ABSTRACT

BEAM, SHAWN CHRISTOPHER. The Influence of Herbicide on Development of Internal Necrosis in ‘Covington’ Sweetpotato and Herbicide Tolerance of Sweetpotato. (Under the direction of Dr. Katherine M. Jennings).

Studies were conducted in Clinton, NC in 2014 and Kinston, NC in 2015 to determine the influence of herbicides applied to the slip propagation bed or applied to the production field on the development of internal necrosis (IN) in No. 1 grade sweetpotato storage roots of ‘Covington’ and ‘NC 05-198’. Two different studies were initiated with the first having herbicide treatments of flumioxazin, *S*-metolachlor, flumioxazin plus *S*-metolachlor, linuron, fomesafen, clomazone, and napropamide applied PRE after bedding seed roots but before crop emergence and paraquat and ethephon applied POST. The second study included PREPLANT herbicide treatments of flumioxazin, flumioxazin followed by (fb) *S*-metolachlor, linuron, fomesafen, and paraquat and PRE treatments after transplant of *S*-metolachlor, clomazone and napropamide and ethephon POST. In the bedding study IN incidence increased in several treatments 30 d after curing but by 60 d no differences were present in any treatment. In the field production study the only treatment that increased IN incidence compared to the weed-free was ethephon. Rate was not significant so IN means were pooled across rate and year and IN was 48% and 49% at 30 and 60 d after curing, respectively. It appears that the herbicide treatments do not increase the incidence of IN.

Studies were conducted in 2015 in Faison, North Carolina to determine tolerance of ‘Covington’ and ‘Murasaki’ sweetpotato to linuron POST. Flumioxazin at 107 g ai ha^{-1} was applied PREPLANT to all plots. Linuron (0, 420, 560, 841, and 1120 g ai ha^{-1}) with or without *S*-metolachlor (803 g ai ha^{-1}) was applied 7 or 14 d after transplanting (DAP). Visual injury to sweetpotato from linuron applied 7 DAP was less (9 to 75%) than when applied at

14 DAP (71 to 93%) but was transient and was not present at 8 wk after treatment (WAT). Marketable yield was greater when linuron was applied 7 DAP (Covington ranged from 25,871 to 39,485 kg ha^{-1} and Murasaki ranged from 16,312 to 24,289 kg ha^{-1}). However, yield from linuron applied 14 DAP was 19,589 to 28,496 kg ha^{-1} and 3,959 to 17,560 kg ha^{-1} for Covington and Murasaki, respectively. Differences in visual injury and yield of sweetpotato were observed between linuron alone and linuron plus *S*-metolachlor.

Studies were conducted in 2015 on grower fields in Bailey, North Carolina to determine the critical timing of yellow nutsedge removal in 'Orleans' sweetpotato. Treatments were yellow nutsedge removal timings of 0 (season long weed-free), 1, 2, 3, 4, 6, 10, and 14 (season long weedy) wk after sweetpotato transplant. Sweetpotato storage roots were harvested 119 d after planting. A negative linear trend for no. 1, canner and marketable (no. 1, jumbo, and canner) sweetpotato storage roots was observed. Marketable yield was fit to a linear regression model and predicted yield loss was approximately 3% for every week yellow nutsedge was allowed to compete with sweetpotato. A positive linear trend in nutsedge density and biomass was also observed.

Studies were conducted in 2015 at the Horticultural Crops Research Station in Clinton, North Carolina to determine the response of sweetpotato and Palmer amaranth to a premix of flumioxazin/pyroxasulfone PRE followed by simulated rainfall. Treatments included flumioxazin/pyroxasulfone at 107, 151, 167, and 280 g ai ha^{-1} and flumioxazin at 107 g ai ha^{-1} followed by *S*-metolachlor at 803 g ai ha^{-1} 7 to 10 d after transplant (DAP). Visual ratings for Palmer amaranth control and sweetpotato injury were recorded 9, 16, 38, and 124 and 8, 14, and 30 DAP at locations (LOC) 1 and 2, respectively. Sweetpotato storage roots were harvested at 124 and 103 DAP for LOCs 1 and 2, respectively. Palmer amaranth control was >91% season long at both LOCs. Sweetpotato injury was slow to develop and no injury was observed until 16 DAP at LOC 1. A linear trend of increasing injury was observed with increasing rate of flumioxazin/pyroxasulfone was observed at LOC 1, at LOC 2 no linear trend was observed 14 DAP. At 38 and 30 DAP for LOC 1 and 2 respectively, the trends were the same. Greatest injury was observed at LOC 1 at 33% with flumioxazin/pyroxasulfone at 280 g ai ha^{-1}. Sweetpotato marketable yield was reduced at LOC 1 with flumioxazin/pyroxasulfone at 280 g ai ha^{-1} but no differences in marketable yield were observed at LOC 2.

Influence of Herbicide on Development of Internal Necrosis in ‘Covington’ Sweetpotato and Herbicide Tolerance of Sweetpotato

by
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DEDICATION

To all those who saw potential in me and encouraged me to chase my dreams.

BIOGRAPHY

Shawn Christopher Beam was born on August 6, 1992 in Concord NC, to Randy and Sharon Beam. One of three children he grew up with an early interest in agriculture helping his great grandfather and father in the family garden and being on the tractor whenever possible. Shawn was an active FFA member and worked on a small vegetable farm when he was in high school. He graduated from Northwest Cabarrus High School in 2010 and moved to North Carolina State University. In 2014, Shawn graduated from North Carolina State University with a Bachelor of Science Degree in Horticultural Science. While at North Carolina State University Shawn further developed his love of horticulture and the pursuit of science by interning with Dr. Penelope Perkins-Veazie in her postharvest physiology lab. Following his graduation from North Carolina State University Shawn stayed to pursue a Master of Science Degree Under the direction of Drs. Katie Jennings, David Monks, and Jonathan Schultheis. Shawn conducted his research evaluating the influence of herbicides on the incidence of internal necrosis in ‘Covington’ sweetpotato, and herbicide tolerance of sweetpotato.

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I thank Drs. Katie Jennings, David Monks, and Jonathan Schultheis for their time, patience, respect and encouraging words. It has been an honor to work with three terrific individuals who make research and academia better through their hard work and devotion to their field. If it weren’t for your help in how to design studies and answering my endless questions this journey would have been so much harder. I thank my parents, Randy and Sharon Beam, for being there to support me in all that I do and encouraging me to pursue my dreams. Thank you to my fellow horticultural weed science graduate students: Dr. Sushila Chaudhari, Nick Basinger, Sam McGowen, and Matt Bertucci. If it wasn’t for your countless hours of help and hard work, my research would not have been possible. It has been a pleasure working with each of you and being able to call each of you friends. Thank you to our technician Matthew Waldschmidt for being there to lend a helping hand. I would like to thank Dr. Cavell Brownie for her assistance in helping me analyze the data for all my studies and answering all of the questions I had. The success of this research is largely due to the hard work and generosity of the following:

Horticultural Crops Research Station, Clinton NC

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Burch Farms

Jones Family Farm

North Carolina Sweet Potato Commission

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CHAPTER 1

The Influence of Herbicide on Development of Internal Necrosis in ‘Covington’ and ‘NC 05-198’ Sweetpotato

(In the format appropriate for submission to Weed Technology)

Sweetpotato internal necrosis

Influence of Herbicides on the Development of Internal Necrosis in ‘Covington’ and ‘NC 05-198’ Sweetpotato (*Ipomoea batatas*)

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Field studies were conducted in Clinton, NC in 2014 and Kinston, NC in 2015 to determine the influence of herbicides applied to the slip propagation bed or applied to the production field on the development of internal necrosis (IN) in No. 1 grade sweetpotato storage roots of ‘Covington’ and ‘NC 05-198’. Two different studies were initiated with the first having herbicide treatments of flumioxazin (0.107, 0.214 kg ai ha^{-1}), *S*-metolachlor (0.796, 1.6 kg ai ha^{-1}), flumioxazin plus *S*-metolachlor (0.107 + 0.796, 0.107 + 1.6 kg ai ha^{-1}), linuron (0.56, 1.12 kg ai ha^{-1}), fomesafen (0.28, 0.56 kg ai ha^{-1}), clomazone (0.42, 0.84 kg ai ha^{-1}), and napropamide (1.12, 2.24 kg ai ha^{-1}) applied PRE after bedding seed roots but before crop emergence and paraquat (0.14, 0.28 kg ai ha^{-1}) and ethephon (0.84, 1.26 kg ai ha^{-1}) applied POST. The second study included PREPLANT herbicide treatments of flumioxazin (0.107, 0.214 kg ai ha^{-1}), flumioxazin followed by (fb) *S*-metolachlor (0.107 fb 0.796, 0.107 fb 1.6 kg ai ha^{-1}), linuron (0.56, 1.12 kg ai ha^{-1}), fomesafen (0.28, 0.56 kg ai ha^{-1}), and paraquat (0.56, 1.12 kg ai ha^{-1}) and PRE treatments after transplant of *S*-metolachlor, clomazone (0.796, 1.6 kg ai ha^{-1}) and napropamide (1.12, 2.24 kg ai ha^{-1}) and ethephon (0.84, 1.26 kg ai ha^{-1}) POST. Yields of sweetpotato in all studies were not affected by herbicide treatments. In the bedding study IN incidence in Covington increased in several treatments 30 d after curing but by 60 d no differences were present in any treatment compared to the weed-free check. In the field production study the only treatment that increased IN incidence in Covington compared to the weed-free check was ethephon. Herbicide rate was not significant so IN means were pooled across rate and year and IN was 48% and 49% at 30 and 60 d after curing, respectively. NC 05-198 had <2% IN incidence at 30 and 60 d after curing. It appears that the herbicide treatments do not increase the incidence of IN.

Nomenclature: Internal necrosis; sweetpotato; *Ipomoea batatas* (L.) Lam.;

Keywords:

The majority, over 90% (J.R. Schultheis, personal communication), of the sweetpotato acreage in North Carolina is planted to ‘Covington’, a variety released by NC State University in 2008 (Yencho et al. 2008). Adoption of Covington was due to disease resistance, high yield, and the uniformity and high percentage of no. 1 grade relative to other grades compared to ‘Beauregard’ which had been a dominant variety grown by North Carolina growers in the past (Yencho et al. 2008). Since the release of Covington, a disorder known as internal necrosis (IN) in storage roots has been discovered (Jiang et al. 2015). Covington isn’t the only susceptible variety but since it is the primary cultivar grown in North Carolina it is the most concerning (Clark et al. 2013b). The cause of IN is not yet known; however, it is thought to be a postharvest physiological disorder. The symptoms of IN are expressed as dark discolored regions within the sweetpotato storage root. The symptoms begin inside the storage root on the proximal end (end that was attached to the stem) and may progress through the root to approximately half of the root length. No external expression of symptoms occur outside the storage root (Clark et al. 2013a; Dittmar et al. 2010).

A similar disorder to IN was reported in 1966 in ‘Owairaka Red’ sweetpotato grown in New Zealand (Neilsen and Harrow 1966). The symptoms were similar to how IN symptoms are expressed in Covington. At first it appeared that this problem was caused by internal cork virus. However cores from affected roots were grafted into healthy roots and no further necrosis occurred in the healthy root tissue. Thus, internal cork virus was eliminated as the cause (Neilson and Harrow 1966). Similar to IN, no external symptoms were observed in New Zealand with this disorder (Neilson and Harrow 1966). It is possible that the disorder observed in 1966 in New Zealand is the same problem North Carolina growers are currently facing. However, it is not possible to know for sure if this reported disorder is the same as the current disorder without evaluating that variety for IN (Clark et al. 2013b; J.R. Schultheis, personal communication).

There is also an interest in screening advanced lines in the sweetpotato breeding program at North Carolina State University for susceptibility to IN. Once such line is 'NC 05-198' which will likely be released by the breeding program for production by the commercial sweetpotato industry (C.G. Yencho, personal communication). It is reported that this variety has little to no incidence of IN compared to Covington (Clark et al. 2013b). This variety was included in this study to further determine the susceptibility of this variety to IN.

Herbicides (glufosinate, flumioxazin, clomazone) and a plant growth regulator (ethephon) were evaluated for possibly being linked to IN. The only treatment that was reported to cause an increased incidence of IN in sweetpotato storage roots compared to the non-treated check was ethephon (Jiang et al. 2013). Clark et al. (2013b) have also reported increased symptoms similar to IN from ethephon.

Materials and Methods

Slip Propagation Bed Study. Covington storage roots were placed in field propagation beds on April 8 at the Horticultural Crops Research Station (35.028977^o N, 78.275692^o W and 35.027756^o N, 78.278100^o W) in Clinton NC [Faceville fine sandy loam (fine, kaolinitic, thermic typic Kandiudults) with pH 5.6 and 0.7% organic matter] and [Norfolk loamy sand (fine-loamy, kaolinitic, thermic typic Kandiudults) with pH 6.1 and 0.8% organic matter], in

2014 and 2015 respectively, then covered with soil. After the storage roots were covered with soil beds were covered with clear polyethylene mulch that remained until plants emerged (Loebenstein and Thottappilly 2009). Slips (non-rooted cuttings) were cut 2 to 3 cm above the soil surface from the beds when the slips averaged 20 to 25 cm in length from the soil surface to the growing point. The slips were then transplanted on June 11, 2014 into another field [Faceville fine sandy loam (fine, kaolinitic, thermic typic Kandiudults) with pH 5.3 and 0.8% organic matter] on the research station (35.025206^o N, 78.277110^o W) for production of storage roots. Slips were cut from beds on June 22, 2015 and transplanted on June 23 into a field [Norfolk loamy sand (fine-loamy, kaolinitic, thermic Typic Kandiuldults) with pH 5.8 and 1.3% organic matter] at the Cunningham Research Station (35.303992^o N, 77.572694^o W) in Kinston, NC.

Treatments included PRE and POST (Table 1.1) herbicide treatments, and non-treated checks (weedy, weed-free) arranged in a randomized complete block design with 3 replications in 2014 and 4 in 2015. Plot size for each treatment was 1.5 m wide by 3 m long. The PRE herbicide treatments were applied after covering storage roots with soil but before the polyethylene mulch was installed. The paraquat treatments were applied 2 wk prior to cutting the slips in 2014 and 4 wk prior to cutting the slips in 2015, ethephon treatments were applied 10 d prior to cutting slips in both years. When the slips were cut and transplanted the plots measured 1.1 by 6 and 1.1 by 7.6 m in 2014 and 2015, respectively. Treatments including plot number and randomization were exactly the same in the propagation bed and the research site in the production field.

Field Production Study. In 2014 a field [Norfolk loamy sand (fine-loamy, kaolinitic, thermic Typic Kandiuldults) with pH 5.5 and 1% organic matter] in Clinton, NC (35.024068 N, 78.279121 W) was transplanted on June 12 with Covington sweetpotato slips. In 2015 a field [Norfolk loamy sand (fine-loamy, kaolinitic, thermic Typic Kandiuldults) with pH 5.6 and 1.3% organic matter] in Kinston, NC (35.303399 N, 77.573167 W) was transplanted on June 23 with Covington and NC 05-198 sweetpotato slips. Both years slips were from a field propagation bed that had not been treated with herbicide.

Treatments included PREPLANT applications, PRE after transplant applications applied 4 d after transplanting (DAP); and ethephon applied 2 wk prior to harvest and nontreated check treatments (weedy and weed-free) were included for comparison (Table 1.2). Treatments were arranged in a randomized complete block design with four replications for Covington in 2014 and four replications for Covington and NC 05-198 in 2015. Plot size was 2 rows each 1.1 m wide by 6 m long in 2014 and 3 rows each 1.1 m wide by 7.6 m in 2015.

Both Studies. Sweetpotato slips (non-rooted cuttings) were transplanted 30 cm apart into the field. The first row of the plot was a guard row and the second (and third) row was the treated row. In both studies Clethodim POST was applied as needed to control emerged grasses late in the season. After herbicides were applied, the plots and guard rows were maintained weed-free of broadleaf weeds, except for the weedy check, for the entire season by hand removal. Standard sweetpotato production practices were implemented throughout the growing season (Kemble 2015).

Data collected included sweetpotato stand count, visual foliar injury from herbicide application, sweetpotato yield by weight and grade, and IN incidence and severity.

Sweetpotato storage roots were harvested 110±5 DAP using a tractor mounted chain digger and then hand graded into jumbo, (>8.9 cm diam.), no. 1 (>4.4 cm but <8.9 cm diam.), and canner (>2.5 cm but <4.4 cm diam.) grades (USDA 2005). Total marketable yield was calculated as the sum of jumbo, No. 1, and canner grades. The storage roots were then weighed by grade. Approximately 60 No. 1 storage roots from each plot were cured at 29.4 C and 95% relative humidity for 7 d. Following curing, sweetpotato storage roots were moved into storage at 14.4 C and 85% relative humidity, recommended storage conditions (Wilson et al. 1976; Edmunds et al. 2003). Evaluation for IN was conducted 70 DAP in the field, at harvest, and 30 and 60 d after curing. At 70 DAP 2 plants from each plot were hand dug and evaluated for IN. The purpose of this evaluation was to determine if IN symptoms appeared during the growing season. Storage roots that were evaluated at 70 DAP and at harvest were not cured. At each evaluation time after the harvest of the roots from the plot, one-third of the No. 1 storage roots from each plot were sliced into approximately 3 mm slices beginning on the proximal end. Slicing continued through one-third the length of the storage root if no IN was found and one-half if IN was found. The slice with the most IN symptomology from each storage root was rated visually-[scale of 1 = no IN present to 5 = very severe] (Figure 1.1). This visual rating included incidence and severity of IN.

Data were analyzed using SAS 9.3 (SAS Institute, Cary NC) and subjected to analysis with analysis of variance using proc GLM and proc MIX. IN rating data were transformed using arcsine transformation to determine the statistical differences between treatments, but untransformed data are presented. Means were separated using Fishers Protected LSD using a p-value of 0.05.

Results and Discussion

Slip Propagation Bed Study. Due to a lack of interaction between year and treatment the yield data were pooled across years and presented. The weed-free treatment yielded 30,295, 3,959, 10,861, and 44,691 kg ha^{-1} of no.1, jumbo, canner, and marketable storage roots, respectively (Table 1.3). In all other herbicide treatments yield of all grades of sweetpotato storage roots were not statistically different when compared to the weed-free check.

Interactions between IN incidence and year and IN incidence and rate of herbicide were not significant. Thus, data are presented averaged across year and rate of treatment. Evaluation at harvest resulted in minimal levels of IN incidence (data not shown). Levels of IN incidence and severity increased by 30 d after curing and had increased slightly more at 60 d after curing (Table 1.4). At 30 d after curing flumioxazin fb *S*-metolachlor (7%), fomesafen (11%), clomazone (20%), and paraquat (7%) had statistically higher incidence of IN when compared to the weed-free check which had an incidence of 0.4%. The only treatment that had statistically higher severity when compared to the weed-free check was clomazone with an average severity score of 1.27. However, by 60 d after curing no treatments had a statistically higher incidence of IN compared to the weed-free check which had an incidence of 11%. It appears that herbicides applied to the slip propagation bed do not increase the incidence or severity of IN. It appears that there are factors other than herbicides that contribute to the occurrence of IN.

Field Production Study. Due to a lack of interaction between years and treatment the yield data for Covington were pooled across years and presented. The weed-free treatment yielded 29,053, 6,353, 8,306, and 43,712 kg ha^{-1} of no.1, jumbo, canner, and marketable storage roots, respectively (Table 1.5). For all other herbicide treatments, the yield of all grades of sweetpotato storage roots was not statistically different when compared to the weed-free check. In 2015, a second variety, NC 05-198 was included in the study. NC 05-198 is an advanced sweetpotato line in the breeding program at North Carolina State University. The weed-free treatment for NC 05-198 yielded 34,165, 12,364, 10,861, and 44,691 kg ha^{-1} of no. 1, jumbo, canner, and marketable storage roots, respectively (Table 1.6). Similar to Covington, yield of all grades of NC 05-198 storage roots across herbicide treatments were not statistically different from the weed-free check.

With respect to IN incidence and severity, treatments were not different across years and herbicide rates in Covington. Thus data are combined and presented across year and rate of treatment. IN evaluation at harvest resulted in minimal levels (<1%) of IN incidence across all treatments including the herbicide, weedy and weed-free treatments (data not shown). At 30 and 60 d after curing both incidence and severity of IN increased (Table 1.7). At both evaluation timings the only treatment that had an increased incidence or severity of IN compared to the weed-free check was ethephon. All other treatments were not statistically different from the weed-free check. Ethephon treatment at 30 and 60 d after curing had 48% and 49% incidence of IN, respectively. However, the weed-free check had 12% and 14% at 30 and 60 d, respectively (Table 1.7). As with Covington, herbicide treatment and rate were not significant in NC 05-198, so means were pooled across rate. IN was observed at low levels (< 1%) at 30 d after curing in the ethephon and fomesafen treatments (data not shown). At 60 d after curing IN was observed again at < 1% in the ethephon, paraquat, linuron, and fomesafen treatments (data not shown).

Increased incidence of IN in the ethephon treatments in Covington compared to the weed-free check is consistent with prior research with this variety (Jiang et al. 2013; Dittmar et al. 2010). However, Dittmar et al., found a significant interaction between ethephon application and rate with higher incidence of IN when ethephon was applied at higher rates (2010). Similar results to those reported by Clark et al. (2013b) was obtained in our study with respect to sweetpotato clone and to the IN incidence obtained with Covington and NC 05-198, the former being much more susceptible to IN incidence than the later. In our study, herbicides do not increase the incidence of IN. Thus weed management practices are not associated with IN that affects the marketability of their crop. This study reaffirms the importance of variety selection to avoid problems such as IN or evaluation of different varieties for their potential different responses to various herbicides.

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Table 1.1. Herbicide treatments in the slip propagation beds, 2014 and 2015.

Treatment	Trade name	Application time	Application rate	Maufacturer	Location
			kg ai ha^{-1}		
Flumioxazin	Valor SX	PRE	0.107	Valent U.S.A Corp.	Walnut Creek, CA
Flumioxazin	Valor SX	PRE	0.214	Valent U.S.A Corp.	Walnut Creek, CA
S-metolachlor	Dual Magnum	PRE	0.796	Syngenta Crop Protection, LLC	Greensboro, NC
S-metolachlor	Dual Magnum	PRE	1.6	Syngenta Crop Protection, LLC	Greensboro, NC
Flumioxazin + *S*-metolachlor	Valor SX + Dual Magnum	PRE	0.107 + 0.796		
Flumioxazin + S-metolachlor	Valor SX + Dual Magnum	PRE	0.107 + 1.6		
Linuron	Linex 4L	PRE	0.56	Tessenderlo Kerley Inc.	Phoenix, AZ
Linuron	Linex 4L	PRE	1.12	Tessenderlo Kerley Inc.	Phoenix, AZ
Fomesafen	Reflex	PRE	0.28	Syngenta Crop Protection, LLC	Greensboro, NC
Fomesafen	Reflex	PRE	0.56	Syngenta Crop Protection, LLC	Greensboro, NC
Clomazone	Command 3ME	PRE	0.42	FMC Corp.	Philadelphia, PA
Clomazone	Command 3ME	PRE	0.84	FMC Corp.	Philadelphia, PA
Napropamide	Devrinol 50-DF	PRE	1.12	United Phosphorus Inc.	Trenton, NJ
Napropamide	Devrinol 50-DF	PRE	2.24	United Phosphorus Inc.	Trenton, NJ
Paraquat	Gramoxone SL 2.0	POST	0.14	Syngenta Crop Protection, LLC	Greensboro, NC
Paraquat	Gramoxone SL 2.0	POST	0.28	Syngenta Crop Protection, LLC	Greensboro, NC
Ethephon	Boll Buster	POST	0.84	Loveland Products Inc.	Greeley, CO
Ethephon	Boll Buster	POST	1.26	Loveland Products Inc.	Greeley, CO

Table 1.2. Herbicide treatments in production fields, 2014 and 2015.

Treatment	Trade name	Application time	Application rate	Manufacturer	Location
			kg ai ha^{-1}		
Flumioxazin	Valor SX	PRE	0.107	Valent U.S.A Corp.	Walnut Creek, CA
Flmioxazin	Valor SX	PRE	0.214	Valent U.S.A Corp.	Walnut Creek, CA
Linuron	Linex 4L	PRE	0.56	Tessnderlo Kerley Inc.	Phoenix, AZ
Linuron	Linex 4L	PRE	1.12	Tessnderlo Kerley Inc.	Phoenix, AZ
Fomesafen	Reflex	PRE	0.28	Syngenta Crop Protection, LLC	Greensboro, NC
Fomesafen	Reflex	PRE	0.56	Syngenta Crop Protection, LLC	Greensboro, NC
Paraquat	Gramoxone SL 2.0	PRE	0.56	Syngenta Crop Protection, LLC	Greensboro, NC
Paraquat	Gramoxone SL 2.0	PRE	1.12	Syngenta Crop Protection, LLC	Greensboro, NC
S-metolachlor	Dual Magnum	PRE after transplant	0.796	Syngenta Crop Protection, LLC	Greensboro, NC
S-metolachlor	Dual Magnum	PRE after transplant	1.6	Syngenta Crop Protection, LLC	Greensboro, NC
Clomazone	Command 3ME	PRE after transplant	0.42	FMC Corp.	Philadelphia, PA
Clomazone	Command 3ME	PRE after transplant	0.84	FMC Corp.	Philadelphia, PA
Napropamide	Devrinol	PRE after transplant	1.12	United Phosphorus Inc.	Trenton, NJ
Napropamide	Devrinol	PRE after transplant	2.24	United Phosphorus Inc.	Trenton, NJ
Flumioxazin fb *S*-metolachlor[a]	Valor SX fb Dual Magnum	PRE fb PRE after transplant	0.107 fb 0.796		
Flumioxazin fb *S*-metolachlor	Valor SX fb Dual Magnum	PRE fb PRE after transplant	0.107 fb 1.6		
Ethephon	Boll Buster	POST	0.84	Loveland Products Inc.	Greeley. CO
Ethephon	Boll Buster	POST	1.26	Loveland Products Inc.	Greeley. CO

[a] fb-followed by

Table 1.3. Effect of herbicides in slip propagation beds on Covington sweetpotato yield at Clinton and Kinston, NC in 2014 and 2015.

Treatment	Rate	Yield (kg ha^{-1})			
	kg ai ha^{-1}	No. 1	Jumbo	Canner	Marketable
Weed-free		30295	3959	10861	44691
Flumioxazin	0.107	29972	2746	9822	42540
Flumioxazin	0.214	29997	2816	10331	43151
S-metolachlor	0.796	29788	3706	10615	44108
S-metolachlor	1.6	29637	437	12241	42315
Flumioxazin + *S*-metolachlor	0.107 + 0.796	29786	2906	9843	42535
Flumioxazin + S-metolachlor	0.107 + 1.6	24173	2839	12641	39651
Linuron	0.56	29307	3601	11286	44194
Linuron	1.12	30343	2772	11021	44136
Fomesafen	0.28	29033	3452	10863	43349
Fomesafen	0.56	29228	2964	9355	42247
Clomazone	0.42	33057	3961	9936	46954
Clomazone	0.84	25734	2718	10129	38567
Napropamide	1.12	29972	1812	9532	41316
Napropamide	2.24	27381	2488	10327	40196
Paraquat	0.14	30141	2955	11583	44680
Paraquat	0.28	27890	2119	9200	39210
Ethephon	0.84	26332	1845	12377	40672
Ethephon	1.26	26608	1117	12888	40377
p-value		NS	NS	NS	NS

Table 1.4. Effect of herbicides in slip propagation beds on Covington sweetpotato internal necrosis 30 and 60 d after curing at Clinton and Kinston, NC in 2014 and 2015.

Treatment	30 d[a]		60 d	
	% incidence	severity[b]	% incidence	severity
Weed-free	0.4 d	1.03 bc	11	1.27
Weedy	3 bcd	1.10 bc	3	1.10
flumioxazin	3 bcd	1.11 bc	11	1.21
S-metolachlor	3 bcd	1.01 c	12	1.22
flumioxazin fb *S*-metolachlor	7 bc	1.17 ab	12	1.26
linuron	2 cd	1.06 bc	4	1.11
fomesafen	11 ab	1.18 ab	10	1.21
clomazone	20 a	1.27 a	15	1.30
napropamide	6 bcd	1.13 bc	9	1.19
paraquat	7 bc	1.18 ab	15	1.29
ethephon	3 cd	1.09 bc	15	1.26
p-value	0.0033	0.007	NS	NS

[a] Days after curing

[b] Average rating (1 to 5) from all roots sampled in that treatment.

Table 1.5. Effect of herbicides in production fields on Covington sweetpotato yield at Clinton and Kinston, NC in 2014 and 2015.

Treatment	Rate	Yield (kg ha^{-1})			
	kg ai ha^{-1}	No. 1	Jumbo	Canner	Marketable
Weed-free		29053	6353	8306	43712
Flumioxazin	0.107	31128	8817	7177	47184
Flumioxazin	0.214	31294	7465	8542	47325
S-metolachlor	0.796	27314	7449	6457	45576
S-metolachlor	1.6	27986	10928	8311	47226
Flumioxazin + *S*-metolachlor	0.107 + 0.796	34053	14389	5649	54091
Flumioxazin + S-metolachlor	0.107 + 1.6	35129	9763	6795	51687
Linuron	0.56	33886	7032	6917	47836
Linuron	1.12	36197	7680	6248	50125
Fomesafen	0.28	31879	7764	7008	46651
Fomesafen	0.56	30990	8837	7684	47512
Clomazone	0.42	37024	6851	9099	52974
Clomazone	0.84	34174	9493	6715	50382
Napropamide	1.12	32165	7248	9193	48606
Napropamide	2.24	30485	5227	9419	45132
Paraquat	0.56	30623	5351	8796	44769
Paraquat	1.12	32644	12627	4129	49401
Ethephon	0.84	31666	9099	5466	46231
Ethephon	1.26	35001	7945	6126	49080
p-value		NS	NS	NS	NS

Table 1.6. Effect of herbicides in production fields on NC 05-198 sweetpotato yield at Kinston, NC 2015.

Treatment	Rate	Yield (kg ha^{-1})			
	kg ai ha^{-1}	No. 1	Jumbo	Canner	Marketable
Weed-free		34165	12364	4210	50739
Flumioxazin	0.107	37301	15040	3764	56108
Flumioxazin	0.214	33998	12406	4014	50418
S-metolachlor	0.796	36688	13591	3443	53722
S-metolachlor	1.6	43295	11570	2760	57625
Flumioxazin + *S*-metolachlor	0.107 + 0.796	41497	9702	5729	56928
Flumioxazin + S-metolachlor	0.107 + 1.6	36632	9158	4084	49874
Linuron	0.56	42682	9130	5506	57318
Linuron	1.12	42905	14525	3959	61388
Fomesafen	0.28	39838	13228	3694	56760
Fomesafen	0.56	40047	15347	3359	58757
Clomazone	0.42	41622	10510	4893	57028
Clomazone	0.84	42417	13145	3401	58963
Napropamide	1.12	35949	19919	3192	59063
Napropamide	2.24	40061	18121	2802	60987
Paraquat	0.56	38862	12030	3959	54851
Paraquat	1.12	38235	10663	18400	53750
Ethephon	0.84	40075	10427	2955	53457
Ethephon	1.26	34527	12726	4238	51491
p-value		NS	NS	NS	NS

Table 1.7. Effect of herbicides in production fields on Covington sweetpotato internal necrosis 30 and 60 d after curing at Clinton and Kinston, NC in 2014 and 2015.

Treatment	30 d[a]		60 d	
	% incidence	severity[b]	% incidence	severity
Weed-free	12 b	1.21 b	14 bc	1.25 bc
Weedy	7 bc	1.18 b	11 c	1.29 bc
flumioxazin	2 c	1.09 b	13 c	1.26 bc
S-metolachlor	5 bc	1.13 b	14 bc	1.24 bc
flumioxazin + *S*-metolachlor	10 b	1.24 b	27 b	1.51 b
linuron	8 b	1.21 b	22 bc	1.37 bc
fomesafen	8 b	1.19 b	12 c	1.24 c
clomazone	10 b	1.22 b	25 bc	1.44 bc
napropamide	13 b	1.19 b	24 bc	1.41 bc
paraquat	12 b	1.25 b	15 bc	1.32 bc
ethephon	48 a	2.22 a	49 a	2.17 a
p-value	<.0001	<.0001	<.0001	<.0001

[a] Days after curing

[b] Average rating (1 to 5) from all roots sampled in that treatment.

Figure 1.1. Sweetpotato internal necrosis (IN) scale used to rate internal necrosis in storage roots.

CHAPTER 2

Tolerance of Sweetpotato (*Ipomoea batatas*) to Linuron POST

Abstract

(In the format appropriate for submission to Weed Technology)

Sweetpotato tolerance to linuron

Tolerance of Sweetpotato (*Ipomoea batatas)* to Linuron POST

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Field studies were conducted in 2015 on grower fields in Faison, North Carolina to determine tolerance of 'Covington' and 'Murasaki' sweetpotato to linuron POST. Flumioxazin at 107 g ai ha^{-1} was applied PREPLANT to all plots. Linuron (0, 420, 560, 841, and 1120 g ai ha^{-1}) with or without *S*-metolachlor (803 g ai ha^{-1}) was applied 7 or 14 d after transplanting (DAP). Visual injury to sweetpotato from linuron applied 7 DAP was less than when applied at 14 DAP but was transient and was not present at 8 wk after treatment (WAT). Marketable yield was greater when linuron was applied 7 DAP compared to treatments applied at 14 DAP Covington ranged from 25,627 to 36,312 kg ha^{-1} and Murasaki ranged from 16,316 to 24,289 kg ha^{-1} yield from linuron applied 14 DAP was 17,424 to 25,606 kg ha^{-1} and 3,959 to 17,563 kg ha^{-1} for Covington and Murasaki, respectively. Differences in visual injury and yield of sweetpotato were observed between linuron alone and linuron plus *S*-metolachlor. In general the addition of *S*-metolachlor caused more injury than linuron alone when applied at both 7 and 14 DAP.

Nomenclature: linuron; sweetpotato, *Ipomoea batatas* (L.) Lam.

Key words: Crop tolerance, crop injury, herbicide tolerance in sweetpotato.

Sweetpotato [*Ipomoea batatas* (L.) Lam] (USDA Plants Database 2015) is an economically important crop in North Carolina and across the United States. In North Carolina approximately 34,803 ha were harvested in 2015 with a farm gate value in excess of $354 million. Production is concentrated primarily in the coastal plain region, which is the eastern part of the state. (USDA-NASS 2016). The market for sweetpotato continues to grow in the United States and Europe and planted acreage continues to increase year to year. From 2000 to 2014 planted ha increased approximately 5% each year (J.R. Schultheis, personal communication). In North Carolina the weed species that are most economically devastating in sweetpotato include Palmer amaranth (*Amaranthus palmeri*), yellow nutsedge (*Cyperus esculentus*), smooth pigweed (*Amaranthus hybridus*), and common lambsquarters (*Chenopodium album*) (Webster 2010). Of these species Palmer amaranth is the most problematic and competitive. Meyers et al. (2010a) reported predicted sweetpotato marketable yield loss as much as 50% with as few as one Palmer amaranth plant per m^{-1} of row. Palmer amaranth should also be controlled to reduce the amount of seeds being added to the seed bank due to its high reproductive capacity. A single mature female plant can produce in excess of 500,000 seed (Keeley et al. 1987; Webster and Grey 2015). That number of seed can exceed 1,000,000 in some instances (A.C. York, personal communication). The reproductive potential of Palmer amaranth makes it capable of infesting fields rapidly.

Like most vegetable crops a limited number of herbicides are registered for application in sweetpotato (Kemble 2015). In addition to applying herbicides to control weeds growers also cultivate between rows prior to vining of the crop and hand remove weeds within rows (Haley and Curtis, unpublished data). No selective POST herbicide is registered for broadleaf weed control in sweetpotato. Growers rely on PRE herbicides almost exclusively for broadleaf weed control. Of the registered PRE herbicides, two of the most commonly used by growers in North Carolina are flumioxazin PREPLANT followed by *S*-metolachlor PRE 10 to 14 d after transplant, and is the standard herbicide program used by growers in North Carolina for Palmer amaranth control (K.M. Jennings, personal communication). This herbicide program provides > 90% season long control of Palmer amaranth but applications of *S*-metolachlor have to be made timely and to a weed-free field to provide good control of pigweed species including Palmer amaranth (Meyers et al. 2010b). However, if *S*-metolachlor is applied too soon after transplant and heavy rains occur, injury (shortening, rounding of storage roots) to the developing sweetpotato storage roots may occur (Meyers et al. 2013). Applying flumioxazin in sweetpotato and in many rotation crops with sweetpotato puts intense selection pressure on weed species and the potential for increased populations of weeds having herbicide resistance to this family of herbicides. Crops commonly grown in rotation with sweetpotato include cotton, corn, peanuts, soybeans (Hayley and Curtis, unpublished data); all are crops that flumioxazin is registered in and commonly used (Anonymous 2010). With the recent report of PPO resistant Palmer amaranth in Arkansas, Tennessee, Missouri, Illinois, and Kentucky (L. Steckel, personal communication) the threat of resistance to North Carolina growers is great. Clomazone and napropamide are also registered for PRE application in sweetpotato. However, control of redroot pigweed (*Amaranthus retroflexus*) and other pigweed species was 55% with clomazone and less than 83% with napropamide (Scott et al. 1995; Jachetta et al. 1979).

Research efforts in sweetpotato are underway to register additional chemistries with other modes of action that will provide good control of pigweed species. One of the chemistries that is being investigated is linuron, a substituted urea herbicide. Linuron has both PRE and POST activity. Linuron has activity on carpetweed, common lambsquarters, pigweed species, common purslane, crabgrass, fall panicum, and other broadleaf and grassy species PRE. Linuron POST controls morningglory species, pigweed species, velvetleaf, annual ryegrass, broadleaf signalgrass and other broadleaf and annual grass species (Anonymous 2007). Researchers (Brandenberger et al. 2009; Hahn 1992; Miller et al. 2013) have reported that linuron provides up to 96% control of Palmer amaranth, 99% control of common lambsquarters, and 90% control of carpetweed. Evidence exists that sweetpotato is tolerant to linuron when applied prior to transplant (Miller et al. 2013). However, limited research has been conducted to determine sweetpotato tolerance to POST transplant applications of linuron. Linuron POST transplant in sweetpotato would be beneficial to growers if it was safe to sweetpotato because it gives both PRE and POST control of broadleaf weeds including Palmer amaranth and some annual grass species. Thus, the objective of this research was to determine tolerance of sweetpotato to linuron POST applied over the top of the crop.

Materials and Methods

Studies were conducted on grower fields in Faison, North Carolina in 2015. Nonrooted sweetpotato cuttings were cut from field propagation beds by hand and were mechanically transplanted with an in row spacing of 30 cm on May 19, 2015. Location one

(35.052524 N, 78.025684 W) was transplanted with ‘Covington’ and location 2 (35.052524 N, 78.079177 W) with ‘Murasaki-29’ (Murasaki hereafter). Soil at both locations was an Autryville loamy fine sand (loamy, siliceous, subactive, thermic arenic Paleudults) with pH 5.4 and 6.1 and 1.2 and 2.2% organic matter at location 1 and 2, respectively. Plot size was 2 rows each 1.1 m wide and 6 m long. The first row of each plot was nontreated and served as a border row; the second row received a treatment. The experimental design was a randomized complete block with four replications. Treatments consisted of a factorial arrangement of two application timings (7 or 14 d after transplant [DAP]) and five rates of linuron (0, 420, 560, 841, 1121g ai ha^{-1}) (Linex 4L, E. I. du Pont de Nemours and Company, Wilmington, DE 19898) with and without *S*-metolachlor (Dual Magnum, Syngenta Crop Protection Inc., Greensboro, NC 27409) at 803 g ai ha^{-1}. No surfactant was included with any rate of linuron. Weedy and weed-free nontreated checks were included for comparison. All plots (except the weedy check) were maintained weed-free with flumioxazin (Valor SX, Valent U.S.A. Corporation, P.O. Box 8025, Walnut Creek, CA 94596) at 107 g ai ha $^{-1}$ PREPLANT, cultivation, and hand removal of weeds weekly. Herbicide applications were made with a CO_2 pressurized back pack sprayer calibrated to deliver 187 L ha^{-1} with a 2 nozzle boom equipped with TeeJet XR 11002VS flat fan nozzles (Spraying Systems Co., Wheaton, IL 60187).

Data recorded included visual crop injury, crop stand count, and storage root yield by weight and grade. Visual crop injury was recorded 1, 2, 4, 8, 10, and 12 WAT (wk after treatment) using a scale of 0 (no injury) to 100% (crop death) (Frans et al. 1986). Sweetpotato storage roots were harvested 105 (location one) and 142 DAP (location two) using a tractor mounted disc turn plow and hand-graded into jumbo, (>8.9 cm diam.), no. 1 (>4.4 cm but <8.9 cm diam.), and canner (>2.5 cm but <4.4 cm diam.) grades (USDA 2005). Total marketable yield was calculated as the sum of jumbo, no. 1, and canner grades.

Data were analyzed using SAS 9.3 (SAS Institute Cary, NC) and subjected to analysis with analysis of variance using proc GLM and proc MIX. Injury data were regressed and Covington data were best fit to a linear model and Murasaki were best fit to a quadratic model to explain the trend in injury that was observed.

Results and Discussion

Sweetpotato Injury. Sweetpotato crop injury was analyzed by cultivar. Crop injury first appeared as interveinal chlorosis at the lower rates of linuron (Figure 2.1) and necrosis on the tips and edges of leaves at the higher rates of linuron (Figure 2.2). These injury symptoms were observed 1 WAT, by 2 WAT the only injury observed was crop stunting. In both cultivars crop injury was transient, however, some injury (1 to 20%) was observed at 8 WAT in Covington but none was observed in Murasaki (data not shown).

Injury to Covington was fit to a linear model at 1, 2 (data not shown) and 4 WAT. At 1 and 2 WAT injury differed between the 7 and 14 DAP treatments. However, no differences were observed between linuron POST alone or with *S*-metolachlor at 1 WAT. Visual injury was less with 7 DAP than 14 DAP treatments (Figure 2.3A). By 4 WAT injury from linuron POST alone was less than linuron plus *S*-metolachlor. A similar trend was observed with 7 DAP treatments overall caused less injury than 14 DAP treatments (Figure 2.3B).

Murasaki injury data were fit to a quadratic model. At all rating dates, when 7 and 14 DAP treatments were compared, injury from linuron plus *S*-metolachlor was greater compared to linuron alone. Similar to the trend observed with injury in Covington, 7 DAP treatments caused less injury than 14 DAP treatments in Murasaki 1 WAT (Figure 2.4A). At 4 WAT the injury in the 7 DAP treatments in the linuron alone and linuron plus *S*-metolachlor treatments had the same trend as at 1 WAT in that linuron alone had less injury than linuron plus *S*-metolachlor (Figure 2.4B). The 14 DAP treatments overall had higher injury than the 7 DAP treatments.

These results however are not consistent with findings of other researchers. Linuron applied at 561, 841, and 1120 g ai ha^{-1} applied 2 WAP had injury that did not exceed 38% at any time during the season (Rouse et al. 2015). Sweetpotato treated with linuron did show injury symptoms longer into the season than other treatments applied (Rouse et al. 2015). Other findings on an experimental line of sweetpotato from Louisiana State University expressed only 11% injury when linuron was applied at 841 g ai ha^{-1} (Miller et al. 2013). The differences in injury to sweetpotato when linuron is applied POST could be cultivar dependent since results from this experiment and other research show differential response of sweetpotato cultivars to linuron.

Sweetpotato Yield. Yield of Covington and Murasaki sweetpotato is different under normal growing conditions and this genetic variation explains the yield differences between the two cultivars. Marketable yield (sum of no. 1, jumbo, canner) of Covington sweetpotato averages 41,484 kg ha^{-1} (Yencho et al. 2008) and Murasaki averages 15,494 kg ha^{-1} (La Bonte et al. 2008). Thus, sweetpotato yield was analyzed by cultivar. Yield of Covington storage roots in the weed-free control was 24,881, 13,584, 2,793, and 41,258 kg ha^{-1} of no. 1, jumbo, canner, and marketable respectively. Yield of marketable storage roots of sweetpotato with linuron or linuron plus *S*-metolachlor POST 7 DAP was not different from the weed-free control (Figure 2.5). However, linuron POST 14 DAP reduced marketable storage root yield. Covington marketable storage root yield was greater with linuron alone compared to linuron plus *S*-metolachlor at 7 and 14 DAP.

Yield of Murasaki weed-free yielded 20,616, 906, 5,069, and 26,591 kg ha^{-1} of no. 1, jumbo, canner, and marketable roots respectively. Yield of marketable roots was not different from the weed-free control when linuron was applied 7 DAP except at the highest rate of linuron at 1120 g ai ha^{-1} (Figure 2.6). The yield of marketable storage roots was less than the weed-free when linuron was applied 14 DAP. Yield of marketable storage roots was greater with linuron plus *S*-metolachlor compared to linuron alone at 7 DAP. At 14 DAP the yield trend was the same as in Covington where the marketable yield was higher in the plots treated with linuron alone than with linuron plus *S*-metolachlor. The decreases in yield that were observed in this study are also inconsistent with findings from prior research. It has been reported that linuron applied 2 WAT at rates of 561, 841, and 1120 g ai ha^{-1} did not reduce yields compared to the weed-free nontreated check (Rouse et al. 2015; Miller et al. 2013).

Covington and Murasaki sweetpotato appeared to be tolerant to linuron alone at 420 g ai ha^{-1} applied 7 DAP. Injury in Covington was >10% 1 WAT which would generally be higher than acceptable injury. However, Murasaki injury was <10% throughout the season with linuron at 420 g ai ha^{-1}. When linuron was applied with *S*-metolachlor injury in both cultivars was greater than the accepted injury level of >10%. However no differences in yield were found when linuron was applied at 420 g ai ha^{-1} 7 DAP. Linuron at 14 DAP reduced yield at all rates of linuron alone or with *S*-metolachlor. Injury increased with increasing rate of linuron and yield was reduced with linuron alone at 840 and 1120 g ai ha^{-1}. The addition of *S*-metolachlor reduced yield at both application timings except in Murasaki where yield was increased with the addition of *S*-metolachlor 7 DAP. Additional studies will need to be conducted to determine the tolerance of other sweetpotato cultivars to linuron POST and to determine if that rate provides adequate weed control of Palmer amaranth and other major weed species in sweetpotato production areas.

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Figure 2.1. Linuron POST injury, interveinal chlorosis, to sweetpotato at 560 g ai ha^{-1} 1 wk after treatment at Faison, NC 2015.

Figure 2.2. Linuron POST injury, necrosis along leaf margins, to sweetpotato at 1120 g ai ha^{-1} 1 wk after treatment at Faison, NC 2015.

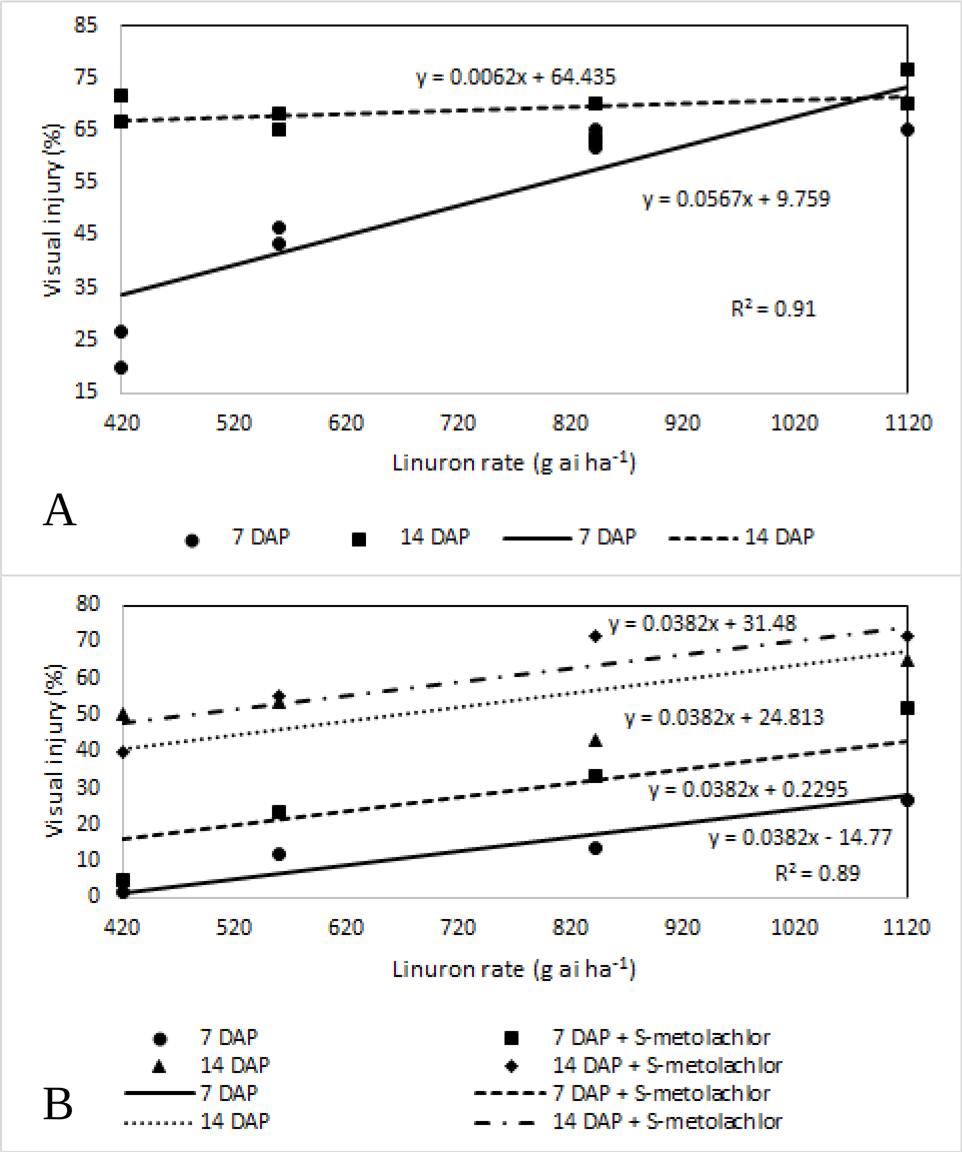

Figure 2.3. Covington injury from linuron and linuron + *S*-metolachlor at Faison, NC 2015. Covington injury 1 WAT (A) and injury 4 WAT (B).

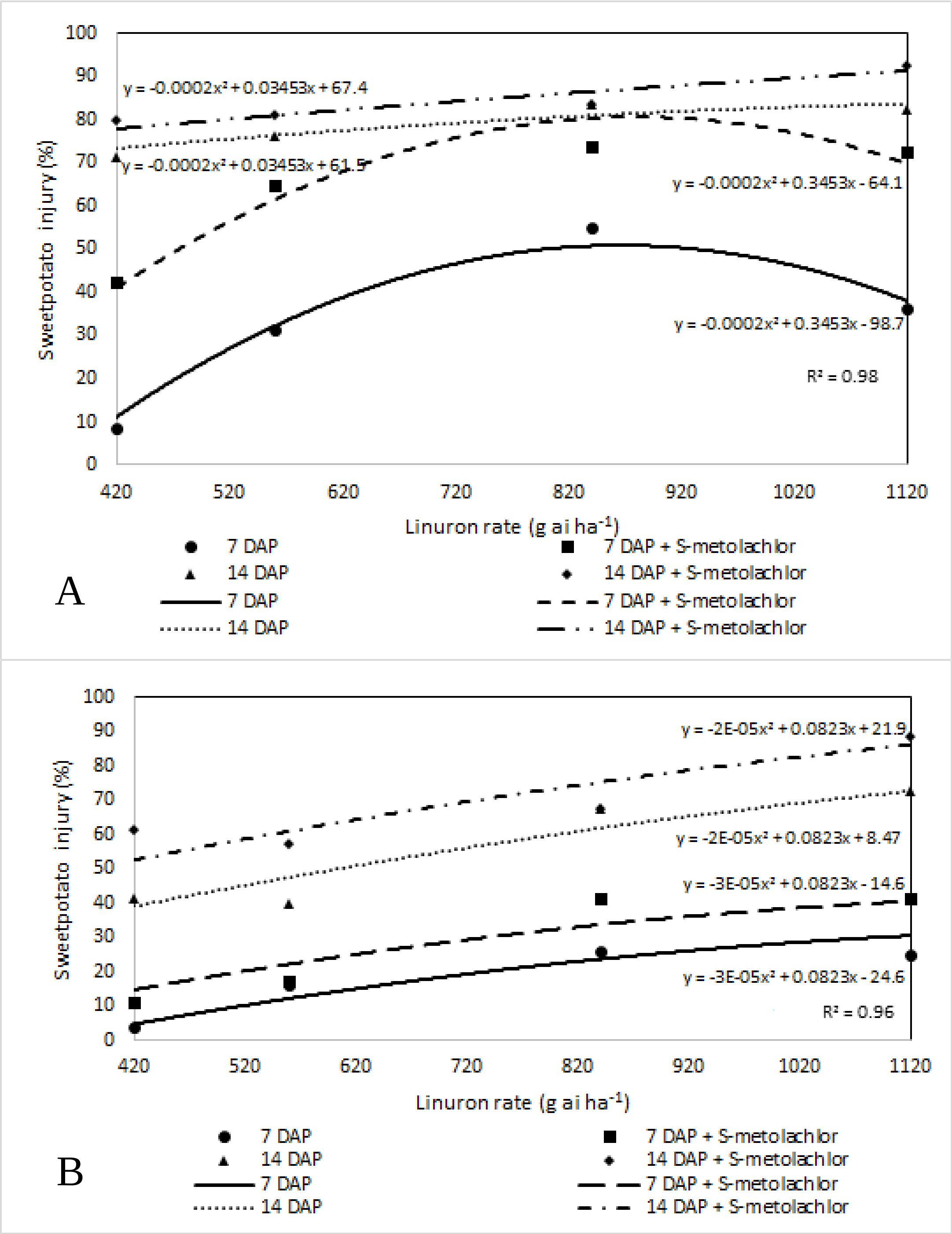

Figure 2.4. Murasaki injury from linuron and linuron + *S*-metolachlor at Faison, NC 2015. Murasaki injury 1 WAT (A) and injury 4 WAT (B).

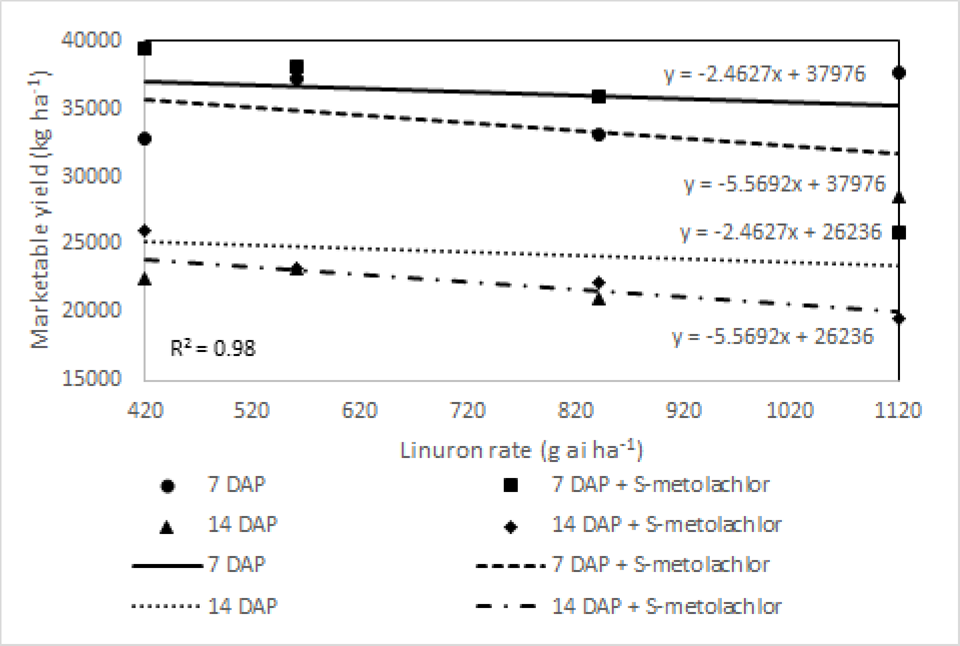

Figure 2.5. Covington marketable yield at Faison, NC 2015.

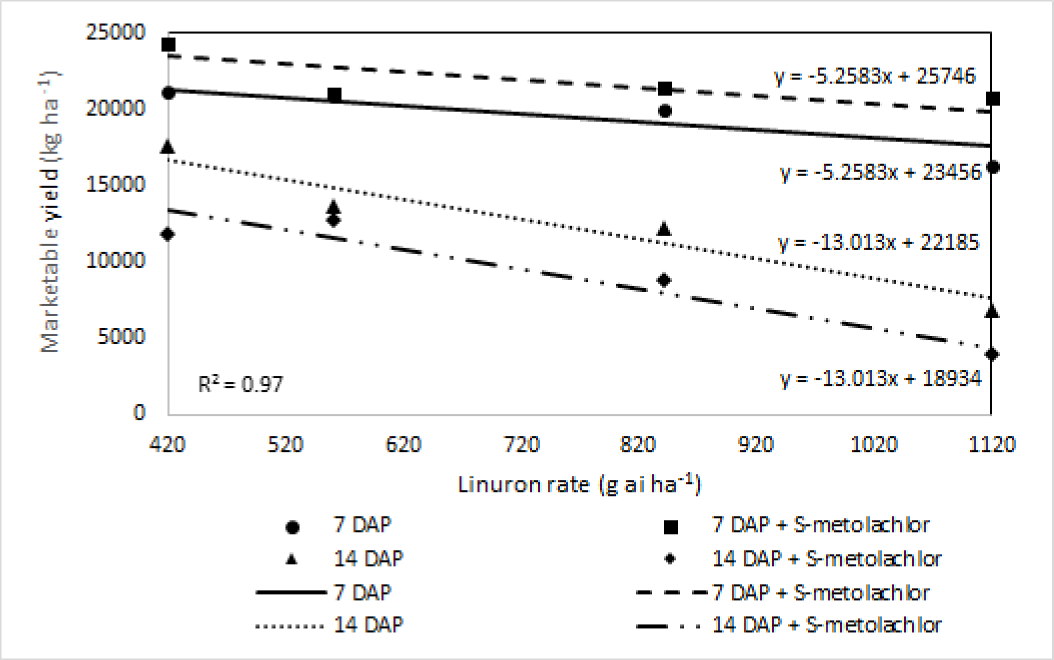

Figure 2.6. Murasaki marketable yield at Faison, NC 2015.

CHAPTER 3

Critical Timing of Yellow Nutsedge (*Cyperus esculentus*) Removal in Sweetpotato (*Ipomoea batatas*)

(In the format appropriate for submission to Weed Technology)

Nutsedge removal in sweetpotato

Critical Timing of Yellow Nutsedge (*Cyperus esculentus*) Removal in Sweetpotato (*Ipomoea batatas*)

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Studies were conducted in 2015 on grower fields in Bailey, North Carolina to determine the critical timing of yellow nutsedge removal in 'Orleans' sweetpotato. Treatments were yellow nutsedge removal timings of 0 (season long weed-free), 1, 2, 3, 4, 6, 10, and 14 (season long weedy) wk after sweetpotato transplant. Sweetpotato storage roots were harvested 119 d after planting. A negative linear trend for no. 1, canner and marketable (no. 1, jumbo, and canner) sweetpotato storage roots was observed the longer yellow nutsedge was allowed to remain in the sweetpotato. Marketable yield was fit to a linear regression model and predicted yield loss was approximately 3% for every week yellow nutsedge was allowed to compete with sweetpotato. A positive linear trend in nutsedge density and biomass was also observed.

Nomenclature: Yellow nutsedge, *Cyperus esculentus* L., CYPES, sweetpotato, *Ipomoea batatas* (L.) Lam.

Key words: Critical period for weed control, weed removal, weed competition, weed interference.

Sweetpotato [*Ipomoea batatas* (L.) Lam] (USDA Plants Database 2015) is an economically important crop in North Carolina and is ranked the number one vegetable crop in value ($350 million) and harvested area (34,803 ha) (USDA-NASS 2016). North Carolina produces over 50% of the national annual production of sweetpotato. The market for sweetpotato continues to grow domestically and abroad, specifically in Europe. (J.R. Schultheis, personal communication).

Palmer amaranth (*Amaranthus palmeri*), yellow nutsedge (*Cyperus esculentus*), smooth pigweed (*Amaranthus hybridus*) and common lambsquarters (*Chenopodium album*) are economically important weed species in sweetpotato in North Carolina (Webster 2010). Of these weeds yellow nutsedge is the second most troublesome weed for sweetpotato growers in North Carolina, behind Palmer amaranth. Yellow nutsedge is considered the sixteenth most troublesome weed worldwide (Holm et al. 1991). Prior to the mid-20th century yellow nutsedge was of minor concern in North Carolina and the southern United States, it is unknown how it suddenly became such a problematic weed (Stoller 1981; DeFelice 2002). Yellow nutsedge is an erect perennial weed that spreads by rhizomes and production of tubers (DeFelice 2002). Due to the spreading habit of yellow nutsedge it can rapidly infest a field if left uncontrolled (Webster 2005; Meyers and Shankle 2015). Yellow nutsedge infests millions of ha of corn, soybean, and other crops across the eastern and central United States and continues to spread (DeFelice 2002).

The critical period for controlling a mixture of redroot pigweed, yellow nutsedge, and sicklepod in organically produced ‘Beauregard’ sweetpotato is 0 to 6 wk after transplanting (WAT) (Seem et al. 2003). Many fields in North Carolina are infested primarily with yellow nutsedge in August and few other weeds (D.W. Monks and J. Jones, personal communication). Although research by Seem et al. (2003) was conducted on a mixed weed population including yellow nutsedge, the critical timing of yellow nutsedge removal in sweetpotato is not known. Yellow nutsedge can cause yield loss in sweetpotato depending on the density. Yield loss of marketable sweetpotato at densities as low as 5 yellow nutsedge per m^{-2} ranges from 6 to 18% (Meyers and Shankle 2015). At densities as high as 90 plants per m^{-2} marketable yield loss can be as high as 67 to 80% (Meyers and Shankle 2015). Yellow nutsedge can reduce marketable sweetpotato yield in several ways including competition for nutrients, water, space, and light. Yellow nutsedge can also reduce marketable sweetpotato yield by its rhizomes growing through the developing storage roots and causing deformation and decay (Meyers and Shankle 2015; DeFelice 2002).

Growers use both cultural and chemical methods to control weeds in sweetpotato. The standard herbicide program in North Carolina is flumioxazin PREPLANT followed by *S*-metolachlor 7 to 10 d after sweetpotato transplanting (DAP) (K.M. Jennings, personal communication). Flumioxazin has no activity on yellow nutsedge whereas *S*-metolachlor PRE has been reported to control yellow nutsedge 78 to 87% at 1.1 kg ha^{-1} in peanut (Grichar et al. 2001). The registered rates of *S*-metolachlor for sweetpotato in North Carolina are 0.8 to 1.1 kg ha^{-1}. This registration is provided by a section 24(c) special local need label (Anonymous 2013). *S*-metolachlor has no activity on emerged weeds, therefore application timing is critical. No POST herbicides are registered in sweetpotato for yellow nutsedge and broadleaf weed control. The only options available for yellow nutsedge control is by cultivation or hand removal. Both of these options are expensive and time consuming to perform, and must be done at a critical time to give the best return for growers. Cost of controlling weeds by hand removal in sweetpotato in North Carolina can range from \$495 to \$988 ha^{-1} depending on how many times it is needed. (T. Burch, personal communication). Thus the objective of this research was to determine the critical timing for yellow nutsedge control in sweetpotato.

Materials and Methods

Studies were conducted on grower fields in Bailey, North Carolina in 2015 (35.827339 N, 78.100903 W and 35.828695 N, 78.100657 W). ‘Orleans’ non-rooted sweetpotato cuttings (slips) were cut by hand from field propagation beds and mechanically transplanted to an in row spacing of 30 cm on June 11, 2015. Soil at both locations was a Norfolk loamy sand (Fine-loamy, kaolinitic, thermic Typic Kandiuldults) with 0.8% organic matter and pH 6.2 and 5.0 at location 1 and 2, respectively. Plots were 1 row 1.1 m wide by 3 m long. Treatments consisted of yellow nutsedge removal timings at 0 (weed-free), 1, 2, 3, 4, 6, 10, 14 (weedy) wk after transplanting (WAP) arranged in a randomized complete block with four replications. After yellow nutsedge removal from each treatment each plot was maintained weed-free by hand for the remainder of the season.

Data recorded included sweetpotato stand count, storage root yield (weight and grade), yellow nutsedge number (individual plants), and yellow nutsedge above ground biomass. Yellow nutsedge number and biomass data were collected at each removal timing. Yellow nutsedge growing in a 30 cm band on top of the bed were counted and weighed. The shoulders of the bed were able to be cultivated early in the season. Once vines started to grow into the row middles cultivation ceased. Any yellow nutsedge present on the shoulders of the beds after was removed but not included in the counts and weights. Sweetpotato storage roots were harvested 119 d after planting (DAP) using a commercial tractor-mounted sweetpotato disc turn plow and then hand-graded into jumbo, (>8.9 cm diam.), no. 1 (>4.4 cm but <8.9 cm diam.), and canner (>2.5 cm but <4.4 cm diam.) grades (USDA 2005). Total marketable yield was calculated as the sum of jumbo, no. 1, and canner grades.

Data were subjected to analysis of variance using proc GLM and proc MIX (SAS 9.3, SAS Institute Inc., Cary, NC) and all yield data were tested for location by nutsedge removal timing interaction. Nutsedge growth data were transformed by logarithmic transformation to detect treatment differences but untransformed data are presented.

Results and Discussion

Sweetpotato yield. Due to a lack of treatment by location interaction data were averaged across locations. Under normal growing conditions, Orleans sweetpotato yields on average 40,033 kg ha^{-1} of marketable storage roots (sum of no. 1, jumbo and canner grades) (LaBonte et al. 2012). Sweetpotato weed-free treatment yielded 18,922, 3,119, 5,140, and 27,181 kg ha^{-1} of no. 1, jumbo, canner, and marketable storage roots, respectively (Table 3.1). During the period of the study a combination of minimal rainfall and high temperatures reduced growth and vigor of the sweetpotato and yellow nutsedge plants (J. Jones, personal communicaton). During the period of the study there was 44.36 cm of rain measured. However, during June, July and August only 17.86 cm of rain was measured. Most of the remaining rainfall was during a two week period at the end of the season at the end of

September and the first of October. No form of supplemental irrigation was applied. Wilt of both the sweetpotato and yellow nutsedge was observed during most weekly visits. However, even with a low yield environment yields were generally improved when yellow nutsedge was removed earlier in the growing season (Table 3.1). A significant linear trend in yield reduction was observed the longer yellow nutsedge was allowed to compete with sweetpotato. That is, yield of all grades except for jumbo decreased as yellow nutsedge remained in sweetpotato. Marketable yield was fit to a linear regression model. The model predicts a marketable yield loss of 700 kg ha^{-1} (3% marketable yield loss) for every wk that yellow nutsedge is allowed to compete with sweetpotato (Figure 3.1). A reduction in marketable yield of 6% would occur if yellow nutsedge is allowed to compete with the sweetpotato crop for more than 2 wk. Predicted yield loss is as much as 40% if yellow nutsedge is allowed to compete season long. These results are similar to prior research in sweetpotato that demonstrated that the critical weed free period of Beauregard sweetpotato with a mixed weed complex was between 2 and 6 wk after transplant (Seem et al. 2003). Likewise, these data are similar to research in plasticulture grown bell pepper which found the critical yellow nutsedge free period to be 3 to 5 WAP (Motis et al. 2004).

Yellow nutsedge growth. There was no interaction between yellow nutsedge removal timing and location on yellow nutsedge density and biomass therefore data were averaged across locations. A positive linear trend was observed, yellow nutsedge density increased over time as it remained in sweetpotato (Table 3.2). An average of 7 yellow nutsedge plants m^{-2} were removed from the weed-free treatment at the time of sweetpotato transplanting. However, season long weedy treatment had an average density of 65 plants m^{-2}, recorded at harvest.

Yellow nutsedge biomass (fresh and dry weight) followed a positive linear trend as it remained in sweetpotato. These results are consistent with prior research that if yellow nutsedge is allowed to grow uncontrolled it will rapidly increase in population density across a field (Webster 2005; Meyers and Shankle 2015).

Yellow nutsedge is a weed that infest many sweetpotato fields in North Carolina and the Southeast U.S. The control options for yellow nutsedge are limited in sweetpotato. In addition cultural management of yellow nutsedge can be difficult due to the vining nature of sweetpotato. It is critical to control yellow nutsedge early in the season to prevent yield and quality loss of sweetpotato (Meyers and Shankle 2015). Further studies will need to be conducted to confirm these results under optimal growing conditions.

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Table 3.1. Effect of yellow nutsedge removal timing on sweetpotato yield at Bailey, NC 2015.

Nutsedge removal timing (wk after transplanting)	Yield (kg ha^{-1})			
	No. 1	Jumbo	Canner	Marketable
Weed-free (0)	18922	3119	5140	27181
1	18922	52	3014	21989
2	16901	714	2701	20316
3	19248	3746	3206	26380
4	15211	3258	3154	21623
6	19027	348	2126	21501
10	13922	976	2648	17546
Weedy (14)	12946	261	1969	15176
p-value[a]	0.0079	0.0552	0.0125	0.0002

[a] P-value for test of linear effect on sweetpotato yield by grade of yellow nutsedge removal date.

Table 3.2. Effect of yellow nutsedge removal timing on yellow nutsedge density and biomass.

Nutsedge removal timing (wk after transplanting)	Nutsedge (no. m^{-2})	Fresh weight (g m^{-2})	Dry weight (g m^{-2})
Weed-free (0)	7	2.56	0.16
1	48	16.45	3.95
2	31	29.78	10.84
3	21	12.62	8.02
4	74	31.67	8.86
6	58	24.33	7.34
10	44	91.21	50.10
Weedy (14)	65	88.14	38.13
p-value[a]	<.0001	<.0001	<.0001

[a] P-value for test of linear effect on yellow nutsedge density and biomass on yellow nutsedge removal date.

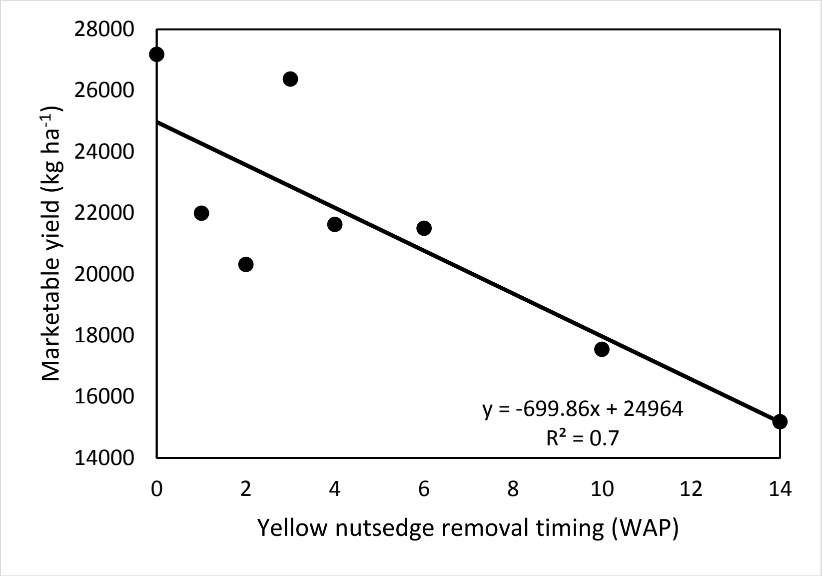

Figure 3.1. Effect of yellow nutsedge removal on marketable sweetpotato yield at Bailey, NC 2015. Points represent observed mean data at each yellow nutsedge removal timing.

CHAPTER 4

Weed Control and Tolerance of Sweetpotato (*Ipomoea batatas*) to Flumioxazin/Pyroxasulfone

(In the format appropriate for submission to Weed Technology)

Flumioxazin/pyroxasulfone sweetpotato tolearance

Palmer amaranth Control and Tolerance of Sweetpotato (*Ipomoea batatas*) to Flumioxazin/Pyroxasulfone

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Studies were conducted in 2015 at the Horticultural Crops Research Station in Clinton, North Carolina to determine the response of sweetpotato and Palmer amaranth to a premix of flumioxazin and pyroxasulfone PRE followed by simulated rainfall. Treatments included flumioxazin/pyroxasulfone at 107, 151, 167, and 280 g ai ha^{-1} and flumioxazin at 107 g ai ha^{-1} followed by *S*-metolachlor at 803 g ai ha^{-1} 7 to 10 d after transplant (DAP). Visual ratings for Palmer amaranth control and sweetpotato injury were recorded 9, 16, 38, and 124 and 8, 14, and 30 DAP at locations (LOC) 1 and 2, respectively. Sweetpotato storage roots were harvested at 124 and 103 DAP for LOCs 1 and 2, respectively. Palmer amaranth control was >91% season long at both LOCs. Sweetpotato injury was slow to develop and no injury was observed until 16 DAP at LOC 1. A linear trend of increasing injury was observed with increasing rate of flumioxazin/pyroxasulfone was observed at LOC 1, at LOC 2 no linear trend was observed 14 DAP. At the second rating, 38 and 30 DAP for LOC 1 and 2 respectively, the trends were the same as the first rating. Greatest injury was observed at LOC 1 at 33% with flumioxazin/pyroxasulfone at 280 g ai ha^{-1}. Sweetpotato marketable yield was reduced at LOC 1 with flumioxazin/pyroxasulfone at 280 g ai ha^{-1} but no differences in marketable yield were observed at LOC 2.

Nomenclature: flumioxazin; pyroxasulfone; sweetpotato, *Ipomoea batatas* (L.) Lam.

Key words: Timing, rate, yield, and injury.

Sweetpotato [*Ipomoea batatas* (L.) Lam] is the single most widely planted vegetable crop in North Carolina, and North Carolina is the largest producer of sweetpotatoes in the United States. In 2015 approximately 34,803 ha were harvested with a value in excess of $350 million. Production occurs across the state but is concentrated in the central coastal plain of North Carolina (USDA-NASS 2016). The market for sweetpotatoes has been steadily growing and planted ha has increased an average of 5% a year since 2000 (USDA-NASS 2016).

In North Carolina the most economically important weed species that occur in sweetpotato include Palmer amaranth (*Amaranthus palmeri*), yellow nutsedge (*Cyperus esculentus*), smooth pigweed (*Amaranthus hybridus*), and common lambsquarters (*Chenopodium album*) (Webster 2010). Palmer amaranth is the most problematic and competitive weed and is the driving force for development of weed management programs. Predicted marketable sweetpotato yield can be reduced by as much as 50% with as little as one Palmer amaranth plant per m^{-1} of crop row (Meyers et al. 2010a). Controlling Palmer amaranth in sweetpotato is critical to prevent yield and quality loss of marketable sweetpotato storage roots. Palmer amaranth control is also critical because of its reproductive capacity which can exceed 500,000 seeds per mature female plant (Keeley et al 1987; Webster and Grey 2015). In some instances this number of seed can be in excess of 1,000,000 (A.C. York, personal communication). Palmer amaranth has the ability to rapidly infest fields and easily spread between fields.

There are a limited number of herbicides registered for use in sweetpotato (Kemble 2015). Sweetpotato growers utilize multiple weed management strategies including herbicides, between row cultivation, and hand removal of weeds (Haley and Curtis, unpublished data). Hand removal is expensive ranging from \$490 to \$980 ha^{-1} (T. Burch, personal communication) but it is economically feasible in some cases due to the high value of the crop. However, if production costs can be reduced, growing sweetpotato could be even more profitable. No selective POST herbicides are registered for broadleaf weed control in sweetpotato. However, glyphosate applied with a wick and carfentrazone directed under a shielded sprayer are registered for use in sweetpotato in North Carolina (Kemble 2015). Populations of Palmer amaranth across North Carolina are resistant to glyphosate (Culpepper et al. 2008). Thus, growers rely on PRE herbicides to provide control of Palmer amaranth and other broadleaf weeds. The recommended PRE herbicide program in North Carolina is flumioxazin PREPLANT followed by *S*-metolachlor PRE after transplant at 7 to 10 d. The sequential program provides >90% season long control of Palmer amaranth if applications are made prior to Palmer amaranth emergence (Meyers et al. 2010b). Flumioxazin is applied in sweetpotato and in many of the crops grown in rotation with sweetpotato. These rotational crops include cotton, corn, peanut, and soybean (Hayley and Curtis, unpublished data); all of these crops have a registration for flumioxazin (Anonymous 2010). Other PPO inhibiting herbicides are also used in these rotational crops. The use of PPO inhibiting herbicides in all of these crops puts intense selection pressure on weeds especially Palmer amaranth to develop resistance. With the recent reports of PPO-resistant Palmer amaranth in Arkansas, Tennessee, Missouri, Illinois, and Kentucky (L. Steckel, personal communication) the threat of resistance developing or already being present but not yet confirmed in North Carolina is great.

Research in sweetpotato are underway to register additional chemistries for controlling Palmer amaranth. One of these chemistries is pyroxasulfone, a very long chain fatty acid synthesis inhibitor. Pyroxasulfone when applied with flumioxazin has excellent PRE activity on pigweed species (>99% control) (Mahoney et al. 2014). However, limited evidence exists to suggest that sweetpotato is tolerant to pyroxasulfone applications (Rouse et al. 2015). The objective of this research was to determine the response of sweetpotato and Palmer amaranth to a premix of flumioxazin and pyroxasulfone PRE followed by (fb) simulated rainfall.

Materials and Methods

Field Study. Studies were conducted at the Horticultural Crops Research Station in Clinton, NC in 2015. Nonrooted 'Covington' sweetpotato plants (slips) were cut from field propagation beds by hand. Sweetpotato slips were transplanted with a mechanical transplanter 10 cm deep spaced 30 cm apart in row at location one (35.023279 N, 78.280429 W) [LOC 1] and location two (35.023712 N, 78.2780429 W) [LOC 2] on June 12, and July 8, 2015, respectively. Soil at LOC 1 and LOC 2 was a Norfolk loamy sand (Fine-loamy, kaolinitic, thermic Typic Kandiudults) and an Orangeburg loamy sand (Fine-loamy, kaolinitic, thermic Typic Kandiudults), respectively, with pH 5.9 and 0.6% organic matter. Plot size was 4 rows each 1.1 m wide by 6 m long. The first and fourth row of each plot was nontreated and served as border rows; the second and third rows received an herbicide treatment. The experimental design was a randomized complete block with four replications. Treatments consisted of a factorial arrangement of four rates of flumioxazin/pyroxasulfone and one rate of flumioxazin followed by *S*-metolachlor 7 to 10 d after transplant [DAP] (Table 4.1) and three irrigation events to simulate rainfall. Herbicide applications were made with a CO_2 pressurized back pack sprayer calibrated to deliver 187 L ha^{-1} through a 2 nozzle boom equipped with TeeJet XR 11002VS flat fan nozzles (Spraying Systems Co., Wheaton, IL 60187). Timing of irrigation was 0 to 2 DAP, 3 to 5 DAP, and 2 wk after planting (WAP). Each irrigation event was the equivalent of 1.9 cm of rainfall. Nontreated (weedy and weed-free) plots were included for comparison in each of the three irrigation events. Supplemental irrigation to the entire field was provided throughout the growing season as necessary to maintain crop growth.

Crop injury and Palmer amaranth control (*Amaranthus palmeri*) were estimated visually on a scale from 0 (no injury or no control) to 100 (crop death or complete control) (Frans et al. 1986) at 9, 16, 30 and 124 DAP and 8, 14 and 30 DAP for LOC 1 and LOC 2 respectively. Sweetpotato storage roots were harvested 124 and 103 DAP at LOC 1 and LOC 2, respectively, using a chain digger and hand-graded into jumbo (>8.9 cm diam.), no. 1 (>4.4 cm but <8.9 cm diam.), and canner (>2.5 cm but <4.4 cm diam.) grades (USDA 2005). Total marketable yield was calculated as the sum of no. 1, jumbo, and canner grades.

Data were subjected to ANOVA and analyzed by proc GLM and proc MIX in SAS 9.3 (SAS Institute Inc., Cary, NC). All data were tested for location by herbicide and location by rainfall treatment interaction. Sweetpotato injury data were transformed using arcsine transformation but untrasformed data are presented. Means of the main effects (herbicide and rainfall treatment) for yield were analyzed using contrast statements. Means were separated using Fisher’s Protected LSD $P \leq 0.05$.

Results and Discussion

Palmer amaranth Control. A treatment by location interaction was not observed and data are presented averaged across locations. The main effect of rainfall and the interaction between rainfall and herbicide treatment was not significant for any treatment ($P > 0.05$), therefore Palmer amaranth control was averaged across location and rainfall treatment. At all rating dates there were no differences between herbicide treatments. At the first three rating dates Palmer amaranth control was >96% for all rates of flumioxazin/pyroxasulfone and flumioxazin fb *S*-metolachlor (Table 4.2). At LOC 1 124 DAP the trend was similar and Palmer amaranth control was >91% at all rates of flumioxazin/pyroxasulfone and flumioxazin fb *S*-metolachlor. These results are similar to previous research that found Palmer amaranth control with fluioxazin/pyroxasulfone to be >95% in soybean with rates similar to those used in this study (Mahoney et al. 2014; Norsworthy et al. 2014).

Sweetpotato Injury. A location by herbicide treatment interaction was observed so data are presented by location. Sweetpotato injury was slow to develop and no injury was present 9 and 8 DAP at LOC 1 and LOC 2 respectively. By 16 DAP at LOC 1, some stunting was observed ranging from 1 to 7 % (Table 4.3). This injury followed a significant linear trend ($P = 0.0001$) of increasing injury with increasing rate of flumioxazin/pyroxasulfone. At LOC 2, no injury was observed. At 38 and 30 DAP at LOC 1 and 2, respectively, crop stunting was observed. LOC 1 had injury ranging from 2 to 33% and followed a significant linear trend ($P < .0001$) of increasing injury with increasing flumioxazin/pyroxasulfone rate. At LOC 2, injury ranged from 1 to 5% but did not follow a linear trend of increasing injury. At this same rating date, 38 and 30 DAP, for LOC 1 and 2, respectively, the interaction of location by rainfall treatment was significant so means are presented by location. At LOC 1 there was a difference between rainfall treatments with injury ranging from 2 to 15% (Table 4.4). At LOC 2 injury ranged from 1 to 3% but no differences were observed between each rainfall treatment. These results are inconsistent to Meyers et al. (2013) that found sweetpotato injury to be as high as 26% when flumioxazin/pyroxasulfone was applied at 89 g ai ha^{-1}. The highest injury in this study was observed to be 33% but when flumioxazin/pyroxasulfone was applied at 280 g ai ha^{-1}. The injury observed in this study when flumioxazin/pyroxasulfone was applied at 167 g ai ha^{-1} was 16% which was similar to injury reported by Miller et al. (2013) and Shankle et al. (2013), who found injury not to exceed 10% when flumioxazin/pyroxasulfone was applied at 160 g ai ha^{-1}.

Sweetpotato Yield. A treatment by location interaction ($P < 0.0001$) was observed therefore data are presented by location. The main effect of rainfall and interaction between rainfall and herbicide treatment was not significant ($P > 0.05$).

At LOC 1, weed-free yielded 22,639, 11,715, 9,303, and 43,557 kg ha^{-1} of no. 1, jumbo, canner, and marketable storage roots, respectively (Table 4.5). Compared with flumioxazin fb *S*-metolachlor flumioxazin/pyroxasulfone at 151, 167, and 280 g ai ha^{-1} reduced no. 1 yield. Marketable and canner yield was reduced only when flumioxazin/pyroxasulfone was applied at 280 g ai ha^{-1}. Jumbo yield was not reduced at any rate of flumioxazin/pyroxasulfone. At LOC 2, sweetpotato in the weed-free treatment yielded 24,391, 3,454, 6,851, and 34,270 kg ha^{-1} of no. 1, jumbo, canner and marketable storage roots, respectively. Compared with the standard herbicide program of flumioxazin fb *S*-metolachlor no differences in yield of any grade for any rate of flumioxazin/pyroxasulfone were observed, except for jumbo in the flumioxazin/pyroxasulfone at 107 g ai ha^{-1}. Prior research has shown that yield reductions from the application of flumioxazin/pyroxasulfone are variable. Meyers et al. (2013) found that yield marketable yield was reduced with the application of flumioxazin/pyroxasulfone compared to flumioxazin alone. However, Miller et al. (2013), Shankle et al. (2013) found that marketable yield was no different than the standard herbicide program.

It appears that sweetpotato is tolerant to flumioxazin/pyroxasulfone PRE except at 280 g ai ha^{-1}. Flumioxazin/pyroxasulfone PRE provides excellent control of Palmer amaranth with minimal crop injury and little to no yield reduction. This combination of chemistries would fit well into North Carolina sweetpotato production and provide another mode of action to manage Palmer amaranth populations in sweetpotato growing regions of the state.

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Table 4.1. Herbicide treatments applied to sweetpotato at Clinton, NC 2015.

Treatment	Rate
	g ai ha^{-1}
Weed-free	
Weedy	
Flumioxazin/pyroxasulfone (123/157)[a]	280
Flumioxazin/pyroxasulfone (73/94)[a]	167
Flumioxazin/pyroxasulfone (66/85)[a]	151
Flumioxazin/pyroxasulfone (47/60)[a]	107
Flumioxazin fb *S*-metolachlor	107 fb 803

[a] Relative amounts of each chemical applied in the total rate.

Table 4.2. Palmer amaranth control with flumioxazin/pyroxasulfone and flumioxazin fb *S*-metolachlor at Clinton, NC 2015.

		Palmer amarnath control (%)			
Treatment	Rate g ai ha^{-1}	8-10 DAP	14- 16 DAP	30-38 DAP	124 DAP[a]
Weedy[b]		0	0	0	0
Weed-free[b]		100	100	100	100
Flumioxazin/pyroxasulfone	107	100	100	97	96
Flumioxazin/pyroxasulfone	151	100	100	99	98
Flumioxazin/pyroxasulfone	167	96	96	96	98
Flumioxazin/pyroxasulfone	280	100	100	100	91
Flumioxazin fb *S*-metolachlor	107 fb 803	100	100	100	96
p-value		NS	NS	NS	NS

[a] Location 1 only.

[b] Not included in statistical analysis.

Table 4.3. Sweetpotato injury from flumioxazin/pyroxasulfone and flumioxazin fb *S*-metolachlor at Clinton, NC 2015.

		Injury (%)			
Treatment	Rate g ai ha^{-1}	16 DAP LOC 1	14 DAP LOC 2	38 DAP LOC 1	30 DAP LOC 2
Weedy[a]		0	0	0	0
Weed-free[a]		0	0	0	0
Flumioxazin/pyroxasulfone	107	1	0	2	1
Flumioxazin/pyroxasulfone	151	5	0	12	1
Flumioxazin/pyroxasulfone	167	5	0	16	5
Flumioxazin/pyroxasulfone	280	7	0	33	1
Flumioxazin fb *S*-metolachlor	107 fb 803	0	0	0	2
p-value[b]		0.0001	NS	<.0001	NS

[a] Not included in statistical analysis.

[b] P-value for test of linear effect on sweetpotato injury from flumioxazin/pyroxasulfone, p-value <0.05 was considered significant.

Table 4.4. Sweetpotato injury averaged across simulated rainfall treatment at Clinton, NC 2015.

	Injury (%)	
	38 DAT	30 DAT
Rainfall	LOC 1	LOC 2
1	2 b	3
2	15 a	1
3	13 a	1
p-value	0.0005	NS

Table 4.5. Effect of flumioxazin/pyroxasulfone on sweetpotato storage root yield at Clinton, NC 2015.

		Yield (kg ha^{-1})							
		No. 1		Jumbo		Marketable		Canner	
Main effect	Treatment	Loc 1	Loc 2	Loc 1	Loc 2	Loc 1	Loc 2	Loc 1	Loc 2
Rainfall (R)	1	17949	18149	10107	3098	36407	26537	8450 ab	5266
	2	17611	18239	12526	3266	36902	27526	6893 b	5996
	3	17807	19398	12273	3661	39355	28886	9362 a	5802
R (P value)		0.9772	0.6794	0.3128	0.7333	0.3792	0.3924	0.0232	0.3938
Herbicide (H)[a]	107	20881 ab	20172 ab	12998 a	991 b	44184 a	27502 b	10372 a	6314 a
	151	12348 cd	21817 ab	14576 a	4108 a	35970 bc	31588 ab	9148 ab	5638 ab
	167	15993 bc	20122 ab	13313 a	4408 a	38190 abc	30811 ab	8986 ab	6255 a
	280	10146 d	17497 b	11225 a	5236 a	28285 d	28133 b	7014 bc	5374 ab
	F fb SM[b]	21837 a	21729 ab	13069 a	5012 a	40129 ab	32144 ab	5388 c	5378 ab
	Weedfree	22639 a	24391 a	11715 a	3454 a	43557 a	34270 a	9303 ab	6851 a
	Weedy	20678 ab	4439 c	4553 b	183 b	32566 cd	8651 c	7435 bc	4004 b
H (P value)		<.0001	<.0001	0.0094	<.0001	<.0001	<.0001	0.0087	0.0375
R × H (P value)		0.0750	0.6921	0.7991	0.4788	0.1299	0.5404	0.6778	0.7648

[a] Means separated using Fisher’s Protected LSD using $P \leq 0.05$.

[b] Flumioxazin followed by *S*-metolachlor.

APPENDIX

Appendix A. Foliar injury of linuron POST on Covington and Murasaki sweetpotato at Faison, NC 2015.

	Sweetpotato Foliar Injury (%)							
	1 WAT		2 WAT		4 WAT		8 WAT	
Treatment[a,b]	Cov	Mur	Cov	Mur	Cov	Mur	Cov	Mur
Weedy	0 f	0 g	0 f	0 i	0 h	0 i	0 c	0 b
Weed-Free	0 f	0 g	0 f	0 i	0 h	0 i	0 c	0 b
Linuron 420 7d	20 e	6 g	10 def	5 i	2 gh	4 hi	3 bc	0 b
Linuron 560 7d	43 cd	29 f	28 cde	10 hi	12 fgh	16 fgh	0 c	0 b
Linuron 840 7d	62 abc	53 de	27 c-f	29 fg	13 fgh	26 ef	3 bc	0 b
Linuron 1120 7d	65 ab	34 f	38 bc	53 e	27 d-g	25 fg	0 c	0 b
S-metolachlor 803 7d	0 f	0 g	0 f	0 i	0 h	0 i	0 c	0 b
Linuron 420 + 803 7d	27 de	40 ef	8 def	19 gh	5 gh	11 ghi	2 c	0 b
Linuron 560 + 803 7d	47 bc	63 cd	25 c-f	24 g	23 e-h	18 fgh	2 c	0 b
Linuron 840 + 803 7d	65 ab	71 bc	33 cd	40 f	33 c-f	41 d	3 bc	0 b
Linruon 1120 + 803 7d	77 a	70 bc	67 a	39 f	52 a-d	41 d	5 bc	0 b
Linuron 420 14 d	72 a	69 bc	68 a	53 e	50 a-d	41 d	10 b	0 b
Linuron 560 14d	68 a	74 bc	73 a	61 de	53 abc	40 de	2 c	0 b
Linuron 840 14d	63 ab	81 ab	73 a	82 bc	43 b-e	68 bc	2 c	0 b
Linuron 1120 14d	70 a	80 ab	82 a	89 ab	65 ab	73 b	10 b	0 b
S-metolachlor 8023 14d	0 f	0 g	0 f	0 i	0 h	0 i	0 c	0 b
Linuron 420 + 803 14d	67 a	78 ab	62 ab	70 cd	40 b-e	61 bc	0 c	0 b
Linuron 560 + 803 14d	65 ab	79 ab	72 a	70 cd	55 abc	58 c	6 bc	0 b
Linuron 840 + 803 14d	70 a	81 ab	83 a	81 bc	72 a	68 bc	23 a	1 a
Linruon 1120 + 803 14d	77 a	90 a	87 a	95 a	72 a	89 a	2 c	3 a
P-value	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001

[a] Rate of linuron in g ai ha^{-1}

[b] Linuron applied alone or with *S*-metolachlor at 803 g ai ha^{-1}

Appendix B. Sweetpotato storage root yield by cultivar and grade at Faison, NC 2015.

	Yield (kg ha^{-1})							
	Ones		Jumbo		Marketable		Canner	
Treatment	Cov	Mur	Cov	Mur	Cov	Mur	Cov	Mur
Weedy	27140 a-d	14392 a-e	12596	0	41753 a	18909 a-f	2017	4516 abc
Weed-Free	24881 b-g	20616 a	13584	906	41258 a	26591 a	2793	5069 abc
Linuron 420 7 d	25750 b-f	17502 ab	4874	0	32876 a-d	21200 a-d	2244	3697 a-e
Linuron 560 7 d	26271 a-e	15100 a-e	8614	0	37208 abc	20839 a-d	2323	5739 a
Linuron 840 7 d	23483 c-i	15068 a-e	5966	498	33045 a-d	20006 a-e	3596	4440 a-d
Linuron 1120 7 d	24761 b-g	10615 b-g	10979	0	37738 abc	16312 c-g	1998	5698 a
S-metolachlor 803 7 d	24737 b-h	17089 ab	10775	0	37789 abc	21857 abc	2277	4767 ab
Linuron 420 + 803 7 d	33756 a	18668 ab	3791	0	39485 abc	24289 ab	1938	5621 a
Linuron 560 + 803 7 d	26921 a-d	15636 a-d	8824	418	38114 abc	21031 a-d	2370	4976 ab
Linuron 840 + 803 7 d	29802 abc	16842 abc	4303	568	35856 abc	21477 a-d	1752	4067 a-d
Linruon 1120 + 803 7 d	19097 e-j	15581 a-d	5622	0	25871 cde	20724 a-d	1152	5144 ab
Linuron 420 14 d	15886 ij	13127 a-f	5803	0	22535 de	17560 b-f	846	4433 a-d
Linuron 560 14 d	18246 f-j	9514 c-h	4014	0	23246 de	13734 d-h	985	4220 a-d
Linuron 840 14 d	17638 g-j	8583 c-d	887	0	21011 e	12270 e-h	2486	3687 a-e
Linuron 1120 14 d	21717 d-j	4025 gh	5989	561	28496 b-e	6903 hi	790	2317 de
S-metolachlor 803 14 d	31345 abc	16654 abc	7871	0	42110 a	20937 a-d	2895	4283 a-d
Linuron 420 + 803 14 d	20416 d-j	8663 d-h	4005	0	26043 cde	11890 fgh	1622	3227 b-e
Linuron 560 + 803 14 d	18172 f-j	7959 e-h	2044	0	23241 de	12810 e-h	3025	4851 ab
Linuron 840 + 803 14 d	16941 hij	6206 fgh	4340	0	22108 de	8806 ghi	827	2560 cde
Linruon 1120 + 803 14 d	14720 j	2335 h	4038	0	19589 e	3959 i	832	1624 e
P-value	0.0002	<.0001	NS	NS	0.0004	<.0001	NS	0.0105