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Rate and Application Timing Effects on Tolerance of Covington Sweetpotato to *S*-Metolachlor

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Field studies were conducted in 2011 and 2012 at the Horticultural Crops Research Station near Clinton, NC, to determine 'Covington' sweetpotato tolerance to *S*-metolachlor rate and application timing. Treatments were a factorial arrangement of four *S*-metolachlor rates (0, 1.1, 2.2, or 3.4 kg ai ha^{-1}) and six application timings (0, 2, 5, 7, 9, or 14 d after transplanting [DAP]). Immediately following application, 1.9 cm of irrigation was applied to individual plots. Sweetpotato injury was minimal for all treatments ($\leq$ 10%). No. 1 grade sweetpotato yield displayed a negative linear response to *S*-metolachlor rate, and decreased from 25,110 to 20,100 kg ha^{-1} as *S*-metolachlor rate increased from 0 to 3.4 kg ha^{-1}. Conversely, no. 1 sweetpotato yield displayed a positive linear response to *S*-metolachlor application timing and increased from 19,670 to 27,090 kg ha^{-1} as timing progressed from 0 to 14 DAP. Total marketable sweetpotato yield displayed a quadratic response to both *S*-metolachlor application rate and timing. Total marketable yield decreased from 44,950 to 30,690 kg ha^{-1} as *S*-metolachlor rate increased from 0 to 3.4 kg ha^{-1}. Total marketable yield increased from 37,800 to 45,780 kg ha^{-1} as application timing was delayed from 0 to 14 DAP. At 1.1 kg ha^{-1} *S*-metolachlor, sweetpotato storage root length to width ratio displayed a quadratic relationship to application timing and increased from 1.87 to 2.23 for applications made 0 to 14 DAP. At 2.2 kg ha^{-1} of *S*-metolachlor, sweetpotato length to width ratio displayed a quadratic response to application timing, increased from 1.57 to 2.09 for 0 to 10 DAP, and decreased slightly from 2.09 to 2.03 for 10 to 14 DAP. Application timing did not influence length to width ratio of sweetpotato storage roots for those plots treated with *S*-metolachlor at either 0 or 3.4 kg ha^{-1}.
Nomenclature: *S*-metolachlor; sweetpotato, *Ipomoea batatas* (L.) Lam. 'Covington'.
Key words: Crop tolerance, herbicide rate.

En 2011 y 2012, se realizaron estudios de campo en la Estación de Investigación de Cultivos Hortícolas, cerca de Clinton, NC, para determinar la tolerancia de la batata 'Covington' según la dosis de *S*-metolachlor y el momento de aplicación. Los tratamientos fueron arreglados en forma factorial con cuatro dosis de *S*-metolachlor (0, 1.1, 2.2, ó 3.4 kg ai ha^{-1}) y seis momentos de aplicación (0, 2, 5 7, 9, ó 14 días después del trasplante [DAP]). Inmediatamente después de la aplicación, se aplicaron 1.9 cm de riego a cada parcela. El daño a la batata fue mínimo en todos los tratamientos ($\leq$10%). El rendimiento de batata grado no. 1 mostró una respuesta linear negativa a las dosis de *S*-metolachlor, y disminuyó de 25,110 a 20,100 kg ha^{-1} al incrementarse la dosis de *S*-metolachlor de 0 a 3.4 kg ha^{-1}. En contraste, el rendimiento de la batata no. 1 mostró una respuesta linear positiva al momento de aplicación de *S*-metolachlor e incrementó de 19,670 a 27,090 kg ha^{-1} cuando se pasó de 0 a 14 DAP. El rendimiento comercializable disminuyó de 44,950 a 30,690 kg ha^{-1} al aumentarse la dosis de *S*-metolachlor de 0 a 3.4 kg ha^{-1}. El rendimiento comercializable aumentó de 37,800 a 45,780 kg ha^{-1} cuando se retrasó el momento de aplicación de 0 a 14 DAP. A 1.1 kg ha^{-1} *S*-metolachlor, el ratio longitud/grosor de las raíces de almacenamiento mostraron una relación cuadrática con el momento de aplicación e incrementaron de 1.87 a 2.23 para aplicaciones hechas de 0 a 14 DAP. A 2.2 kg ha^{-1} de *S*-metolachlor, el ratio longitud/grosor mostró una respuesta cuadrática en respuesta al momento de aplicación, e incrementó de 1.57 a 2.09 de 0 a 10 DAP, y disminuyó ligeramente de 2.09 a 2.03 de 10 a 14 DAP. El momento de aplicación no influenció el ratio longitud/grosor de las raíces de almacenamiento de la batata para las parcelas tratadas con *S*-metolachlor ya sea a 0 ó 3.4 kg ha^{-1}.

Approximately 47% of sweetpotato hectareage in the United States is grown in North Carolina (NCDA and CS 2012). In 2011, 26,300 ha of sweetpotatoes were harvested in North Carolina with a gross farm value greater than $226 million (NCDA and CS 2012). Palmer amaranth [*Amaranthus palmeri* (S.) Wats.] is the most common and troublesome weed in North Carolina sweetpotato production (Webster 2010). Season-long Palmer amaranth interference can reportedly reduce total marketable 'Beauregard' and 'Covington' sweetpotato yield 36 to 81% at densities of 0.5 to 6.5 Palmer amaranth plants m^{-1} of crop row, respectively (Meyers et al. 2010a).

North Carolina sweetpotato growers control Palmer amaranth through the use of PRE herbicides, cultivation, mowing, herbicide-wicking of row middles, and hand-removal (J. Haley and J. Curtis, unpublished data). Meyers et al. (2010b) proposed a PRE herbicide system consisting of flumioxazin preplant plus *S*-metolachlor after transplanting, which provided $>$ 90% residual Palmer amaranth control in sweetpotato. Despite the ability of *S*-metolachlor to control Palmer amaranth (as well as numerous grasses, small-seeded broadleaf weeds, and yellow nutsedge [*Cyperus esculentus* L.]), some North Carolina sweetpotato growers are reluctant to use

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S-metolachlor citing concerns of the impact of the herbicide on sweetpotato storage root shape. S-metolachlor is a soil-applied chloroacetamide herbicide that inhibits the biosynthesis of fatty acids, lipids, proteins, isoprenoids, and flavonoids in susceptible plant species (Senseman 2007). In North Carolina, S-metolachlor is registered at 0.8 to 1.1 kg ha^{-1} for sweetpotato by a section 24(C) special local needs registration. Unlike pretransplant-applied flumioxazin, S-metolachlor is applied posttransplant, so it is not negatively affected by the soil disturbance that occurs in conjunction with transplanting. Haley and Curtis (unpublished data) reported 22% of North Carolina sweetpotato growers used S-metolachlor in 2005.

Historical accounts of S-metolachlor effects on sweetpotato root shape have been inconclusive. Porter (1994) reported that 2.2 kg ha^{-1} metolachlor caused some sweetpotato storage roots to be shorter and rounder than roots from the nontreated check and treatments with reduced rates of metolachlor. However, in 1995 Porter reported Beauregard, 'Hernandez', 'Jewel', and 'Darby' sweetpotato plants treated with metolachlor at 1.1, 2.2, and 3.4 kg ha^{-1} showed no evidence of misshapen storage roots. Monks et al. (1998) reported metolachlor PRE at 1.1 or 2.2 kg ha^{-1} in Beauregard and Jewel sweetpotatoes did not result in shorter roots when compared to the cultivated control. Meyers et al. (2010b) reported Beauregard and Covington sweetpotato storage root length to width ratio differed slightly over S-metolachlor application timing. Root length to width ratios were 2.1 and 2.2 for treatments containing S-metolachlor applied immediately after transplanting and 2 wk after transplanting (WAP), respectively (Meyers et al. 2010b). In 2012, Meyers et al. reported S-metolachlor application timing to be the most influential factor affecting sweetpotato storage root length to width ratio. No. 1 and marketable sweetpotato yields and storage root length to width ratio were reduced when S-metolachlor applications were made within 1 d after transplanting (DAP) and followed by 3.8 cm irrigation or rainfall (Meyers et al. 2012). Meyers et al. (2013) reported visual Covington sweetpotato injury and reduced no. 1, jumbo, and total marketable yield in one of 2 yr when S-metolachlor was applied within 1 DAP. Although delaying an S-metolachlor application until 14 DAP provides increased sweetpotato tolerance, Palmer amaranth control efficacy will be reduced if weeds are present at the time of application (Meyers et al. 2010b).

With that in mind, the objectives of this research were to determine the influence of S-metolachlor rate and application timing on sweetpotato tolerance and storage root yield, quality, and length to width ratio and to develop a predictive model which will allow sweetpotato growers and researchers to better understand the influence of S-metolachlor rate and application timing on sweetpotato.

Materials and Methods

Studies were conducted at the Horticultural Crops Research Station (35°1.4010″N, 78°16.7580″W) near Clinton, NC, in 2011 and 2012. Nonrooted generation 2 (G2) Covington sweetpotato slips (shoot-tip cuttings) were cut from field propagation beds by hand and transplanted on June 15, 2011, and June 13, 2012. Both fields were Orangeburg or Norfolk loamy sand or both (fine-loamy, siliceous, thermic Typic Paleudults) with pH 6.1, < 1% humic matter, and were representative of soils used for North Carolina sweetpotato production. Plot size was two rows, each 106 cm wide and 5.5 m long. The first row of each plot was nontreated and served as a border row; the second row was treated. Covington, a rose-skinned, orange-fleshed table-stock variety (Yencho et al. 2008), is grown on approximately 85% of sweetpotato hectarage in North Carolina (J. R. Schultheis, personal communication).

Treatments consisted of a factorial treatment arrangement of four S-metolachlor (Dual Magnum®, 0.9 kg L^{-1}, Syngenta Crop Protection, Inc., Greensboro, NC) rates (0, 1.1, 2.2, or 3.4 kg ai ha^{-1}) and six application timings (0, 2, 5, 7, 10, and 14 DAP). S-metolachlor rates used in the present study represent one, two, and three times the maximum registered rate in North Carolina. All plots were maintained weed-free by hand-removing emerged weeds weekly. 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 POST to both studies as needed to control goosegrass [*Eleusine indica* (L.) Gaertn.] and large crabgrass [*Digitaria sanguinalis* (L.) Scop.]. Treatments were applied with a CO_2-pressurized backpack sprayer calibrated to deliver 187 L ha^{-1} at 124 kPa and fitted with two 8003 XR nozzle tips (Teejet 8003 XR, Teejet Technologies, Springfield, IL). Immediately following S-metolachlor applications, individual treated plots were irrigated with 1.9 cm of irrigation via a rainfall simulator. This irrigation volume is slightly greater than the maximum recommended first irrigation volume (1.3 cm) stated on the product label (Anonymous 2006). The experimental design was a randomized complete block with four replications. Fertility and insect management was conducted in accordance with recommendations by Kemble (2013).

Foliar sweetpotato injury was visually evaluated 15 and 27 DAP using a scale of 0 (no crop injury) to 100% (crop death). Sweetpotato storage roots were harvested 107 and 121 DAP in 2011 and 2012, respectively, using a tractor-mounted chain digger. Storage roots from the treated row of each plot were hand-graded into jumbo (> 8.9 cm in diameter), no. 1 (> 4.4 cm but < 8.9 cm), and canner (> 2.5 cm but < 4.4 cm) (USDA 2005) and weighed. Total marketable yield was calculated as the sum of jumbo, no. 1, and canner grades. Twenty no. 1 storage roots were randomly chosen from each plot to determine the influence of treatment on storage root shape. The length and width of each storage root was measured according to grading standards (USDA 2005) and length to width ratio calculated.

Data were subjected to ANOVA and analyzed by SAS (SAS/STAT® 9.2, SAS Institute Inc., Cary, NC) PROC MIXED with fixed effects of S-metolachlor rate and application timing and random effects of year and replication within year. Visual sweetpotato injury ratings were arcsin transformed. However, untransformed data are presented. When ANOVA indicated a significant rate or application timing effect, data were subjected to regression analysis against rate, application timing, or both by SAS PROC MIXED to determine best-fit models. Least squares means generated by SAS PROC MIXED were used to estimate coefficients for linear and quadratic models via SAS PROC GLM.

Results and Discussion

Sweetpotato Injury. Stunting was the only form of sweetpotato injury observed. Stunting injury did not correspond to either *S*-metolachlor rate or application timing and was $\leq$ 10% for all treatments 15 DAP (data not shown). Stunting injury was transient and by 27 DAP no stunting was evident with any treatment. Visible stunting in the present study was similar to stunting previously reported by Meyers et al. (2012, 2013).

Sweetpotato Yield. Due to a lack of interaction between *S*-metolachlor rate or application timing and year for no. 1, canner, and total marketable yields, these data were analyzed across both 2011 and 2012. Jumbo yield, however, displayed an *S*-metolachlor application timing by year interaction and was therefore analyzed by year. Due to a lack of *S*-metolachlor rate by application timing interaction, yield data for all grades were analyzed for rate effects across all application timings, and for application timing effects across all rates. No. 1 sweetpotato yield displayed a negative linear response to *S*-metolachlor rate and decreased from 25,110 to 20,100 kg ha^{-1} as rate increased from 0 to 3.4 kg ha^{-1} (Figure 1). Conversely, no. 1 yield displayed a positive linear response to *S*-metolachlor application timing and increased from 19,670 to 27,090 kg ha^{-1} as application progressed from 0 to 14 DAT (Figure 2). The models in the present study predicts roughly a 530-kg ha^{-1} increase in no. 1 sweetpotato yield for every day *S*-metolachlor application is delayed between 0 and 14 DAP. Total marketable sweetpotato yield displayed a quadratic response to both *S*-metolachlor rate and application timing. Total marketable yield decreased from 44,950 to 30,690 kg ha^{-1} as *S*-metolachlor rate increased from 0 to 3.4 kg ha^{-1} (Figure 1), and increased from 37,800 to 45,780 kg ha^{-1} as application timing progressed from 0 to 14 DAT (Figure 2).

Jumbo and canner yields were not influenced by either *S*-metolachlor rate or application timing. Jumbo yields were greater in 2011 than 2012. In 2011, jumbo yields averaged 8,180 kg ha^{-1} across all rates and application timings (data not shown). In 2012, jumbo yields averaged 23,220 kg ha^{-1} across all rates and all application timings (data not shown). Increased jumbo yield in 2012 is likely due to an additional 2 wk of growing time compared to 2011. Two-year canner yield average was 3,272 kg ha^{-1} across all rates and application timings (data not shown).

Miller et al. (2011) reported a reduction in no. 1 sweetpotato yield in treatments of *S*-metolachlor applied at transplanting compared to 10 DAP. However, Miller et al. (2011) also reported that neither application timing (0, 5, and 10 DAP) nor rate (0, 0.8, and 1.5 kg ha^{-1}) of *S*-metolachlor affected marketable sweetpotato yields. Meyers et al. (2012) reported that *S*-metolachlor applied immediately after transplanting reduced no. 1 and total marketable sweetpotato yields compared to the nontreated check and *S*-metolachlor applied 2 WAP. The same trend was reported by Meyers et al. (2013) in one of 2 yr. In the current study, no. 1 and marketable yield were greatly influenced by both *S*-metolachlor rate and application timing. Belehu et al. (2004) reported that sweetpotato slips contain 4 to 10 macroscopic, preformed root primordia per node on leaf bases that have the ability to form adventitious roots within 24 h. However, damage to preformed root primordia will prevent the formation of adventitious roots (Belehu et al. 2004), thereby decreasing root development immediately after transplanting and causing reduced growth. The reduction in adventitious roots also means that fewer total adventitious roots have the potential to become storage roots.

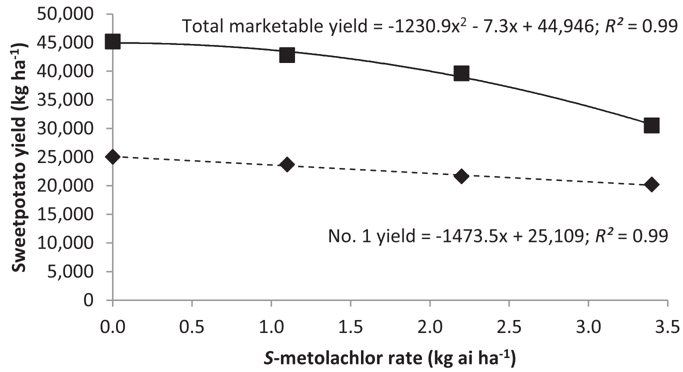

Figure 1. Response of no. 1 (◆) and total marketable (■) 'Covington' sweetpotato yields to *S*-metolachlor rate pooled across all applications timings (0, 2, 5, 7, 9, and 14 d after transplanting) and years (2011 and 2012) at Clinton, NC. Points represent observed mean data. Lines represent predicted values.

Sweetpotato Storage Root Length to Width Ratio. Due to a lack of *S*-metolachlor rate or application timing by year interaction, data for sweetpotato storage root length to width ratio were analyzed across both 2011 and 2012. Due to an *S*-metolachlor rate by application timing interaction, storage root length to width ratio data were analyzed for the effect of rate at each application timing and for the effect of application timing at each rate. At 1.1 kg ha^{-1} of *S*-metolachlor, sweetpotato storage root length to width ratio

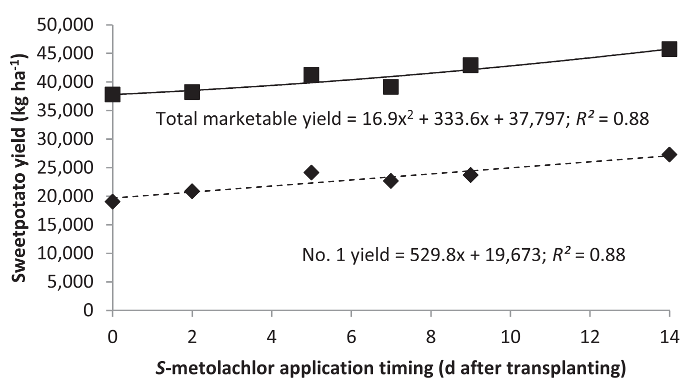

Figure 2. Response of no. 1 (◆) and total marketable (■) 'Covington' sweetpotato yields to *S*-metolachlor application timing pooled across all rates (0, 1.1, 2.2, and 3.4 kg ha^{-1}) and years (2011 and 2012) at Clinton, NC. Points represent observed mean data. Lines represent predicted values.

displayed a quadratic response to application timing and increased from 1.87 to 2.23 for applications made 0 to 14 DAP (Figures 3 and 4). At 2.2 kg ha^{-1} of *S*-metolachlor, sweetpotato length to width ratio displayed a quadratic response to application timing and increased from 1.57 to 2.09 for 0 to 10 DAP and decreased slightly from 2.09 to 2.03 for 10 to 14 DAP (Figure 3). Application timing did not influence length to width ratio of sweetpotato storage roots for those plots treated with *S*-metolachlor at either 0 or 3.4 kg ha^{-1} (data not shown). Additionally, *S*-metolachlor rate did not influence no. 1 storage root length to width ratio. These results concur with the findings by Meyers et al. (2010b, 2012) who reported reduced sweetpotato storage root length to width ratio when *S*-metolachlor was applied immediately after transplanting.

A decreased storage root length to width ratio is likely the result of injury to the distal end of the storage root. This end is responsible for longitudinal expansion of the storage root early in root ontogeny (Firon et al. 2009; Wilson and Lowe 1973). After establishment of the storage root, distal root tissues function as normal secondarily thickened roots with normal secondary root structure and complete lignification of the stele (Wilson and Lowe 1973). It is plausible that injury to the distal end of developing storage roots would reduce their length, thereby decreasing overall storage root length to width ratio. Storage root length to width ratio is one of many quality factors that define a sweetpotato variety. Covington storage roots, for example, have an average length to width ratio of 2.0 (Yencho et al. 2008). When the ratio decreases, sweetpotato storage roots become more round, less aesthetically pleasing, and less marketable. Depending upon the sweetpotato shipper's market, rounder storage roots may even be sold at a lower unit price or culled.

Although the present study demonstrates the possibility of sweetpotato crop injury and yield loss with *S*-metolachlor, it is important to note that when applied at the current recommended rate of 0.8 kg ha^{-1}, predicted no. 1 and total marketable yield losses due to *S*-metolachlor–induced injury were minimal. Sweetpotato receiving a recommended rate of 0.8 kg ha^{-1} *S*-metolachlor would result in only a 4.7 and 1.8% reduction of no. 1 and total marketable yields compared to a nontreated check, respectively. The nontreated check yielded 1,180 kg ha^{-1} more no. 1 sweetpotatoes than the predicted yield of sweetpotato receiving 0.8 kg ha^{-1} of *S*-metolachlor. Assuming that a realistic 20% of the no. 1 sweetpotatoes harvested would be culled at the packing line for skinning, shriveling, or rots associated with postharvest handling and storage, 944 kg ha^{-1} remain. In the United States, sweetpotatoes are typically marketed in 18-kg boxes with an average market price of $15 per box. Therefore, the gross reduction in production value associated with yield loss due to applying 0.8 kg ha^{-1} *S*-metolachlor is approximately $780 ha^{-1} (equivalent to 52 18-kg boxes ha^{-1} and not including the cost associated with the herbicide application) compared to the nontreated check. A loss of this magnitude would likely be negated by improved weed control from an *S*-metolachlor application. Palmer amaranth at a density of one plant per meter of

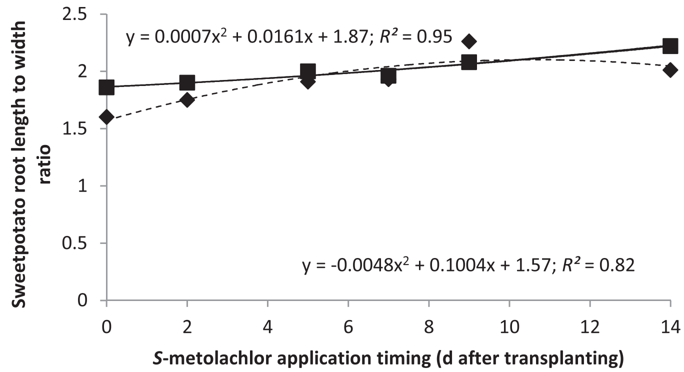

Figure 3. Response of no. 1 'Covington' sweetpotato storage root length to width ratio to *S*-metolachlor at 1.1 (■) and 2.2 kg ha^{-1} (◆) application timing pooled across years (2011 and 2012) at Clinton, NC. Points represent observed mean data. Lines represent predicted values.

crop row, if allowed to grow and compete for the entire season, will reduce no. 1 sweetpotato yield 46% (Meyers et al. 2010a). This yield reduction (presumably 9,240 kg ha^{-1} in the present study after packing), would contribute to a gross loss of approximately $7,700 ha^{-1} given the previously mentioned pack-out efficiency and unit price. It is important to note that all weeds in the present study were removed by hand routinely to isolate the effect of *S*-metolachlor on sweetpotato crop tolerance without the confounding effect weed control. The predictive yield models for rate emphasize the importance of proper spray calibration as an unintentional increase in rate will adversely influence no. 1 and total marketable sweetpotato yields.

With respect to *S*-metolachlor application timing, no. 1 sweetpotato yield was 7,420 kg ha^{-1} greater when *S*-metolachlor application was delayed until 14 DAP than when it was applied 0 DAP. The increased yield would have a gross value of approximately $4,950. However, delaying an *S*-metolachlor application until 14 DAP will result in reduced Palmer amaranth control if the weeds are emerged at application. An additional hand-weeding event prior to application would improve control (Meyers et al. 2013) and would cost roughly $250 to $300 ha^{-1} (H. Pettit, personal communication). In the present study, the additional cost of hand-weeding prior to a delayed *S*-metolachlor application 14 DAP would be justified for growers who have access to sufficient labor. However, most growers transplant sweetpotatoes over a period of several weeks and may not have the ability to divide labor amongst hand-weeding and transplanting operations. For the majority of sweetpotato growers a delayed *S*-metolachlor application would be more practical if it were combined with a proper flumioxazin application pretransplanting and, if necessary, cultivation between rows just prior to an *S*-metolachlor application.

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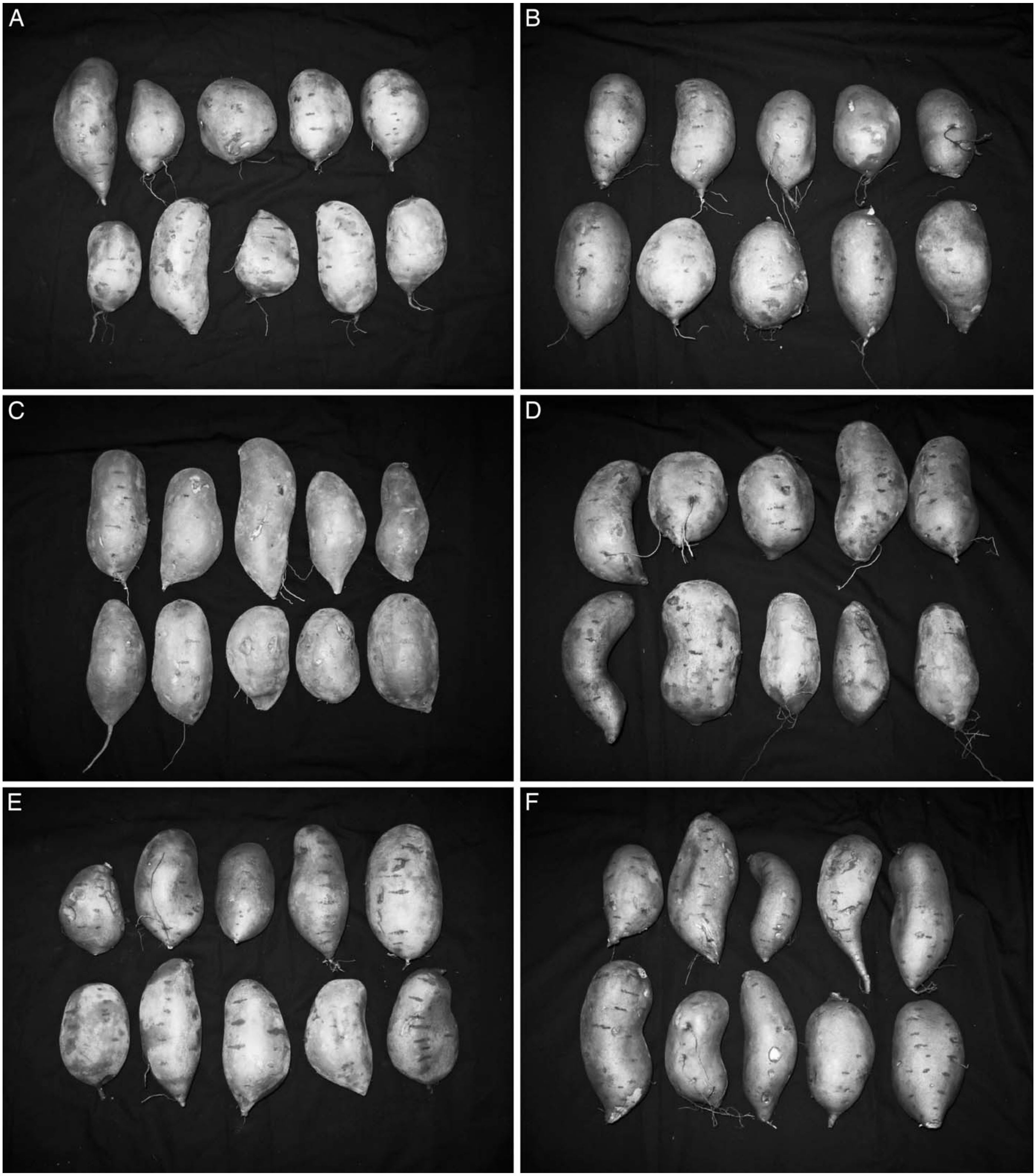

Figure 4. A sample of sweetpotato storage roots from plots receiving *S*-metolachlor at 1.1 kg ai ha^{-1} at (A) 0, (B) 2, (C) 5, (D) 7, (E) 9, and (F) 14 d after transplanting at Clinton, NC, in 2011.

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