and 15% for bicyclopyrone alone and bicyclopyrone fb *S*-metolachlor respectively. Plant stunting for all other herbicide treatments was ≤1% at 2 WAT. By 4 WAT, all treatments except bicyclopyrone alone and bicyclopyrone fb *S*-metolachlor showed 0% stunting, with bicyclopyrone alone and bicyclopyrone fb *S*-metolachlor ranging from 33 to 40%.

No differences in Palmer amaranth control were observed between herbicide treatments at 4 WAT, as control was ≥99% (Table 4). Control of Palmer amaranth at 100% was achieved for all herbicide treatments at 8 WAT except for flumioxazin fb *S*-metolachlor, which provided 97% control.

Canner, no. 1 or jumbo root yield did not differ across treatments. Total marketable yield for all treatments, with the exception of bicyclopyrone (50g) fb *S*-metolachlor, were statistically similar, ranging from 39,800 to 49,200 kg ha^{-1}. Marketable yield for bicyclopyrone (50g) fb *S*-metolachlor was lower than all other herbicide treatments at 22,500 kg ha^{-1}.

Weather concerns may have had a significant effect on field studies in 2017. Due to high rainfall in the first 2 weeks of the study in 2017, the first field cultivation which was scheduled to occur between POST *S*-metolachlor applications and POST-directed applications was delayed. Delayed cultivation resulted in significantly reduced weed control. Despite subsequent cultivation and weeding by hand, higher weed densities were observed in plots in 2017 compared to 2016 or 2018 (data not recorded). Increased weed densities have been shown to decrease the amount of herbicide that can be absorbed from the soil by the target or crop plants (Winkle 1981). Additionally, the bacteria and microorganism communities that exist in the weed rhizosphere can contribute to more rapid herbicide degradation than occurs under typical weed-free conditions (Lappin 1985, Yu 2003). The decreased level of weed control may have been a factor in contributing to lower yields in 2017 compared to 2016 and 2018.

Combined results from the greenhouse and field studies show a significant effect on yield and plant vigor with increased application rates of bicyclopyrone. At rates corresponding to 2x and 3x the desired registration application rate (50 g ai ha^{-1}), plant injury ranged between 34 to 37% at 8 WAT in greenhouse trials, which is an unacceptable loss level to growers (KM Jennings, personal communication). At application rates over 50 g ha^{-1}, plant height and injury were negatively affected, as was yield. The current application recommendation for flumioxazin on sweetpotato is only for PREPLANT (Meyers et al. 2014, Kelly et al. 2006) and requires rainfall or irrigation for activation. Additionally, while flumioxazin, *S*-metolachlor and clomazone all provide significant residual control of weeds, control can be negatively affected if the soil is disturbed by cultivation after application (Barkley et al. 2016; Meyers et al. 2013a).

However, bicyclopyrone PREPLANT or POST should not be applied immediately before or after significant rainfall events greater than 2.5 cm as considerable plant injury and yield loss were observed by movement of the herbicide into the root zone immediately after application. Additional care with application, including cultivation to cover the leaf and vine tips, is necessary for late season POST-directed applications of bicyclopyrone. If bicyclopyrone comes into contact with the mature plant leaves and vines, substantial injury including leaf chlorosis, necrosis and stunting can occur, leading to reduced yields.

Registration of bicyclopyrone PREPLANT for sweetpotato would provide a new option to control weeds. The addition of a new herbicide MOA would help ease selection pressure where flumioxazin has been typically applied, especially in areas where herbicide-resistant weeds have already developed. Since research has shown bicyclopyrone to have higher biological activity than other herbicides in the triketone family (mesotrione, tembotrione and suclotrione) use of bicyclopyrone would also mean that lower herbicide rates could be applied to an environment while still achieving the same level of weed control in a field (Hartzler 2015).

However, additional testing is recommended to evaluate bicyclopyrone on additional soil types and sweetpotato clones to ensure crop safety and supplementary research should be done to evaluate the potential for increasing the application timing window.

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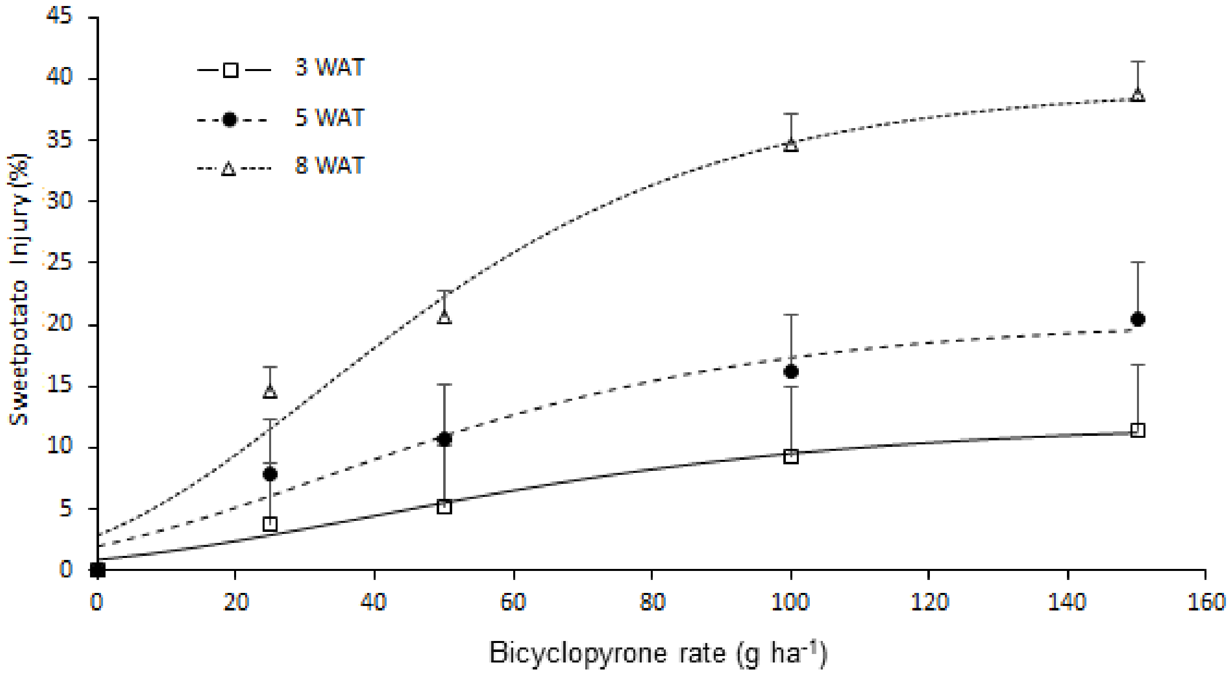

Figure 1. The influence of bicyclopyrone rate on sweetpotato injury (PI), including chlorosis, necrosis and leaf deformation, combined over application timings, varieties, replications and runs, in 2018 greenhouse studies in Greensboro, NC. Points represent observed mean and vertical lines represent the mean ± SE. PI_{3WAT} = 12.02926 X exp (-2.593211 X exp (-1.205016 X x)); R^2 = 0.98. PI_{5WAT} = 20.527111 X exp (-2.356288 X exp (-1.326617 X x)); R^2 = 0.96. PI_{8WAT} = 39.35286 X exp (-2.635441 X exp (-1.529212 X x)); R^2 = 0.98.

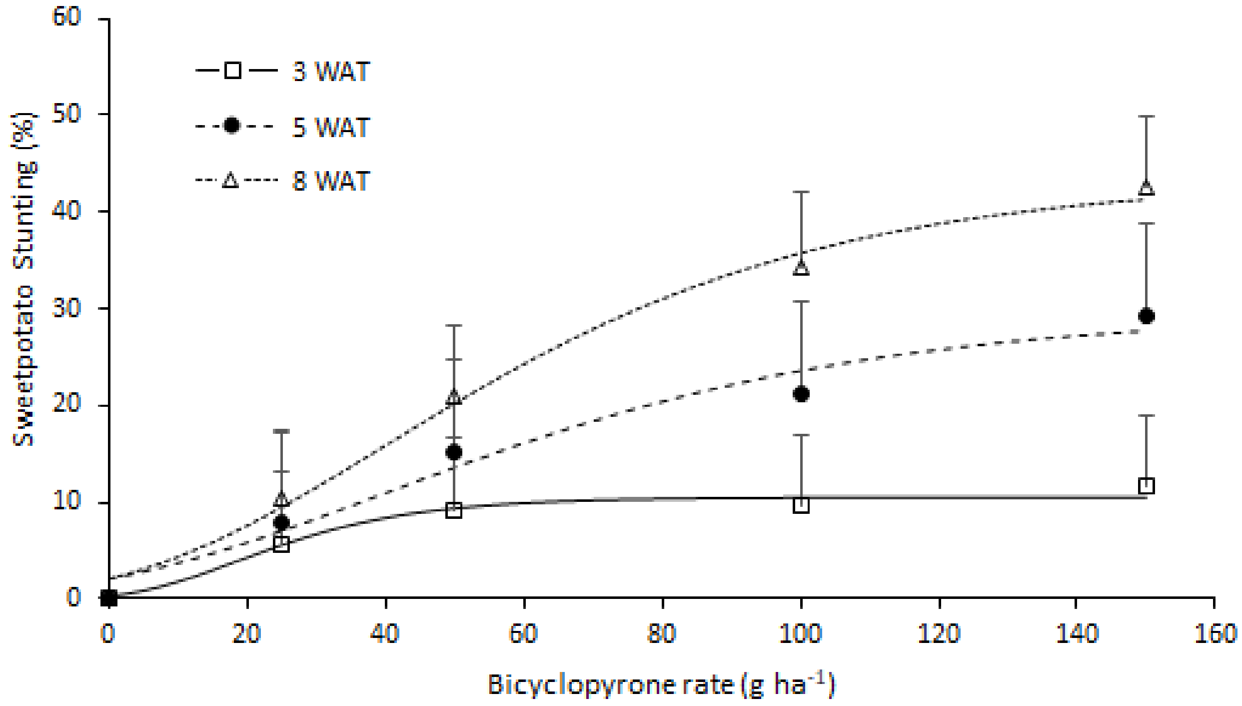

Figure 2. The influence of bicyclopyrone rate on sweetpotato stunting (ST), combined over application timings, varieties, replications and runs, in 2018 greenhouse studies in Greensboro, NC. Points represent observed mean and vertical lines represent the mean ± SE. $ST_{3WAT} = 10.4989 X \exp(-3.54734 X \exp(-3.43519 X x))$; $R^2 = 0.97$. $ST_{5WAT} = 29.7647 X \exp(-2.64555 X \exp(-1.22382 X x))$; $R^2 = 0.97$. $ST_{8WAT} = 43.5044 X \exp(-2.99881 X \exp(-1.37158 X x))$; $R^2 = 0.99$.

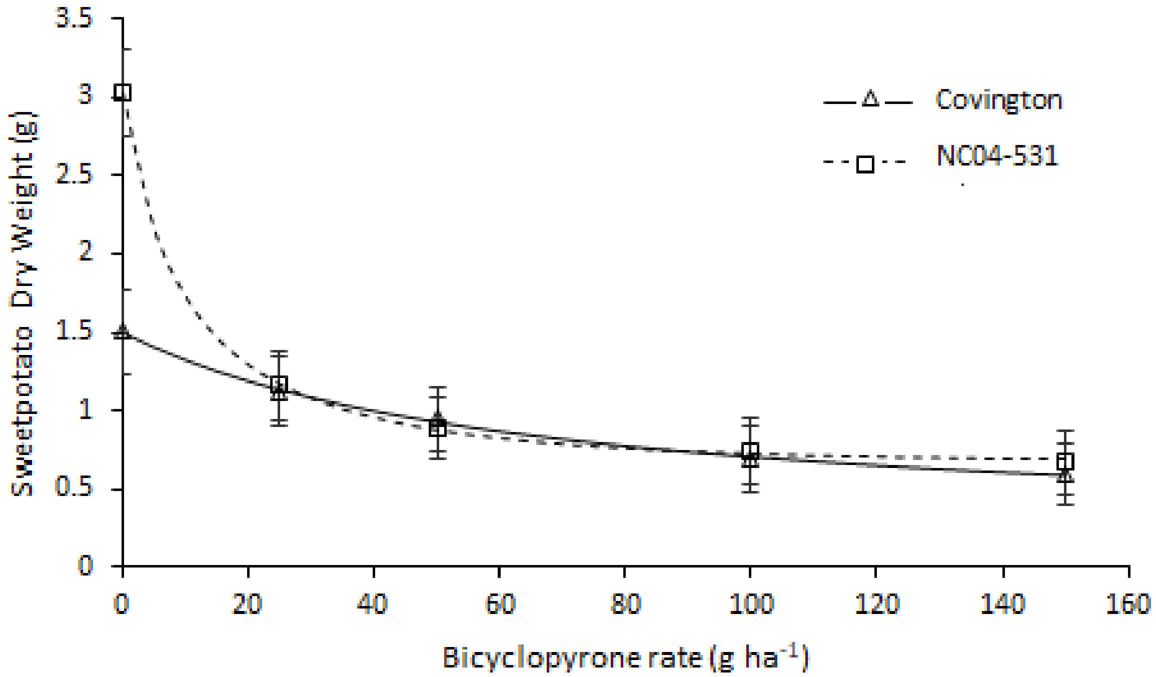

Figure 3. The influence of bicyclopyrone rate on sweetpotato dry weight (DW), combined over application timings, replications and runs, in 2018 greenhouse studies in Greensboro, NC. Points represent observed mean and vertical lines represent the mean ± SE. $DW_{COV} = 0.3275 / (1 – 0.7816 \text{ X } \exp(-0.1889 \text{ X } x))$; $R^2 = 1.00$. $DW_{NC04\text{-}531} = 0.6776 / (1 – 0.7660 \text{ X } \exp(-1.2248 \text{ X } x))$; $R^2 = 1.00$

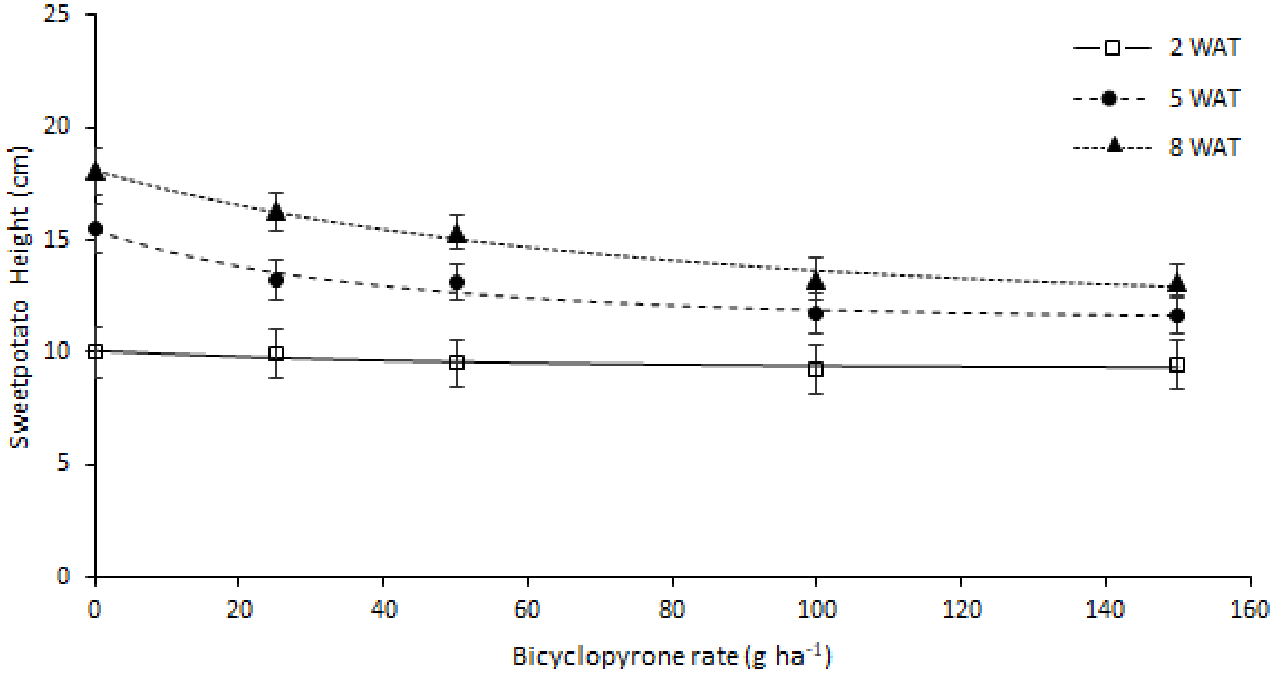

Figure 4. The influence of bicyclopyrone rate on sweetpotato plant height (HT), combined over application timings, varieties, replications and runs, in 2018 greenhouse studies in Greensboro, NC. Points represent observed mean and vertical lines represent the mean ± SE. $HT_{2WAT} = 3.6624 / (1 – 0.0769 X \exp(-0.9482 X x))$; $R^2 = 0.78$. $HT_{5WAT} = 4.5226 / (1 - 0.2556 X \exp(-1.0176 X x))$; $R^2 = 0.96$. $HT_{8WAT} = 4.7091 / (1 – 0.3389 X \exp(-0.4964 X x))$; $R^2 = 0.98$.

Table 1. Herbicide treatments applied to sites in Clinton, NC in 2016, 2017 and 2018.

Treatment	Rate	Application timing[a]	Study Year
	g ai ha^{-1}		
Bicyclopyrone	50	PREPLANT	2016, 2017, 2018
Bicyclopyrone fb	50	PREPLANT	2016, 2017, 2018
S-metolachlor [b]	800	POST	
Bicyclopyrone fb	100	PREPLANT	2016, 2017
S-metolachlor	800	POST	
Flumioxazin	107	PREPLANT	2016, 2017, 2018
Flumioxazin fb	107	PREPLANT	2016, 2017, 2018
S-metolachlor	800	POST	
Flumioxazin fb	107	PREPLANT	2016, 2017, 2018
S-metolachlor fb	800	POST	
Bicyclopyrone[c]	50	POST-directed	
Clomazone fb	420	PREPLANT	2017, 2018
S-metolachlor	800	POST	

[a] *S*-metolachlor applied 11±3 DAP.

[b] Abbreviations: fb, followed by; POST, post over the top application; DAP, days after transplanting; WAT, weeks after transplanting.

[c] POST-directed applied 4±1 WAT; X-77, no adjuvant and Induce were added to this treatment in 2016, 2017 and 2018 respectively.

Table 2. Sources of herbicide treatments used in this study.

Common name	Trade name	Manufacturer	Manufacturer location	Manufacturer website
Flumioxazin	Valor SX	Valent U.S.A. Corp.	Walnut Creek, CA	www.valent.com
S-metolachlor	Dual Magnum	Syngenta Crop Protection, Inc.	Greensboro, NC	www.syngentacropprotection-us.com
Clomazone	Command 3ME	FMC Corp.	Philadelphia, PA	www.fmccrop.com
Bicyclopyrone	--	Syngenta Crop Protection, Inc.	Greensboro, NC	www.syngentacropprotection-us.com
Sethoxydim	Poast	BASF Corp.	Research Triangle Park, NC	www.basf.com

Table 3 Effect of herbicide treatments on Beauregard sweetpotato injury, stunting and yield at Clinton, NC in 2016.[a b]

	Application	Injury			Stunting		Yield			
	Timing	3 WAT	5 WAT	8 WAT	3 WAT	5 WAT	Canner	No.1	Jumbo	Marketable[c]
Herbicide		%					10^3 kg ha^{-1}			
Weed-free	-	-	-	-	-	-	4.3	34.7 ab	13.0 abc	52.0 a
Nontreated weedy	-	-	-	-	-	-	4.0	9.1 de	2.5 d	15.6 c
Bicyclopyrone (50 g)	PP	14 b	3	0 b	5	7 b	4.2	27.0 bc	7.8 bcd	39.2 b
Flumioxazin	PP	0 d	0	0 b	0	0 c	5.0	22.5 c	4.5 d	32.0 b
Bicyclopyrone (50 g) fb *S*-metolachlor	PP POST	2 c	0	4 b	0	0 c	4.3	34.8 ab	15.7 ab	54.8 a
Bicyclopyrone (100 g) fb *S*- metolachlor[c]	PP POST	23 a	9	5 b	3	33 a	2.9	19.8 cd	6.6 cd	29.3 b
Flumioxazin fb *S*-metolachlor	PP POST	0 d	0	1 b	0	0 c	4.0	40.3 a	19.8 a	64.2 a
Flumioxazin fb *S*-metolachlor fb bicyclopyrone (50 g)	PP POST POST-D	0 d	0	28 a	4	0 c	5.8	7.4 e	0 d	13.2 c
P value		<0.0001	0.1019	0.0001	0.1923	<0.0001	0.3616	<0.0001	0.0003	<0.0001

[a] Means within columns followed by the same letter are not significantly different according to Fisher's Protected LSD (α = 0.05). Means with no letter in a column do not differ according to Fisher's Protected LSD (α = 0.05). The nontreated weedy and weed-free check were not included in the statistical analysis of sweetpotato injury and stunting.

[b] Abbreviations: fb, followed by; WAT, weeks after transplanting; PP, PREPLANT application; POST, post over the top application; POST-D, POST-directed application.

[c] Marketable is the aggregate of jumbo, no. 1, and canner grades of sweetpotato roots.

Table 4. Effects of herbicide treatments on Palmer amaranth control at Clinton, NC in 2016, 2017 and 2018.[ab]

	Application	2016		2017		2018	
	Timing	4 WAT	8 WAT	4 WAT	8 WAT	4 WAT	8 WAT
Herbicide				%			
Bicyclopyrone (50 g)	PP	97	67	59 c	10 c	99	100
Flumioxazin	PP	95	82	98 a	67 b	100	100
Bicyclopyrone (50 g) fb *S*-metolachlor	PP POST	100	89	59 c	10 c	100	100
Bicyclopyrone (100 g) fb *S*- metolachlor[c]	PP POST	100	94	89 b	35 b	-	-
Flumioxazin fb *S*-metolachlor	PP POST	100	95	98 a	95 a	100	97
Flumioxazin fb *S*-metolachlor fb bicyclopyrone (50 g)	PP POST POST-D	98	82	98 a	92 a	100	100
Clomazone fb *S*-metolachlor[d]	PP POST	-	-	9 d	0 c	100	100
P value		0.1428	0.1491	<0.0001	<0.0001	0.4215	<0.0783

[a] Abbreviations: WAT, w after transplanting; fb, followed by; PP, PREPLANT application; POST, post over the top application; POST-D, POST-directed application.

[b] Means within columns followed by the same letter are not significantly different according to Fisher's Protected LSD ($\alpha = 0.05$).

[c] Study conducted in 2016 and 2017.

[d] Study conducted in 2017 and 2018.

Table 5. Effect of herbicide treatments on Covington sweetpotato injury, stunting and yield at Clinton, NC in 2017.[a b]

	Application	Injury			Stunting		Yield			
	Timing	2 WAT	4 WAT	8 WAT	2 WAT	4 WAT	Canner	No.1	Jumbo	Marketable[c]
Herbicide		---------------------- % ----------------------					--------------------10^3 kg ha^{-1}----------------			
Weed-free	-	-	-	-	-	-	4.5 ab	22.5 a	16.5 b	44.3 a
Nontreated weedy	-	-	-	-	-	-	2.9 a-d	3.1 c	5.3 c	12.0 b
Bicyclopyrone (50 g)	PP	59 b	85 a	96 a	35 a	83 ab	0.2 d	2.7 c	5.3 c	9.0 b
Flumioxazin	PP	0 d	0 c	0 c	0 b	0 c	5.0 a	16.8 b	17.5 ab	40.0 a
Bicyclopyrone (50 g) fb *S*-metolachlor	PP POST	12 c	16 b	88 b	0 b	72 b	2.0 bcd	5.5 c	5.3 c	13.5 b
Bicyclopyrone (100 g) fb *S*- metolachlor[c]	PP POST	85 a	94 a	96 a	57 a	89 a	0.7 cd	2.7 c	5.3 c	9.4 b
Flumioxazin fb *S*-metolachlor	PP POST	0 d	0 c	0 c	0 b	0 c	4.7 ab	18.3 ab	24.7 a	48.5 a
Flumioxazin fb *S*-metolachlor fb bicyclopyrone (50 g)	PP POST POST-D	0 d	0 c	1 c	0 b	0 c	3.5 abc	15.0 b	19.5 ab	38.7 a
Clomazone fb *S*-metolachlor	PP POST	0 d	0 c	0 c	0 b	0 c	3.1 a-d	4.3 c	6.6 c	15.0 b
P value		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0197	<0.0001	0.0003	<0.0001

[a] Means within columns followed by the same letter are not significantly different according to Fisher's Protected LSD (α = 0.05). Means with no letter in a column do not differ according to Fisher's Protected LSD (α = 0.05). The nontreated weedy and weed-free check were not included in the statistical analysis of sweetpotato injury and stunting.

[b] fb, followed by; WAT, weeks after transplanting; PP, PREPLANT application; POST, post over the top application; POST-D, POST-directed application.

[c] Marketable is the aggregate of jumbo, no. 1, and canner grades of sweetpotato roots.

Table 6. Effect of herbicide treatments on Covington sweetpotato injury, stunting and yield at Clinton, NC in 2018.[a b]

	Application Timing	Injury		Stunting		Yield			
		2 WAT	4 WAT	2 WAT	4 WAT	Canner	No.1	Jumbo	Marketable[c]
Herbicide		----------------------%		----------------------		----------------------10^3 kg ha^{-1}-------------------			
Weed-free	-	-	-	-	-	8.3	27.6	13.7	49.2 a
Nontreated weedy	-	-	-	-	-	5.9	25.5	9.5	40.7 a
Bicyclopyrone (50 g)	PP	11 a	10 ab	8 b	33 a	6.0	25.6	8.5	39.8 a
Flumioxazin	PP	0 b	1 c	1 c	0 b	4.9	24.2	13.5	42.2 a
Bicyclopyrone (50 g) fb *S*-metolachlor	PP POST	10 a	12 a	15 a	40 a	5.2	15.1	2.5	22.5 b
Flumioxazin fb *S*-metolachlor	PP POST	1 b	0 c	0 c	0 b	6.4	29.1	12.0	47.0 a
Flumioxazin fb *S*-metolachlor fb bicyclopyrone (50 g)	PP POST POST-D	0 b	4 b	0 c	0 b	4.2	28.1	14.5	46.5 a
Clomazone fb *S*-metolachlor	PP POST	0 b	1 c	0 c	0 b	7.0	28.5	10.8	45.9 a
P value		<0.0001	<0.0001	<0.0001	<0.0001	0.4253	0.1365	0.4184	0.0316

[a] Means within columns followed by the same letter are not significantly different according to Fisher's Protected LSD (α = 0.05). Means with no letter in a column do not differ according to Fisher's Protected LSD (α = 0.05). The nontreated weedy and weed-free check were not included in the statistical analysis of sweetpotato injury and stunting.

[b] fb, followed by; WAT, weeks after transplanting; PP, PREPLANT application; POST, post over the top application; POST-D, POST-directed application.

[c] Marketable is the aggregate of jumbo, no. 1, and canner grades of sweetpotato roots.

APPENDIX

Appendix A

Rainfall and Irrigation for Horticultural Crops Research Station in Clinton NC in 2017

Date	Moisture Total	Unit	Type
May 31, 2017	4.27	cm	rain
June 5, 2017	2.87	cm	rain
June 13, 2017	1.27	cm	sprinkler, lateral move
June 15, 2017	1.27	cm	sprinkler, lateral move
June 15, 2017	1.55	cm	rain
June 16, 2017	0.33	cm	rain
June 17, 2017	0.91	cm	rain
June 18, 2017	0.03	cm	rain
June 20, 2017	1.73	cm	rain
June 21, 2017	0.03	cm	rain
June 22, 2017	0.51	cm	rain
June 23, 2017	0.03	cm	rain
June 24, 2017	3.66	cm	rain
June 30, 2017	3.12	cm	rain
July 3, 2017	1.55	cm	rain
July 4, 2017	0.03	cm	rain
July 7, 2017	0.08	cm	rain
July 8, 2017	0.30	cm	rain
July 9, 2017	1.35	cm	rain
July 10, 2017	2.95	cm	rain
July 15, 2017	0.38	cm	rain
July 16, 2017	0.23	cm	rain
July 17, 2017	0.05	cm	rain
July 18, 2017	0.13	cm	rain
July 19, 2017	1.32	cm	rain
July 21, 2017	1.91	cm	sprinkler, lateral move
July 25, 2017	1.27	cm	sprinkler, lateral move
July 29, 2017	0.28	cm	rain
August 4, 2017	1.27	cm	sprinkler, lateral move
August 5, 2017	0.13	cm	rain
August 6, 2017	1.98	cm	rain
August 7, 2017	0.28	cm	rain
August 8, 2017	0.18	cm	rain
August 9, 2017	0.18	cm	rain
August 11, 2017	0.74	cm	rain
August 12, 2017	2.97	cm	rain
August 13, 2017	0.51	cm	rain

August 15, 2017	1.80	cm	rain
August 16, 2017	0.03	cm	rain
August 17, 2017	1.57	cm	rain
August 23, 2017	1.32	cm	rain
August 28, 2017	0.13	cm	rain
August 29, 2017	0.10	cm	rain
August 31, 2017	0.53	cm	rain
September 1, 2017	2.29	cm	rain
September 2, 2017	0.18	cm	rain
September 3, 2017	0.03	cm	rain
September 5, 2017	1.22	cm	rain
September 6, 2017	6.60	cm	rain
September 7, 2017	0.03	cm	rain
September 12, 2017	2.51	cm	rain
September 15, 2017	0.03	cm	rain
September 21, 2017	0.30	cm	rain
October 5, 2017	1.27	cm	sprinkler, lateral move
October 7, 2017	1.83	cm	rain
October 8, 2017	0.66	cm	rain
October 9, 2017	0.10	cm	rain
October 10, 2017	0.10	cm	rain
October 16, 2017	0.33	cm	rain
October 23, 2017	0.20	cm	rain
October 25, 2017	0.03	cm	rain