Evaluation of 12 Sweetpotato Clones in Coastal South Carolina for Yield and Insect Resistance Using Organic and Conventional Cultural Practices

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SUMMARY. **The yield and insect resistance of 12 sweetpotato (*Ipomoea batatas*) clones grown in two different production systems (organic black plastic mulch and conventional bare ground) were evaluated in 2016 and 2017 in coastal South Carolina. Significant differences in total storage root yield, marketable storage root yield, U.S. No. 1 storage root yield, and percent of U.S. No. 1 storage roots in all trials were found, except for percent of U.S. No. 1 storage roots in 2017 for the organic black plastic mulch trial. In the organic black plastic mulch trials, 'Bonita' and USDA-04-136 consistently produced high marketable yields, whereas 'Ruddy' and USDA-W388 consistently produced the lowest marketable yields. 'Averre', 'Beauregard', 'Covington', and USDA-09-130 exhibited variable performance, with marketable yields among the highest in a single year. For the conventional trials, USDA-04-136 consistently produced high marketable yields, whereas 'Ruddy' and USDA-W-388 consistently produced the lowest marketable yields. 'Averre', 'Bonita', 'Covington', and USDA-09-130 exhibited variable performance, with marketable yields among the highest in a single year. For the organic black plastic mulch, significant differences were detected in the percent of uninjured roots and percent white grub (primarily *Plectris aliena*) damage in 2016 and in wireworm (Elateridae)-cucumber beetle (*Diabrotica*)-flea beetle (*Systena*) severity index (WDS severity index) in 2016 and 2017. USDA-04-136 and USDA-W-388 consistently had the lowest WDS severity index, whereas 'Covington' consistently had the highest WDS severity index. For the conventional trials, significant differences were found among clones in both years for all insect rating variables, except for percent sweetpotato weevil (*Cylas formicarius elegantulus*) damage. 'Ruddy', USDA-04-136, and USDA-W-388 consistently yielded the highest percent of uninjured roots, whereas 'Averre', 'Bonita', SC-1149-19, and USDA-09-130 consistently had the lowest percent of uninjured roots. The research reported here for yield and insect resistance under conventional and organic production systems will be useful for producers in the selection of cultivars suitable for growth in South Carolina.**

Sweetpotato (*I. batatas*) is an important specialty crop in the United States, with more than 150,000 acres harvested in 2019 and valued at more than $725 million [U.S. Department of Agriculture (USDA), National Agricultural Statistics Service (NASS), 2021]. Production of sweetpotato has been increasing over the past 15 years, and consumption is the highest it has been since the 1930s (USDA, 2017). Organic sweetpotato production accounts for 4.1% of organic vegetable production and is valued at more than $77 million annually (USDA, NASS, 2020). There is interest in increasing production for this market because of the potential economic benefits. Boyette Brothers Produce (Wilson, NC), which produces nearly 1% of the total acreage of U.S. organic sweetpotato, has seen a 20% to 25% increase in organic sweetpotato sales over the past few years (Niblock, 2017).

Sweetpotato production in the United States has undergone several periods of differential production because of changes in market demand (USDA, 2017). Sweetpotato was heavily produced before the 1930s, but acreage waned as market demand fell (Kays and Kays, 1998). Acreage under sweetpotato production has been rising since 2004, as it has regained popularity as a health food (Kays, 2005; USDA, 2017). As sweetpotato production has grown, so has the need to look at alternative cultivation methods, such as using drip irrigation and plasticulture, to improve quality and yields and for control of diseases, weeds, and insects. Along with the rise of sweetpotato production acreage, the popularity of certified organic and sustainably produced has grown extensively. For the purposes of this research, organic refers to sweetpotatoes that are grown on USDA "Certified Organic" lands and subject to all regulations found in the National Organic Program (NOP) [USDA, Agricultural Marketing Service (AMS), NOP, 2013] and using fertilizer and pesticide inputs listed on the Organic Material Resources Institute and the National Organic Standards Board general list. One of the primary issues faced by organic sweetpotato production is suppressing weeds without the use of synthetic herbicides. Sweetpotato grown under plastic mulch with drip irrigation resulted in improved weed suppression, and this system has been demonstrated to be a viable alternative to standard bare ground sweetpotato cultivation for organic production (Brown et al., 1998; Duque, 2020; Eguchi et al., 1994; Hochmuth and Howell, 1983; Novak et al., 2007; Nwosisi et al., 2017, 2019; Sideman, 2015; Wees et al., 2015). The increased market demand for organically grown sweetpotatoes can be seen in the growth of acreage in the United States, which doubled over the past decade, whereas conventional sweetpotato

Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.4047	acre(s)	ha	2.4711
29.5735	fl oz	mL	0.0338
0.3048	ft	m	3.2808
0.0929	ft^2	m^2	10.7639
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
0.4536	lb	kg	2.2046
1.1209	lb/acre	$kg \cdot ha^{-1}$	0.8922
0.0254	mil(s)	mm	39.3701
(°F − 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

production grew by only 2% annually over this same period (USDA, NASS, 2009, 2010, 2019, 2020).

Plasticulture, or the use of plastic mulch, may serve to aid in increasing the yield of sweetpotato due to several effects including more efficient water use and its propensity to repel certain insects (Andino and Motsenbocker 2004; Antignus, 2000; Antignus et al., 2001; Necibi et al., 1992; Nwosisi et al., 2017). Although little research has been done to indicate the level of management that can be achieved on subterranean insects important in sweetpotato production, the instances of decreased damage in aboveground crops suggests that sweetpotato may likewise benefit from plasticulture to deter insects. Weed, disease, and insect management options for organic sweetpotato production are limited, making selection of resistant cultivars critical. Many insect pests damage sweetpotato roots in the United States (Cuthbert, 1967; Schalk et al., 1991; Sorensen, 2009); one of the worst of these pests is the wireworm-cucumber beetle-flea beetle (WDS) severity index (Chalfant et al., 1990). This complex of insect pests consists of several species of wireworms (e.g., *Melanotus communis* and *Conoderus* sp.), banded and spotted cucumber beetles (*Diabrotica balteata* and *Diabrotica undecimpunctata howardi*), and flea beetles (*Systena* sp.) (Chalfant et al., 1990; Cuthbert and Davis, 1970). Two species of white grubs (*Plectris aliena* and *Phyllophaga ephilida*), sweetpotato flea beetle (*Chaetocnema confinis*), and sweetpotato weevil (*Cylas formicarius elegantulus*) can cause substantial damage to sweetpotato in the United States (Sorensen, 2009). For insect pests of sweetpotato, host resistance has been demonstrated as an effective management strategy (Collins et al., 1991; Jackson and Bohac, 2006; Jackson et al., 2012; Lawrence et al., 2005). The development and deployment of resistance has been the primary focus of the sweetpotato breeding program at the USDA, Agricultural Research Service (ARS), U.S. Vegetable Laboratory, Charleston, SC (USVL) since its inception more than 50 years ago (Bohac et al., 2000, 2001, 2002; Jackson and Bohac, 2006; Jackson et al., 2010; Jones and Bouwkamp, 1992; Jones et al., 1986; Ryan-Bohac et al., 2006). Therefore, the objective of the research reported here was to evaluate sweetpotato clones (cultivars and insect-resistant breeding lines) for performance under conventional and organic production systems, and to document the species composition and relative abundance of wireworms in the study fields, in Charleston, SC.

Materials and methods

Plant materials. In 2016 and 2017, 12 sweetpotato clones were evaluated in field trials at two locations in Charleston, SC, under two production systems [organic black plastic mulch and conventional bare ground (Table 1)]. All 12 clones were evaluated in both years and in both production systems. All clones have either been released publicly or are advanced selections from sweetpotato breeding programs. Insect-resistant (‘Ruddy’) and -susceptible (SC-1149-19) controls were also included. Vine cuttings (slips) ≈12 inches long produced annually from storage roots for all experiments were cut from plant-nursery beds no more than 3 d before planting. The slips for the plots in the organic fields were derived from cuttings that had been taken from experimental lines and cultivars that had not been treated with any pesticides, hormones, or fertilizers; as per § 205.290(a)(2) of NOP (USDA, AMS, NOP, 2013).

Evaluation of sweetpotato clones using organic black plastic mulch. The organic black plastic mulch trial was conducted at the Clemson University Coastal Research and Education Center in Charleston, SC 29414 (lat. 32°47′34.5″N, long. 80°04′14.1″W). Soils in the organic fields used in this study are primarily Thermo Typic Endoqualfs Yonges Fine Sandy Loam with pH 6.4 to 7.2 and 1.1% to 1.6% organic matter; the fields have been under organic certification for 14 years (USDA, AMS, NOP, 2013). Watermelon (*Citrullus lanatus*) was grown in the study fields preceding each trial. Plots were a single row of 10 plants, and the experiment was arranged in a randomized complete block design with four replications. The beds were fertilized with 75 and 160 lb/acre nitrogen, respectively, for years 2016 and 2017, using 10N–0.9P–6.7K (Nature Safe; Darling Ingredients, Cold Spring, KY) and mineralization was accounted for due to the high sand content of the coastal soils. The 30-inch beds were rough bedded, rototilled, and shaped, and drip tape added at a depth of 2 to 3 inches. The beds were then covered with two layers of black plastic mulch to prevent nutsedge (*Cyperus* sp.) from piercing the mulch layers and opening the beds for establishment of other weeds. Each layer of black plastic mulch was 1.25 mils thick for a combined two-layered thickness of 2.5 mils. The planting date for the organic plots was 8 June 2016 and 7 June 2017. All plots were hand weeded at weekly intervals until canopy closure (≈4 to 6 weeks) and at biweekly intervals thereafter to harvest. The trials were watered to keep the soil at an optimal 20% saturation and 5 cbar soil tension by manually checking the soil moisture level by clumping soil and observing the ability of the soil to adhere to itself. If necessary, the soil in the plots was watered once or twice per week for 1.5 h. After 120 d, the vines on top of the bed were flail mowed as low as possible, the plastic was lifted, and sweetpotatoes dug using a single-row potato digger (Model D-10M; U.S. Small Farm Equipment Co., Worland, WY). Extra care was taken to remove irrigation tapes as the digger moved through the beds.

Conventional bare ground trial. The conventional bare ground trials were conducted at USVL (lat. 32°48′04.6″N, long. 80°03′56.4″W). Soil in these fields was primarily Yonges loamy fine sand (Aeric Paleaquults) with pH 6.0 to 6.4 and less

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Table 1. Flesh and skin color, germplasm source, and origin of 12 sweetpotato clones evaluated using organic black plastic mulch and conventional bare ground production systems in 2016 and 2017.

Clone	Flesh color	Skin color	Germplasm source[z]	Origin
Averre	Orange	Copper	NCSU	North Carolina
Beauregard	Orange	Copper	NCSU	Louisiana (Rolston et al., 1987)
Bonita	Cream	Tan	JFF	Louisiana (LaBonte et al., 2011)
Covington	Orange	Copper	NCSU	North Carolina (Yencho et al., 2008)
Monaco	Orange	Red	NCSU	North Carolina
NC09-122	Orange	Red	NCSU	North Carolina
Ruddy	Orange	Red	USVL	South Carolina (Bohac et al., 2002)
SC-1149-19	Orange	Copper	USVL	South Carolina
USDA-04-136	Orange	Red	USVL	South Carolina
USDA-09-130	Orange	Copper	USVL	South Carolina
USDA-10-721	Orange	Red	USVL	South Carolina
USDA-W-388	Light yellow	Red	USVL	South Carolina

[z] NCSU = North Carolina State University, Raleigh, NC; JFF = Jones Family Farms, Bailey, NC; USVL = U.S. Department of Agriculture, Agricultural Research Service, U.S. Vegetable Laboratory, Charleston, SC.

than 1% organic matter. Corn (*Zea mays*) preceded the trials, and the residue was mowed and disced into the soil before bed formation. Narrow beds (≈15 inches wide) were prepared by forming soil into rows ≈12 inches tall and 40 inches apart. Fertilizer [1000 lb/acre of 4N–3.5P–10K (Nutrien, Saskatoon, SK, Canada)] was incorporated into the soil before bedding. Formed beds were treated with 0.35 lb/acre clomazone (Command 3ME; FMC, Philadelphia, PA) and 1.1 lb/acre napropamide (Devrinol 2-XT; United Phosphorus, King of Prussia, PA). Plots consisted of a single row of 10 plants spaced 1 ft apart in the row, and the experiment was arranged in a randomized complete block design with four replications. The transplanting date was 16 June 2016 and 15 June 2017. When weekly rainfall was not adequate (<1 inch) during the growing season, supplemental overhead irrigation was applied until all plots had received a total of 1 inch. All plots were hand weeded at weekly intervals until canopy closure (≈4 to 6 weeks) and at biweekly intervals thereafter to harvest. At 120 d after planting, plots were mowed with a flail mower to remove foliage and then storage roots were harvested with a single-row potato digger (Model D-10M; U.S. Small Farm Equipment Co.).

WIREWORM SPECIES COMPOSITION AND RELATIVE ABUNDANCE. Species composition and relative abundance of the wireworms in the study fields was assessed in 2016 and 2017 using wheat (*Triticum aestivum*) seed baits (Doane, 1981; Jansson and Lecrone, 1989; Toba and Turner, 1983). In each field, a grid of wheat seed baits was established to uniformly encompass the portion of the field under cultivation. Baits consisted of organically produced wheat seed soaked in aerated water for 36 h before placement in the soil. Bait (50 mL) was then placed in a hole (6 cm diameter, 15 cm deep) at each sampling point, and the hole was then backfilled with soil to ≈2 cm above the soil surface and was marked with a wire flag. Sampling intervals in 2016 were 17 June to 5 July (organic), and 12 to 27 Oct. (conventional). In 2017, the sampling intervals were 16 June to 5 July (organic), and 9 to 30 May (conventional). After the sampling interval, baits and the soil surrounding them (11 cm diameter × 22 cm deep) were removed, placed individually in labeled polyethylene bags, and returned to the laboratory, where they were held at 8 °C until sorting. Each sample was passed through two wire mesh screens (6.5- and 3.5-mm mesh), and the number of wireworms and species of each wireworm was recorded. Species determination was made by use of published taxonomic keys (Day et al., 1971; Quate and Thompson, 1967; Rabb, 1963; Riley and Keaster, 1979). Confirmation of the species determination was made by rearing the wireworms to adulthood. To do this, wireworms were placed individually in transparent 45-mL plastic vials (12 dram, No. 55-12; Thornton Plastics Co., Salt Lake City, UT) with sifted field soil and three seeds of germinated wheat. Wireworms were held at 25 °C in continuous darkness and were transferred to clean vials with fresh soil and wheat seeds weekly until adults (i.e., click beetles) emerged.

DATA ANALYSES. After harvest, storage roots were cured at 85 °F and 85% relative humidity (RH) for 5 d and then stored at 58 °F and 80% RH until roots were further processed for yield estimation and insect damage ratings. Two weeks after curing, storage roots were washed by hand to remove soil and other debris to allow for visual rating of insect damage. To allow storage roots to completely dry after washing, 1 month after harvest storage root yield and insect damage ratings were conducted. The storage roots were graded and weighed according to the following grades: jumbo (>3.5 inches diameter and/or >9 inches long), U.S. No. 1 (1.75–3.5 inches diameter and 3–9 inches long), and canner (1–1.75 inch diameter and 2–9 inches long) (USDA, 2005). For each plot, the number of roots and weight by grade were recorded. Total yield was the summation of U.S. No. 1, canner, jumbo, and cull-grade storage roots. Marketable yield was the summation of U.S. No. 1 roots, canner roots, and jumbo roots. Storage roots were saved and used for generating plant beds for the following year's trials. All individual storage roots were visually rated for insect damage by previously published procedures (Schalk et al., 1991). We calculated the WDS severity index (Cuthbert and Davis, 1971) by averaging the rating given to each root (1 = 1–5 holes or scars; 2 = 6–10 holes or scars; 4 = more than 10 holes or scars). Injury by white grubs (primarily *P. aliena*), sweetpotato flea beetles, and sweetpotato weevils was calculated as the percentage of total roots that had any damage by these insects.

Table 2. Monthly precipitation and mean temperature in Charleston, SC, throughout the growing season of 2016 and 2017, and the 30-year average (1989–2019).

	Precipitation (inches)^z			Mean temp (°F)^z		
Month	2016	2017	30-yr avg^y	2016	2017	30-yr avg
June	3.14	6.47	5.65	82.3	78.4	79.0
July	4.38	8.64	6.53	86.2	82.1	82.1
Aug	3.72	8.17	7.15	83.8	81.6	80.9
Sep	12.27	6.75	6.10	79.8	77.7	76.0
Oct	10.48	3.57	3.75	70.2	69.8	66.9
Overall	33.99	33.57	29.18	80.5	77.9	77.0

^{z}1 inch = 25.4 mm, (°F – 32) ÷ 1.8 = °C.

^{y}The 30-year averages for precipitation and all mean temperatures were compiled from data collected at the National Weather Service Weather Station in Charleston, SC (lat. 32°53′42.6″N, long. 80°01′39.2″W), whereas the 2016 and 2017 precipitation was collected from rain gauges at the U.S. Department of Agriculture, Agricultural Research Service, U.S. Vegetable Laboratory, Charleston, SC (lat. 32°48′04.6″N, long. 80°03′56.4″W).

The percentages of uninjured roots (undamaged by any of the soil insect pests) also were determined for each clone. The data were analyzed as a randomized complete block design with four replications. Data from each experimental trial were subjected to analysis of variance using PROC GLM (SAS version 9.4; SAS Institute, Cary, NC) to test the effect of sweetpotato clone. Clone and year were treated as fixed effects and blocks and appropriate error terms as random effects. When significant year-by-clone interactions existed, data were analyzed and presented by year. Mean comparisons were produced using Fisher's protected least significant difference at the 5% probability level.

Results

The monthly precipitation and mean temperatures for the growing seasons in 2016 and 2017, along with the 30-year averages (1989–2019), are presented (Table 2). Both years were wetter than normal, but in 2016 most of the rainfall was later in the season due to three named Atlantic Ocean tropical storm systems (Hermine, Julia, and Matthew), whereas 2017 had higher rainfall amount but was similar to the normal precipitation pattern for Charleston, SC. In 2016, temperatures were 3.5 °F higher than normal, whereas in 2017 temperatures were close to the 30-year average.

In total, 314 wireworms were collected in the study (Table 3). The southern potato wireworm (*Conoderus falli*), was the most collected species (82%), followed by gulf wireworm [*Conoderus amplicollis* (13%)], peanut wireworm [*Conderus scissus* (4%)], and common wireworm [*M. communis* (1%)]. Southern potato wireworm was the only species present in all four fields; each of the other species was present in two of the four fields. Wireworms occurred in greater density in 2016 study fields (mean = 1.7 wireworms/m^2) than the 2017 study fields (mean = 0.57 wireworms/m^2) across organic black plastic mulch and bare ground fields (two-sample t = 5.9, df = 179, $P \leq 0.0001$).

Clones exhibited significant differences ($P \leq 0.05$) in total yield, marketable yield, U.S. No. 1 yield, and percent of U.S. No. 1 storage roots in both production systems and in both years [data were separated by year to account for the significant year-by-entry interaction ($P \leq 0.001$)], except that no difference in the percent of U.S. No. 1 storage roots was found in 2017 for the organic black plastic mulch trial (Tables 4 and 5). For the 2016 organic black plastic mulch trial (Table 4), total yield in bushels per acre (1 bushel = 50 lb) ranged from 14 bushels/acre ('Ruddy') to 565 bushels/acre ('Bonita'), U.S. No. 1 yield ranged from two bushels/acre (SC-1149-19) to 347 bushels/acre ('Bonita'), and the percent of U.S. No. 1 roots ranged from 9.7% (SC-1149-19) to 62.1% ('Beauregard'). In the 2017 organic black plastic mulch trial (Table 4), total yield ranged from 85 bushels/acre ('Ruddy' and USDA-W-388) to 879 bushels/acre ('Covington'), marketable yield ranged from 80 bushels/acre ('Ruddy') to 779 bushels/acre ('Covington'), and U.S. No. 1 yield ranged from seven bushels/acre (USDA-W-388) to 372 bushels/acre ('Covington'). In the 2016 conventional bare ground trial (Table 5), total yield ranged from 126 bushels/acre ('Ruddy') to 658 bushels/acre (USDA-04-136), marketable yield ranged from 126 bushels/acre ('Ruddy') to 580 bushels/acre (USDA-04-136), U.S. No. 1 yield ranged from 75 bushels/acre ('Ruddy') to 395 bushels/acre (USDA-09-130), and the percent of U.S. No. 1 roots ranged from 46% ('Beauregard') to 85% (USDA-10-721). For the 2017 bare ground trial (Table 5), total yield ranged from 77 bushels/acre (USDA-W-388) to 903 bushels/acre (USDA-04-136), marketable yield ranged from 72 bushels/acre (USDA-W-388) to 651 bushels/acre (USDA-04-136), U.S. No. 1 yield ranged from seven bushels/acre (USDA-W-388) to 260 bushels/acre (USDA-04-136), and the percent of U.S. No. 1 roots ranged from 10% (USDA-W-388) to 61% ('Monaco'). In the organic black

Table 3. Sampling information and summary statistics for wireworms collected under organic black plastic mulch (BPM) and conventional bare ground sweetpotato production in Charleston, SC.

Yr	Field	Area sampled (m^2)^z	Bait samples (no.)	Total wireworms	Southern potato wireworm	Gulf wireworm	Peanut wireworm	Common wireworm	Mean wireworms	SE	Range
				(no. wireworms)							
2016	BPM	576	16	21	18	0	0	3	1.3	0.38	0–4
2016	Bare ground	5400	125	220	184	36	0	0	1.8	0.20	0–12
2017	BPM	1728	39	34	23	4	6	1	0.90	0.17	0–3
2017	Bare ground	7250	89	39	32	0	7	0	0.43	0.064	0–2

^{z}1 m^2 = 10.7639 ft^2.

Table 4. Total and marketable yield, U.S. No. 1 yield, and percent U.S. No. 1 grade storage roots for 12 sweetpotato clones grown in 2 years in Charleston, SC, using organic black plastic mulch production practices.

		Total yield (bushels/acre)[y]		Marketable yield (bushels/acre)[x]		U.S. No. 1 yield (bushels/acre)		U.S. No. 1 yield (%)[w]	
Clone[z]	Skin/flesh color	2016	2017	2016	2017	2016	2017	2016	2017
Averre	Copper/orange	330 bc[v]	654 a–c	252 b	626 a	72 cd	229 a–c	28.4 b–d	36.5
Beauregard	Copper/orange	550 a	291 d–f	550 a	233 de	342 ab	133 c–f	62.1 a	57.0
Bonita	Tan/white	565 a	720 ab	565 a	620 ab	347 a	342 ab	61.4 a	55.2
Covington	Copper/orange	297 c	879 a	222 b	779 a	113 c	372 a	51.1 ab	42.0
Monaco	Red/orange	238 c	340 d–f	202 bc	320 c–e	84 cd	185 b–e	41.8 a–c	57.9
NC09-122	Red/orange	181 cd	380 c–e	175 b–d	343 b–d	77 cd	166 c–f	43.8 ab	48.3
Ruddy	Red/orange	14 d	85 f	14 d	80 e	3 d	20 ef	22.3 b–d	24.9
SC-1149-19	Copper/orange	22 d	135 ef	22 cd	130 de	2 d	55 d–f	9.7 d	42.6
USDA-04-136	Red/orange	515 ab	554 b–d	515 a	514 a–c	269 ab	198 b–d	52.3 ab	38.5
USDA-09-130	Copper/orange	521 a	366 c–f	487 a	314 c–e	240 b	151 c–f	49.3 ab	48.1
USDA-10-721	Red/orange	22 d	169 ef	22 cd	135 de	5 d	70 c–d	22.1 b–d	52.1
USDA-W-388	Red/light yellow	34 d	85 f	34 cd	83 e	4 d	7 f	11.8 cd	8.1

[z] NC designation indicates advanced selection from the North Carolina State University Sweetpotato Breeding Program, Raleigh, NC; USDA designation indicates advanced selection from the U.S. Department of Agriculture, Agricultural Research Service, U.S. Vegetable Laboratory Sweetpotato Breeding Program, Charleston, SC.

[y] Total yield was the summation of U.S. No. 1, canner, jumbo, and cull-grade storage roots; 1 50-lb (22.7 kg) bushel/acre = 56.0426 kg·ha^{-1}.

[x] Marketable yield = U.S. No. 1 roots + canner roots + jumbo roots. U.S. No. 1 = roots 2–3.5 inches diameter and 3–9 inches long; canner = roots 1–2 inches diameter and 2–7 inches long; jumbo = roots larger than either of the other grades, but marketable; 1 inch = 2.54 cm.

[w] The percent of marketable roots that were U.S. No. 1.

[v] Within a column, means followed by the same letter are not significantly different at $P \leq 0.05$ (n = 4) using Fisher's protected least significant difference test.

plastic mulch trials, 'Bonita' and USDA-04-136 consistently produced high marketable yields, whereas 'Ruddy' and USDA-W388 consistently produced the lowest marketable yields. 'Averre', 'Beauregard', 'Covington', and USDA-09-130 exhibited variable performance, with marketable yields among the highest in a single year. For the conventional trials, USDA-04-136 consistently produced high marketable yields, whereas 'Ruddy' and USDA-W-388 consistently produced the lowest marketable yields. 'Averre', 'Bonita', 'Covington', and USDA-09-130 exhibited variable performance, with marketable yields among the highest in a single year.

For evaluation of insect resistance of clones grown on organic black plastic mulch, significant differences ($P \leq 0.05$) were detected in the percent of uninjured roots and percent grub damage in 2016 and in WDS severity index in 2016 and 2017 (Table 6). In 2016, the percent of uninjured roots ranged from 21% ('Ruddy') to 90% (USDA-W-388), WDS severity index ranged from 0.146 (USDA-10–721) to 1.296 ('Averre'), and the percent grub damage ranged from 0.0% (four clones) to 18.9% ('Bonita'), whereas in 2017 the WDS severity index ranged from 0.262 (USDA-W-388) to 1.535

Table 5. Total and marketable yield, U.S. No.1 yield, and percent U.S. No. 1 grade storage roots for 12 sweetpotato clones grown in 2 years in Charleston, SC, using conventional production practices.

		Total yield (bushels/acre)[y]		Marketable yield (bushels/acre)[x]		U.S. No. 1 yield (bushels/acre)		U.S. No. 1 yield (%)[w]	
Clone[z]	Skin/flesh color	2016	2017	2016	2017	2016	2017	2016	2017
Averre	Copper/orange	419 cd[v]	553 b	325 c–e	521 ab	169 c–e	310 a	52.1 cd	59.5 ab
Beauregard	Copper/orange	464 b–d	289 cd	289 c–e	267 d	134 de	157 b–d	46.3 d	58.6 ab
Bonita	Tan/white	566 a–c	102 de	537 ab	99 e	334 ab	49 de	62.1 a–d	49.7 a–c
Covington	Copper/orange	457 b–d	521 b	241 d–f	450 bc	123 de	101 c–e	51.1 cd	42.0 a–d
Monaco	Red/orange	456 b–d	427 bc	395 b–d	405 b–d	285 a–c	250 ab	72.2 a–c	61.6 a
NC09-122	Red/orange	365 de	302 c	356 c–e	302 cd	218 b–d	185 bc	61.1 b–d	61.1 a
Ruddy	Red/orange	126 f	106 de	126 f	106 e	75 e	37 e	59.5 b–d	34.5 cd
SC-1149-19	Copper/orange	255 ef	89 de	248 d–f	88 e	139 de	24 e	55.9 b–d	27.0 de
USDA-04-136	Red/orange	658 a	903 a	580 a	651 a	356 a	260 ab	61.4 b–d	40.0 b–d
USDA-09-130	Copper/orange	584 ab	334 c	518 ab	316 cd	395 a	159 b–d	76.2 ab	50.2 a–c
USDA-10-721	Red/orange	432 cd	107 de	412 bc	101 e	352 a	35 e	85.5 a	34.5 cd
USDA-W-388	Red/light yellow	219 ef	77 de	204 ef	72 e	122 de	7 e	59.6 b–d	10.2 e

[z] NC designation indicates advanced selection from the North Carolina State University Sweetpotato Breeding Program, Raleigh, NC; USDA designation indicates advanced selection from the U.S. Department of Agriculture, Agricultural Research Service, U.S. Vegetable Laboratory Sweetpotato Breeding Program, Charleston, SC.

[y] Total yield was the summation of U.S. No. 1, canner, jumbo, and cull-grade storage roots; 1 50-lb (22.7 kg) bushel/acre = 56.0426 kg·ha^{-1}.

[x] Marketable yield = U.S. No. 1 roots + canner roots + jumbo roots. U.S. No. 1 = roots 2–3.5 inches diameter and 3–9 inches long; canner = roots 1–2 inches diameter and 2–7 inches long; jumbo = roots larger than either of the other grades, but marketable; 1 inch = 2.54 cm.

[w] The percent of marketable roots that were U.S. No. 1.

[v] Within a column, means followed by the same letter are not significantly different at $P \leq 0.05$ (n = 4) using Fisher's protected least significant difference test.

Table 6. Insect damage ratings for 12 sweetpotato clones grown in 2 years in Charleston, SC, using organic black plastic mulch production practices.

		Uninjured roots (%)[y]		WDS severity index (0–4)[x]		Sweetpotato flea beetle damage (%)		Grub damage (%)[w]		Sweetpotato weevil damage (%)	
Clone[z]	Skin/flesh color	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017
Averre	Copper/orange	30.5 de[v]	58.7	1.296 e	0.545 a–c	0.7	0.0	5.5 ab	2.4	0.0	0.0
Beauregard	Copper/orange	45.5 c–e	57.0	0.768 cd	0.635 a–d	1.9	0.0	11.0 bc	2.5	0.0	0.0
Bonita	Tan/white	55.4 b–d	53.6	0.684 b–d	0.718 a–d	3.7	0.0	18.9 c	2.5	0.0	0.0
Covington	Copper/orange	32.2 de	42.0	1.292 e	0.999 b–e	0.0	0.0	0.4 a	0.0	0.0	0.0
Monaco	Red/orange	76.3 ab	31.5	0.279 ab	1.535 e	1.7	0.8	3.6 ab	1.6	0.0	0.0
NC09-122	Red/orange	69.9 a–c	37.6	0.324 ab	1.224 de	0.0	0.0	3.0 ab	7.9	0.0	0.0
Ruddy	Red/orange	21.0 e	65.2	0.959 de	0.390 ab	0.0	0.0	0.0 a	3.1	0.0	0.0
SC-1149-19	Copper/orange	72.0 a–c	43.1	0.280 ab	0.963 b–e	0.0	0.0	0.0 a	4.2	0.0	0.0
USDA-04-136	Red/orange	73.6 ab	55.0	0.310 ab	0.542 a–c	0.5	0.0	7.0 ab	0.4	0.0	0.0
USDA-09-130	Copper/orange	63.8 a–c	40.9	0.487 a–c	1.101 c–e	0.3	0.0	1.5 ab	2.3	0.0	0.0
USDA-10-721	Red/orange	85.4 a	58.6	0.146 a	0.687 a–d	0.0	0.0	0.0 a	3.6	0.0	0.0
USDA-W-388	Red/light yellow	89.6 a	74.8	0.167 a	0.262 a	0.0	0.0	0.0 a	0.7	0.0	0.0

[z] NC designation indicates advanced selection from the North Carolina State University Sweetpotato Breeding Program, Raleigh, NC; USDA designation indicates advanced selection from the U.S. Department of Agriculture, Agricultural Research Service, U.S. Vegetable Laboratory Sweetpotato Breeding Program, Charleston, SC.

[y] The percent of roots that were free of insect damage.

[x] Wireworm-cucumber beetle-flea beetle severity index (WDS severity index): 1 = 1–5 scars, 2 = 6–10 scars, and 4 = >10 scars, averaged overall roots. Minimum score = 0.0 and maximum score = 4.0. A higher value indicates more damage occurred on the roots.

[w] The percent damaged caused by primarily white grubs.

[v] Within a column, means followed by the same letter are not significantly different at $P \leq 0.05$ (n = 4) using Fisher's protected least significance difference test.

('Monaco'). For the conventional bare ground trials (Table 7), significant differences ($P \leq 0.05$) were found among clones in both years for all insect rating variables, except for the percent sweetpotato weevil damage. In 2016, all the roots from 'Averre' had insect damage, whereas 58% of USDA-W-388 roots had insect damage. For 2017, 'Bonita' had the highest number of insect-damaged roots, whereas 'Ruddy' had only 5% insect-damaged roots. WDS severity index was higher in 2016 than in 2017 and ranged from 0.407 (USDA-W-388) to 2.864 ('Averre') and 0.148 (USDA-W-388) to 1.828 ('Bonita'), respectively. The lowest percent of sweetpotato flea beetle damage occurred on roots of NC09-122 in both years, whereas the highest percent occurred on roots of USDA-09-130 (20%) in 2016 and on roots of 'Bonita' (34%) in 2017. Grub damage was highest on 'Averre' (47%) and SC-1149-19 (23%) and the lowest on 'Bonita' (0%) in both years. 'Ruddy', USDA-04-136, and USDA-W-388 consistently yielded the highest percent of uninjured roots, whereas 'Averre', 'Bonita', SC-1149-19, and USDA-09-130 consistently had the lo-

Table 7. Insect damage ratings for 12 sweetpotato clones grown in 2 years in Charleston, SC using conventional production practices.

		Uninjured roots (%)[y]		WDS severity index (0–4)[x]		Sweetpotato flea beetle damage (%)		Grub damage (%)[w]		Sweetpotato weevil damage (%)	
Clone[z]	Skin/flesh color	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017
Averre	Copper/orange	0.0 d[v]	23.9 f	2.864 f	1.328 ef	14.5 cd	18.3 bc	46.6 c	12.7 bc	0.0	8.6
Beauregard	Copper/orange	21.3 c	29.4 ef	1.720 bc	0.894 c–e	13.0 b–d	19.9 cd	4.5 ab	0.7 a	0.0	7.8
Bonita	Tan/white	2.9 d	19.7 f	2.616 ef	1.828 f	17.0 cd	33.6 de	0.0 a	0.0 a	0.0	1.2
Covington	Copper/orange	1.8 d	44.4 de	2.775 ef	0.587 b–d	2.2 ab	4.7 ab	2.8 ab	4.3 ab	0.5	7.6
Monaco	Red/orange	40.2 b	64.4 cd	0.929 a	0.380 a–c	11.1 a–d	12.8 a–c	0.8 ab	7.0 ab	0.0	3.2
NC09-122	Red/orange	11.7 cd	75.5 a–c	1.691 b	1.224 e	0.7 a	0.0 a	13.3 b	7.9 ab	2.6	0.0
Ruddy	Red/orange	39.6 b	95.0 a	0.763 a	0.043 a	3.1 ab	1.7 a	2.3 ab	0.0 a	0.0	0.0
SC-1149-19	Copper/orange	13.2 cd	28.3 ef	2.228 b–e	0.909 de	31.7 e	39.1 e	6.0 ab	23.1 c	0.0	0.6
USDA-04-136	Red/orange	38.2 b	74.2 bc	0.977 a	0.187 ab	8.6 a–d	9.4 a–c	0.0 a	0.2 a	0.0	3.2
USDA-09-130	Copper/orange	8.6 cd	33.6 ef	1.776 b–d	1.143 e	19.7 d	11.7 a–c	5.5 ab	3.9 ab	0.0	2.4
USDA-10-721	Red/orange	4.0 d	59.1 cd	2.293 d–f	0.391 a–d	7.5 a–c	0.7 a	0.0 a	3.5 ab	0.0	0.1
USDA-W-388	Red/light yellow	58.2 a	80.5 ab	0.407 a	0.148 ab	2.1 ab	3.8 ab	2.3 ab	1.3 ab	0.0	0.0

[z] NC designation indicates advanced selection from the North Carolina State University Sweetpotato Breeding Program, Raleigh, NC; USDA designation indicates advanced selection from the U.S. Department of Agriculture, Agricultural Research Service, U.S. Vegetable Laboratory Sweetpotato Breeding Program, Charleston, SC.

[y] The percent of roots that were free of insect damage.

[x] Wireworm-cucumber beetle-flea beetle severity index (WDS severity index): 1 = 1–5 scars, 2 = 6–10 scars, and 4 = >10 scars, averaged overall roots. Minimum score = 0.0 and maximum score = 4.0. A higher value indicates more damage occurred on the roots.

[w] The percent damaged caused by primarily white grubs.

[v] Within a column, means followed by the same letter are not significantly different at $P \leq 0.05$ (n = four replicates) using Fisher's protected least significant difference test.

west percent of uninjured roots. NC09-122 and USDA-10-721 exhibited variable performance, with large differences between years for all insect variables rated. 'Monaco', 'Ruddy', USDA-04-136, and USDA-W-388 exhibited the lowest levels of insect damage across all traits measured, whereas 'Averre' was the most damaged.

Discussion

Over the past 6 years, the total yield of conventionally produced sweetpotatoes in the United States has ranged from 19,000 lb/acre (380 bushels/acre) in 2018 to 22,400 lb/acre (448 bushels/acre) in 2017 (USDA, NASS, 2021). The total yield per acre across all clones in our study was lower than the national average: 13,500 lb/acre (270 bushels/acre) in 2016 and 13,900 lb/acre (278 bushels/acre) in 2017. The total yield of 'Averre', 'Beauregard', 'Bonita', 'Covington', 'Monaco', NC09-122, USDA-04-136, and USDA-09-130 are within the range of the national average for 2014–19 regardless of production system. The average total yield of sweetpotato cultivars grown in New Hampshire under black plastic mulch in 2008, 2009, 2010, and 2013 ranged from 274 to 503 bushels/acre and the overall average was 375 bushels/acre (Sideman, 2015). For cultivars grown on black plastic mulch in Canada in 2011 ($n = 5$) and 2012 ($n = 15$), total yield averaged 371 bushels/acre, marketable yield averaged 284 bushels/acre, and yield of U.S. No. 1 storage roots averaged 109 bushels/acre (Wees et al., 2015). Nwosisi et al. (2017) evaluated performance of 14 cultivars grown under various mulches in Tennessee in 2016 and total yield ranged from 143 to 785 bushels/acre. In 2 years of trials with sweetpotato grown under black plastic mulch in Pennsylvania, total marketable yield ranged from 82 to 706 bushels/acre and 321 to 433 bushels/acre, respectively (Duque, 2020). Average total yield for clones in our study grown under organic black plastic mulch was lower in 2016 and similar in 2017 to other studies (Brown et al., 1998; Duque, 2020; Nwosisi et al., 2017; Sideman, 2015; Wees et al., 2015). We observed similar trends as Duque (2020) with respect to variability in marketable yield depending on year. The lower yields we observed are attributed to the inclusion of advanced selections from the sweetpotato breeding program at USVL. Jackson (2007) noted that there is a relationship between yields and insect damage that should be considered when interpreting results with the resistant material. However, if total yield, marketable yield, and yield of U.S. No. 1 grade storage roots are compared for 'Beauregard' and 'Covington', the two most widely grown cultivars in the United States, our results are comparable to other studies (Duque, 2020; Jackson and Bohac, 2006; Jackson and Harrison, 2013; Jackson et al., 2012; Nwosisi et al., 2017; Sideman, 2015; Wees et al., 2015).

We found that wireworm species composition and densities varied somewhat in our study fields. Such field-to-field variation is not surprising, and may be due to several factors, including localized climatic conditions, cropping history, insecticide usage, and soil factors that differentially influence click beetle oviposition and survival of wireworms (Chalfant et al., 1990; Day et al., 1971; Hoffman, 2007; Willis et al., 2010). The four species that we collected have been previously reported as sweetpotato pests in the southern United States (Chalfant et al., 1990; Day et al., 1971; Deen and Cuthbert, 1955). We found significant differences in insect damage among clones regardless of production system. It appears that wireworm densities did not consistently reflect WDS severity index or damage to sweetpotato roots. This may be, in part, because *Diabrotica* and *Systena* densities were not recorded.

The insect damage that we observed can be compared with other studies (Jackson and Bohac, 2006; Jackson and Harrison, 2013; Jackson et al., 2012), but only regarding conventional bare ground plots. For more than a decade, studies conducted in Charleston, SC, have demonstrated a high level of resistance in 'Ruddy' to all insect pests, as evidenced by the low percentage of roots injured (Jackson et al., 2012). Our results are similar to previous studies (Jackson and Harrison, 2013; Jackson et al., 2012) for 'Ruddy' in 2017, with greater insect damage observed in 2016. This could be due to variability in insect pressure, especially the WDS complex, between years as we observed, and as has been reported (Jackson et al., 2012). In the case of 'Beauregard' and 'Covington', our results are comparable to Jackson and Bohac (2006), Jackson and Harrison (2013), and Jackson et al. (2012). Although the focus of this study was not to determine the effect of black plastic mulch on subterranean insects, our results indicated a potential effect in reducing total insect damage. For example, 'Averre', 'Beauregard', 'Bonita', and USDA-09-130 have consistently shown insect resistance comparable to SC-1149-19 (susceptible control) over multiple years of evaluation in conventional bare ground trials conducting in the USVL sweetpotato breeding program (data not shown). These clones performed as expected in our study on the bare ground trials, but there was substantially less root damage from insects when grown under organic black plastic mulch in both years. Jackson and Harrison (2013) indicated that 'Bonita' was comparable to SC-1149-19, which is a susceptible control for the commonly seen sweetpotato pests in the United States. This trend was more pronounced in 2016 when wireworm densities and overall insect damage were greater, as indicated by the performance of our resistant ('Ruddy') and susceptible (SC-1149-19) controls, which showed much higher damage than seen in previous studies (Jackson and Harrison, 2013; Jackson et al., 2012). It appears that using black plastic mulch may be a potential nonchemical management option for control of sweetpotato insect pests, especially when combined with host resistance. Future studies should be designed to investigate the effect of plastic mulches on subterranean insects in sweetpotato.

The effect of plastic mulch on insect pests has been infrequently studied, and much of this work has addressed insects that live and feed on aboveground plant tissues (Csizinszky et al., 1995; Greer and Dole, 2003; Kring and Schuster, 1992). To our knowledge, our study documents the effect of organic black plastic mulch production on insect damage in sweetpotato and is lacking from the literature. We also posit that black plastic mulch offers a potential sustainable method for the management of soil-borne insects, such as wireworms, sweetpotato flea beetles, and grubs. Use of plastic mulches in yam led to a significant reduction in damage to tubers by yam beetles (*Heteroligus* sp.), a subterranean pest (Tobih and Okonmah, 2009). Captures of predaceous carabid beetles (Carabidae) were generally reduced when black plastic mulch was used for groundcover management in an apple (*Malus* ×*domestica*) orchard, although it is not clear if this was due to effects on the subterranean larvae or the adults (beetles) that live aboveground and were the life stage monitored (Miñarro and Dapena, 2003). The mechanism(s) causing reduced wireworm damage to sweetpotatoes under black plastic mulch production is not known, but may be due to increased sub-surface soil temperatures that repel wireworms to cooler soil that is deeper than the storage roots (Villani and Wright, 1990).

Although further research needs to be carried out, it appears that plastic mulch may deter subterranean insects. In addition, considering that most of the clones included in this study are from the USVL sweetpotato breeding program, it is critical to test potential germplasm on plastic mulch in multiple seasons, as we observed significant differences in yield depending on year. Overall, the results of this study show that black plastic mulch is a viable production system for organic sweetpotato in South Carolina, as well as other southern states in the United States. We recommend 'Averre', 'Beauregard', 'Covington', USDA-04-136, and USDA-09-130 as orange-fleshed clones and 'Bonita' as a white-fleshed clone that produce consistently high yields on organic black plastic mulch, and 'Averre', 'Beauregard', 'Covington', 'Monaco', NC09-122, USDA-04-136, and USDA-09-130 in conventional production. In conventional systems, 'Monaco' has the added benefit of providing insect resistance, which is lacking in commercially produced sweetpotato cultivars. The use of black plastic mulch did increase the overall undamaged storage roots due to insect pests and suggests that increases in marketable yields may be possible. We did not cull storage roots based on insect damage in our study, but we suggest that further research is needed in this area. The overall number of storage roots damaged by insect pests was lower in the study that used black plastic mulch, suggesting that increases in marketable yields may be possible. Last, we suggest that follow-up studies are undertaken on economic analysis to further guide and inform producers about the economic benefits of modifying current practice to include black plastic mulch, which will require extra labor costs to manage.

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