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S-metolachlor and rainfall effects on sweetpotato (*Ipomoea batatas* L. [Lam]) growth and development

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ABSTRACT

The herbicide *S*-metolachlor is used to control or suppress annual grasses, nutsedges and several broadleaf weeds in sweetpotato. However, a decline in storage root quality is suspected when an excessive rainfall occurs within 24 h after application. A sunlit, controlled environment experiment was conducted to investigate sweetpotato response to five levels of *S*-metolachlor (0.00, 0.86, 1.72, 2.58 and 3.44 kg ha^{-1}), and two levels of simulated rainfall (0 and 38 mm at 51 mm h^{-1}) immediately after application. Sweetpotato slips were transplanted into white polyvinyl chloride pots filled with sandy loam soil. *S*-metolachlor treatments were applied to slips and a simulated rainfall treatment delivered immediately after transplanting and herbicide treatment. All pots were transferred to sunlit growth chambers that were maintained at 30/22 °C, day/night temperatures and ambient carbon dioxide concentration (400 μL L^{-1}) for 60 days. An evapotranspiration-based irrigation system was used to supply water and nutrients. Plant biomass components and quality of storage roots were recorded 60 days after transplanting. There was no difference between rainfall treatments across *S*-metolachlor rates for vine lengths, leaf numbers and leaf area. These parameters, however, declined linearly and significantly with increase in *S*-metolachlor concentration. Total storage root weight declined linearly with increased *S*-metolachlor concentration; the decline was steeper with simulated rainfall. Yield of marketable storage roots declined by 18 and 31% in the absence of rainfall and 55 and 79% in the presence of rainfall with *S*-metolachlor at minimum (0.86 kg ha^{-1}) and maximum (1.43 kg ha^{-1}) recommended label rates, respectively, used to control weeds. Yield reduction was directly proportional to the rate of *S*-metolachlor applied in the absence or presence of rainfall; 77 and 123 g fresh weight kg^{-1} ha^{-1} *S*-metolachlor for no-rainfall and rainfall treatment, respectively. These results can be used to improve management decisions to optimize yield under field conditions as well as to mitigate risk of injury that could be associated with the use of *S*-metolachlor in sweetpotato production systems.

1. Introduction

Sweetpotato [*Ipomoea batatas* (L.) Lam.] is the sixth most important food crop in the world and fifth most important crop in developing countries (International Potato Center, 2010). World sweetpotato production was 103 million metric tons in 2013 with China accounting for 71% (Food and Agriculture Organisation, 2014). In the same year, the United States produced 1.3 million metric tons from 45,800 ha with a crop value of $552 million (USDA-NASS, 2014a). Mississippi ranked second in acreage among US sweetpotato producing states with 7,891 ha yielding a crop value of $57.2 million, behind North Carolina with 21,400 ha (USDA-NASS, 2014b). In the United States, storage roots are the primary economic product derived from sweetpotato production systems for human consumption, although other plant components are used in other countries for various purposes.

Weeds are a major challenge to sweetpotato production, with hophornbeam copperleaf (*Acalypha ostryifolia* Riddell), pigweed (*Amaranthus spp.*), yellow nutsedge (*Cyperus esculentus* L.), and purple nutsedge (*Cyperus rotundus* L.) being problematic in the southern US (Kelly et al., 2006). Moody and Ezumah (1974) reported yield losses of 22, 78 and 91% due to uncontrolled weed growth in Hawaii, West Indies and Nigeria, respectively. In other studies,

Abbreviations: DAT, days after transplanting; SR, storage root.

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weed interference has caused yield reductions ranging from 14 to almost 70% in various sweetpotato cultivars (LaBonte et al., 1999; Harrison and Jackson, 2011).

The critical weed-free period for Beauregard sweetpotato is 2–6 weeks after transplanting (Seem et al., 2003). Therefore, weed control early in the crop growing season is important. In most commercial sweetpotato production systems, growers utilize hand weeding, herbicides and cultivation in their weed management programs. Chemical weed control is an important part of sweetpotato production systems because mechanical cultivation is restricted to the initial stages of the crop due to the prostrate growth habit of sweetpotato and labor for manual weed control has become scarce and expensive.

The herbicide *S*-metolachlor is used in sweetpotato weed management systems because it effectively controls or suppresses a wide spectrum of grass and small-seeded broadleaf weeds. In addition, it is the only herbicide that is labeled to control or suppress yellow nutsedge in Beauregard sweetpotato (Anonymous, 2006). *S*-metolachlor is a non-ionizable compound with a water solubility of 488 mg L^{-1} at 20 °C. The chemical has soil organic carbon-water (K_{oc}) and distribution (K_d) coefficient values of 21.6 and 0.11 mL g^{-1}, respectively, for sandy soil with 0.9% organic matter (OM), 2.2% clay, and pH of 6.5 (Senseman, 2007). *S*-metolachlor has the potential to leach in soils with less than 2% OM (Senseman, 2007) and high risk of injury in coarse textured soils especially if rainfall occurs immediately after application, and as a result growers are advised not to water over 1.3 cm in the first irrigation after treatment (Anonymous, 2006). Increased soybean [*Glycine max* (L.) Merr] and dry edible bean (*Phaseolus vulgaris* L.) injury with increasing soil moisture have been reported with pre-emergence applications above the recommended rates of dimethenamid and metolachlor (Osborne et al., 1995; Poling et al., 2009). *S*-metolachlor is primarily absorbed by roots and shoots, but shoot tissues are generally more sorptive and it is also the site of herbicidal activity (Senseman, 2007; Obando, 2012). It is primarily transported upwards and categorized as a mitosis inhibitor as it affects the biosynthesis of several plant components such as fatty acids, lipids, proteins, isoprenoids, and flavonoids in susceptible plants (Senseman, 2007). The label approved for use in sweetpotato indicates that *S*-metolachlor can be applied preplant (PRE) to weeds and post-plant to field-grown Beauregard slips.

Despite the high level of efficacy for *S*-metolachlor in controlling many grass and broadleaf weed species, some growers are hesitant to use it in their weed management programs because misshaped storage roots have been attributed to use of this herbicide under certain environmental conditions (Meyers et al., 2012). Though field research has been conducted to determine the effects of *S*-metolachlor applied post-transplant on sweetpotato growth, yield, and storage root quality (Meyers et al., 2012), these effects have never been reported for sweetpotatoes grown under a controlled environment such as Soil-Plant-Atmosphere-Research (SPAR) plant growth chambers. This facility has the ability to precisely measure and control environmental variables, and as such allows for the minimization of many covarying and confounding factors that occur in field experiments (Reddy et al., 2001). Monks et al. (1981) observed metolachlor injury on sweetpotato when applied at 3.4 kg ha^{-1}. Meyers et al. (2012) reported 7 and 28% stunting for plots treated immediately after transplanting with 2.2 and 3.4 kg ha^{-1} *S*-metolachlor, respectively, when compared to the untreated check. They also reported that plots receiving *S*-metolachlor immediately after transplanting yielded less US no. 1, canners, and marketable roots than the untreated check. There is limited information on the effects of *S*-metolachlor applied post-transplant on sweetpotato growth and development, particularly as affected by rainfall.

Storage root length and diameter are standard factors used to classify storage roots into grade categories. An increase in shorter and rounder roots will reduce total marketable storage root (SR) yield. Shorter, rounder sweetpotato storage roots have been associated with *S*-metolachlor application under certain conditions (Meyers et al., 2012). However, these symptoms can also be caused by other abiotic stressors such as drought, weed interference, soil type, and excess fertilization (Clark and Moyer, 1988; LaBonte et al., 2008).

Sweetpotato SR initiation is a complex process driven by environmental and management factors. Sweetpotato production begins by transplanting stem cuttings (slips). Transplanted slips produce adventitious roots from the nodes and from the cut-end of the slips within few days of transplanting (Belehu et al., 2004; Pardales, 1993). Some of these roots develop into economically important storage roots through proliferation of cambial cells that form starch-accumulating parenchyma cells (Belehu et al., 2004; Ravi et al., 2009; Villordon et al., 2009). The transformation of adventitious roots into storage roots starts around 2 weeks after transplanting of slips in the field (Togari, 1950; Lowe and Wilson, 1974; Firon et al., 2009; Villordon et al., 2010). Thus, adverse environmental factors such as moisture stress (Gajanayake et al., 2013), unfavorable temperature and management including application of herbicides for the control of weeds during this stage may have detrimental effects on final sweetpotato SR quantity and quality. In recent years, attempts have been initiated to develop gene transfer technology to improve environmental stress tolerance of sweetpotato crop plants and thereby reducing the loss of crop production due to adverse climatic and soil conditions (Kasukabe et al., 2006). The objective of this study was to quantify sweetpotato growth and developmental responses including storage roots to *S*-metolachlor and a simulated rainfall event immediately after transplanting under sunlit, but controlled environmental conditions.

2. Materials and methods

2.1. Experimental facility

This experiment was conducted in three sunlit computer-controlled plant growth chambers known as Soil-Plant-Atmosphere-Research (SPAR) chambers at the Rodney Foil Plant Science Research Center, Mississippi State University, Mississippi State (33°28′ N, 88°47′ W), Mississippi, USA. The SPAR chambers have the capability to precisely control atmospheric carbon dioxide concentration and temperature at determined set points under near ambient levels of solar radiation as described by Reddy et al. (2001). Briefly, each SPAR chamber consists of a steel soil bin (1 m deep by 2 m long by 0.5 m wide) to accommodate the root system and a Plexiglas chamber (2.5 m high by 2 m long by 1.5 m wide) to accommodate aerial plant parts. The Plexiglas transmits 97% of the visible solar radiation to pass without spectral variability in absorption (Zhao et al., 2003). A heating and cooling system that is connected to air ducts passes conditioned air through the plant canopy with sufficient velocity (4.7 km h^{-1}) to cause leaf flutter, mimicking field conditions. Variable density shade cloths (Hummert Seed Co., St. Louis, MO, USA) that surround the canopy to simulate solar radiation attenuation was adjusted regularly to match canopy height and to eliminate the need for border plants.

2.2. Plant culture and treatments

Field-grown sweetpotato, Beauregard (B14), slips were transplanted into white polyvinyl chloride pots (20 cm diameter and 30 cm height) filled with 3:1 by volume sand and top soil with physical characteristics of 6% clay, 13% silt and 81% sand with 0.67% organic matter. A total of 40 pots, 4 pots for each treatment (5 herbicide rates by 2 rainfall levels) were randomly assigned to 3 SPAR units and arranged in 7 rows, 26.6 cm row spacing and placed at 25 cm apart within the row. Two extra pots were added for the control to make number of pots in each SPAR unit equal. Each pot, fitted with a detachable plastic bottom and filled with coarse gravel (600 g) at the bottom, allowed excess water and nutrients to drain. A single slip containing four nodes was transplanted into each pot with two nodes below and two nodes above the soil surface. Nodes above the soil surface contained two recently fully expanded leaves.

Treatments consisted of factorial arrangement of five rates of *S*-metolachlor (0.0, 0.86, 1.72, 2.58, and 3.44 kg ha^{-1}) by two rainfall regimes (0 and 38 mm) with four replications. The no herbicide treatment in each set of the two rainfall treatments was considered as an untreated check and used for comparison. The minimum *S*-metolachlor label use rate (0.86 kg ha^{-1}) based on our soil type was taken as the base and multiplied by 1, 2, 3 and 4 to obtain the rates used in this study. After studying rainfall data, 38 mm was determined to be an average rainfall amount enough to cause flooding in Mississippi. Soil moisture was maintained at field capacity in all pots at the time of transplanting the slips and in consistent with grower practice, herbicide treatment was applied immediately after transplanting. *S*-metolachlor (Dual Magnum®, Syngenta Crop Protection Inc., Greensboro, NC, USA) was applied using water as a carrier with a tractor-mounted compressed-air spraying system fitted with TeeJet 8002 XR flat fan nozzles (TeeJet spraying Systems Co., Wheaton, IL, USA) that delivered 140 L ha^{-1} at 180 kPa. During the herbicide application, wind speed was 1 mph NE, prevailing air temperature was 28 °C and the mean relative humidity was 51%. After the herbicide treatment applications, half of the pots were subjected to 38 mm of rainfall at 50.8 mm h^{-1} intensity within 24 h. A pre-calibrated rainfall simulator modeled after Meyer and Harmon (1979), which reproduced droplet size, fall velocity, and kinetic characteristics similar to a natural rain event, was used to simulate the rainfall treatment. Rainfall droplets were delivered from a height of 2.4 m (Meyer and McCune, 1958) and the actual amount of rainfall was measured at the plant height level with rain gauges.

The herbicide and the rainfall treatments were imposed on the potted plants outside the SPAR facility after which they were moved into the chambers. All SPAR chambers were maintained at 30/22 °C, day/night temperatures and 400 μL L^{-1} carbon dioxide concentrations throughout the experiment. The mean air temperature (day/night) and CO_2 concentration among the three SPAR chambers were not significantly different and recorded as 29.5 ± 0.1 and 22.0 ± 0.05 °C, day/night, and 408 ± 5 μL L^{-1} respectively. Similar to temperature and carbon dioxide concentrations, vapour pressure deficit (VPD) in the three growth chambers estimated as per Murray (1967) from the relative humidity and temperature measurements using relative humidity and temperature sensors (HMV 70Y, Vaisala Inc., San Jose, CA, USA) installed in the returning path of airline ducts, were not significantly different and recorded as 2.18 ± 0.12 and 1.69 ± 0.08 for day and night periods, respectively.

An evapotranspiration-based irrigation with full-strength Hoagland nutrient solution (Hewitt, 1952) was delivered to each plant twice a daily, 08:00 and 16:00 h, through a computer-controlled pressure-compensated drip irrigation system to ensure optimum water and nutrient conditions. Evapotranspiration rates (ET) expressed on a ground area basis (L d^{-1}) throughout the treatment period was measured in each SPAR unit as the rate at which condensate was removed by the cooling coils at 900-s intervals (McKinion and Hodges, 1985; Reddy et al., 2001; Timlin et al., 2007) by measuring the mass of water in collecting devices connected to a calibrated pressure transducer. Any excess irrigation solutions were drained through the hole in bottom of the pots and the SPAR soil bins. The average daily ET values were 9.84± 0.0.86 L d^{-1} during the experimental period.

2.3. Measurements and statistical analysis

At the final harvest, 60 days after transplanting (DAT), main vine lengths were measured and total leaf number counted on all plants. Plant components were separated and leaf area was measured using a Li-COR 3100 Leaf Area Meter (LiCOR Inc., Lincoln, NE, USA). Fresh SR were separated into marketable and non-marketable lots counted and weighed. A SR was considered marketable at 60 days on the basis of shape quality (not so curved, crooked, constricted or misshapen) with the potential of attaining a marketable SR size (diameter shall be not less than 1″ and length not less than 2″) by 90 days. Leaves, stems (vines and petioles and buried portion of the slip), and roots were oven-dried at 80 °C for over 72 h and then weighed to determine individual component dry weights.

The experimental data were subjected to analysis of variance using the General Linear Model procedure of the Statistical Analysis System (SAS Institute, Inc., 2008) to determine main factor effects and treatment interactions. Means were separated by Fisher's protected LSD test at the 0.05 level of probability. Regression analyses were performed on measured plant variables and *S*-metolachlor rates. Best-fit equations were determined using coefficient of variation and root mean square error. Graphical analysis was carried out using SigmaPlot 11.0 (Systat Software Inc., San Jose, CA, USA).

3. Results and discussion

Sweetpotato SR initiation, elongation and bulking are a complex series of events controlled by both genes that regulate these events and the environment that modulates these processes. In the field, several environmental factors co-vary simultaneously and it will be difficult to understand the cause and effect relationships of the treatments. To our knowledge, this is the first study to quantify SR growth and development in sweetpotato under a wide range of *S*-metolachlor rates and rainfall events using environment-controlled sunlit plant growth chambers.

3.1. Vine length, leaf numbers and leaf area development

There was no difference between rainfall and no-rainfall treatments for vine length, therefore the data were combined for rainfall treatments and analyzed as a function of *S*-metolachlor rate (Fig. 1A). Vine length per plant declined linearly with increase in *S*-metolachlor rate, 71.93 cm $plant^{-1}$ kg^{-1} *S*-metolachlor applied. When compared to the untreated check, vine length decreased by 12 and 26% for the minimum (0.86 kg ha^{-1}) and maximum (1.43 kg^{-1}) recommended herbicide label rates, respectively, for weed control measures in sweetpotato. Soltani et al. (2004) reported that PRE incorporation and PRE applications of 3.2 kg ha^{-1} *S*-metolachlor decreased sugar beet (*Beta vulgaris* L.) length by 11–14% in one of two locations. Similarly, Grichar et al. (2001) reported stunting of peanuts (*Arachis hypogaea* L.) with *S*-metolachlor applied PRE at 1.5 and 2.2 kg ha^{-1}.

Similar to vine length per plant, there was no difference between rainfall and no-rainfall across *S*-metolachlor rates for leaf numbers on the vines (Fig. 1B). Therefore, data on rainfall levels were combined and analyzed as a function of herbicide rate. Unlike vine length response to *S*-metolachlor rates, leaf number per plant declined quadratically with increase in *S*-metolachlor rate (Fig. 1B). Fewer leaves were produced at minimum (79 leaves $plant^{-1}$) and maximum (73 leaves $plant^{-1}$) recommended herbicide rates and the highest rate (30 leaves $plant^{-1}$) used in this study. Similar to leaf number per plant, *S*-metolachlor treatment affected leaf area and

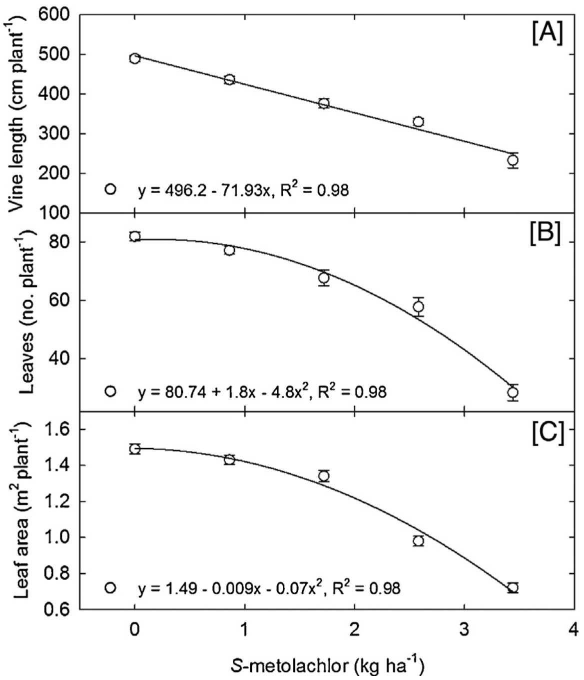

Fig. 1. *S*-metolachlor and rainfall effects on (A) vine length, (B) leaf number and (C) leaf area of 'Beauregard' sweetpotato grown in Soil-Plant-Atmosphere-Research growth chambers at 30/22 °C day/night temperatures and harvested 60 days after transplanting in 2012. There was no difference between rainfall levels for these parameters and data were averaged between rainfall treatments across *S*-metolachlor rates. Values represent the mean of eight plants and the error bars are ±SE of the mean.

the response was quadratic with increase in *S*-metolachlor rates (Fig. 1C).

Fewer leaves on plants treated with higher rates of *S*-metolachlor could be due to uptake and movement of the herbicide in the plant since the chemical has been reported to be absorbed by roots and transported upwards (Senseman, 2007) to the sites of cell division and cell elongation or expansion of sweetpotato plants and thus disrupting over all canopy development. Vine length that includes all growing internodes, total leaf area that includes all leaves and leaf numbers that represent all leaves on all branches are recognized as basic phenomena of shoot morphogenesis and growth. As internodes elevate other organs, leaves particularly, for effective PAR capture and interception (Reddy et al., 1997), any factor that affects growth and developmental processes of these organs will affect overall canopy development and finally yield. In a similar study conducted in the field, Bollman and Spraque (2008) observed 23% injury and reduction in leaf area with PRE application of *S*-metolachlor on sugar beet. Also, prior studies involving several sweetpotato cultivars indicate that a lower leaf area may limit storage root yield due to a low canopy photosynthate supply, weak SR sink and poor translocation of photosynthate to the SR (Austin and Lang, 1973; Lowe and Wilson, 1974; Bouwkamp and Hassam, 1988; Bhagsari, 1990).

3.2. Storage root numbers

There was no difference between the rainfall treatments for total and marketable SR numbers per plant; therefore data on no-rainfall and rainfall treatments were pooled and analyzed as a function of *S*-metolachlor rate (Fig. 2). When *S*-metolachlor rate increased from 0.86 to 3.44 kg ha^{-1}, there was a linear decline in the number of total and marketable SR per plant (Fig. 2). A similar decline in fruit numbers of summer squash (*Cucurbita pepo* L.) was observed with

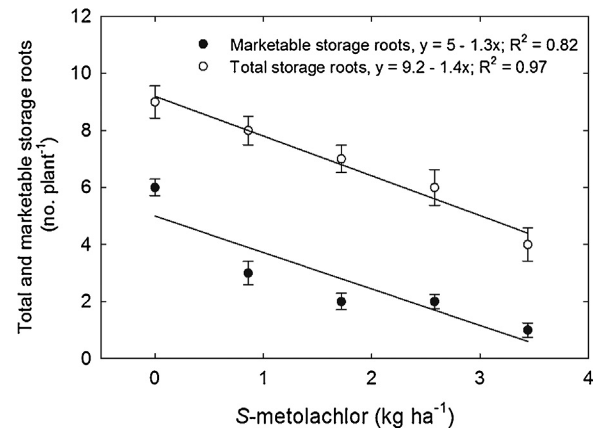

Fig. 2. *S*-metolachlor and rainfall effects on marketable and total storage root numbers of 'Beauregard' sweetpotato grown in Soil-Plant-Atmosphere-Research growth chambers at 30/22 °C day/night temperatures and harvested 60 days after transplanting in 2012. There was no difference between rainfall levels for these parameters and data were averaged between rainfall treatments across *S*-metolachlor rates. Values represent the mean of eight plants and the error bars are ±SE of the mean.

S-metolachlor applied PRE and PRE followed by POST treatments (Sosnoskie et al., 2008).

3.3. Plant component biomass

There was an interaction between *S*-metolachlor and rainfall for leaf, stem, and root biomass ($P < 0.05$). Leaf biomass was less with rainfall compared to no-rainfall following treatments of *S*-metolachlor at any rate (Fig. 3). As *S*-metolachlor rate increased from 0.86 to 3.44 kg ha^{-1}, there was a quadratic decline in leaf biomass. In comparison with the untreated check, leaf biomass per plant declined 8–17% for the minimum and the maximum recommended rates, respectively, and as high as 69% at the highest rate tested in this study under no-rainfall treatment. With rainfall, leaf biomass per plant decreased by 11–22% for minimum and maximum recommended label rates, respectively, relative to the untreated check, but when *S*-metolachlor rate increased to 3.44 kg ha^{-1}, leaf biomass declined by 76%.

Stem biomass per plant with no-rainfall treatment declined quadratically by 5 and 9% at minimum and maximum recommended label rates of *S*-metolachlor, respectively, and 31% when the herbicide rate increased to 3.44 kg ha^{-1}. Similarly, relative to the untreated check, stem biomass per plant decreased quadratically by 13–25% for minimum and maximum recommended label rates of *S*-metolachlor, respectively, with rainfall, and as high as 88% at the highest rate of *S*-metolachlor used in this study (Fig. 3). The reduction in stem biomass due to *S*-metolachlor and rainfall interaction was slightly more than observed reductions with leaf biomass.

Root biomass per plant decreased linearly with increasing rate of *S*-metolachlor, 82.62 and 84.37 g plant^{-1} kg^{-1} *S*-metolachlor applied with no-rainfall and rainfall treatments, respectively (Fig. 3). In comparison with the untreated check, with no-rainfall treatment, when *S*-metolachlor was applied at the minimum and maximum recommended label rates, root biomass per plant declined by 16 and 26%, respectively, and by 62% at the highest *S*-metolachlor rate used in this study. When rainfall occurred immediately after herbicide application, root biomass per plant declined by 21 and 36% with increasing *S*-metolachlor rate for minimum and maximum recommended label rates, respectively, relative to the untreated check (Fig. 3).

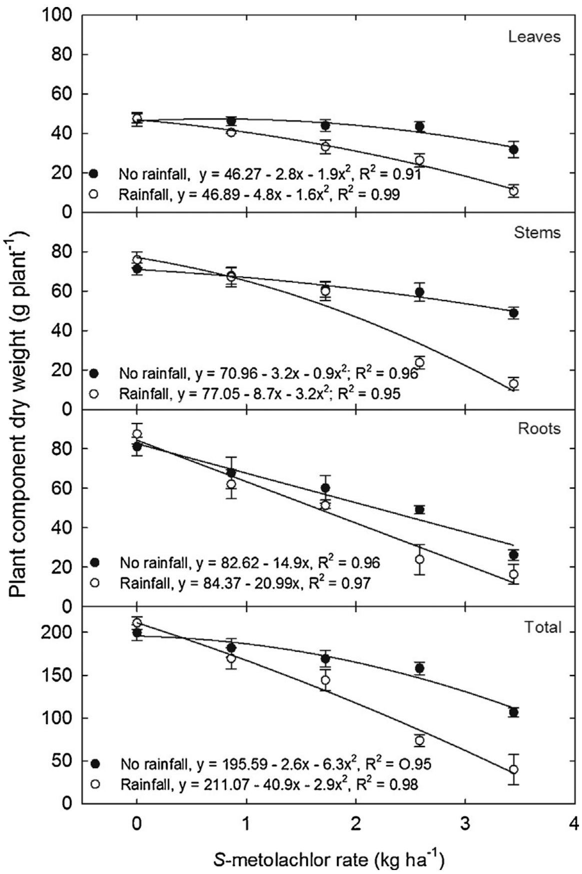

Fig. 3. *S*-metolachlor and rainfall effects on leaf, stem, root, and total dry weight of 'Beauregard' sweetpotato grown in Soil-Plant-Atmosphere-Research growth chambers at 30/22 °C day/night temperatures and harvested 60 days after transplanting in 2012. Values represent the mean of four plants and the error bars are ±SE of the mean.

Similar to leaf and stem biomass, *S*-metolachlor by rainfall interaction was observed for total biomass. Total biomass per plant declined quadratically in the presence and absence of rainfall application (Fig. 3). Similar to our results, biomass decline of 16 and 36% in black bean (*Phaseolus vulgaris* L.) and sugarbeet (*Beta vulgaris* L.), respectively, with PRE applications of *S*-metolachlor was observed under field conditions (Soltani et al., 2004; Bollman and Spraque, 2008). The herbicide effect was intensified in the presence of rainfall on leaf, stem, and root dry weights, which could be attributed to rainfall moving the herbicide into the root initiation zone of sweetpotato slips making it bioavailable for uptake leading to herbicide injury. Similar to our results, Cardina and Swann (1988) also reported delayed emergence and reduced growth in peanuts, when *S*-metolachlor treatment was followed by irrigation.

3.4. Storage root yield

There was *S*-metolachlor by rainfall interaction for total and marketable SR weights (Figs. 4 and 5). *S*-metolachlor and rainfall completely suppressed SR formation at the two highest treatments (2.58 and 3.44 kg ha^{-1}) (Fig. 4). Most of the adventitious roots did not turn into storage roots and the effect was intensified when rainfall occurred immediately after herbicide was applied to transplanted slips. As *S*-metolachlor rate increased from 0.86 to 3.44 kg ha^{-1}, total SR weight showed a linear decline for both rainfall and no-rainfall, whereas marketable storage root weight declined quadratically with rainfall event and linearly with no-rainfall treatment. In comparison to the untreated check, marketable SR weight decreased linearly from 20 to 73% with no-rainfall, but when rainfall occurred it decreased quadratically from 70 to 99% as *S*-metolachlor rate increased from 0.8 to 3.44 kg ha^{-1} (Fig. 5A). Marketable SR yield, however, was 17% higher with rainfall compared to no-rainfall for the untreated check. Total SR weight declined from 12 to 76% and 50 to 96% with no-rainfall and rainfall treatments as *S*-metolachlor rate increased from 0.8 to 3.44 kg ha^{-1}, respectively, when compared to the untreated check (Fig. 5B). The marketable SR weight decline in the presence of rainfall in this study is in agreement with an earlier study by Glaze and Hall (1986) that reported a reduction in marketable SR weight resulting from the application of 4.5 kg ha^{-1} metolachlor. Total marketable

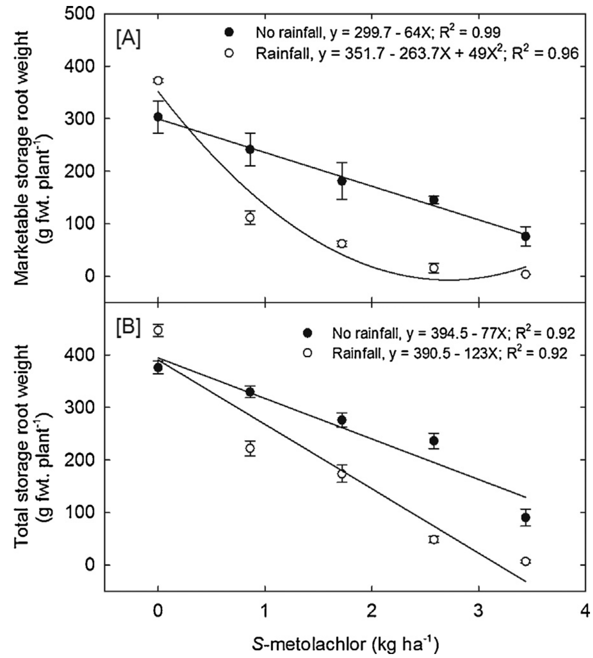

Fig. 4. Effects of *S*-metolachlor and rainfall on (A) marketable and (B) total storage root fresh weight of 'Beauregard' sweetpotato grown in Soil-Plant-Atmosphere-Research growth chambers at 30/22 °C day/night temperatures and harvested 60 days after transplanting in 2012. Values represent the mean of four plants and the error bars are ±SE of the mean.

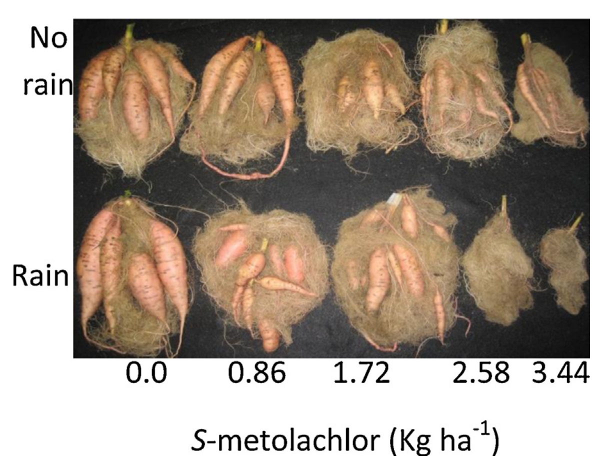

Fig. 5. Pictorial representation of the effects of *S*-metolachlor and rainfall on storage root development of 'Beauregard' sweetpotato grown in Soil-Plant-Atmosphere-Research growth chambers at 30/22 °C day/night temperatures and harvested 60 days after transplanting in 2012.

SR weight decline was more severe with the rainfall treatment, which could be attributed to low organic matter (0.68%) and clay (5.8%) content of the soil used in this study. *S*-metolachlor mobility in the soil solution has been reported to be affected by high organic matter content (>2.0%), clay mineral content and surface area (Nennemann et al., 2001; Senseman, 2007; Alletto et al., 2013; Gannon et al., 2013). In a peanut study, Cardina and Swann (1988) observed delayed emergence and reduced growth when irrigation followed metolachlor application at planting. Similar to our observations with rainfall event, Bollman and Spraque (2008) attributed the death of sugarbeet plants to increased absorption of *S*-metolachlor due to a rainfall event following PRE application of the herbicide. The contact of herbicide with emerging roots might have influenced cell division and bulking process in sweetpotato resulting in fewer SR at the highest rates with rainfall treatment.

This study illustrates that sweetpotato growth and development was influenced by changes in *S*-metolachlor rate, particularly SR yield and quality. Furthermore, the growth and developmental responses were modulated by rainfall (at least 38 mm at 51 mm h^{-1}) event immediately after the herbicide application. Storage root quality and quantity declined with increasing *S*-metolachlor rates. However, the benefit of weed control may compensate the potential injury since weed competition and interference can reduce yield by 14–91% (Moody and Ezumah, 1974; LaBonte et al., 1999; Harrison and Jackson, 2011). The results obtained in this study will be useful in making informed decisions about herbicide rate selection, irrigation scheduling and to manage sweetpotato transplanting operations in the field to minimize risk of storage root injury. However, field-level experimentation and other combination of rainfall and other environmental conditions are needed to assist on-farm recommendation.

Acknowledgments

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