Interspecific and intraspecific interference of Palmer amaranth (*Amaranthus palmeri*) and large crabgrass (*Digitaria sanguinalis*) in sweetpotato

Nicholas T. Basinger[1], Katherine M. Jennings[2], David W. Monks[3], David L. Jordan[4], Wesley J. Everman[5], Erin L. Hestir[6], Matthew D. Waldschmidt[7], Stephen C. Smith[1] and Cavell Brownie[8]

[1]Graduate Research Assistant, Department of Horticultural Science, North Carolina State University, Raleigh, NC, USA; [2]Associate Professor, Department of Horticultural Science, North Carolina State University, Raleigh, NC, USA; [3]Professor, Department of Horticultural Science, North Carolina State University, Raleigh, NC, USA; [4]Professor, Department of Crop and Soil Science, North Carolina State University, Raleigh, NC, USA; [5]Associate Professor, Department of Crop and Soil Science, North Carolina State University, Raleigh, NC, USA; [6]Assistant Professor, Department of Civil and Environmental Engineering, University of California, Merced, CA, USA; [7]Research Technician, Department of Horticultural Science, North Carolina State University, Raleigh, NC, USA and [8]Emeritus Professor, Department of Statistics, North Carolina State University, Raleigh, NC, USA

Abstract

Field studies were conducted in 2016 and 2017 in Clinton, NC, to determine the interspecific and intraspecific interference of Palmer amaranth (*Amaranthus palmeri* S. Watson) or large crabgrass [*Digitaria sanguinalis* (L.) Scop.] in 'Covington' sweetpotato [*Ipomoea batatas* (L.) Lam.]. *Amaranthus palmeri* and *D. sanguinalis* were established 1 d after sweetpotato transplanting and maintained season-long at 0, 1, 2, 4, 8 and 0, 1, 2, 4, 16 plants m^{-1} of row in the presence and absence of sweetpotato, respectively. Predicted yield loss for sweetpotato was 35% to 76% for *D. sanguinalis* at 1 to 16 plants m^{-1} of row and 50% to 79% for *A. palmeri* at 1 to 8 plants m^{-1} of row. Weed dry biomass per meter of row increased linearly with increasing weed density. Individual dry biomass of *A. palmeri* and *D. sanguinalis* was not affected by weed density when grown in the presence of sweetpotato. When grown without sweetpotato, individual weed dry biomass decreased 71% and 62% from 1 to 4 plants m^{-1} row for *A. palmeri* and *D. sanguinalis*, respectively. Individual weed dry biomass was not affected above 4 plants m^{-1} row to the highest densities of 8 and 16 plants m^{-1} row for *A. palmeri* and *D. sanguinalis*, respectively.

Introduction

A significant increase in sweetpotato [*Ipomoea batatas* (L.) Lam.] production area in the southeastern United States has occurred in the past decade, increasing from 33,548 ha in 2007 to 51,800 ha in 2017 (USDA-NASS 2017). Sweetpotato has proven to be a valuable crop with a national farm gate value of $705.7 million in 2016, up from $298.4 million in 2006 (USDA-NASS 2017). North Carolina is the largest sweetpotato-producing state, accounting for 54% of U.S. production (USDA-NASS 2017). North Carolina, California, Mississippi, and Louisiana account for 94% of sweetpotato production in the United States (USDA-NASS 2017). Unfortunately, due to its prostrate growth habit and relatively slow growth, sweetpotato does not compete well with problematic weeds, resulting in reduced yields (Meyers et al. 2010; Seem et al. 2003). Palmer amaranth (*Amaranthus palmeri* S. Watson) and large crabgrass [*Digitaria sanguinalis* (L.) Scop.] are among the top five most common weeds in North Carolina sweetpotato, with *A. palmeri* being identified as the most troublesome weed (Webster 2010). *Amaranthus palmeri* has been reported to be taller, to have a faster growth rate and greater leaf area, and to produce more overall biomass when compared with other *Amaranthus* species (Horak and Loughin 2000). Season-long *A. palmeri* interference is seen in vegetable crops, with reduced yield of 94% in bell pepper (*Capsicum annum* L.) (Norsworthy et al. 2008), 67% in tomato (*Solanum lycopersicum* L.) (Garvey et al. 2013), 36% to 81% in sweetpotato (Meyers et al. 2010), with the greater yield losses associated with higher *A. palmeri* densities.

Limited herbicide options exist for use in sweetpotato (Kemble 2017). Growers rely on PRE herbicides, which do not always provide efficacious weed control and require rainfall for activation. POST herbicide options for *A. palmeri* control in sweetpotato are limited to between-row applications of carfentrazone or glyphosate (Kemble 2017). The lack of POST herbicides forces growers to use tillage for control of weeds until row closure, at which time growers have no additional control options for dicotyledonous weeds other than mowing weeds above the crop

canopy and hand weeding, which is a costly control measure (KM Jennings, personal communication).

Digitaria sanguinalis is commonly found in fruit and vegetable crops (Webster 2010) but has not been highly ranked as a problematic weed due to efficacious POST herbicides such as clethodim, fluazifop, or sethoxydim (Kemble 2017). Although these graminicides can be effective, grasses escaping herbicide application or sprayed after substantial establishment may continue to compete with the crop and reduce yields. Furthermore, herbicide resistance management for *D. sanguinalis* should be considered, as resistance to acetyl-CoA carboxylase herbicides, including those registered for use in sweetpotato has been reported (Heap 2018; Hidayat and Preston 1997; Laforest et al. 2017; Volenberg and Stoltenberg 2002). While its impact on sweetpotato has not been reported, season-long, *D. sanguinalis* reduced yield in bell pepper by 46% (Norsworthy et al. 2008), snap bean (*Phaseolus vulgaris* L.) by 47% to 50% (Aguyoh and Masiunas 2003), and watermelon [*Citrullus lanatus* (Thunb.) Matsum. & Nakai] by 82% (Monks and Schultheis 1998).

A better understanding of the interactions of *A. palmeri* and *D. sanguinalis* with sweetpotato would allow for better decision making regarding their control. Thus, the objectives of this study were to determine (1) the effect of five densities of *A. palmeri* and *D. sanguinalis* on sweetpotato biomass and storage root yield and quality, (2) the intraspecific response of *A. palmeri* and *D. sanguinalis* across five densities with and without sweetpotato, and (3) the effect of sweetpotato on growth of *A. palmeri* and *D. sanguinalis*.

Materials and Methods

Field studies were conducted with 'Covington' sweetpotato at the Horticultural Crops Research Station near Clinton, NC (35.1°N, 81.16°W) on a Norfolk loamy sand (fine-loamy, kaolinitic, thermic Typic Kandiudults) with humic matter 0.31% and pH 5.9 in 2016 and an Orangeburg loamy sand (fine-loamy, kaolinitic, thermic Typic Kandiudults) with humic matter 0.47% and pH 5.9 in 2017. Nonrooted 'Covington' sweetpotato 20- to 30-cm-long cuttings were mechanically planted approximately 7.6-cm deep into ridged rows 1 m apart in the entire study at an in-row spacing of approximately 30 cm on June 9, 2016, and June 12, 2017. At 1 d after transplanting, sweetpotato plants were removed by hand in the no-sweetpotato treatments. On the same day, treatment rows assigned *A. palmeri* or *D. sanguinalis* were broadcast seeded on the soil surface and lightly raked to a depth of approximately 1.0 cm. After weed seeding, the entire study was irrigated with 1.3 cm of water using overhead irrigation to aid in weed seed establishment. No additional irrigation was applied, in either year, after the initial irrigation event. Treatments consisted of a single weed species (*A. palmeri* or *D. sanguinalis*) at five weed densities grown with and without sweetpotato arranged in a randomized complete block design with three replications (Supplementary Figures S1 and S2). *Amaranthus palmeri* and *D. sanguinalis* were hand thinned to treatment densities of 0 (weed-free), 1, 2, 4, and 8 and 0 (weed-free), 1, 2, 4, and 16 plants m^{-1} of row, respectively, when *A. palmeri* was approximately 8 cm tall, and *D. sanguinalis* had two expanded leaves. At the time of weed thinning, sweetpotato averaged one to two newly expanded leaves on each plant. Densities of *A. palmeri* and *D. sanguinalis* were based on those used in previous research (Aguyoh and Masiunas 2003; Bensch et al. 2003; Fu and Ashley 2006; Meyers et al. 2010). Plots consisted of two bedded rows, each 1-m wide by 5-m long, with the first row being a weed-free buffer row planted to sweetpotato and the second row

a treatment row. Treatment rows were maintained at specific weed treatment densities, and border rows were maintained free of weeds season-long by weekly removal by hand. Cultural practices for conventional sweetpotato production in North Carolina were followed (Kemble 2017). Season-long rainfall and growing degree-day data are presented in Table 1.

Two days before sweetpotato harvest, 5 sweetpotato plants and 5 plants of each weed species were randomly harvested at the soil level from each plot to determine aboveground biomass. Samples were placed in 2-ply paper yard waste bags measuring 40 by 30 by 89 cm and fresh biomass was recorded. Samples were then placed in a propane-heated, forced-air drier for 96 h at 80 C. Once dry, samples were removed and weighed immediately to determine dry biomass. To determine fresh and dry sweetpotato and weed biomass on a per plant basis, total sweetpotato or weed biomass within a treatment and replication was divided by the number of plants harvested. To determine dry biomass per meter of row, individual weed biomass was multiplied by sweetpotato plant and/or weed number in 1 m of row, respectively.

Sweetpotato storage roots were harvested at 113 d after transplanting (DAT) in 2016 and at 107 DAT in 2017. In both years storage roots were harvested with a tractor-mounted two-row chain digger and hand sorted into jumbo (≥8.9 cm in diameter), no. 1 (≥4.4 cm but <8.9 cm), and canner (≥2.5 but <4.4 cm) grades (USDA 2005) and weighed. Total marketable yield was calculated as the sum of jumbo and no. 1 grades.

Data for crop biomass, individual weed biomass, weed biomass per meter of row, yield, and quality were subjected to ANOVA using PROC MIXED in SAS (SAS v. 9.4, SAS Institute, Cary, NC). Treatment, year, and treatment by year were considered fixed effects, while replication within year was treated as a random effect. Year was treated as a fixed effect to further evaluate components of the year by treatment interaction, such as year by weed density and year by crop presence or absence. If the treatment by year interaction was not significant, a contrast statement was used to test for a linear trend for dependent variables (averaged over year) with increasing weed density, calculated separately for each weed species. All response variables, except canner yield, were square-root transformed to reduce both data skewness and variance heterogeneity before carrying out the mixed model ANOVA. Least-squares means for these response variables are reported without the applied transformations and separated according to Tukey's HSD ($P \leq 0.05$). Mean percent reduction in sweetpotato no. 1, jumbo, and marketable yield due to weed density was calculated

Table 1. Monthly rainfall (mm) and growing degree days (GDD; base 10 C) at Horticultural Crops Research Station, Clinton, NC, from May to September 2016 and 2017.[a]

	Rainfall[b]		GDD	
Month	2016	2017	2016	2017
	— mm —		— C —	
May	136	142	330	357
June	93	150	473	437
July	155	86	569	527
August	107	125	538	493
September	287	132	437	393
Total	778	635	2,347	2,207

[a] Nonrooted cuttings were planted on June 9, 2016, and June 12, 2017, and harvested on September 30, 2016, and September 27, 2017. Data were collected from an on-site weather station.
[b] Rainfall totals do not include 13 mm of irrigation applied at 1 d after planting, after which no additional irrigation was applied.

for each weed species using treatment differences of least-squared means and modeled using a single rectangular hyperbola function, as described by Cousins (1985), for each weed species using Equation 1:

$$Y_R = \frac{(ID)}{1 + \left(\frac{ID}{A}\right)} \qquad [1]$$

where Y_R is the yield loss due to weed competition density, I is the percent yield loss as a function of weed density as weed density approaches zero, D is weed density, and A is the percent yield loss as weed density approaches infinity. Yield loss for weed-free plots was considered to be zero, because yield loss estimates were calculated based on the yield of the weed-free plots. SAS PROC NLIN was used to fit the rectangular hyperbola to means of percent yield reduction for each weed species.

Weed biomass per meter of row and individual weed dry biomass were log transformed and then subjected to ANOVA using PROC GLM. If ANOVA indicated significant effects ($\alpha \le 0.05$) of weed density and crop versus no crop, linear or nonlinear regression analysis was performed as follows: for each weed species in the presence of sweetpotato, weed biomass per meter of row and individual weed biomass were regressed against weed density and fit to a linear model in Equation 2:

$$Y = Y_0 + ax \qquad [2]$$

where Y is the estimated biomass per meter of row, y_0 is the y-intercept, a is the slope for the predicted values of weed biomass per meter of row, and x is weed density. Individual weed biomass in the absence of a crop fit a linear-plateau model (Equation 3) and was regressed against weed density, which is composed of two functions: the first describes the linear increase or decrease of weed biomass at lower weed densities, and the second describes the plateau of weed biomass at high weed densities, as described by Schabenberger and Pierce (2002):

$$Y = \begin{cases} y_0 + ax \text{ if } x < x_0 \\ y_0 + ax_0 \text{ if } x \ge x_0 \end{cases} \qquad [3]$$

where y_0 is the y-intercept of the initial segmented line, a is the slope of the line, and x_0 is the weed density at which the two functions join. Y values for x less than x_0 fit the linear function, while Y values for x greater than or equal to x_0 are constant. Due to the limited number of weed densities established in this study, the linear-plateau model provides an informative approximation for individual weed biomass response as weed density increases (Byrd and Coble 1991; Rodgers et al. 1996).

Results and Discussion

Interspecific Interference

Marketable yield decreased as the density of *A. palmeri* or *D. sanguinalis* increased. No treatment by year interaction for sweetpotato yield was observed (P = 0.12); therefore, data were combined over years. Marketable yield loss associated with *A. palmeri* density ranged from 50% with 1 *A. palmeri* plant m^{-1} of row to 79% with 8 plants m^{-1} of row, respectively, when compared with the weed-free check (Figure 1A). Marketable yield reduction by *D. sanguinalis* was similar to marketable yield reduction caused by *A. palmeri* but at higher weed densities. Marketable
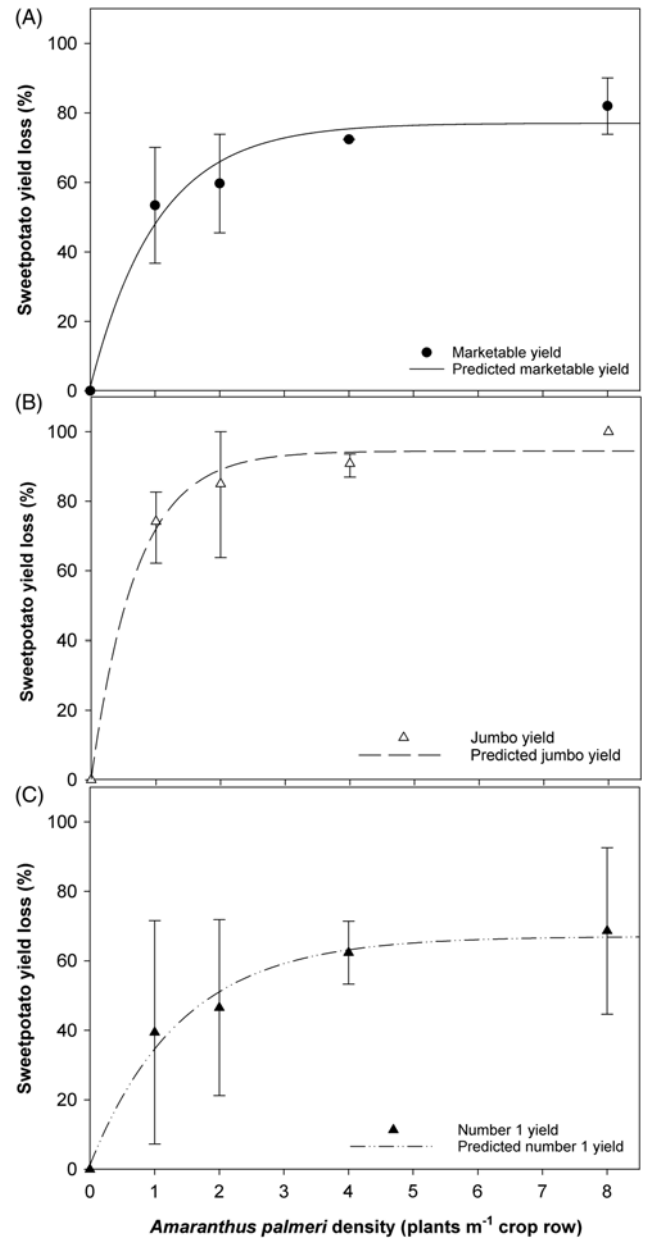

Figure 1. 'Covington' sweetpotato yield loss as a percent of the weed-free treatment yield as a function of increasing *Amaranthus palmeri* density per meter of row. Sweetpotato were grown at the Horticultural Crops Research Station Clinton, NC, in 2016 and 2017. Marketable yield values are calculated by summing no. 1 and jumbo grades, and values are averaged over 2016 and 2017. Bars represent standard error of the mean at each measured density. Data were fit to a rectangular hyperbola model with equation: $Y_R = (ID)/[1 + (ID/A)]$, where Y_R is the marketable yield reduction due to weed competition density, I is the percent yield loss as a function of weed density as weed density approaches zero, D is defined by weed density, and A is the percent yield loss as weed density approaches infinity. Equation parameters for the data are given with standard errors in parentheses after each value. When the sweetpotato crop was present, (A) $I = 119.4(38.96)$, $A = 86.93$ (7.745), $R^2 = 0.93$ for marketable yield; (B) $I = 255.60(94.91)$, $A = 102.70(6.74)$, $R^2 = 0.95$ for jumbo yield; (C) $I = 70.75(45.47)$, $A = 77.81(17.94)$, $R^2 = 0.71$ for no. 1 yield.

yield was reduced by 35% and 76% with 1 and 16 *D. sanguinalis* plants m^{-1} of row, respectively (Figure 2A). Loss of jumbo yield is a significant contributor to overall marketable yield loss at weed densities as low as 1 plant of either species m^{-1}. Jumbo grade had greater yield loss with 1 plant m^{-1} for *A. palmeri* (73%) and *D. sanguinalis* (75%) (Figures 1B and 2B) than the no. 1 grade
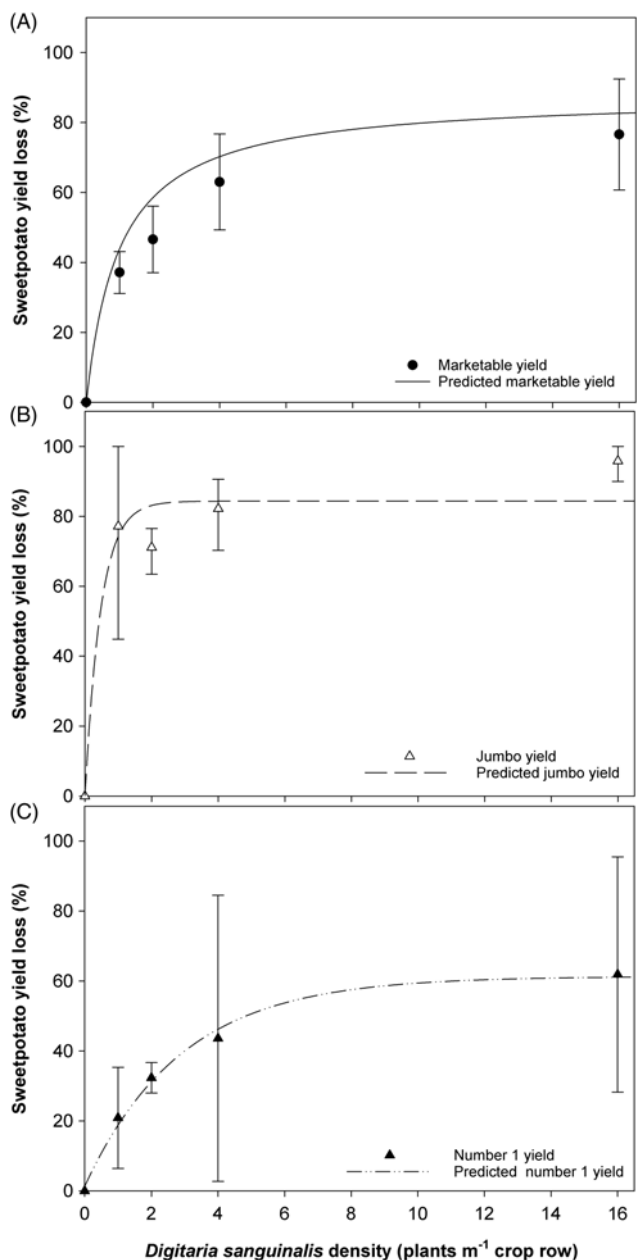
Figure 2. 'Covington' sweetpotato yield loss as a percent of the weed-free treatment yield as a function of increasing *Digitaria sanguinalis* density per meter of row. Sweetpotato were grown at the Horticultural Crops Research Station Clinton, NC, in 2016 and 2017. Marketable yield values are calculated by summing no. 1 and jumbo grades, and values are averaged over 2016 and 2017. Bars represent standard error of the mean at each measured density. Data were fit to a rectangular hyperbola model with equation: $Y_R = (ID)/[1 + (ID/A)]$, where Y_R is the yield reduction due to weed competition density, I is the percent yield loss as a function of weed density as weed density approaches zero, D is defined by weed density, and A is the percent yield loss as weed density approaches infinity. Equation parameters for the data are given with standard errors in parentheses after each value. When the sweetpotato crop was present, (A) $I = 61.07(15.33)$, $A = 83.01$ (7.611), $R^2 = 0.92$ for marketable yield; (B) $I = 318.10(241.3)$, $A = 91.45(9.20)$, $R^2 = 0.87$ for jumbo yield; (C) $I = 29.17(18.44)$, $A = 71.08(21.33)$, $R^2 = 0.59$ for no. 1 yield.

for both weed species (35% for *A. palmeri* and 19% for *D. sanguinalis*) at the same density (Figures 1C and 2C).

Results for estimated marketable yield loss per weed as weed density approaches zero (parameter I) for *A. palmeri* and *D. sanguinalis* were 119% and 61%, respectively. The higher
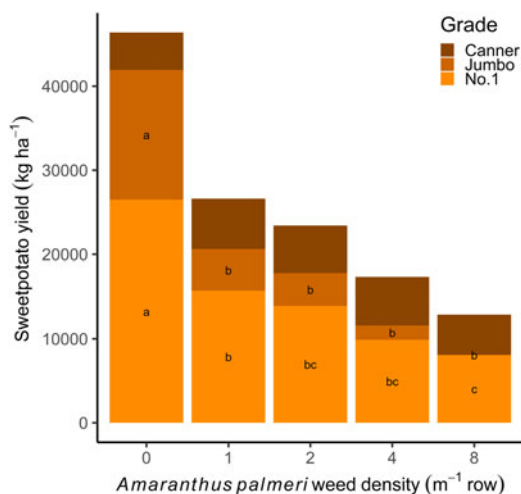

Figure 3. Effect of *Amaranthus palmeri* density on 'Covington' sweetpotato yield (kg ha^{-1}) by grade. Sweetpotato were grown at the Horticultural Crops Research Station Clinton, NC, in 2016 and 2017. Within each grade, bars with the same letter are not different according to Tukey's HSD (P ≤ 0.05).

estimated marketable yield loss as weed density approaches zero for *A. palmeri* relative to *D. sanguinalis* indicated higher competitive capacity of *A. palmeri* at low densities. These results for *A. palmeri* are consistent with another study in sweetpotato (Meyers et al. 2010) but higher than in soybean [*Glycine max* (L.) Merr.] (Bensch et al. 2003), peanut (*Arachis hypogaea* L.) (Burke et al. 2007), and corn (*Zea mays* L.) (Massinga et al. 2001). Estimated yield loss as weed density approaches zero in the present study indicates that *A. palmeri* and *D. sanguinalis*, even at low densities, can greatly reduce sweetpotato marketable yield. The initial yield loss as weed density approaches zero for *D. sanguinalis* was less than *A. palmeri* at lower densities. However, sweetpotato yield loss from interference by *D. sanguinalis* was higher than yield loss reported in snap bean (Aguyoh and Masiunas 2003). For parameter A, the asymptote of the regression model estimating the maximum yield loss due to weed density was 87% for *A. palmeri* and 83% for *D. sanguinalis*. Meyers et al. (2010) estimated a maximum marketable yield loss of 90% at *A. palmeri* densities of 6.5 plants m^{-1} of sweetpotato row. Findings from our study further support the findings of Meyers et al. (2010), who also reported the highly competitive nature of *A. palmeri* with sweetpotato. To reduce interference of *A. palmeri* and *D. sanguinalis*, which are commonly reported in sweetpotato, growers should use a combination of efficacious PRE herbicides, as outlined by Meyers et al. (2013), in combination with tillage, hand removal, and mowing (*A. palmeri* only). Although POST herbicides for *A. palmeri* are limited, POST herbicide options for selective grass control in sweetpotato are available (Kemble 2017) and should be used when *D. sanguinalis* is less than 10 cm to minimize yield loss. If *D. sanguinalis* resistance is suspected, then alternative methods should be analyzed for control. Growers should not dismiss the impact of either weed, as a single *A. palmeri* or *D. sanguinalis* per meter of row reduced marketable yield by 50% and 35%, respectively (Figures 1 and 2).

Reduction in marketable yield loss was due to a decrease in weight of no. 1 and jumbo sweetpotato grades. *Amaranthus palmeri* decreased the yield of no. 1 and jumbo grades at all densities greater than 1 plant m^{-1} row when compared with weed-free sweetpotato yields (Figure 3). Similarly, *D. sanguinalis* at 1 plant m^{-1} row
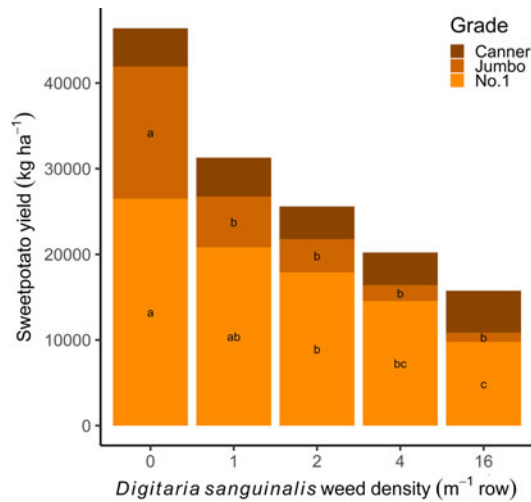
Figure 4. Effect of *Digitaria sanguinalis* density on 'Covington' sweetpotato yield (kg ha^{-1}) by grade. Sweetpotato were grown at the Horticultural Crops Research Station Clinton, NC, in 2016 and 2017. Within each grade, bars with the same letter are not different according to Tukey's HSD (P ≤ 0.05).

decreased the weight of sweetpotato jumbo grade when compared with the weed-free check (Figure 4). *Digitaria sanguinalis* densities greater than 2 plants m^{-1} row decreased no. 1 grade sweetpotato yield relative to the weed-free check, with 16 plants m^{-1} causing the greatest loss of no. 1 and jumbo grades. Yield for the canner grade was not affected by any density of either weed. These findings further demonstrate the negative impact of *A. palmeri* and *D. sanguinalis* on sweetpotato yields at low weed densities.

Interspecific competition is also reflected in biomass reduction of one or both plant species competing with each other (Aguyoh and Masiunas 2003; Webster and Grey 2015) Interactions between year, crop versus no crop, and weed density were not significant (P ≥ 0.05); therefore, means pooled over years were obtained for density and crop versus no crop combinations for each weed species. Biomass per meter of row of *A. palmeri* and *D. sanguinalis* increased with increasing weed density (Figures 5 and 6). The presence of sweetpotato reduced overall biomass per meter of row for both weed species at densities of 1, 2, and 4 plants m^{-1} row. Furthermore, sweetpotato reduced the rate of bioaccumulation for *D. sanguinalis*, as can be seen when comparing the slopes of biomass accumulation of both weeds (Figures 5 and 6). We believe that this was an effect of weed height, as *A. palmeri* quickly establishes and reduces the light reaching the sweetpotato canopy, whereas *D. sanguinalis* does not exceed the sweetpotato canopy height as quickly as *A. palmeri* and is therefore less competitive with sweetpotato for light. The impact of *A. palmeri* on light interception with the sweetpotato canopy has been documented by others (Meyers et al. 2010). Individual weed biomass of *A. palmeri* and *D. sanguinalis* was similar across weed densities when grown with sweetpotato (Figures 7 and 8). Individual weed biomass for *A. palmeri* and *D. sanguinalis*, however, was lower for all weed densities when grown in the presence of sweetpotato compared with weeds grown without sweetpotato. The reduced individual biomass and biomass per meter of row for both weeds, when grown with sweetpotato, indicate that interspecific interference is occurring between sweetpotato and weeds. Crop biomass reductions are generally associated with increased weed competition and yield losses (Aguyoh and Masiunas 2003; Norsworthy et al. 2008). However, in this study, although weed biomass was lower when
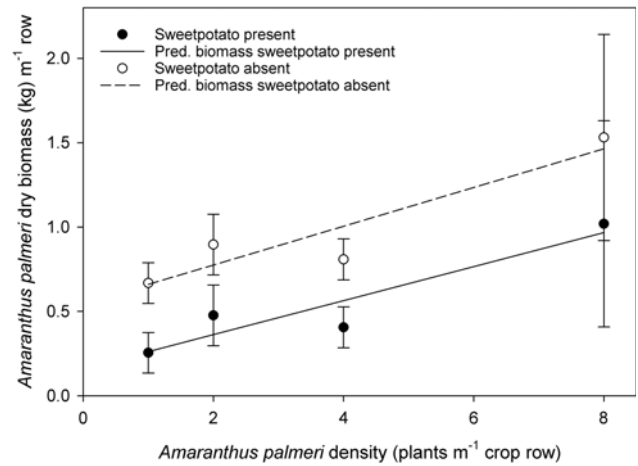

Figure 5. *Amaranthus palmeri* dry biomass per meter of row (kg m^{-1} row) as a function of increasing *A. palmeri* density per meter of row in the presence or absence of conventionally grown 'Covington' sweetpotato. Studies were conducted at the Horticultural Crops Research Station, Clinton, NC, in 2016 and 2017. Dry biomass per meter of row for mean values, with bars representing standard error of the mean, over 2016 and 2017 for crop presence and absence were fit to a linear model with the equation: $y = y_0 + ax$. Equation parameters for the data are given with standard errors in parentheses after each value. When the sweetpotato crop was present, $y_0 = 0.161(0.123)$, $a = 0.101(0.0266)$, $R^2 = 0.88$. When crop was absent, $y_0 = 0.545(0.146)$, $a = 0.115(0.0317)$, $R^2 = 0.87$.
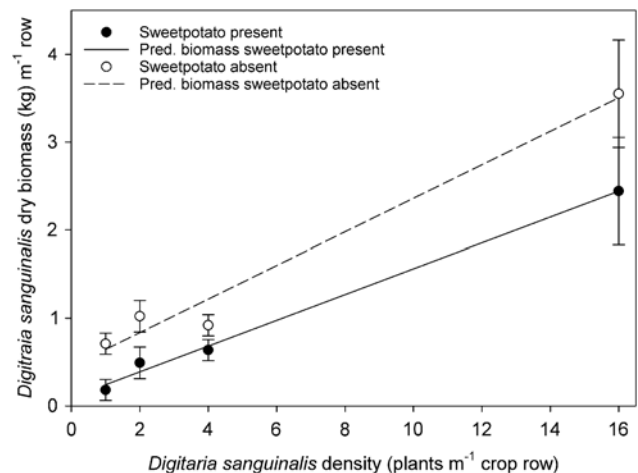

Figure 6. *Digitaria sanguinalis* dry biomass per meter of row (kg m^{-1} row) as a function of increasing *D. sanguinalis* density per meter of row in the presence or absence of conventionally grown 'Covington' sweetpotato. Studies were conducted at the Horticultural Crops Research Station, Clinton, NC, in 2016 and 2017. Dry biomass per meter of row for mean values, with bars representing standard error of the mean, over 2016 and 2017 for crop presence and absence were fit to a linear model with the equation: $y = y_0 + ax$. Equation parameters for the data are given with standard errors in parentheses after each value. When the sweetpotato crop was present, $y_0 = 0.0956(0.0621)$, $a = 0.146(0.00747)$, $R^2 = 0.99$. When crop was absent, $y_0 = 0.455(0.176)$, $a = 0.191(0.0212)$, $R^2 = 0.97$.

grown with sweetpotato, increased weed density did not reduce sweetpotato biomass, despite the reduction in sweetpotato yield at the same densities.

Intraspecific Competition

Individual dry biomass of each weed species growing without sweetpotato decreased as weed density increased (Figures 7 and 8). In the absence of sweetpotato, individual dry biomass of
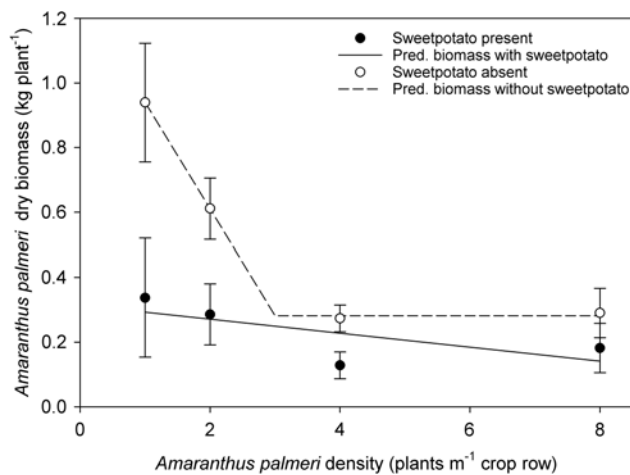
Figure 7. Mean *Amaranthus palmeri* individual dry biomass (kg), with bars representing standard error of the mean, as a function of increasing *A. palmeri* density per meter of row in the presence or absence of conventionally grown 'Covington' sweetpotato. Studies were conducted at the Horticultural Crops Research Station, Clinton, NC, in 2016 and 2017. Equation parameters for the data are given with standard errors in parentheses after each value. Dry biomass per meter of row for mean values averaged over 2016 and 2017 for crop presence was fit to a linear model with equation: $y = y_0 + ax$, where equation parameters are $y_0 = 0.314(0.0713)$, and $a = -0.0217(0.0155)$. Regression for individual weed biomass in the absence of sweetpotato was fit to a linear-plateau model: $Y = y_0 + ax$, if $x < x_0$, and $Y = y_0 + ax_0$, if $x \geq x_0$, where $y_0 = 1.268(0.0265)$, $a = -0.328(0.0168)$, and $x_0 = 3.00(0.0850)$, $R^2 = 0.99$.
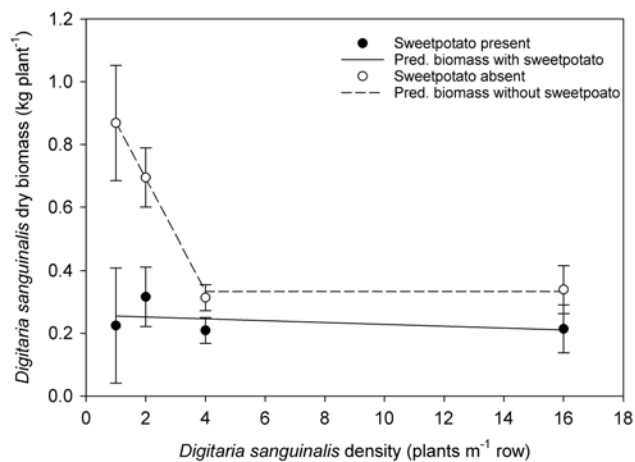

Figure 8. Mean individual *Digitaria sanguinalis* dry biomass (kg), with bars representing standard error of the mean, as a function of increasing *D. sanguinalis* density per meter of row in the presence or absence of conventionally grown 'Covington' sweetpotato. Studies were conducted at the Horticultural Crops Research Station, Clinton, NC, in 2016 and 2017. Equation parameters for the data are given with standard errors in parentheses after each value. Dry biomass per meter of row for mean values averaged over 2016 and 2017 for crop presence was fit to a linear model with equation: $y = y_0 + ax$, where equation parameters are $y_0 = 0.26(0.039)$, and $a = -0.0030(0.0047)$. Regression for individual weed biomass in the absence of sweetpotato was fit to a linear-plateau model: $Y = y_0 + ax$, if $x < x_0$, and $Y = y_0 + ax_0$, if $x \geq x_0$, where $y_0 = 1.05(0.0256)$, $a = -0.179(0.00966)$, and $x_0 = 4.00(0.1618)$, $R^2 = 0.99$.

both weeds was fit to a linear-plateau model. Individual weed biomass was greatest for both weeds at the lowest density. *Amaranthus palmeri* and *D. sanguinalis* individual plant biomass decreased 71% from 1 (lowest density) to 3 (estimated) plants m^{-1} of row and 62% from 1 (lowest density) to 4 plants m^{-1} of row, respectively, and remained unchanged at densities above 4 plants m^{-1} row for both weeds (Figures 7 and 8). This finding was similar

to the trend observed in peanut (Burke et al. 2007) for *A. palmeri*. We believe that the reduction in individual weed biomass for *A. palmeri* and *D. sanguinalis* at lower weed densities when grown without sweetpotato is due to increasing intraspecific competition as weed density increases. At the higher densities of both weeds, the impact of intraspecific competition has limited effect on further decreasing individual weed biomass. The established threshold is the density at which all weeds achieve maximum accumulated biomass before intraspecific competition begins. Further biomass increases would require densities resulting in weed mortality due to intraspecies competition, and such densities were not evaluated in this study.

This study demonstrates that *A. palmeri* and *D. sanguinalis* have the ability to reduce yield at densities as low as 1 to 2 plants m^{-1} row. Sweetpotato competes with *A. palmeri* or *D. sanguinalis*, resulting in reduced weed biomass. This observation suggests that sweetpotato with rapid canopy establishment and dense growth habit may provide additional competition with weeds and reduce yield loss, as proposed by Harrison and Jackson (2010). Future studies should establish critical weed-free periods for these weeds in sweetpotato, investigate competitiveness of resistant weed biotypes with sweetpotato, and determine weed interference with sweetpotato under varying management practices (planting density, irrigation, and crop rotation).

Author ORCID. Nicholas T. Basinger ⓘ https://orcid.org/0000-0002-7317-5835.

References

Aguyoh JN, Masiunas JB (2003) Interference of large crabgrass (*Digitaria sanguinalis*) with snap beans. Weed Sci 51:171–176

Bensch CN, Horak MJ, Peterson D (2003) Interference of redroot pigweed (*Amaranthus retroflexus*), Palmer amaranth (*A. palmeri*), and common waterhemp (*A. rudis*) in soybean. Weed Sci 51:37–43

Burke IC, Schroeder M, Thomas WE, Wilcut JW (2007) Palmer amaranth interference and seed production in peanut. Weed Technol 21:367–371

Byrd JD, Coble HD (1991) Interference of common cocklebur (*Xanthium strumarium*) and cotton (*Gossypium hirsutism*). Weed Technol 5:270–278

Cousins R (1985) A simple model relating yield loss to weed density. Ann Appl Biol 107:239–252

Fu R, Ashley RA (2006) Interference of large crabgrass (*Digitaria sanguinalis*), redroot pigweed (*Amaranthus retroflexus*), and hairy galinsoga (*Galinsoga ciliate*) with bell pepper. Weed Sci 54:364–372

Garvey PV, Meyers SL, Monks DW, Coble HD (2013) Influence of Palmer amaranth (*Amaranthus palmeri*) on the critical period of weed control in plasticulture-grown tomato. Weed Technol 27:165–170

Harrison HF, Jackson DM (2010) Response of two sweetpotato cultivars to weed interference. Crop Prot 30:1291–1296

Heap I (2018) The International Survey of Herbicide Resistant Weeds. www.weedscience.org. Accessed: March 28, 2018

Hidayat I, Preston C (1997) Enhanced metabolism of fluazifop acid in a biotype of *Digitaria sanguinalis* resistant to the herbicide fluazifop-p-butyl. Pestic Biochem Phys 57:137–146

Horak MJ, Loughin TM (2000) Growth analysis of four *Amaranthus* species. Weed Sci 48:347–355

Kemble JM (2017) Southeastern U.S. Vegetable Crop Handbook. 18th ed. Lenexa, KS: Farm Journal Media. Pp 93–95

Laforest M, Soufiane B, Simard M, Obeid K, Page E, Nurse RE (2017) Acetyl-CoA carboxylase overexpression in herbicide-resistant large crabgrass (*Digitaria sanguinalis*). Pest Manag Sci 73:2227–2235

Massinga RA, Currie RS, Horak MJ, Boyer J (2001) Interference of Palmer amaranth in corn. Weed Sci 49:202–208

Meyers SL, Jennings KM, Monks DW (2013) Herbicide-based weed management programs for Palmer amaranth (*Amaranthus palmeri*) in sweetpotato. Weed Technol 27:331–340

Meyers SL, Jennings KM, Schultheis JR, Monks DW (2010) Interference of Palmer amaranth (*Amaranthus palmeri*) in sweetpotato. Weed Sci 58:199–203

Monks DW, Schultheis JR (1998) Critical weed-free period for large crabgrass (*Digitaria sanguinalis*) in transplanted watermelon (*Citrullus lanatus*). Weed Sci 46:530–532

Norsworthy JK, Oliveira MJ, Jha P, Malik M, Buckelew JK, Jennings KM, Monks DW (2008) Palmer amaranth and large crabgrass growth with plasticulture-grown bell pepper. Weed Technol 22:296–302

Rodgers JB, Murray DS, Verhalen LM, Claypool PL (1996) Ivyleaf morning-glory (*Ipomoea hederacea*) interference with cotton (*Gossypium hirsutum*). Weed Technol 10:107–114

Schabenberger O, Pierce FJ (2002) Contemporary Statistical Models for the Plant and Soil Sciences. Boca Raton, FL: CRC Press. 738 p

Seem JE, Creamer NG, Monks DW (2003) Critical weed-free period for 'Beauregard' sweetpotato (*Ipomoea batatas*). Weed Technol 17:686–695

[USDA] U.S. Department of Agriculture (2005) United States Standards for Grades of Sweetpotatoes. Washington, DC: U.S. Department of Agriculture. 5 p

[USDA-NASS] U.S. Department of Agriculture-National Agricultural Statistics Service (2017) Quick Stats. https://www.nass.usda.gov. Accessed: May 19, 2018

Volenberg D, Stoltenberg D (2002) Altered acetyl-coenzyme A carboxylase confers resistance to clethodim, fluazifop and sethoxydim in *Setaria faberi* and *Digitaria sanguinalis*. Weed Res 42:342–350

Webster TM (2010) Weed survey—southern states: vegetable, fruit, and nut subsection. Pages 246–257 *in* Proceedings of the Southern Weed Science Society. Vol. 63. Westminster, CO: Southern Weed Science Society

Webster TM, Grey TL (2015) Glyphosate-resistant Palmer amaranth (*Amaranthus palmeri*) morphology, growth, and seed production in Georgia. Weed Sci 63:264–272