ABSTRACT

WOODARD, ALYSSA JANE. Assessment of Sweetpotato Clones and Stem Cutting Planting Orientations in Organic Sweetpotato Production. (Under the direction of Drs. Jonathan Schultheis and David Suchoff).

In North Carolina (NC), organic sweetpotato production has more than doubled in area harvested from 2011 to 2019. However, research based production information has not matched this growing market. Consequently, information to help growers make research-based decisions regarding best practices for organic sweetpotato yield and quality is limited. Therefore we conducted two studies aimed to determine optimal management practices that address the needs of organic sweetpotato producers.

In the first study, we conducted on-farm field trials during the 2020 and 2021 growing seasons to evaluate 13 sweetpotato clones for their fit and productivity in an organic production system. Data collected included vine and internode measurements, growth habit ratings, and yield. In addition, roots were cured and stored for eight months following harvest. Roots were sampled throughout this time to observe changes to starch and sugar composition during curing and throughout storage. Findings from this study indicate that the majority of clones had a moderate to spreading growth habit, however, ‘Monaco’ and ‘NC 10-0433’ had more upright growth, with short internodes and the shortest vine lengths. Clones with this architecture may be of particular interest for weed management strategies in organic production systems. Many clones yielded statistically similar to ‘Covington,’ the NC standard, however, some clones yielded as low as 52% to 65% of ‘Covington.’ Delaying harvest from ~105 to ~126 days after planting significantly increased yield for some clones, with more clones seeing this benefit in 2020 than 2021. Carbohydrate contents were affected by curing and long term storage, with clones differing in both carbohydrate composition and their responses to curing and storage. These findings indicate potential differences in eating quality and storage stability.

The second study evaluated the planting orientations of sweetpotato stem cuttings. ‘Monaco’ stem cuttings were planted with different orientations using a standard transplanter (vertical), a standard transplanter with a sleeve attachment (portion of cutting horizontal), and a horizontal transplanter. In addition, two stem cutting lengths (25 cm and 38 cm) and two harvest times (~108 days after planting and ~126 days after planting) were investigated. In 2020, marketable yields were highest when planted horizontally, lowest when planted vertically, and intermediate with the sleeve attachment. Marketable yields were 16% higher when planted horizontally as compared to vertical. However, in 2021, there were no significant differences in marketable yield when comparing planting orientations. A significant main effect of orientation influenced USDA No. 1 yields, with yields of the horizontal treatment averaging 18% higher than the vertical treatment. Regardless of planting orientation, delaying harvest until ~126 days after planting is recommended to increase yields for ‘Monaco.’ In addition, No. 1 roots from the horizontal orientation were longer than the sleeve or vertical orientations, by 1.7 cm and 1.9 cm, respectively. Results of this study suggest shifting production practices to use horizontal transplanters could increase sweetpotato crop yields and improve land use efficiency.

Assessment of Sweetpotato Clones and Stem Cutting Planting Orientations in Organic Sweetpotato Production

by
Alyssa Jane Woodard

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APPROVED BY:

Dr. Jonathan R. Schultheis
Committee Co-Chair

Dr. David H. Suchoff
Committee Co-Chair

Dr. Alex L. Woodley

Dr. Katherine M. Jennings

DEDICATION

To my Mom-Mom. You were a blessing in my life. I miss you more than words can describe.

BIOGRAPHY

Alyssa Jane Woodard was born and raised in Abington, Pennsylvania. Growing up, she enjoyed spending countless hours playing outside, where she developed an interest in nature, particularly plants. During her undergraduate degree, she joined Dr. Rachel Spigler's evolutionary ecology lab, and her experiences there shaped her love for plant science and field research. Moreover, a summer urban agriculture internship during her undergraduate studies introduced her to small-scale organic production and helped guide her towards pursuing a path in horticultural science. Upon graduating from Temple University with a degree in Biology and a minor in Sustainable Food Systems, she completed a research internship at the Rodale Institute. Her time spent there assisting with various organic agriculture studies further reinforced her interest in sustainable agriculture research. In 2019 she moved to Raleigh to join Dr. Chris Reberg-Horton's team at NCSU, working primarily on breeding improved cover crops for the Southeast US. From there, she started her graduate program with Drs. David Suchoff and Jonathan Schultheis.

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CHAPTER ONE

Evaluation of Sweetpotato Clones Grown in an Organic Production System

ABSTRACT

Sweetpotato [*Ipomoea batatas* (L.) Lam.] is one of North Carolina’s most important organic commodity crops and is partially responsible for the state’s continued increase in organic sales. Organic systems require unique management practices to ensure continued sustainability while meeting certification requirements. However, limited research-backed grower recommendations exist that are tailored to organic systems. To address this, we conducted on-farm field studies in Nash County during the 2020 and 2021 growing seasons to evaluate 13 sweetpotato clones for their fit and productivity in an organic system. Clones were evaluated for vine growth habit and were evaluated for yield early and late in the season (105 and 126 days after planting, respectively). In addition, roots from each clone were sampled throughout 8 months of storage to observe changes to carbohydrate composition after curing and throughout storage. In both years most varieties had similar yields to ‘Covington’, which is the NC standard. Yield increases were observed for some clones when harvest was delayed, with more clones seeing this benefit in 2020 than 2021. The majority of clones had a moderate to spreading growth habit, however, ‘Monaco’ and ‘NC 10-0433’ had more upright growth with short internodes and the shortest vine lengths. This plant architecture is predicted to contribute to the management of improved weed suppression and weed tolerance and may be a potential tool to include in weed management strategies for organic systems. Carbohydrate contents were affected by curing and long term storage, with clones differing both in carbohydrate composition and their responses to curing and storage.

INTRODUCTION

Sweetpotatoes [*Ipomoea batatas* (L.) Lam.] are an important crop globally, with annual global production averaging over 92 million metric tons from 2010 through 2019 (FAOSTAT, 2022). As of 2020, the United States was the 7th top country for sweetpotato production (FAOSTAT, 2022). Within the United States, North Carolina (NC) is the largest producer, harvesting over 42,300 hectares and producing over 831 million kg in 2021, which was approximately 68.6% of the total area harvested and 63.5% of the crop in the US that year (USDA NASS, 2022a).

In the United States, in 2011, total organic crop sales were valued at $2.2 billion (USDA NASS, 2012). The organic food industry has seen rapid growth in recent years, and by 2019, organic crop sales were valued over $5.7 billion (USDA NASS, 2020). This growth has been mirrored in NC. In 2011, total organic crop sales were valued at $12.1 million; by 2019, sales were valued over $65.4 million (USDA NASS, 2012, 2020). This increase in sales of organic products is most likely tied to an increasing amount of certified organic land. In 2011, NC reported 3,900 ha for all field crops (USDA NASS, 2012). By 2019, this value increased to 15,700 ha (USDA NASS, 2020). However, organic sweetpotato production makes up only a fraction of the NC sweetpotato industry. In 2019, 1,400 ha of organic sweetpotatoes were harvested, representing only 3.5% of NC’s total sweetpotato production area (39,500 ha; USDA NASS, 2020).

Timing of sweetpotato harvest is typically determined by exposing representative hills and evaluating the size of the roots. Since sweetpotato growth is indeterminate, delaying harvest can increase yields, given favorable environmental conditions (USDA, 2016). Growers want enough growth such that the majority of roots fall into the No. 1 grade (roots 4.4 cm to 8.9 cm in diameter and 7.6 cm to 22.9 cm in length; USDA, 2005), but delaying harvest too late can result in oversized roots, which fall into a less profitable grade. The rate at which roots expand differs depending on cultivar (Lowe and Wilson, 1974a, 1974b) and environmental conditions (Arancibia et al., 2014; Hartman and Gaylord, 1943; Kays, 1985; Reynolds et al., 1994). Extension publications categorize clones as early (90 to 100 DAP), mid (101 to 115 DAP) and late season (>115 DAP; Jennings et al., 2019). For example, to optimize the yield of No. 1 roots, 'Monaco' is recommended to be harvested between 115 and 140 DAP, whereas 'Beauregard' and 'Covington' can be harvested between 100 and 120 DAP (Yencho and Pecota, 2022b). Two harvests, early (~100 DAP) and late (~120 DAP) can give a better comparison of yield potential of clones, which may size at different rates.

Research tailored to organic sweetpotato systems have been limited. A few studies have investigated the incorporation of winter cover crops into organic sweetpotato systems (Hahn, 2020; Pellegrino et al., 2021; Treadwell et al., 2008). Recent organic variety trials have looked into sweetpotatoes grown on plastic (Wadl et al., 2022) or using various organic mulches (Nwosisi et al., 2017, 2019); neither of which reflect the typical organic management practices in NC. Therefore, we evaluated 13 sweetpotato clones grown under standard NC organic practices to determine their fit and productivity in the system.

Sweetpotato clones with upright growth habits may have higher tolerance to weeds than clones with spreading vines (Chaudhari et al. 2020; Harrison and Jackson, 2011; La Bonte et al., 1999). It is proposed that clones with this growth habit could more effectively shade weeds due to a dense canopy with greater height early in the season compared to clones with a spreading morphology (Harrison and Jackson, 2011). In addition, it is speculated that the reduced rate of canopy expansion of upright clones can be beneficial to weed management by extending the period in which growers can cultivate, since the vines take longer to grow between rows compared to spreading vines (Harrison and Jackson, 2011; Smith et al., 2022). Thus, with heavy reliance on repeated cultivation for weed management in organic sweetpotato, there is interest in using upright clones as one strategy to improve weed management for the crop.

Additionally, we investigated differences in carbohydrates within and among clones after curing and storage. Carbohydrates, including starch, sucrose, fructose, and glucose are important components of sweetpotato storage roots. In fact, starch accounts for 65% to 70% of root dry weight (Padmaja, 2009). Carbohydrates contribute to the flavor profile, eating and processing quality, and texture of roots (Kays et al., 2005; Kitahara et al., 2017; Takahata et al., 1995). Namely, the sucrose, glucose, and fructose content in raw roots is strongly correlated with the sugars present in cooked roots (Lewthwaite et al., 1997). In addition, during cooking, amylase enzymes mediate starch hydrolysis, forming maltose, a key sugar contributing to the flavor profile of cooked roots (Morrison et al., 1993). The diversity of starch and sugar content among clones has been well established (Kays et al., 2005; Krochmal-Marczak et al., 2020; Morrison et al., 1993; Nabubya et al., 2017; Zhang et al., 2002).

Following harvest, sweetpotato roots are typically held at 29°C and 85% to 90% relative moisture for three to five days, in a process known as curing. This curing process aids in wound healing, which reduces moisture loss and infection, and sets the skin (Edmunds et al., 2008). In addition, chemical changes occur during the curing process, which improve the culinary characteristics of the sweetpotatoes (Edmunds et al., 2008), including developing the flavor profile and creating a moist mouthfeel (Padmaja, 2009). Generally, the curing process reduces starch content and increases sugars (Picha, 1987; Walter and Hoover, 1984).

Sweetpotato root quality needs to be maintained during storage until the subsequent season’s crop is harvested in order to fit into the NC production system. Throughout storage, roots continue to respire; starches are converted into sugars, which are oxidized to provide energy for the cells. This loss of dry matter can cause pithiness, or air pockets in the root tissue, as the intercellular space expands, which reduces root quality (Truong et al., 2018). Although generally starch content decreases and sugars increase during storage, there is evidence of cultivar-dependent responses, including differences in the rates of change or deviations from this generalized response entirely (Picha, 1987; Walter and Hoover, 1984; Zhang et al., 2002). The knowledge of cultivar-dependent responses invites study of each new clone, thus justifying the current study.

Near-infrared spectroscopy (NIRS) has been shown to be a reliable method to quantify sweetpotato root starch (Diaz et al., 2014; Katayama et al., 1996; Lebot et al., 2009; Lu et al., 2006; Tumwegamire et al., 2011) and sugar levels (Katayama et al., 1996; Lebot et al., 2009; Tumwegamire et al., 2011). It is a favorable method compared to chemical assays because it allows for effective rapid evaluation of samples, allowing multiple analyses to be performed with a single sampling, and produces no chemical waste.

The objectives of the current study were to 1) evaluate yield of 13 sweetpotato clones grown under standard organic practices and harvested early and late in the season 2) compare growth habits of sweetpotato clones 3) evaluate changes in sweetpotato carbohydrates before and after curing, and throughout storage.

MATERIALS AND METHODS

Experiments were conducted in 2020 and 2021 on a commercial certified organic farm in Momeyer, NC (lat. 35°58’11”N, long. 78°4’51”W). The soil was a Norfolk loamy sand (fine-loamy, kaolinitic, thermic Typic Kandiudults) in 2020, and Georgeville silt loam (fine, kaolinitic, thermic Typic Kanhapludults) and Gritney sandy loam (fine, mixed, semiactive, thermic Aquic Hapludults) in 2021. The preceding crop in the experimental field for 2020 was soybean [*Glycine max* (L.) Merr] followed by a rye (*Secale cereale* L.) cover crop, and cucumber (*Cucumis sativa*) for 2021. Both fields had been maintained under organic production for at least 7 years. In March, the soil was amended with an application of chicken broiler litter at a rate of approximately 6.7 Mg ha^{-1}. Although an exact nutrient analysis was not obtained for the litter samples, it is estimated that it contained on average 29 kg N Mg^{-1}, 20 kg P Mg^{-1}, and 24 kg K Mg^{-1} (Nutrient Management Team, 2022a). Broiler poultry litter in NC is expected to have 60% of the nitrogen, and 100% of the phosphorus and potassium is plant available when incorporated into the soil (Nutrient Management Team, 2022b). Therefore the estimated fertilizer rate was approximately 115 kg ha^{-1} N, 134 kg ha^{-1} P, and 163 kg ha^{-1} K.

Thirteen clones were evaluated in both years (Table 1.1). In addition, two harvest dates were investigated, 105 days after planting (DAP) and 126 DAP, resulting in a 13 clone × 2 harvest time full factorial randomized complete block design with three blocks in 2020 and four blocks in 2021. Harvest time was nested within blocks.

Due to limited or no availability of organically produced stem cuttings for the clones investigated, all stem cuttings in 2020 were conventionally produced. Seed potatoes were grown in the 2020 season to supply organic stem cuttings in 2021. However, due to limited seed root and cutting production, not all clones were able to be sourced organically. The following clones were supplemented with conventionally grown cuttings: ‘Purple Majesty’, ‘NC 10-0433’, and ‘Beauregard’.

Unrooted stem cuttings were planted using a 2-row bare root transplanter (B & S Enterprises, Inc. Elizabeth City, NC) in 2020 and a 4-row transplanter (Checchi & Magli, Budrio, Italy) in 2021. Stem cuttings were planted on 15 June 2020 and 30 June 2021. Plots were 7.6 m in length and were one row wide, with a between-row spacing of 91 cm. Stem cuttings were planted at an in-row spacing of 30.5 cm, resulting in a population of 35,880 plants ha^{-1}. Standard organic management practices were followed throughout the season (Jennings et al., 2019; Table 1.2). Plots were managed for weeds by cultivation approximately every ten days until canopy closure and by weekly hand removal throughout the season. Figure 1.1 includes the monthly rainfall and average temperatures during the growing season.

Data Collection

Stand counts were taken 7 and 16 DAP in 2020 and 2021, respectively. When possible dead plants were replaced with extra cuttings after recording the initial stand count.

Four weeks after planting, plots were rated for growth habit on a scale of 1 to 9, with a score of 1 indicating plant growth was upright and a score of 9 indicating plant growth was spreading (Fig. 1.2). Length of the longest vine was recorded for five representative plants per plot during plant growth scoring. In addition, internode length was measured on these same plants by averaging the length of three internodes, starting with the fifth node from the growing tip and measuring towards the base of the plant.

At the end of the growing season, the vegetation was mowed prior to harvest. A 4-row sweetpotato disc (Sweetpotato flip plow, Strickland Bros. Enterprises, Inc., Spring Hope, NC) was used to harvest roots for both harvests in 2020 and for the early harvest in 2021. A 2-row chain digger (Yield Max Gen. II, Strickland Bros. Enterprises, Inc., Spring Hope, NC) was used for the late harvest in 2021. Storage roots were harvested on 28 September (105 DAP) and 19

October in 2020 (126 DAP) and on 13 October (105 DAP) and 3 November (126 DAP) in 2021. Roots were graded using USDA standards (2005) into canners (2.5 cm to 4.4 cm diameter), No. 1's (4.4 cm to 8.9 cm diameter, 7.6 cm to 22.9 cm length), jumbos (greater than 8.9 cm diameter) and culls. Marketable roots were defined as the combination of No. 1's, canners, and jumbos (Wadl et al., 2022). Culls were defined as any root containing rot, severely misshapen, or rendered otherwise unmarketable. The weight and number of roots for each grade was recorded. However, in the 2021 late harvest, many roots were cut during the harvesting process and therefore count data were deemed unreliable. Therefore count data are not presented.

Immediately following harvest No. 1 roots from each plot were held at 15.6°C until after fresh root samples could be taken, this time spanned 3 days in 2020 and 1 day in 2021, prior to initiating curing. Roots were cured at 26°C for 6 days, except for in the case of the 2020 late harvest, in which roots were cured for 7 days. Relatively humidity varied during curing; in 2020 the early harvest was cured at an average of 56%, whereas the late harvest had an average of 69%. In 2021, the average relative humidity exceeded 90% for both harvests. Following curing, temperature and humidity were reduced to 15.6°C with average relative humidity ranging between 60% and 75% for long-term storage. Roots were sampled for internal quality data at six time points after harvest: before curing (fresh), after curing [1 ± 1 days after curing (DAC)], 1 month after harvest (24 ± 2 DAC), 2.5 months after harvest (73 ± 4 DAC), 5 months after harvest (145 ± 4 DAC), and 8 months after harvest (235 ± 3 DAC). Roots were not sampled immediately after curing for the 2020 early harvest. Roots were peeled, excluding the purple-skin, purple-flesh clones ('Purple Majesty', 'Purple Splendor', 'LA 14-41P'), and a subsample of 3 roots were used to create a composite. Samples were sliced using a food processor (PrepStar Food Processor, Hamilton Beach, Glen Allen, VA) and a 75 g sample was stored at -20°C until freeze drying. Samples were freeze dried (VirTis SP Scientific, Model # 24DX48 GPFD 35L EL-85, SP Industries, Warminster, PA) at a pressure of 100 mtorr, shelf temperature progressing from -8°C to 8°C, and condenser temperature of -85°C for 7 days.

Following freeze drying, samples were ground to 1 mm (CT 193 Cyclotex laboratory mill, FOSS Analytics, Denmark). Near-infrared absorbance (NIR) spectra for the dried samples were collected with a scanning NIR spectrometer (FOSS XDS Rapid Content Analyzer, XM-1100 series, FOSS Analytics, Denmark) and the software ISIscan (version 4.12, FOSS Analytics, Denmark). The spectra collected were used to estimate sample values of starch, fructose, glucose, and sucrose. Prediction equations used for this study were developed by the Sweetpotato and Potato Breeding and Genetics Program at NC State University using the software WinISI (version 4.6, FOSS Analytics, Denmark). For starch calibration the coefficient of determination (R2) = 0.977 with standard error of calibration (SEC) = 2.1702. For starch validation, R2 = 0.9703 with the standard error of cross validation (SECV) = 2.4598. For fructose, calibration R2 = 0.98 with SEC = 0.0441 and validation R2 = 0.9744 with SECV = 0.0469. For glucose, calibration R2 = 0.9859 with SEC = 0.0558 and validation R2 = 0.9828 with SECV = 0.0615. For sucrose, calibration R2 = 0.9596 with SEC = 0.1947 and validation R2 = 0.9544 with SECV = 0.2067.

Data were analyzed using the GLIMMIX procedure in SAS version 9.4 (SAS Institute, Cary, NC). For stand counts, internode lengths, growth habit, and vine length analyses, clone and year were treated as fixed effects. Block nested within year was treated as a random effect. For analyses of yield, clone, harvest time, and year were treated as fixed effects. Block nested within harvest × year was treated as a random effect. Least squared mean separation was completed using Tukey’s HSD adjustment at a significance of $P \leq 0.05$ when appropriate. Due to the nonnormal nature of proportion data, a beta distribution was used when analyzing the proportion of marketable yields that were No. 1 grade. Cull weight data were square root transformed prior to analysis in order to ameliorate heteroskedasticity.

For the analysis of carbohydrates using NIRS, the late harvest data from both years, with sampling dates up to and including 5 months after harvest were used in the analysis. Data from the 8 month sampling were not included in the analysis due to time constraints. To analyze the effects of curing, a repeated measures analysis was performed. Clone, sample time, year, and their interactions were included as fixed effects. Block nested within year was a random effect. Sample timing was the within-subject factor and the subject was plot × year. The covariance matrix used for each analysis was determined by comparing corrected Akaike Information Criteria (AICc). The model with the lowest AICc was determined to be the best fit.

A separate analysis was performed to analyze carbohydrate content throughout storage. Clone, year, and days after curing were included as fixed effects. Block nested within year was a random effect. Sample timing was the within-subject factor and the subject was plot × year. Again, the covariance matrix used for each analysis was determined by comparing AICc. For each carbohydrate, higher order polynomial regression models were tested and the model with the lowest AICc was determined to be the best fitting model. For each analysis, a linear response to days after curing was deemed the most appropriate model in each case.

RESULTS

Stand Counts

Initial stand counts varied by year ($P = 0.0017$) and clone ($P < 0.0001$; Table 1.3). There was better survival in 2020 than 2021, with stand counts averaging 24.4 out of 25 plants per plot in 2020 (98%) and 23.5 out of 25 plants in 2021 (94%). ‘NC 17-0221’ averaged only 21.4 plants per plot (86%) and had lower stands than all other clones, excluding ‘Purple Splendor’, which had an intermediate value.

Vine Length, Internode Length, and Growth Habit

Vines were longer in 2021 than 2020 ($P = 0.0397$). In 2020, vines averaged 69.0 cm when measured 31 DAP. In 2021, the average vine length was 73.5 cm at 29 DAP. Vine lengths were different among clones ($P < 0.0001$) ranging from 35.0 cm to 97.0 cm. ‘Carolina Ruby’ had the longest vine length, whereas ‘Monaco’ and ‘NC 10-0433’ had the shortest vines (Table 1.4).

The average distance between nodes was influenced by the interaction of clone and year ($P = 0.0158$; Table 1.5). In both years, ‘NC 17-0221’ was the clone with the longest length between nodes, with a length of 8.0 cm in 2020 and 9.0 cm in 2021. Clones with the shortest lengths in both years were ‘Monaco’ (3.0 cm in 2020, 4.0 cm in 2021) and ‘NC 10-0433’ (3.0 cm in both years).

Clones had different growth habit ratings ($P < 0.0001$; Table 1.4). ‘Carolina Ruby’ scored the highest, indicating the highest degree of prostrate growth, whereas ‘Monaco’ and ‘NC 10-0433’ scored the lowest, indicating that they have more upright growth.

Strong positive correlations were observed among vine length, internode distance, and growth habit rating ($P < 0.0001$; Fig. 1.3).

Marketable Yield

Marketable yields were affected by a clone × harvest × year interaction ($P = 0.0256$). In 2020, marketable yield ranged from 18,287 kg ha^{-1} (‘Ruddy’) to 37,020 kg ha^{-1} (‘Beauregard’) at early harvest, and from 21,019 kg ha^{-1} (‘NC 10-0433’) to 66,270 kg ha^{-1} (‘Bayou Belle’) at late harvest (Table 1.6). In 2021, marketable yield ranged from 21,740 kg ha^{-1} (‘NC 10-0433’) to 38,314 kg ha^{-1} (‘Purple Majesty’) at early harvest, and from 16,694 kg ha^{-1} (‘Carolina Ruby’) to

50,555 kg ha^{-1} (‘Purple Majesty’) at late harvest (Table 1.7). In both years, there were more differences in yield among clones at the late harvest than at the early harvest.

Some clones responded stronger to delaying harvest than others. In 2020, ‘Bayou Belle’ ‘Beauregard’ ‘Bonita’ ‘Covington’ ‘Purple Majesty’ ‘Purple Splendor’ ‘Ruddy’ ‘LA 14-41P’ and ‘NC 17-0221’ had significant increases in yield when harvest was delayed (Table 1.6). In 2021, fewer clones saw yield increases when harvest was delayed; only ‘Beauregard’ ‘Purple Majesty’ ‘Purple Splendor’ and ‘NC 10-0433’ saw significant yield boosts (Table 1.7).

No. 1 Yield

The yield of No. 1 grade roots was also affected by a clone × harvest × year interaction ($P = 0.0029$). In 2020, No. 1 yield ranged from 6,386 kg ha^{-1} (‘Ruddy’) to 26,930 kg ha^{-1} (‘Purple Majesty’) at early harvest, and from 11,436 kg ha^{-1} (‘NC 10-0433’) to 49,975 kg ha^{-1} (‘Bayou Belle’) at late harvest (Table 1.6). In 2021, No. 1 yield ranged from 11,213 kg ha^{-1} (‘LA 14-41P’) to 23,109 kg ha^{-1} (‘Purple Majesty’) at early harvest, and from 8,600 kg ha^{-1} (‘Carolina Ruby’) to 30,683 kg ha^{-1} (‘Purple Majesty’) at late harvest (Table 1.7). Similarly to the marketable yield results, at the late harvests there were more differences in yields among clones than at the early harvests.

Similar to the response for marketable yield, some clones produced more No. 1 grade roots due to delayed harvest. In 2020, ‘Bayou Belle’ ‘Beauregard’ ‘Bonita’ ‘Covington’‘Murasaki-29’ ‘Purple Majesty’ ‘Ruddy’ ‘LA 14-41P’ and ‘NC 17-0221’ had significant increases in No. 1 yield when harvest was delayed (Table 1.6). In 2021, fewer clones saw yield increases when harvest was delayed; only ‘Beauregard’ ‘Purple Majesty’ ‘Purple Splendor’ and ‘NC 10-0433’ had significant yield increases (Table 1.7).

Percent No. 1's

The percent of marketable yield that was No. 1 roots was influenced by the interaction of clone × harvest (*P* = 0.0030; Table 1.8). At early harvest, 'Purple Majesty' had the highest percentage, with No. 1's comprising 69.0% of the marketable yield. 'LA 14-41P' and 'Ruddy' had the lowest percentages of No. 1's, with only 44.3% and 43.7%, respectively. However, at late harvest, all clones had a similar proportion of roots that were No. 1. In addition, the percent of marketable yield that was No. 1 roots was influenced by the interaction of clone × year (*P* = 0.0253; Table 1.8). In 2020, the percentage of No. 1's ranged from 51.2% ('Ruddy') to 74.2% ('Bayou Belle'). In 2021, percentages ranged from 41.7% ('LA 14-41P') to 61.4% ('Purple Majesty').

Cull Weights

The weight of culled roots depended on the clone (*P* < 0.0001), harvest time (*P* = 0.0013), and year (*P* = 0.0006). 'Carolina Ruby' had the most culls, more than double the next highest clone (Fig. 1.4). 'Carolina Ruby' had a high amount of culled storage roots because of its susceptibility to crack with fluctuations in soil moisture, which results in roots that are unmarketable (Fig. 1.5). 'Monaco' and 'Purple Majesty' had the fewest culls of all the clones. Averaged across all clones and years, there were more culls at late harvest (2,098 kg ha^{-1}) than at early harvest (877 kg ha^{-1}; data not shown). In addition, there were more culls in 2021 (2,000 kg ha^{-1}) than 2020 (974 kg ha^{-1}; data not shown).

Effects of Curing and Time in Storage on Starch

For all clones, starch content was lower in the cured samples than the fresh samples, however, we observed higher starch values in 2020 than 2021 (*P* = 0.0496; Fig 1.6). In addition, a clone × year interaction influenced starch content during curing (*P* < 0.0001; Fig. 1.7). 'NC 10-

0433' had the lowest amount of starch in both years (45.8 g per 100 g dry weight (DW) in 2020 and 46.6 g per 100 g DW in 2021). In 2020, 'Purple Splendor' had higher starch content than all other clones, with 72.5 g per 100 g DW. In 2021, it still had one of the higher amounts of starch, with 55.6 g per 100 g DW, however, a few other clones had similar amounts. In general, the orange-flesh clones had lower starch content than the other clones.

Throughout storage, starch content changed, however, clones had different starting starch content and the rate of degradation varied among the clones ($P < 0.0001$; Fig 1.8a). Linear regression model parameters for the days after curing (DAC) × clone interaction are presented in Table 1.9. Starch degraded at the highest rate for 'Bayou Belle', with starch content decreasing by 0.1241 g per 100 g DW every day. However, starch content was stable for 'Murasaki-29' 'Purple Splendor' and 'LA 14-41P' throughout 5 months of storage (slope $P > 0.05$). The changes to starch content throughout storage also depended on the sample year ($P = 0.0010$; Fig 1.8b, Table 1.9). In 2020, samples had higher initial starch content and higher rates of starch degradation than samples from 2021. Lastly, a clone × year interaction ($P < 0.0001$) influenced the starch content of sweetpotato roots (Fig. 1.9a-b). When averaged over all storage sampling dates, similar clones in both years had the highest and lowest amounts of starch, with the orange-fleshed clones having lower starch content than white- or purple-fleshed clones. 'NC 10-0433' had the lowest starch content in both years, with 35.3 g per 100 g DW in 2020 and 32.5 g per 100 g DW.

Effects of Curing and Time in Storage on Sucrose

A clone × sample time × year interaction influenced the sucrose content of sweetpotato roots during the curing process ($P = 0.0003$; Table 1.10). Clones responded differently to the curing process. In 2020 and 2021, sucrose content increased for 'Bonita', 'Murasaki-29', 'Purple

Splendor', 'NC 17-0221', but decreased for 'Carolina Ruby' and 'LA 14-41P', and was similar before and after curing for 'Covington'. The remaining clones responded differently to curing in 2020 than 2021. For example, 'Bayou Belle' had similar levels before and after curing in 2020, but had a lower amount of sucrose after curing in 2021. The sucrose content was different across clones before and after curing (Table 1.10). Of the fresh samples, 'Bayou Belle' and 'NC 10-0433' were among the clones in both years with the highest amounts of sucrose. However, after curing, 'Murasaki-29' was typically one of the clones with the highest amounts of sucrose. 'LA 14-41P' had low amounts of sucrose in both the fresh and cured samples in both years.

A clone × sample time × year interaction influenced the sucrose content of sweetpotato roots during storage ($P = 0.0003$; Fig. 1.10). Model parameters for the linear regression, separated by year, are presented in Table 1.11. Clones varied in the amount of sucrose at the beginning of the storage process. In 2020, sucrose ranged from 0.1231 g per 100 g FW ('LA 14-41P') to 1.8373 g per 100 g FW ('Murasaki-29'). In 2021, sucrose ranged from 0.5442 g per 100 g FW ('LA 14-41P') to 2.1221 g per 100 g FW ('Purple Splendor'). In 2020, sucrose content increased with storage for all clones, excluding 'Purple Splendor' and 'LA 14-41P', for which sucrose content remained constant throughout storage (Table 1.11; slope $P > 0.05$). Similarly, in 2021 sucrose content increased during storage for most clones. However, for 'Purple Splendor', sucrose content decreased throughout storage, decreasing at a rate of 0.00348 g per 100 g fresh weight (FW) per day. Sucrose content was stable throughout storage for 'Beauregard', 'Purple Majesty', 'Ruddy', and 'LA 14-41P' (Table 1.11; slope $P > 0.05$). Sucrose content increased at the fastest rates for 'Bayou Belle' in both years, with an increase of 0.01024 g per 100 g FW in 2020 and an increase of 0.01483 g per 100 g FW in 2021.

Effects of Curing and Time in Storage on Glucose

A clone × sample time × year interaction influenced the glucose content of sweetpotato roots during curing ($P = 0.0062$; Table 1.12). The majority of clones saw an increase in glucose content with curing, with the exception of 'Mursaski-29' in both years and 'Purple Splendor' in 2021, which maintained similar glucose levels before and after curing. 'NC 17-0221' generally had low glucose before and after curing. 'Purple Splendor' had very low estimates in 2021. 'Ruddy', 'Bayou Belle', and 'NC 10-0433' had among the highest glucose levels of all clones before and after curing.

Glucose content changed throughout storage, however, clones varied in glucose content and the rate of change varied among the clones ($P = 0.0004$; Fig 1.8c). Model parameters for the linear regression modeling clone glucose content over time are presented in Table 1.13. At the start of storage, 'Ruddy' had the highest amount of glucose, whereas 'Murasaki-29', 'Purple Splendor', and 'NC 17-0221' were among the clones with the lowest amounts. In general the orange-flesh clones had higher glucose content than the other clones. Most clones did not have a significant change in glucose content through 5 months of storage (Table 1.13; slope $P > 0.05$). However, glucose increased over time for 'Purple Splendor', 'LA 14-41P', and 'NC 10-0433', with 'NC 10-0433' accumulating glucose at the highest rate (0.001667 g per 100 g FW per day). Uniquely, glucose content decreased over time for 'Carolina Ruby'. We also observed that glucose content changed throughout storage, but differed between the years ($P < 0.0001$; Fig 1.8d). Linear regression model parameters for each year are presented in Table 1.13. In 2020, glucose levels remained stable during 5 months of storage, whereas in 2021, glucose increased at a rate of 0.00149 g per 100 g FW per day. Additionally, sweetpotato glucose content was influenced by a significant clone × year interaction ($P < 0.0001$; Fig. 1.9c-d). In both years, ‘Ruddy, ‘Bayou Belle’ and ‘NC 10-0433’ had among the highest glucose levels of all the clones, whereas ‘NC 17-0221’, ‘Murasaki-29’, and ‘Purple Splendor’ typically had the lowest levels of glucose. In general the orange-flesh clones had higher glucose content than the other clones.

Effects of Curing and Time in Storage on Fructose

A clone × sample time × year interaction influenced the fructose content during the curing process ($P = 0.0080$; Table 1.14). Most clones had more fructose after curing than before; excluding ‘Murasaki-29’ and ‘NC17-0221’ in both years, and ‘Purple Majesty’ in 2021, which maintained similar amounts of fructose throughout the curing process. In both years, ‘Bayou Belle’, ‘Ruddy’, and ‘NC 10-0433’ typically had the highest amounts of fructose, both before and after curing, whereas ‘Bonita’, ‘Murasaki-29’, and ‘NC17-0221’ typically had the lowest amounts of fructose.

Significant interactions of sample timing × year ($P < 0.0001$), sample timing × variety ($P = 0.0012$), and variety × year ($P = 0.0002$) influenced the amount of fructose in roots throughout the storage process (Fig. 1.8e-f and 1.9e-f; Table 1.15). Linear regression model parameters for each clone in relation to DAC are detailed in Table 1.15 and plotted in Fig. 1.8e. At the start of storage, clones had different amounts of fructose. ‘Ruddy’ averaged the highest amount (1.1042 g per 100 g FW) and ‘Murasaki-29’ had the lowest (0.0858 g per 100 g FW). For 9 of the 13 clones tested, fructose content did not significantly change throughout 5 months of storage (slope $P > 0.05$). Fructose content increased during storage for 3 clones (‘Murasaki-29’, ‘LA 14-41P’, and ‘NC 10-0433’) and decreased through storage for ‘Carolina Ruby’. The rate of change of fructose content over time also differed between years (Fig. 1.8f; Table 1.15). In 2020, roots started with higher fructose levels than in 2021. In addition, in 2020, fructose content was stable throughout storage (slope $P > 0.05$), whereas in 2021, fructose content increased at a rate of

0.00124 g per 100 g FW per day. In both years, the same clones generally had higher or lower fructose content, although the exact values differed between years (*P* = 0.0002; Fig. 1.9e-f). ‘Bayou Belle’, ‘Ruddy’, and ‘NC10-0433’ were the clones with the highest fructose content, whereas ‘Murasaki-29’, ‘Purple Splendor’, and ‘NC17-0221’ had the lowest fructose averaged throughout storage.

DISCUSSION

In our study, we found differences in clone growth habit, measured in terms of vine length, internode length, and visual growth habit scores (Table 1.4 and 1.5). The strong positive correlations among all of these measures (Fig. 1.3) indicates that the same clones that had the longest vines typically had the longest internode distances and were the clones with the highest degree of prostrate growth. We were interested in sweetpotato vine growth habit because of its potential contribution to tolerance of weed interference. It is suggested that clones with upright growth habits have higher tolerance to weeds than clones with spreading vines (Chaudhari et al. 2020; Harrison and Jackson, 2011; La Bonte et al., 1999). La Bonte et al. (1999) found that three of the five most weed tolerant clones in their study, measured in terms of yield reduction, had bunch or medium internode growth habits. However, they found no difference in weed biomass among clones, suggesting similar weed suppression capabilities. In a comparison between ‘Carolina Bunch’ (upright) and ‘Beauregard’ (spreading), Harrison and Jackson (2011) determined that ‘Carolina Bunch’ was not as strongly impacted by weed interference as ‘Beauregard,’ since Beauregard shoot biomass and root yields were reduced to a greater extent in weedy treatments. They also calculated a shorter weed-free period with ‘Carolina Bunch’, implying that the vigorous upright shoots could better suppress weeds than spreading vines. They suggested that upright clones may be more tolerant to weed due to more effective shading by the canopy. In a greenhouse replacement series study, Chaudhari et al. (2020) determined that 'NC10-275', an upright clone, was more competitive than two weed species, whereas, 'Covington,' a spreading clone, was determined to only be more competitive than one of the weed species, when determining competitive ability by measuring shoot biomass. In addition, it is speculated that the reduced rate of canopy expansion of upright clones can be beneficial for prolonged cultivation, as the vines take longer to grow between rows compared to spreading vines (Harrison and Jackson, 2011; Smith et al., 2022).

Since fields were maintained weed-free in this study in order to optimize yields, we were unable to test for weed tolerance of sweetpotatoes with different growth habits. However, the previously mentioned research regarding growth habits suggests that 'Monaco' and 'NC 10-0433,' the clones with the most upright growth habits (Table 1.4 and 1.5), may be of particular interest for weed management in organic production systems. One of the shortcomings of past research on this matter is that only one clone was used to represent a growth habit (Chaudhari et al. 2020; Harrison and Jackson, 2011). This creates uncertainty if the advantage is in fact a direct result of the growth habit. Additional work testing multiple clones of various canopy structures in organic management systems is necessary to validate this theory.

Between 2012 and 2021, average sweetpotato yield in NC has ranged from 15,693 kg ha^{-1} to 24,660 kg ha^{-1} (USDA, NASS, 2022b). Nwosisi et al. (2021) reported a 90% probability value for organic sweetpotato marketable yields to fall between 24,850 kg ha^{-1} and 35,014 kg ha^{-1}. In our study, marketable yields ranged from 16,694 kg ha^{-1} to 66,270 kg ha^{-1}, and No. 1 yields ranged from 6,386 kg ha^{-1} to 49,975 kg ha^{-1} (Table 1.6 and 1.7). 'Covington', the most widely grown cultivar in NC, yielded marketable weights ranging from 35,055 kg ha^{-1} to 53,560 kg ha^{-1} and No. 1 yields between 21,412 kg ha^{-1} to 36,905 kg ha^{-1}. Yields from our study are much higher than the reported yields of irrigated, conventional roots produced in South Carolina; in which 'Covington' marketable yields were 241 bushels per acre [13,506 kg ha^{-1}] in 2016 and 450 bushels per acre [25,219 kg ha^{-1}] in 2017 (Wadl et al., 2022). However, Nwosisi et al. (2017) reported highest marketable yields of 39,719 kg ha^{-1} with 'Beauregard,' and 'Covington' yielded over 30,000 kg ha^{-1} when grown organically with mulch and irrigation in Tennessee. No. 1 yields of 'Covington' from this study are similar to or exceed the 406 bushels per acre average [22,753 kg ha^{-1}] reported for the 2021 National Sweetpotato Collaborator Group (2022) variety trial. In our study, many clones yielded statistically similar to 'Covington,' however, some clones yielded as low as 52% to 65% of 'Covington' (Tables 1.6 and 1.7).

Delaying harvest increased marketable yield for only some of the clones (Tables 1.6 and 1.7). Other research has noted that all cultivars do not respond the same to an extension of the growing season. For example, in a study of sweetpotato grown on black plastic, researchers observed differences in response between 'Georgia Jet' and 'Beauregard,' concluding season delay benefited 'Georgia Jet' more (Wees et al., 2016). In a study in Brazil, harvest at 150 DAP resulted in the highest yields of total and marketable roots for some cultivars, but for others there was no yield increase when harvest was delayed from 120 DAP to 150 DAP or 180 DAP. (Azevedo et al., 2014).

'Carolina Ruby' and 'NC 10-0433' did not increase in yield with delayed harvest due to abiotic disorders. 'Carolina Ruby' did not have increases in marketable or No. 1 yield in both years due to a relatively high incidence of cracked roots, which resulted in unmarketable roots (Fig. 1.4 and 1.5). 'NC 10-0433' saw yield increases in 2021 but not 2020 because at the late harvest in 2020 many roots air cracked and were unmarketable as a result of the drastic temperature fluctuation during the morning harvest. We would recommend waiting until later in the day to harvest this clone in order to avoid rapid temperature fluctuations common in early morning.

Fewer clones had a yield increase between harvests in 2021 (Table 1.7). This is likely due to the late planting in that year pushing harvest dates into mid-October and early November. These later harvest dates resulted in cooler temperatures (Figure 1.1), averaging below the 70°F to 88°F range [21.1 °C to 31.1 °C], which is the optimum range for sweetpotato growth (Kemble, 2022). Others have reported that cool temperatures impact sweetpotato yields (Arancibia et al., 2014; Reynolds et al., 1994). For example, Reynolds et al. (1994) reported increases in total yield and table grade yield (roots 5 to 9 cm in diameter) between their early and middle harvest dates (harvests occurring in late August through late September, between 87 to 107 DAT for early harvest and 104 to 121 DAT for middle harvest). However, they did not observe increases when harvests were delayed until October. Similarly, Arancibia et al. (2014) attributed inconsistent results of yield increases to cooler temperatures later in the growing season, finding a net benefit in delaying harvest for early plantings, but not necessarily when delaying harvests of later plantings.

Since No. 1 is the premium sweetpotato grade, growers want to maximize the percentage of yield that falls within this category. In both years of our study ‘LA 14-41P’ had a lower proportion of No 1. roots than the clones with the highest proportions (Table 1.8). In addition, ‘LA 14-41P’ and ‘Ruddy’ had the lowest proportions at the early harvest (Table 1.8), suggesting harvest at approximately 105 days, or this stage of development, is not the optimal time for these clones. A later harvest date may increase No. 1 yields for these clones, which is also suggested by the significant yield increase for marketable and No. 1 yields for these clones when harvest was delayed in 2020 (Table 1.6).

Whether analyzed during the curing process or throughout storage, clones varied in their amount of starch, sucrose, glucose, and fructose (Table 1.9-1.15, Fig. 1.7-1.10). It has been well established that clones have differences in starch and sugars content (Kays et al., 2005; Krochmal-Marczak et al., 2020; Morrison et al., 1993; Nabubuya et al., 2017; Zhang et al., 2002). In our results, typically, orange-fleshed clones had lower starch content (Fig. 1.7, Table 1.9) and higher glucose content (Fig. 1.9, Table 1.12 and 1.13) than the purple-fleshed and white-fleshed clones. This aligns with US market preferences for “dessert type” roots that are moist, sweet, orange-fleshed, rather than “staple type” which have white or yellow flesh and have a drier texture (Mwanga et al., 2017).

During the curing process, starch content decreased (Fig. 1.6) and fructose and glucose increased (Table 1.12 and 1.14). Our results support findings with other clones (Picha, 1987; Walter and Hoover, 1984). However, unlike Picha (1987) and Walter and Hoover (1984) who observed sucrose content increase during curing, we saw more variation in sucrose response. Some clones had sucrose content increase, others decrease, some remained constant, and many had different responses depending on the sampling year (Table 1.10).

Throughout storage, starch content decreased for 10 of the 13 clones studied (Table 1.9, Fig. 1.8). This matches the commonly observed pattern of starch reduction throughout storage (Nabubuya et al., 2017; Walter and Hoover, 1984; Zhang et al., 2002). Although these researchers observed starch degradation rates for all clones in their studies, there is documented cultivar-effects, with starch degradation rates differing between clones (Zhang et al., 2002), which may help explain why three clones we observed had stable starch content throughout 5 months in storage.

Starch broke down the fastest for ‘Bayou Belle’ (Table 1.9), suggesting that this clone does not hold up as well as other clones during storage. In addition, this clone had the highest rate of sucrose accumulation (Table 1.11), further indicating that the root chemistry is less stable than other clones and that long periods of storage could reduce root quality. In contrast, ‘Murasaki-29’, ‘Purple Splendor’ and ‘LA 14-41P’ all maintained starch levels through 5 months of storage, suggesting that these clones may have better storage capacity. However, it is also important to consider other factors of root quality for a more complete analysis, including β–carotene content in orange-fleshed clones or anthocyanin content in purple-fleshed clones.

In regards to sugars, glucose and fructose were stable throughout storage, but sucrose increased for most clones through 5 months (~145 days) of storage (Table 1.11, 1.13, 1.15, Fig. 1.8 and 1.10). Morrison et al. (1993) observed minor changes in sugars throughout 180 days of storage for four clones. Up through 46 weeks [322 days] of storage, Picha (1987) observed increase of fructose and glucose, particularly within the first 4 to 14 weeks after curing. However, they did observe cultivar effects, 1 of the 6 clones maintaining constant levels of fructose and glucose throughout storage and they observed different patterns in sucrose content during storage for white- and orange-fleshed clones. Walter and Hoover (1984) also documented cultivar effects during their study of 24 weeks [168 days] of storage, but saw increased sucrose and combined fructose and glucose content throughout storage. Other researchers have also documented different responses depending on the clone during 180 days of storage (Zhang et al, 2002). During 8 weeks [56 days] of storage, Nabubuya et al. (2017) also observed increases of glucose and minor increases of sucrose in a study of five clones.

During storage, ‘NC 10-0433’ was the only clone that had increases in all three sugars (Table 1.11, 1.13 and 1.15), with the highest rates of accumulation for glucose and fructose.

Furthermore, it had the lowest starch content of fresh roots and it maintained the lowest starch content of all clones throughout storage (Fig. 1.7 and 1.9).

It is likely that differences in root carbohydrates between years is due to a number of environmental conditions. Root carbohydrate composition is not static. The quantity and pattern of sucrose, glucose, and fructose content is known to change throughout storage root development and differ among clones (Adu-Kwarteng et al., 2014; La Bonte et al., 2000). Krochmal-Marczak et al. (2020) observed differences in average starch and total sugar content of clones depending on year across a three year study and attributed the differences to weather conditions. Rosero et al. (2020) investigated 20 genotypes at six locations over two seasons and observed differences in composition of sweetpotato genotypes across locations. In regards to specific environmental conditions, they observed increases in total soluble solids associated with high temperatures, but a negative correlation between total soluble solids and accumulated rainfall. Although differences in carbohydrates across years cannot be attributed to specific environmental conditions in the current study, it is notable that an additional 20 cm of precipitation fell during the 2020 season compared to 2021 (Fig. 1.1).

One caveat of this work is that it only analyzes storage up to 5 months after harvest. Market conditions may necessitate a longer storage period. In addition, inclusion of other root constituents would give a more complete picture of quality throughout storage. For example, β-carotene of orange-fleshed or anthocyanin content of purple-fleshed clones are important components that contribute to human health. During 8 months of storage, changes in carotenoids are expected, but response has been reported to be cultivar-dependent (Grace et al., 2014). In addition, anthocyanin content decreased for ‘NCPUR06-20’ during 8 months of storage (Grace et al., 2014).

Overall, when considering only the purple flesh clones, ‘LA 14-41P’ typically yielded the lowest out of the three clones tested (Table 1.6 and 1.7) and had the lowest percentage of No. 1 roots (Table 1.8). ‘Purple Majesty’ and ‘Purple Splendor’ were among the highest yielding clones, on par with ‘Covington’ (Table 1.6 and 1.7). However, ‘LA 14-41P’ has resistance to guava root knot nematode (K.V. Pecota, personal communication), while the other two purple clones are susceptible (Schwarz et al., 2021). Guava root knot nematode is a serious pest of sweetpotato and there are many crops that serve as a host (Philbrick et al., 2020). There are currently quarantine protocols in place to limit its spread. Clones with resistance are highly sought after, and therefore breeding high yielding, consumer-accepted clones with this resistance is a key goal of breeding programs. ‘LA14-41P’ and ‘Purple Splendor’ have stable starch – potentially indicating better storage potential (Table 1.9). “LA14-41P’ does have really low sucrose content though (Table 1.10 and 1.11) and its acceptance by US consumers will need to be evaluated. One thing to consider if planting ‘Purple Majesty’ is that it has low tolerance to flooding and it is susceptible to Southern Root Knot nematode, another problematic nematode species present in the region (Yencho and Pecota, 2022a).

Although ‘Murasaki-29’ yields were generally low in this study (Table 1.6 and 1.7), it is a unique and readily marketed variety with reddish purple skin and white to yellow flesh. It has a good disease and pest resistance package, with resistance to Fusarium wilt and Southern root knot nematode, and moderate resistance to Streptomyces, the Wireworm Diabrotica Systena complex, and flea beetle (La Bonte et al., 2008; Jennings et al., 2019). Notably, this cultivar has resistance to Guava Root Knot nematode (Schwarz et al., 2021). Therefore it is a suitable option where the market resides.

In regards to the orange-flesh clones, ‘Covington’ yielded well. It was among the top 3 highest yielding orange clones at all harvests and years (Table 1.6 and 1.7). Many of the other orange-fleshed clones performed similarly to ‘Covington’ and may be options for production in organic systems. Notably, ‘Monaco’ has a really good insect and disease package, including moderate resistance to Wireworm Diabrotica Systena complex, which ‘Covington’ is susceptible to. It also has resistance to Fusarium wilt and Southern Root Knot nematode, and moderate resistance to Streptomyces and flea beetle (Jennings et al., 2019; Yencho and Pecota, 2022b). Although ‘Monaco’ had statistically comparable yields to ‘Covington’ in this study, its marketable yields ranged between 71% to 105% of ‘Covington’ and No. 1 yields ranging from 63% to 105% of ‘Covington’ in this study. Past reports have documented that ‘Monaco’ averaged 85% of the total marketable yield of ‘Beauregard’ and 81% of ‘Covington’ (Yencho and Pecota, 2022b). In addition, ‘Monaco’ has an upright growth habit (Table 1.4), which could potentially be a better growth habit to contribute to weed management for organic sweetpotatoes. One downside is that it produces a lot of latex when the root ends are broken, which is a visual defect since it adheres to the root during the packing process.

CONCLUSION

The NC standard, ‘Covington’ consistently performed as one of the top yielding orange-fleshed clones. However, depending on disease, pest, and weed pressures, other clones should also be considered by organic growers. Furthermore, ‘Purple Majesty’ and ‘Purple Splendor’ seem to be promising new clones for the purple-fleshed market. The majority of clones in this study had a moderate to spreading growth habit, however, ‘Monaco’ and ‘NC 10-0433’ had more upright growth with short internodes and the shortest vine lengths. This plant architecture is predicted to contribute to improved weed suppression and weed tolerance and it should be further investigated and considered as a weed management strategy. Our results document the differences in carbohydrate content of 13 clones grown under organic management, and their changes during curing and storage. Clones varied in its carbohydrate composition and response to curing and storage, indicating potential differences in eating quality and storage stability.

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Table 1.1 Flesh and skin color, root shape, and germplasm source, of 13 sweetpotato clones evaluated in 2020 and 2021.

Clone	**Skin Color**	**Flesh Color**	**Root Shape**[Z]	**Additional Notes**	**Germplasm Source**[Y]	
					2020	**2021**
Bayou Belle	red	orange	RE, E, A		NCSU	NCSU
Beauregard	rose	orange	RE, E		NCSU	NCSU
Bonita	cream	white	RE, E, LE	Few lenticels. Smooth skin	NCSU	NCSU
Carolina Ruby	red	orange	RE, E	Observed cracking due to moisture	NCSU	NCSU
Covington	rose	orange	RE, E		NCSU	JFF
Monaco	dark rose	orange	RE, E	Previously known as NC 04-0531	NCSU	NCSU
Murasaki-29	red-purple	white-yellow	E, LE		NCSU	JFF
Purple Majesty	purple	purple	R, RE, E	Previously known as NCPUR13-0315	NCSU	NCSU
Purple Splendor	purple	purple	R, RE, B	Previously known as NCPUR13-0030	NCSU	NCSU
Ruddy	red	orange	E, LE		NCSU	NCSU
LA 14-41P	purple	light purple	E, LE	Prominent lenticels. Lots of root hairs	JFF	NCSU
NC 10-0433	cream to copper	orange	RE, E, LE	Observed air cracking	NCSU	NCSU
NC 17-0221	tan	cream	RE, E, A		NCSU	NCSU

[Z] R = round, RE = round-elliptic, E = elliptic, LE = long-elliptic, B = blocky, A = asymmetric
[Y] NCSU = North Carolina State University, Raleigh, NC; JFF = Jones Family Farms, Bailey, NC

Table 1.2 Timing of cultural practices.

Cultural Practice	**Date**					
2020						
Poultry Litter Application	March					
Planting	15 June					
Stand Counts	22 June					
Growth Habit Measures	16 July					
Cultivation	23 June	25 June	9 July	16 July	20 July	
Hand Weed Removal	2 July	9 July	23 July	30 July	7 Aug	14 Aug
Harvest	28 Sept	19 Oct				
2021						
Poultry Litter Application	Early March					
Planting	30 June					
Stand Counts	16 July					
Growth Habit Measures	29 July					
Cultivation	8 July	16 July	21 July	30 July	6 Aug	
Hand Weed Removal	16 July	26 July	5 Aug	11 Aug	19 Aug	2 Sept
Harvest	13 Oct	3 Nov				

Table 1.3 Main effects of clone and year on initial stand counts.

Clone	**Initial Stand (Percent of Cuttings Planted)**[Z]
Bayou Belle	24.1 (96) a[Y]
Beauregard	24.2 (97) a
Bonita	23.8 (95) a
Carolina Ruby	24.3 (97) a
Covington	24.5 (98) a
Monaco	23.3 (93) a
Murasaki-29	24.4 (98) a
Purple Majesty	24.1 (96) a
Purple Splendor	23.0 (92) ab
Ruddy	24.7 (99) a
LA 14-41P	24.4 (98) a
NC 10-0433	24.5 (98) a
NC 17-0221	21.4 (86) b
P-Value	<0.0001
Year	
2020	24.4 (98)
2021	23.5 (94)
P-Value	0.0017

[Z] Stand counts are based on the potential maximum count of 25 plants per plot. Counts were taken prior to replacing dead/missing plants with extra cuttings.

[Y] Means followed by the same letter are not different (Tukey's honest significant difference; α=0.05).

Table 1.4 Vine length measurements and growth habit ratings for each clone, averaged over both years.

Clone	**Vine Length^{Z} (cm)**	**Growth Habit Rating^{Y}**
Bayou Belle	87.5 ab^{X}	8.2 ab
Beauregard	79.5 bc	7.2 bcd
Bonita	87.0 ab	7.4 bc
Carolina Ruby	97.0 a	8.9 a
Covington	87.0 ab	7.1 bcde
Monaco	41.0 f	2.2 i
Murasaki-29	74.5 bcd	5.8 efg
Purple Majesty	64.5 de	5.4 fg
Purple Splendor	57.0 e	4.9 gh
Ruddy	74.0 cd	6.0 defg
LA 14-41P	62.0 de	3.9 h
NC 10-0433	35.0 f	2.2 i
NC 17-0221	80.0 bc	6.6 cdef
P-value	<0.0001	<0.0001

^{Z}Vine lengths were measured on five representative plants per plot, from the growing tip of the longest vine to the plant base. Averages are rounded to the nearest 0.5 cm.

^{Y}Visual growth habit rating scale; 1=upright growth 9=spreading growth.

^{X}Means followed by the same letter within response are not different (Tukey’s honest significant difference; α=0.05).

Table 1.5 Interaction of clone × year on average internode length.

Clone	**Internode Length^Z (cm)**	
	2020	**2021**
Bayou Belle	6.5 b^Y	8.5 ab
Beauregard	6.5 b	7.5 b
Bonita	7.5 ab	8.5 ab
Carolina Ruby	7.0 ab	8.0 b
Covington	7.0 ab	7.5 b
Monaco	3.0 d	4.0 ef
Murasaki-29	5.0 c	5.5 cd
Purple Majesty	5.0 c	5.5 cd
Purple Splendor	4.5 c	5.0 de
Ruddy	5.5 c	6.0 c
LA 14-41P	5.0 c	5.0 cd
NC 10-0433	3.0 d	3.0 f
NC 17-0221	8.0 a	9.0 a
P-value	0.0158	

[Z] Internode lengths were measured on five representative plants per plot, by averaging the length of three internodes, starting with the fifth node from the growing tip and measuring towards the base of the plant. Averages are rounded to the nearest 0.5 cm.

[Y] Means followed by the same letter within year are not different (Tukey's honest significant difference; α=0.05).

Table 1.6 Marketable yield and No. 1 yield for early and late harvests for the 2020 season.

	Marketable Yield[Z] (kg ha^{-1})		**No. 1 Yield (kg ha^{-1})**	
Clone	**Early[Y]**	**Late**	**Early**	**Late**
Bayou Belle	34,796 a[X]	66,270 a*[W]	25,262 a	49,975 a*
Beauregard	37,020 a	55,831 ab*	23,718 ab	32,198 bcd*
Bonita	32,729 a	48,382 abc*	20,607 ab	30,686 bcd*
Carolina Ruby	30,613 a	32,453 cd	20,646 ab	20,424 de
Covington	35,840 a	53,560 ab*	26,668 a	36,905 abc*
Monaco	34,447 a	38,200 bcd	23,653 ab	23,085 de
Murasaki-29	20,245 a	30,070 cd	9,832 bc	20,005 de*
Purple Majesty	35,648 a	53,533 ab*	26,930 a	38,078 ab*
Purple Splendor	36,910 a	55,531 ab*	22,221 ab	29,078 bcd
Ruddy	18,287 a	39,705 bcd*	6,386 c	25,998 bcde*
LA 14-41P	23,785 a	40,713 bcd*	11,610 bc	24,833 cde*
NC 10-0433	24,665 a	21,019 d	15,823 abc	11,436 e
NC 17-0221	33,044 a	56,313 ab*	20,671 ab	32,025 bcd*

[Z] Sweetpotato grades are based on USDA standards (2005). Canners were defined as roots with 2.5 cm to 4.4 cm diameter, No. 1's were defined as 4.4 cm to 8.9 cm diameter and 7.6 cm to 22.9 cm length, and jumbos were roots greater than 8.9 cm diameter. Marketable yield is the sum of No. 1, jumbo and canner grades.

[Y] Early harvest was 105 DAP. Late harvest was 126 DAP.

[X] Means followed by the same lowercase letter are not different within a column (Tukey's honest significant difference; α=0.05).

[W] Means followed by an asterisk are different across rows, within grade (Tukey's honest significant difference; α=0.05).

Table 1.7 Marketable yield and No. 1 yield for early and late harvests for the 2021 season.

	Marketable Yield^{Z} (kg ha^{-1})		**No. 1 Yield (kg ha^{-1})**	
Clone	**Early^{Y}**	**Late**	**Early**	**Late**
Bayou Belle	36,983 ab^{X}	42,561 abc^{W}	21,078 a	22,560 abc
Beauregard	30,988 ab	44,619 abc*	17,057 a	26,618 ab*
Bonita	31,486 ab	39,873 abc	16,790 a	21,168 abcd
Carolina Ruby	22,829 ab	16,694 d	11,928 a	8,600 d
Covington	35,055 ab	45,149 abc	21,412 a	27,231 ab
Monaco	36,907 ab	40,505 abc	22,457 a	23,183 abc
Murasaki-29	24,301 ab	31,724 cd	12,959 a	18,950 bcd
Purple Majesty	38,314 a	50,555 a*	23,109 a	30,683 a*
Purple Splendor	36,958 ab	49,333 ab*	19,644 a	27,627 ab*
Ruddy	27,933 ab	29,252 cd	14,241 a	17,622 bcd
LA 14-41P	29,110 ab	32,825 bcd	11,213 a	14,539 cd
NC 10-0433	21,740 b	40,261 abc*	11,356 a	21,165 abcd*
NC 17-0221	29,749 ab	36,900 abc	18,983 a	17,561 bcd

^{Z}Sweetpotato grades are based on USDA standards (2005). Canners were defined as roots with 2.5 cm to 4.4 cm diameter, No. 1's were defined as 4.4 cm to 8.9 cm diameter and 7.6 cm to 22.9 cm length, and jumbos were roots greater than 8.9 cm diameter. Marketable yield is the sum of No. 1, jumbo and canner grades.

^{Y}Early harvest was 105 DAP. Late harvest was 126 DAP.

^{X}Means followed by the same lowercase letter are not different within a column (Tukey's honest significant difference; α=0.05).

^{W}Means followed by an asterisk are different across rows, within grade (Tukey's honest significant difference; α=0.05).

Table 1.8 Interaction of clone × harvest and clone × year on percent No. 1 of marketable yield.

	Percent No. 1 Grade (%)			
	Harvest^{Y}		**Year**	
Clone	**Early**	**Late**	**2020**	**2021**
Bayou Belle	65.7 ab^{X}	64.3 a	74.2 a	54.7 ab
Beauregard	59.3 abc	59.1 a	61.3 abc	57.1 a
Bonita	58.0 abc	58.3 a	63.2 abc	53.0 ab
Carolina Ruby	59.5 abc	56.6 a	65.4 abc	50.3 ab
Covington	67.4 ab	64.9 a	71.6 ab	60.3 a
Monaco	64.7 ab	58.8 a	64.9 abc	58.7 a
Murasaki-29	50.9 bc	62.5 a	57.5 abc	56.1 ab
Purple Majesty	69.0 a	66.2 a	73.3 a	61.4 a
Purple Splendor	56.2 abc	54.3 a	56.0 bc	54.5 ab
Ruddy	43.7 c	63.2 a	51.2 c	56.0 ab
LA 14-41P	44.3 c	52.5 a	55.2 c	41.7 b
NC 10-0433	57.9 abc	55.6 a	60.3 abc	53.2 ab
NC 17-0221	62.0 ab	52.8 a	59.6 abc	55.3 ab
P-Value	0.0030		0.0253	

[Z] Sweetpotato grades are based on USDA standards (2005). Canners were defined as roots with 2.5 cm to 4.4 cm diameter, No. 1's were defined as 4.4 cm to 8.9 cm diameter and 7.6 cm to 22.9 cm length, and jumbos were roots greater than 8.9 cm diameter. Marketable yield is the sum of No. 1, jumbo and canner grades.

[Y] Early harvest was 105 DAP. Late harvest was 126 DAP.

[X] Means followed by the same lowercase letter are not different within a column (Tukey's honest significant difference; α=0.05)

Table 1.9 Linear regression parameters modeling storage root starch content for each clone throughout storage and for each sample year throughout storage.

	Intercept (g per 100 g DW)			Slope (g per 100 g DW per day)		
	Estimate	Standard Error	P-Value	Estimate	Standard Error	P-Value
Clone × DAC^{Z}						
Bayou Belle	43.7798	1.6369	0.5243	-0.12410	0.01291	<0.0001
Beauregard	45.0737	1.4921	0.8678	-0.02474	0.01029	0.0174
Bonita	50.7025	1.5306	0.0002	-0.04287	0.01096	0.0001
Carolina Ruby	45.7938	1.5302	0.5277	-0.08009	0.01253	<0.0001
Covington	41.5029	1.5306	0.0319	-0.08475	0.01096	<0.0001
Monaco	50.7056	1.5424	0.0002	-0.07409	0.01234	<0.0001
Murasaki-29	53.9055	1.5636	<0.0001	-0.00688	0.01176	0.5591
Purple Majesty	52.3327	1.4921	<0.0001	-0.03694	0.01029	0.0005
Purple Splendor	57.2174	1.4921	<0.0001	-0.01025	0.01029	0.3207
Ruddy	44.8248	1.5932	<0.0001	-0.07421	0.01412	<0.0001
LA 14-41P	56.1499	1.5306	<0.0001	-0.01656	0.01096	0.1330
NC 10-0433	39.9213	1.5420	0.0019	-0.10650	0.01234	<0.0001
NC 17-0221	56.5693	1.5306	<.0001	-0.03564	0.01096	0.0014
Year × DAC						
2020	53.0511	1.3355	<0.0001	-0.06988	0.006189	<0.0001
2021	47.0132	0.9039	<0.0001	-0.04363	0.005980	<0.0001

^{Z}DAC = days after curing

Table 1.10 Sucrose content of sweetpotato clones before and after curing in 2020 and 2021.

	Sucrose Content (g per 100g fresh weight)[Z]			
	2020		**2021**	
Clone	**Fresh**	**Cured**	**Fresh**	**Cured**
Bayou Belle	1.4011 a[Y]	1.4091 abcd	1.8150 a	1.2697 def*[X]
Beauregard	1.0365 bc	1.0753 def	1.0942 cde	1.3108 def*
Bonita	0.9975 bc	1.5304 abc*	1.0485 def	1.2891 def*
Carolina Ruby	1.3742 a	1.0428 ef*	1.4407 b	1.2169 f*
Covington	1.4660 a	1.6245 ab	1.4011 bc	1.4330 cdef
Monaco	1.3231 ab	1.3140 bcdef	1.3244 bcd	1.5627 bcde*
Murasaki-29	1.1425 abc	1.7699 a*	0.9740 ef	1.8774 ab*
Purple Majesty	0.5150 d	0.2795 g*	1.3046 bcd	1.2439 ef
Purple Splendor	0.9170 c	1.3599 bcde*	1.3855 bc	2.0736 a*
Ruddy	1.2068 abc	1.0055 f	1.5823 ab	1.2456 ef*
LA 14-41P	0.4874 d	0.05336 g*	0.8994 ef	0.5268 g*
NC 10-0433	1.4136 a	1.2164 cdef	1.8490 a	1.6423 bc*
NC 17-0221	0.8898 c	1.3140 bcdef*	0.7356 f	1.5674 bcd*
Clone × Sample Time ×Year P-value				0.0003

[Z] Values are based on predictions using Near Infrared Spectroscopy (NIRS) calibrations.

[Y] Means followed by the same lowercase letter are not different within a column (Tukey's honest significant difference; α=0.05).

[X] Means followed by an asterisk are different across rows, within year (Tukey's honest significant difference; α=0.05).

Table 1.11 Linear regression parameters modeling storage root sucrose content for each clone throughout storage, modeled separately for 2020 and 2021.

	Intercept (g per 100 g FW)			**Slope (g per 100 g FW per day)**		
	Estimate	**Standard Error**	**P-Value**	**Estimate**	**Standard Error**	**P-Value**
2020						
Bayou Belle	1.4455	0.1111	0.0003	0.01024	0.000821	<0.0001
Beauregard	1.08085	0.1051	0.3919	0.001601	0.000711	0.0325
Bonita	1.5225	0.1111	<0.0001	0.001750	0.000821	0.0421
Carolina Ruby	1.05944	0.1051	0.5110	0.008499	0.000711	<0.0001
Covington	1.6933	0.1111	<0.0001	0.008003	0.000821	<0.0001
Monaco	1.3616	0.1111	0.0023	0.006855	0.000821	<0.0001
Murasaki-29	1.8373	0.1111	<0.0001	0.002819	0.000821	0.0019
Purple Majesty	0.3352	0.1051	<0.0001	0.004215	0.000711	<0.0001
Purple Splendor	1.3925	0.1051	0.0006	-6.55E-6	0.000711	0.9927
Ruddy	0.9895	0.0846	<0.0001	0.005070	0.000821	<0.0001
LA 14-41P	0.1231	0.1111	<0.0001	0.001674	0.000821	0.0511
NC 10-0433	1.2285	0.1111	0.0400	0.005689	0.000821	<0.0001
NC 17-0221	1.3441	0.1111	0.0034	0.003702	0.000821	0.0001
2021						
Bayou Belle	1.2786	0.1136	0.9170	0.01483	0.001823	<.0001
Beauregard	1.34616	0.1028	0.4429	0.000435	0.001307	0.7402
Bonita	1.2136	0.1028	0.6076	0.006171	0.001307	<.0001
Carolina Ruby	1.21076	0.1048	0.5961	0.008533	0.002097	0.0001

Table 1.11 (continued).

Covington	1.471	0.1028	0.0522	0.00883	0.001307	<.0001
Monaco	1.5924	0.1035	0.0028	0.007677	0.001534	<.0001
Murasaki-29	1.9237	0.1038	<0.0001	0.003233	0.001494	0.0339
Purple Majesty	1.26318	0.1028	0.9728	-0.00081	0.001307	0.5398
Purple Splendor	2.1221	0.1028	<0.0001	-0.00348	0.001307	0.0095
Ruddy	1.2667	0.0816	<0.0001	0.004156	0.002468	0.0965
LA 14-41P	0.5442	0.1028	<0.0001	-0.00067	0.001307	0.6095
NC 10-0433	1.6651	0.1035	0.0003	0.009722	0.001534	<.0001
NC 17-0221	1.5415	0.1028	0.0100	0.004395	0.001307	0.0012

Table 1.12 Glucose content of sweetpotato clones before and after curing in 2020 and 2021.

	Glucose Content (g per 100g fresh weight)^Z			
	2020		**2021**	
Clone	**Fresh**	**Cured**	**Fresh**	**Cured**
Bayou Belle	0.5097 b^Y	0.9624 bc*^{X}	0.5388 ab	1.1889 a*
Beauregard	0.4893 b	0.9544 bc*	0.2095 cd	0.7893 b*
Bonita	0.04533 ef	0.3620 efg*	0.1302 de	0.5612 bcd*
Carolina Ruby	0.3189 bc	0.9331 bc*	0.2170 cd	0.8742 ab*
Covington	0.0626 ef	0.6141 cde*	0.1362 de	0.5711 bc*
Monaco	0.09608 def	0.5407 def*	0.1111 de	0.3409 cde*
Murasaki-29	0.08223 def	0.1034 g	0.1099 de	0.2308 de
Purple Majesty	0.2826 cd	0.8974 bcd*	0.1960 cd	0.5703 bc*
Purple Splendor	0.1208 def	0.4074 efg*	7.77E-15 e	0.02555 e
Ruddy	1.0624 a	1.6014 a*	0.6740 a	1.1738 a*
LA 14-41P	0.2637 cde	0.8530 bcd*	0.08049 de	0.7066 b*
NC 10-0433	0.5291 b	1.1796 b*	0.3721 bc	0.8535 ab*
NC 17-0221	0.03916 f	0.2069 fg*	0.03024 de	0.2973 cde*
Clone × Sample Time ×Year P-value				0.0062

^{Z} Values are based on predictions using Near Infrared Spectroscopy (NIRS) calibrations.

^{Y}Means followed by the same lowercase letter are not different within a column (Tukey's honest significant difference; α=0.05).

^{X}Means followed by an asterisk are different across rows, within year (Tukey's honest significant difference; α=0.05).

Table 1.13 Linear regression parameters modeling storage root glucose content for each clone throughout storage and for each sample year throughout storage.

	Intercept (g per 100 g FW)			Slope (g per 100 g FW per day)		
	Estimate	Standard Error	P-Value	Estimate	Standard Error	P-Value
Clone × DAC[Z]						
Bayou Belle	1.3225	0.08202	<0.0001	0.001073	0.0006	0.0744
Beauregard	1.0441	0.07424	<0.0001	0.000596	0.00048	0.2120
Bonita	0.6172	0.07616	<0.0001	-0.0004	0.00051	0.4292
Carolina Ruby	0.9193	0.07671	<0.0001	-0.00195	0.00058	0.0009
Covington	0.7712	0.07616	<0.0001	-0.00027	0.00051	0.5972
Monaco	0.6166	0.07692	<0.0001	-0.00064	0.00057	0.2669
Murasaki-29	0.2343	0.07825	<0.0001	0.000996	0.00054	0.0688
Purple Majesty	0.7558	0.07424	<0.0001	0.000511	0.00048	0.2841
Purple Splendor	0.2979	0.07424	<0.0001	0.001155	0.00048	0.0164
Ruddy	1.6809	0.06065	<0.0001	-0.00021	0.00064	0.7436
LA 14-41P	0.7698	0.07616	<0.0001	0.001179	0.00051	0.0215
NC 10-0433	1.2873	0.07686	<0.0001	0.001667	0.00057	0.0041
NC 17-0221	0.3728	0.07616	<0.0001	0.000712	0.00051	0.1617
Year × DAC						
2020	0.7346	0.08379	0.1141	-0.00001	0.00021	0.9572
2021	0.6112	0.05659	<0.0001	0.00149	0.000208	<0.0001

[Z] DAC = days after curing

Table 1.14 Fructose content of sweetpotato clones before and after curing in 2020 and 2021.

	Fructose Content (g per 100g fresh weight)^{Z}			
	2020		**2021**	
Clone	**Fresh**	**Cured**	**Fresh**	**Cured**
Bayou Belle	0.3692 b^{Y}	0.6572 bc*^{X}	0.3487 ab	0.7518 a*
Beauregard	0.3516 b	0.6497 bc*	0.1370 cde	0.4814 bc*
Bonita	0.05888 e	0.2718 def*	0.02092 e	0.2812 cde*
Carolina Ruby	0.2362 bcd	0.6378 bc*	0.1268 cde	0.5346 ab*
Covington	0.09759 de	0.4368 cd*	0.09011 de	0.3519 bcd*
Monaco	0.1171 cde	0.4013 d*	0.07814 de	0.1974 def*
Murasaki-29	0.07346 e	0.07987 f	0.01878 e	0.03134 f
Purple Majesty	0.3305 b	0.7301 b*	0.1964 cd	0.3913 bcd*
Purple Splendor	0.1564 cde	0.3462 de*	0 e	0.01222 f
Ruddy	0.7855 a	1.1242 a*	0.4606 a	0.7481 a*
LA 14-41P	0.2729 bc	0.6666 bc*	0.09235 de	0.486 bc*
NC 10-0433	0.3809 b	0.8135 b*	0.2423 bc	0.5339 ab*
NC 17-0221	0.03614 e	0.1233 ef	0 e	0.0771 ef
Clone × Sample Time ×Year P-value				0.0080

^{Z} Values are based on predictions using Near Infrared Spectroscopy (NIRS) calibrations.

^{Y}Means followed by the same lowercase letter are not different within a column (Tukey's honest significant difference; α=0.05).

^{X}Means followed by an asterisk are different across rows, within year (Tukey's honest significant difference; α=0.05).

Table 1.15 Linear regression parameters modeling storage root fructose content for each clone throughout storage and for each sample year throughout storage.

	Intercept (g per 100 g FW)			**Slope (g per 100 g FW per day)**		
	Estimate	**Standard Error**	**P-Value**	**Estimate**	**Standard Error**	**P-Value**
Clone × DAC^{Z}						
Bayou Belle	0.8502	0.05143	<0.0001	0.0007	0.000396	0.0801
Beauregard	0.6711	0.04655	<0.0001	0.00045	0.000315	0.1537
Bonita	0.3493	0.04771	<0.0001	0.00044	0.000336	0.1947
Carolina Ruby	0.5938	0.04811	<0.0001	-0.0012	0.00038	0.0021
Covington	0.5116	0.04771	<0.0001	-8E-05	0.000336	0.8048
Monaco	0.3988	0.04818	<0.0001	-0.0003	0.000378	0.3731
Murasaki-29	0.0858	0.04904	<0.0001	0.00081	0.00036	0.0263
Purple Majesty	0.5349	0.04655	<0.0001	0.00054	0.000315	0.0872
Purple Splendor	0.2134	0.04655	<0.0001	0.00055	0.000315	0.0862
Ruddy	1.1042	0.03875	<0.0001	-0.0002	0.000421	0.7261
LA 14-41P	0.5477	0.04771	<0.0001	0.00092	0.000336	0.0071
NC 10-0433	0.8469	0.04813	<0.0001	0.00098	0.000378	0.0106
NC 17-0221	0.1612	0.04771	<0.0001	0.00061	0.000336	0.0741
Year × DAC						
2020	0.5375	0.05795	0.0045	-0.0001	0.000134	0.2956
2021	0.3686	0.03914	<0.0001	0.00124	0.000132	<0.0001

^{Z}DAC = days after curing

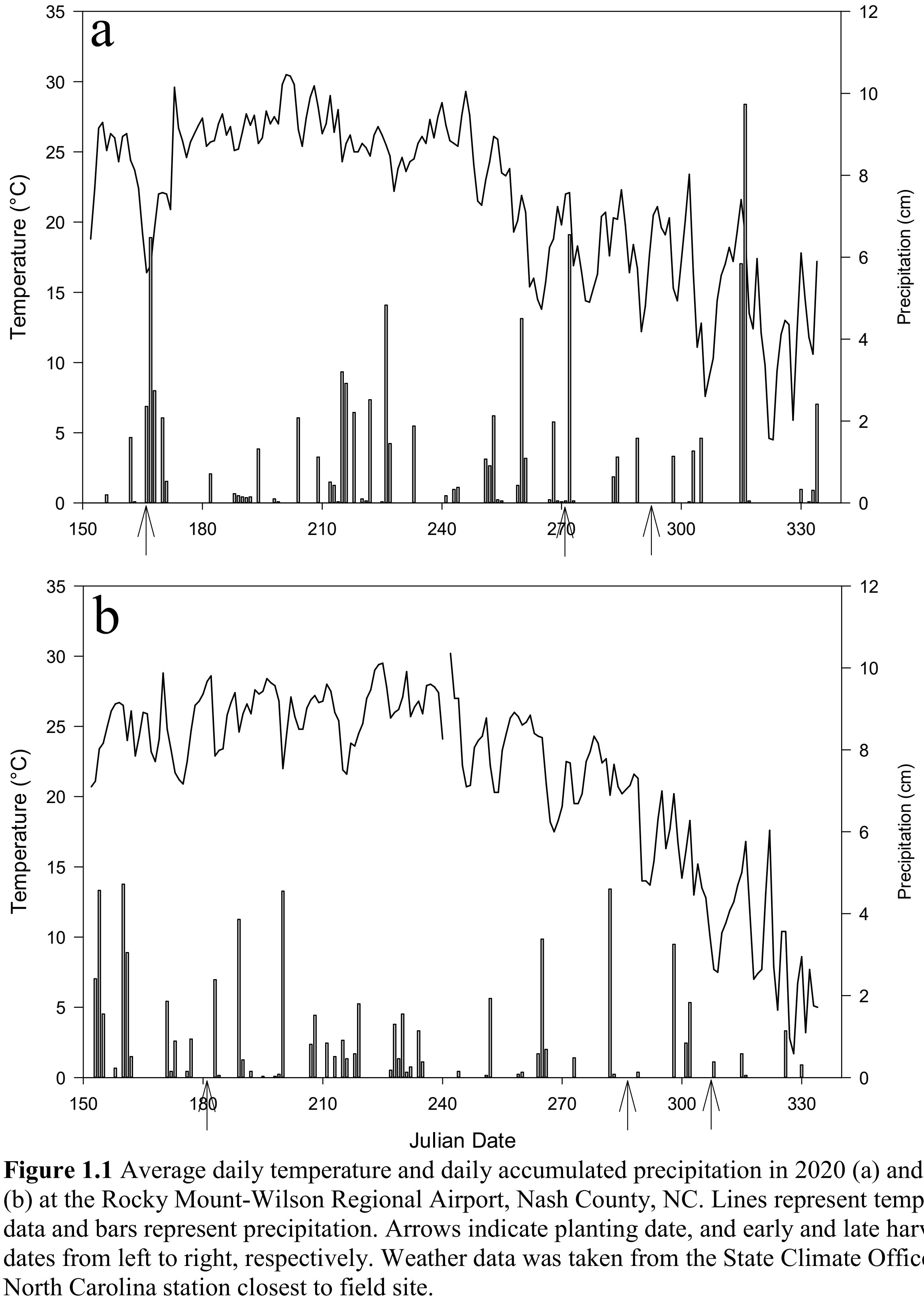

Figure 1.1 Average daily temperature and daily accumulated precipitation in 2020 (a) and 2021 (b) at the Rocky Mount-Wilson Regional Airport, Nash County, NC. Lines represent temperature data and bars represent precipitation. Arrows indicate planting date, and early and late harvest dates from left to right, respectively. Weather data was taken from the State Climate Office of North Carolina station closest to field site.

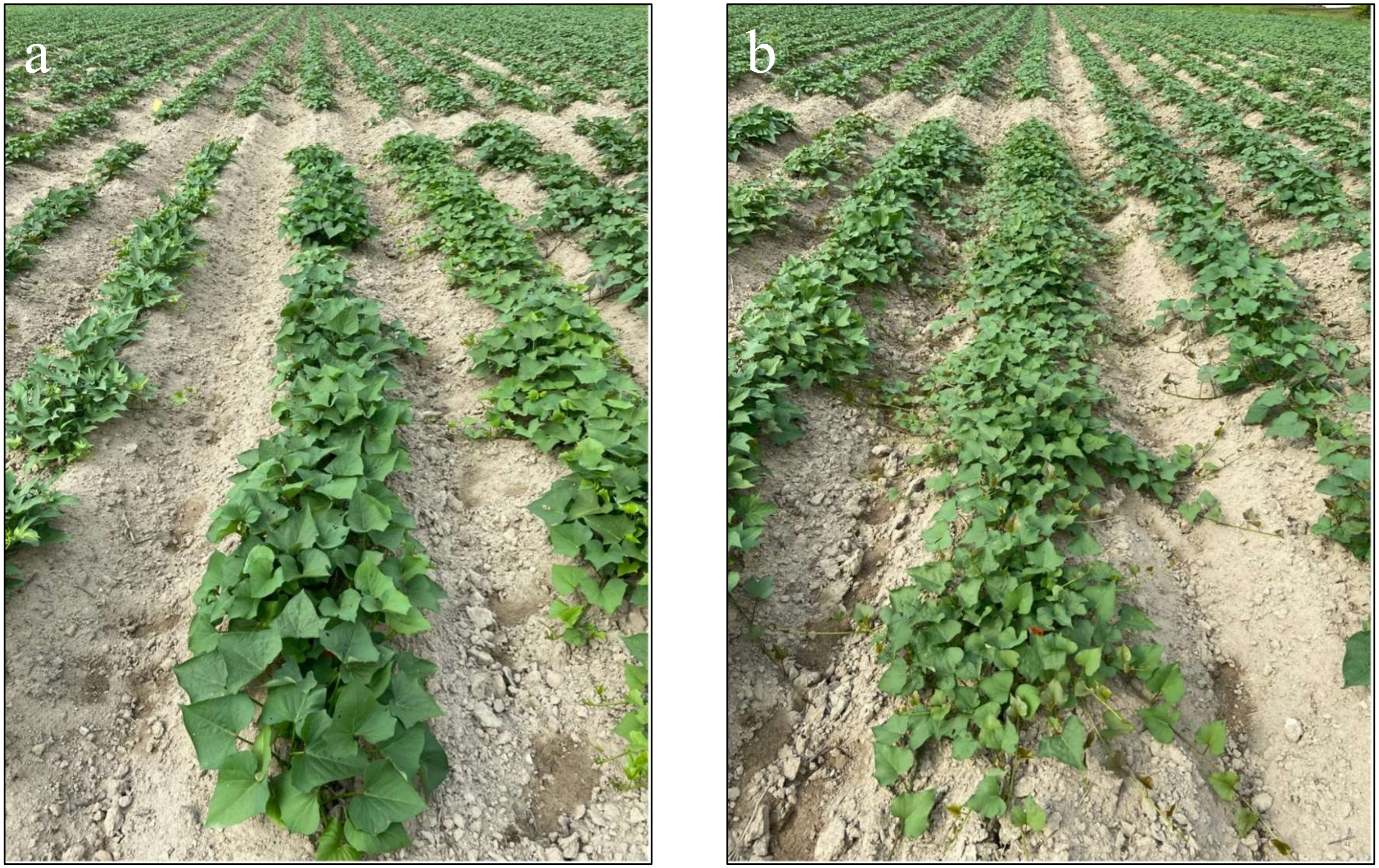

Figure 1.2 Sweetpotato growth habits. Clones with an upright growth habit, such as ‘Monaco’, were scored ‘1’ on the rating scale (a). Clones with a spreading growth habit, such as ‘Carolina Ruby’, were scored ‘9’ on the scale (b).

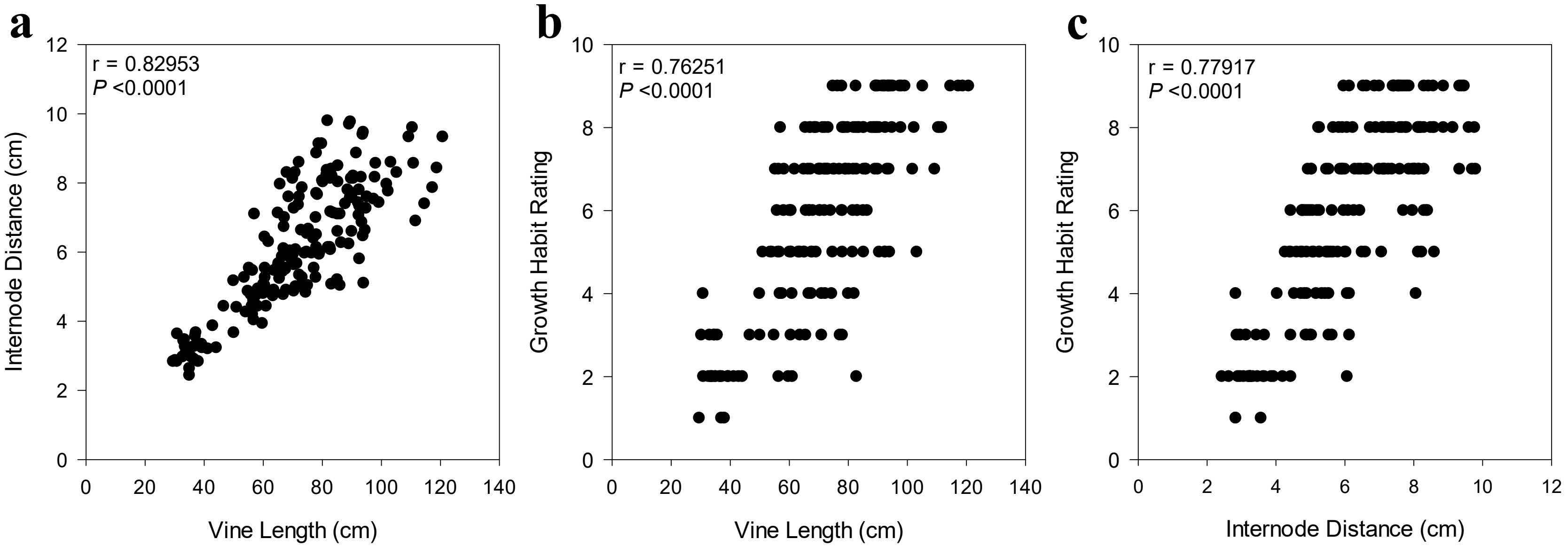

Figure 1.3 Correlations between vine length and internode distance (a), vine length and growth habit rating (b), and internode distance and growth habit rating (c), presented with Pearson correlation coefficients. The length of the longest vine was recorded for five representative plants per plot. Internode length was measured on these same plants by averaging the length of three internodes, starting from the fifth node from the growing tip and measuring towards the crown of the plant. For the growth habit rating scale plants with upright growth were scored 1 and plants with prostrate growth were scored 9.

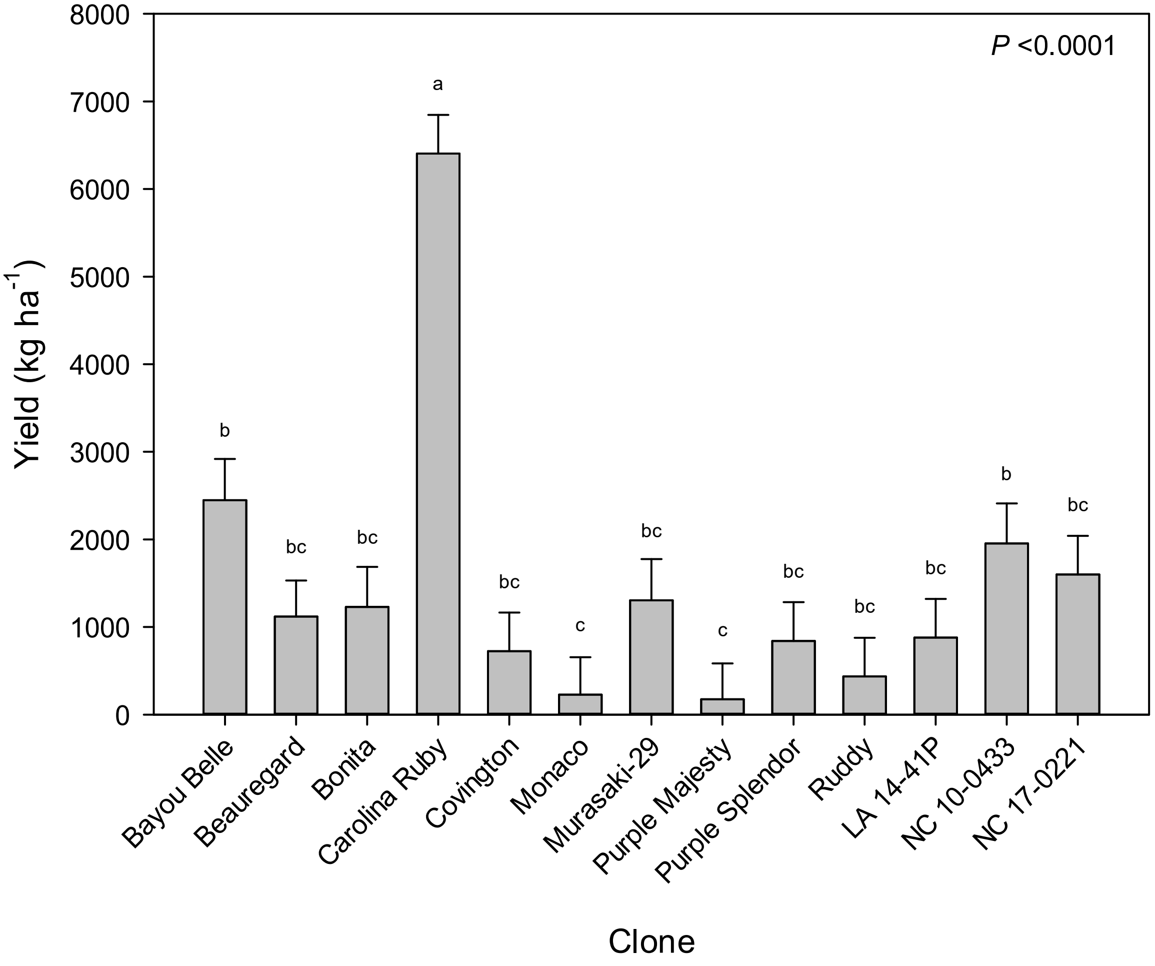

Figure 1.4 Main effect of clone on cull yield. Culls were defined as any root containing rot, severely misshapen, or rendered otherwise unmarketable. Clones with the same letter above the bar are not different (Tukey's honest significant difference; $\alpha=0.05$). Error bars reflect standard error.

Figure 1.5 ‘Carolina Ruby’ is prone to cracking due to fluctuations in moisture, which results in unmarketable storage roots.

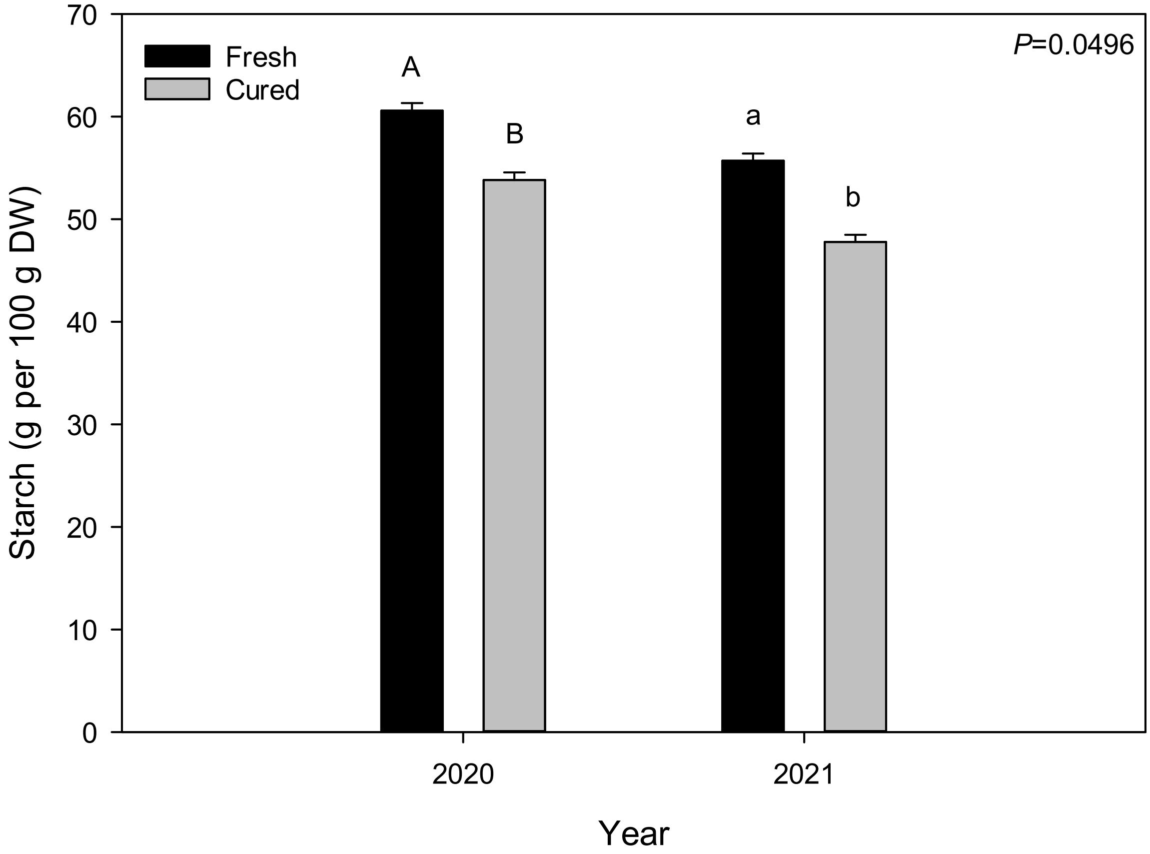

Figure 1.6 Sweetpotato starch content of fresh roots and cured roots, averaged over all clones. Sampling times with the same letter above the bar are not different, within year (Tukey's honest significant difference; α=0.05). Error bars reflect standard error. Values are based on predictions using NIRS calibrations.

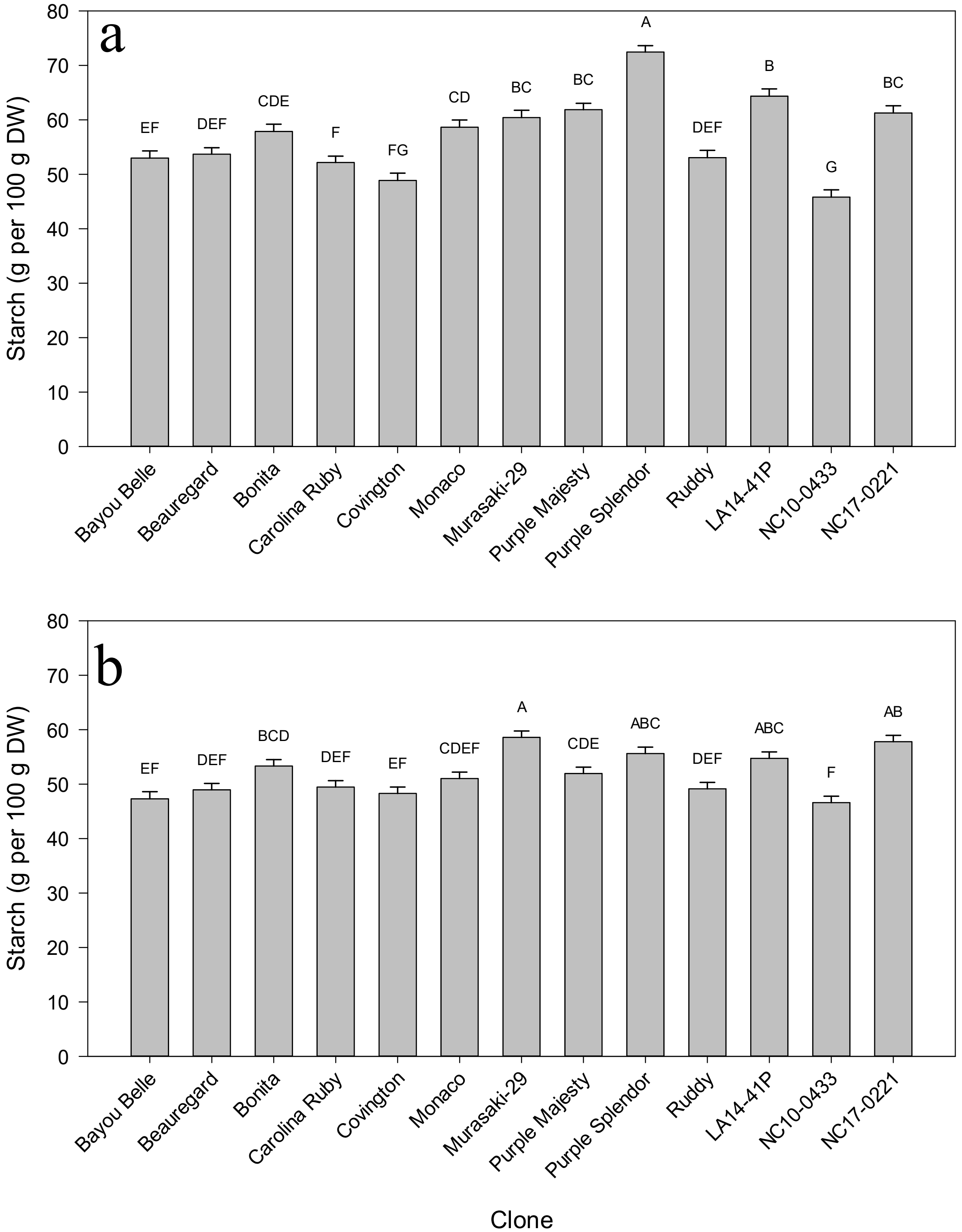

Figure 1.7 Average starch content of sweetpotato clones during the curing process in 2020 (a) and 2021 (b). Clones with the same letter above the bar, within year, are not different (Tukey's honest significant difference; α=0.05). Error bars reflect standard error. Values are based on predictions using NIRS calibrations.

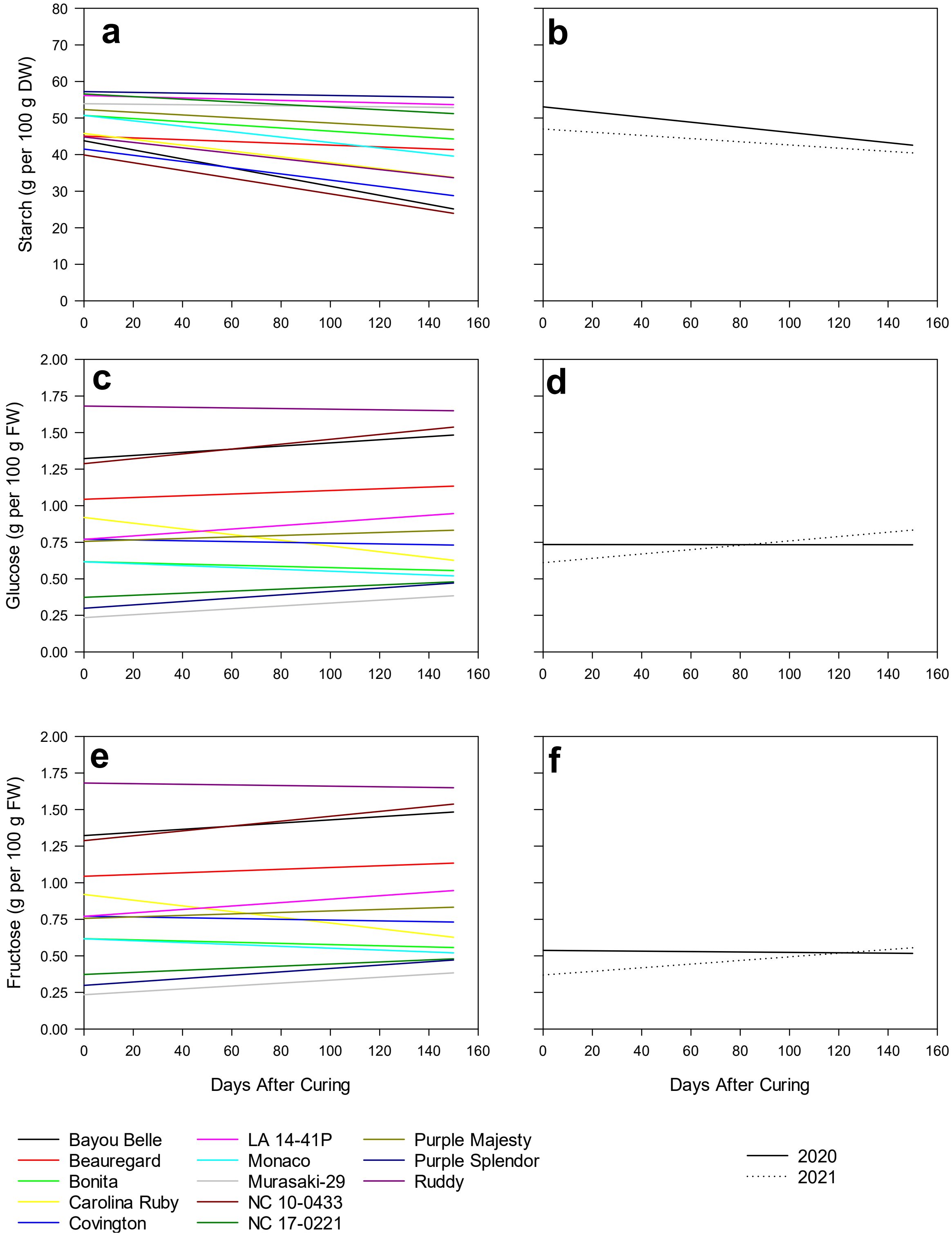

Figure 1.8 Linear regression equations of starch, glucose, and fructose content through 5 months of storage for clones (a, c, and e, respectively) and years (b, d, and f, respectively). Values are based on predictions using NIRS calibrations.

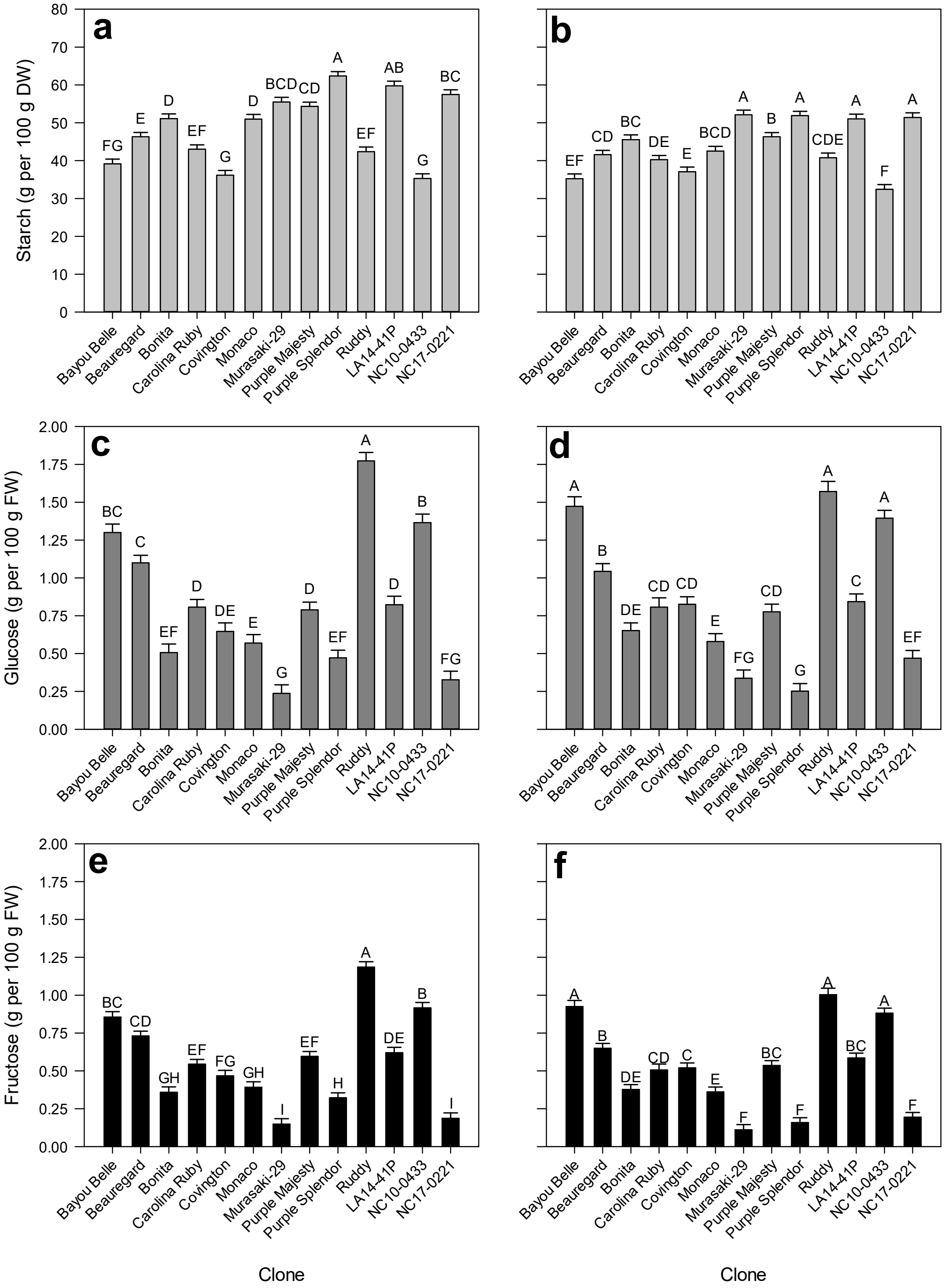

Figure 1.9 Average starch, glucose, and fructose content of sweetpotato clones through 5 months of storage in 2020 (a, c, and e, respectively) and 2021 (b, d, and f, respectively). Clones with the same letter above the bar are not different within response and year (Tukey's honest significant difference; α=0.05). Error bars reflect standard error. Values are based on predictions using NIRS calibrations.

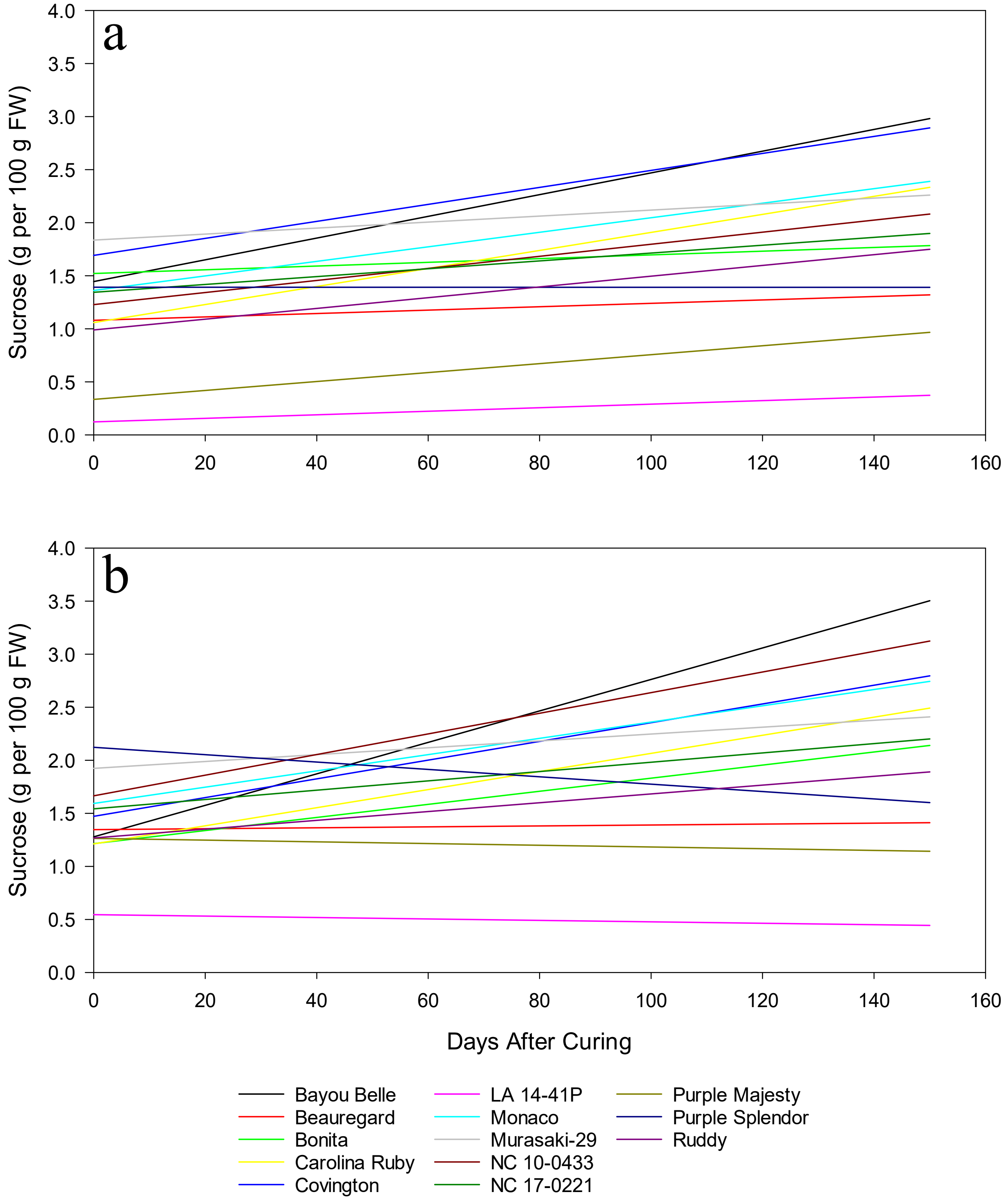

Figure 1.10 Linear regression equations of sucrose content through 5 months of storage for clones in 2020 (a) and 2021 (b). Values are based on predictions using NIRS calibrations.

CHAPTER TWO

Planting Orientation of Stem Cuttings in Organic Sweetpotato Production

ABSTRACT

Sweetpotato [*Ipomoea batatas* (L.) Lam.] has become one of North Carolina's most important organic commodity crops; however, yields tend to be lower in organic fields compared to conventional fields. Traditional field establishment utilizes unrooted stem cuttings that are transplanted vertically in the soil. Producers in some other countries transplant cuttings horizontally and empirical evidence from NC sweetpotato producers suggest that this method may improve yields. An organically managed field study using 'Monaco' was conducted in 2020 and 2021 in Bailey, North Carolina to evaluate three planting orientations: vertical, sleeve (portion of cutting horizontal), and horizontal. Two stem cutting lengths (25 cm and 38 cm) were investigated, as well as two different harvest times (~108 days and ~126 days), resulting in a 3 transplant orientations × 2 stem lengths × 2 harvest times full factorial randomized complete block design with 4 blocks. Early and late harvests were nested within blocks. In 2020, marketable yields were 16% higher for the horizontal orientation compared to vertical orientation, with intermediate yields with the sleeve attachment. However, in 2021, there were no significant differences in marketable yield among planting orientations. In both years, No. 1 yields were significantly higher when cuttings were planted horizontally compared to vertically, with an average increase of 18%. Results of this study indicate that delaying harvest until ~126 days is recommended to increase yields for 'Monaco,' regardless of planting orientation. This study provides evidence that a horizontal planting orientation could increase crop yields and improve land use efficiency for organic sweetpotatoes.

INTRODUCTION

One criticism regarding organic production systems is that generally yields are lower than conventional systems; although yield differences are dependent on the crop, growing region, and other important contextual information (de Ponti et al., 2012; Seufert et al., 2012; Smith et al., 2019). In a review article, Reganold and Wachter (2016) reported that yield averages can range from 8% to 25% lower in organic systems than conventional, with the difference varying depending on the crop analyzed. Other researchers have analyzed yield stability, or the variation in yield over time, between organic and conventional systems, concluding that organic has lower stability as well (Knapp and van der Heijden, 2018; Smith et al., 2019). Specifically, for sweetpotatoes [*Ipomoea batatas* (L.) Lam.] in the Southeastern US, organic systems have been estimated to yield 2% lower than conventional systems based on a meta-analysis of yield data from 2005 through 2017 (Nwosisi et al., 2021).

Lower average yields in organic commodities is problematic as we aim to increase food production with a growing global population, particularly with the growing demand for organic foods. The United States is the largest single market for organic foods, valued at approximately $49.5 billion and comprising 41% of the global market in 2020 (Willer et al., 2022). Fueled by the pandemic, in 2020, US organic product sales increased by $17 billion, the largest single year growth recorded (Willer et al., 2022). Therefore it is imperative to find ways to improve land use-efficiency in organic systems in order to continue to meet market demands.

In sweetpotato, we investigated the orientation of planting as one potential method to improve yields. Traditional field establishment of sweetpotato in the US utilizes unrooted stem cuttings that are transplanted vertically into the soil. However in some other countries cuttings are oriented at an angle or horizontally (Coleman et al., 2006; Low et al., 2009; Yan et al., 2022;

Zhang et al., 2009) and empirical evidence from NC sweetpotato producers suggest that horizontal orientation may improve yields. Published research on this matter has indicated mixed results. Some researchers have found no differences in yield between vertical and horizontal orientations (Dlamini et al., 2021; du Plooy et al., 1992; Monks, 1981). Dayal and Sharma (1993) observed higher yields with vertical than horizontal. Pakkies et al. (2019) and Belehu and Hammes (2010) both had higher yields with horizontal. Still others have found mixed results within their studies, observing cultivar-specific responses (Chen et al., 1982; Hall, 1986; Levett, 1993).

New research comparing planting orientations is necessary because the published research has faults that limit its applicability to NC growers. Firstly, most studies comparing planting orientations only analyzed data collected from one season. This limits the universality of the results and suggests results could be relevant only to the conditions of that location and season. In addition, the evidence of cultivar-specific responses demands research evaluating cultivars that are important to present-day growers in NC. Another drawback of the published literature is that many relied on hand planting to implement orientation treatments. Chen et al. (1982) is one of the only studies to adapt a mechanical transplanter, but their results evaluating orientations are confounded by using different transplant lengths for the horizontal and vertical treatments. Growers in the US rely on mechanical transplanters to plant cuttings due to their economy, therefore it is necessary to test a mechanized system in order for the results to be directly applicability to commercial growers in the region.

Recently, a sleeve adaptor has been developed as an attachment to the vertical planter (Fig. 2.1). Crafted with painted steel, it surrounds the stem cuttings while they are in the clips and traveling to the release point. It also bends the cutting to form an angled orientation when planted and there is speculation that this may increase yields. There is great interest in this attachment, seeing as it would be a relatively low-cost investment for a grower. Therefore, we chose to include it as one of our planting orientation treatments in this study.

The number of storage roots a plant sets is determined early in the growing season and the roots expand in size throughout the remainder of the season (Lowe and Wilson, 1974b; Scott and Bouwkamp, 1975; Villordon et al., 2009b). However, many different environmental factors influence root bulking (Kays, 1985), including moisture (Hartman and Gaylord, 1943) and temperature (Arancibia et al., 2014; Reynolds et al., 1994). Given favorable environmental conditions, sweetpotato roots will continue to increase in size, and therefore delaying harvest can increase yields (USDA, 2016). Due to this indeterminate characteristic of the crop, the timing of sweetpotato harvest is typically determined by exposing a few hills to evaluate the size of the storage roots. The ideal harvest time would maximize the storage roots that are No. 1 grade (roots 4.4 cm to 8.9 cm in diameter and 7.6 cm to 22.9 cm in length; USDA 2005), so as to minimize roots that fall into a less profitable grade due to their size.

Adventitious roots arise from root primordia on the nodes or from wound callous on the cut end of the stem cutting (Belehu et al., 2004). Based off of this understanding, it is theorized that more nodes buried would permit higher sweetpotato storage root yields. Therefore Southeastern US extension publications generally recommend burying more nodes when planting to increase yields (Boudreaux, 2009; Granberry et al., 2007; Shankle and Reddy, 2020). However, studies investigating this relationship present mixed results. Although they used planting depth as a proxy for number of nodes buried, Thompson et al. (2017) found higher yields at 6 inch [15 cm] planting depths compared to 2 inch [5 cm] depths. Hall (1986) reported no effect on marketable root yields, but found the effects on No. 1 yields were cultivar dependent. Rós (2017) found that the number of buried nodes had no impact on number or yield of roots using 'Uruguaina' in a one-year study. In our study, we investigated two stem cutting lengths to tease apart if the number of nodes buried correlates with yields or if longer cuttings can improve yields.

For this study we used the cultivar Monaco because it has several beneficial attributes for organic production. It has a good pest and disease resistance package, including resistance to Fusarium wilt and Southern Root Knot nematode, and moderate resistance to Streptomyces soil rot, flea beetle, and the Wireworm Diabrotica Systena complex. In addition, it has an upright growth habit, which may contribute to tolerance of weed interference and would allow for prolonged cultivations (Smith et al., 2022). However, this cultivar typically yields lower than 'Covington' (Yencho and Pecota, 2022), the most commonly grown cultivar in NC, which may limit its adoption by growers.

We had three main objectives for this study. 1. Evaluate if the planting orientation of stem cuttings impacts yield. 2. Harvest at two different dates (~90 and 120 days after planting (DAP)) to evaluate if altering orientation delayed storage root bulking. 3. Evaluate two stem cutting lengths (25 cm and 38 cm) to investigate if cutting length and/or the number of nodes buried influences yield.

We hypothesized that: 1. the highest yields would be obtained with the horizontal planting orientation, medium yields with the sleeve, and the lowest yields with vertical orientation. We hypothesized that the horizontal orientation may have higher yields because this planting method could bury more nodes under the soil surface. 2. We anticipated higher yields at the later harvest. If horizontal increased the number of roots per plant, we anticipated that this orientation would need a longer season for roots to grow to No. 1 grade dimensions. 3. We predicted that cuttings that had more nodes buried would have higher yields.

MATERIALS AND METHODS

Experiments were conducted in 2020 and 2021 at Jones Family Farms, in Bailey, NC (lat. 35°49’32”N, long. 78°7’45”W). The soil is Norfolk loamy sand (fine-loamy, kaolinitic, thermic Typic Kandiudults) and Gritney sandy loam (fine, mixed, semiactive, thermic Aquic Hapludults). Fields used in the experiment had been managed organically for at least 7 years. The preceding crop for both years was soybeans [*Glycine max* (L.) Merr]. In June, prior to sweetpotato planting, poultry litter was applied and incorporated at a rate of approximately 6.7 Mg ha^{-1}. An exact nutrient analysis of the litter applied was not obtained. The nutrient composition varies depending on if the source was broiler or layer chickens, with average nutrient compositions of 29 kg N, 20 kg P, 24 kg K Mg^{-1} and 24 kg N, 22 kg P, 20 kg K Mg^{-1}, respectively (Nutrient Management Team, 2022a). According to standard nutrient management guidelines for poultry litter in NC, it is assumed that 60% of the nitrogen, and 100% of the phosphorus and potassium is plant available when incorporated (Nutrient Management Team, 2022b). Therefore it is estimated that approximately 96 to 116 kg ha^{-1} N, 134 to 150 kg ha^{-1} P, and 133 to 163 kg ha^{-1} K were applied to the trial.

Three transplant orientation treatments were investigated: vertical, vertical transplanter with a sleeve attachment (portion of stem/transplant cutting horizontal; referred to as “sleeve”), and horizontal. Two stem cutting lengths (25 cm and 38 cm from cut end to growth tip) were evaluated as well as two harvest times (104 and 127 DAP in 2020 and 111 and 125 DAP in 2021) resulting in a 3 transplant orientations × 2 stem lengths × 2 harvest times full factorial randomized complete block design with four blocks. Harvest time was nested within blocks. The sweetpotato cultivar Monaco was used in both years of this study.

Planting occurred on 10 June 2020 and 9 June 2021. Treatment plots contained two rows spaced 1.1 m apart and 7.6 m long. There were two row buffers between plots in 2020 and no buffers in 2021. Cuttings were planted with an in-row spacing of 27 cm with a standard commercial two-row bare root transplanter (2-row bare root transplanter; B & S Enterprises, Inc. Elizabeth City, NC). The vertical transplant orientation was achieved by normal operation of the transplanter. For the sleeve transplant treatment, a painted steel sleeve attachment (B & S Enterprises, Inc. Elizabeth City, NC) was mounted onto the transplanter to guide the stem cuttings down into the opener (Fig. 2.1). When released into the furrow, the stem cutting has a slanted orientation, with a portion of the cutting having a horizontal orientation. A separate transplanter was used to achieve horizontal stem cutting placement (Fig. 2.2). In 2020, this tool was a 4-row horizontal transplanter constructed by Jones Family Farms. In 2021, a 2-row horizontal transplanter constructed by Jones Family Farms was used. A furrow is opened, approximately 13 cm deep, in which stem cuttings are placed, by hand, horizontally in the soil with the top 8 to 10 cm of the stem cutting remaining above the soil line. The furrow is then closed, securing the stem cutting in place.

Standard organic management practices were followed throughout the season (Jennings et al., 2019; Table 2.1). Plots were managed for weeds by cultivation approximately every ten days until canopy closure and with weekly hand removal throughout the growing season. Table 2.2 includes the monthly rainfall and average temperatures during the growing seasons.

Data Collection

Prior to transplant, nodes were counted on 12 stem cuttings per plot.

Stand counts were taken 12 and 6 DAP in 2020 and 2021, respectively. On the same date, the number of nodes above the soil line were recorded for 12 plants per plot, in order to calculate the number of nodes buried for each treatment.

At harvest, sweetpotato vines were mowed and storage roots were harvested using a customized single-row chain digger (Strickland Brothers, Nashville, NC). Only one row per plot was harvested for data collection. Roots were graded using USDA standards (2005) into canners (2.5 cm to 4.4 cm diameter), No. 1 (4.4 cm to 8.9 cm diameter, 7.6 cm to 22.9 cm length), jumbos (greater than 8.9 cm diameter) and culls. Marketable yield was calculated as the sum of canners, No. 1's, and jumbos (Yencho and Pecota, 2022). Culls were defined as any root containing rot, severely misshapen, or rendered otherwise unmarketable. The weight and number of roots for each grade were recorded. In addition, the length and maximum circumference of 10 representative No. 1 roots per plot were recorded. The maximum circumference was used to calculate root diameter.

Data were analyzed using mixed models with the GLIMMIX procedure in SAS version 9.4 (SAS Institute, Cary, NC). Transplant orientation, stem length, harvest time, and year were treated as fixed effects. Block within harvest × year was treated as a random effect. Least squared mean separation was completed using Tukey's HSD adjustment at a significance of $P \leq 0.05$. Due to the nonnormal nature of proportion data, a beta distribution was used when analyzing the proportion of marketable yields made up by individual grades. Means were back transformed for reporting. Cull weight and count data were square root transformed prior to analysis in order ameliorate heteroskedasticity.

RESULTS

Stand Counts

Stand counts were similar for all orientation and stem cutting length treatments (P >0.05; data not shown). Stand counts differed by study year ($P = 0.0007$), with average stands of 27.9 plants in 2020 and 26.5 plants in 2021.

Total Nodes

Total nodes were significantly ($P = 0.0003$) affected by the interaction of stem cutting length and year (Fig. 2.3a). In both years, 38 cm cuttings had more nodes than 25 cm cuttings; however, in 2021 there was a larger difference in the number of nodes than in the prior year.

Buried Nodes

A significant interaction ($P = 0.0030$) of stem cutting length and year affected the number of nodes buried (Fig. 2.3b). In both years, more nodes were buried for the 38 cm stem cuttings than the 25 cm cuttings. However, in 2021, more nodes were buried for each stem length than were buried in 2020. In addition, a significant interaction ($P = 0.0064$) of stem cutting length and orientation affected the number of nodes buried. The average number of nodes buried differed by orientation for only the 25 cm length, with more nodes buried with the horizontal orientation than the vertical and sleeve orientations (Fig. 2.4).

Significant, but weak positive correlations were found between the average number of nodes buried and marketable yield ($P = 0.0246$), the number of marketable roots ($P = 0.0033$), No. 1 yield ($P = 0.0232$), and the number of No. 1 roots ($P = 0.0161$; Fig. 2.5).

No. 1 Root Dimensions

The effect of harvest time on root diameter differed in the study years ($P = 0.0007$; Fig. 2.6). In 2020, roots were wider at the late harvest compared to the early harvest, sizing up by 0.6

cm. However, in 2021, root diameter was similar at both harvests. Stem cutting length and planting orientation had no impact on root diameter ($P > 0.05$).

Significant main effects of stem cutting length ($P = 0.0125$), orientation ($P < 0.0001$), and harvest time ($P = 0.0002$) influenced No. 1 root length (Fig. 2.7a-c). Roots from 38 cm stem cuttings were 0.5 cm longer than roots from 25 cm cuttings. Roots from stem cuttings that were planted horizontally were significantly longer than roots from the sleeve and vertical orientations by 1.7 cm and 1.9 cm, respectively. Roots harvested later in the season were 1.5 cm longer than roots harvested earlier in the season.

Marketable Yield

The horizontal planting orientation had higher marketable yields than the vertical orientation in 2020, but all orientations had similar yields in 2021 ($P = 0.0126$; Table 2.3). Marketable yield was also affected by harvest time ($P < 0.0001$; Table 2.3), in which yields increased 49% when harvest was delayed. However, marketable yields were similar for both stem cutting lengths ($P > 0.05$; Table 2.3). The number of marketable roots was affected by the interaction of stem cutting length and year ($P = 0.0002$; Table 2.4). In 2020, plants grown from both stem cutting lengths yielded similar numbers of marketable roots. However, in 2021, plants grown from 38 cm stem cuttings yielded approximately 0.7 more marketable roots per plant than those grown from 25 cm cuttings. In addition, we observed differences in the number of marketable roots between harvest times ($P = 0.0004$; Table 2.4); plants at late harvest averaged approximately 0.7 more marketable roots per plant than those harvested earlier in the season. The number of marketable roots was similar for all planting orientations ($P > 0.05$; Table 2.4).

No. 1 Yield

No. 1 yield was higher with the horizontal orientation treatment than sleeve and vertical orientations (*P* = 0.0008; Table 2.3). Yield with the horizontal orientation was 18% higher than the vertical orientation. In addition to increased weights, the horizontal orientation also had approximately 0.3 more No. 1 roots per plant than the vertical orientation, and sleeve was intermediate (*P* = 0.0167; Table 2.4). No. 1 root weights (*P* = 0.0239) and counts (*P* = 0.0237) also increased when harvest was delayed, but the magnitude of these increases varied by study years (Table 2.3 and 2.4). In 2020, the total weight of No. 1 roots increased by 74%, whereas in 2021 yield only increased by 22%. Similarly, in 2020 late harvested plants produced 0.8 more No. 1 roots, but in 2021 late harvested plants only yielded 0.4 more roots per plant. Stem cutting length had no impact on No. 1 yields or counts (*P* > 0.05; Table 2.3 and 2.4).

The proportion of marketable yield that was No. 1 grade depended on the planting orientation (*P* = 0.0018). No. 1 grade roots made up a significantly higher proportion of the marketable weight with the horizontal orientation (63%) than either the sleeve (59%) or vertical orientations (56%; Fig. 2.8a).

Jumbo Yield

No differences were observed in jumbo root yield among the planting orientation treatments in 2020. However, in 2021 the horizontal orientation had lower jumbo yields than the sleeve and vertical orientations (*P* = 0.0360; Table 2.3). In addition, the yield of jumbo roots was influenced by stem cutting length (*P* = 0.0011; Table 2.3); 25 cm stem cuttings yielded 2,061 kg ha^{-1} more than the 38 cm stem cutting treatment. We also measured a jumbo weight increase by 159% when harvest was delayed until late season (*P* < 0.0001; Table 2.3).

The number of jumbo roots per plant was significantly influenced by the main effects of orientation ($P = 0.0050$), stem cutting length ($P = 0.0002$), harvest time ($P < 0.0001$), and year ($P = 0.0008$; Table 2.4). The horizontal orientation yielded significantly fewer jumbo roots than the vertical orientation, representing a 27% reduction. In addition, there was a 26% reduction in the number of jumbo roots per plant when longer stem cuttings were used. However, delaying harvest until later in the season resulted in more jumbo roots than at the early harvest. In addition, the number of jumbo roots per plant was higher in 2021 than 2020.

A significant interaction ($P = 0.0141$) of stem cutting length and harvest time affected the proportion of marketable yield by weight that was from jumbo roots (Fig. 2.9). At the early harvest, jumbo roots made up a higher percentage of the marketable weights with the 25 cm stem cutting treatment. However, there was no difference between stem cutting lengths at the late harvest, although there was a trend of a higher percentage of jumbo roots at the 25 versus 38 cm plant length. Jumbo roots made up a lower proportion of the marketable yield with the horizontal planting orientation compared to the vertical orientation, with the sleeve orientation having intermediate values ($P = 0.0080$; Fig. 2.8b). In 2020, 12.3% of the marketable yield was from jumbo roots, but in 2021, 23.1% of the weight was from jumbo roots, nearly double that of the previous year ($P < 0.0001$), when averaged over harvests, stem cutting lengths, and all orientations.

Canner Yield

The number ($P = 0.0017$) and weight ($P = 0.0171$) of canner roots was significantly affected by the interaction of stem cutting length and year (Table 2.3 and 2.4). In 2020, both stem cutting lengths had similar sweetpotato weights and counts. However, in 2021, the 38 cm cuttings yielded higher weight and counts than the 25 cm cuttings. The number of canner roots was also significantly influenced by the interaction of harvest time and year (*P* = 0.0115; Table 2.4). In 2020, the early harvest averaged 0.5 more roots per plant than the late harvest. However, in 2021 both harvest times had similar numbers of roots. The yield and number of canners were similar for all planting orientations (*P* > 0.05; Table 2.4).

The proportion of marketable yield that was canner grade decreased when harvest was delayed until later in the season. However, this difference was more pronounced in 2020 (*P* = 0.0433; Fig. 2.10). Canner roots also made up a larger proportion of marketable yield with 38 cm stem cuttings than 25 cm cuttings, 23.6% and 19.0%, respectively (*P* = 0.0002). Planting orientation had no effect on the proportion of canners (*P* > 0.05).

Cull Yield

Although there were some significant differences attributed to treatments, the weight or the number of cull roots comprised less than 2% of the total yields and were of no practical significance in this study. A significant interaction (*P* = 0.0412) of stem cutting length, harvest and year affected the yield of cull roots (Fig. 2.11). In 2020, there was no difference in yield among the stem cuttings lengths or harvest times. However, in 2021, 38 cm cuttings had lower yields at early harvest than either cutting length at late harvest, and 25 cm cuttings at early harvest had intermediate yields. A significant (*P* = 0.0435) main effect of harvest time affected the number of cull roots per plant. There were 0.072 cull roots per plant at the late harvest, more than double the number at the early harvest, 0.035 roots.

Average Root Sizes

In both years, there was a significant main effect of harvest time on the average size of No. 1 (*P* = 0.0034) and jumbo roots (*P* = 0.0372; Table 2.5). Roots from both grades were larger at the late harvest. The average weight of canner roots (*P* = 0.0043) and the average weight of marketable roots (*P* = 0.0420) had significant interactions of harvest by year (Table 2.5). Canner roots increased in size from early to late harvest in 2020, but this increase was not observed in 2021. For marketable roots, the average size increased between early and late harvests in both years, but there was a larger difference in 2020.

The average size of marketable roots was also influenced by the interaction of stem cutting length and year (*P* = 0.0081), in which roots were larger in 2021 when 25 cm stem cuttings were used (Fig. 2.12). The average size of No. 1 roots was also influenced by the interaction of planting orientation and year (*P* = 0.0282; Fig. 2.13). In 2020, the horizontal treatment had larger roots than the sleeve and vertical treatments. However, in 2021, all treatments had similar root sizes. Lastly, jumbo roots were approximately 10% larger in 2021 than in 2020 (*P* = 0.0097; Table 2.5).

DISCUSSION

Longer stem cuttings had more nodes and more nodes buried (Fig. 2.3). Our node counts were taken soon after a cultivation event in 2021, which likely explains why more nodes were buried in that year compared to the prior year. Although correlations were weak, we found that more nodes buried correlated with higher marketable and No. 1 yields (Fig. 2.5). Thompson et al. (2017) attributed higher yields of ‘Covington’ planted at deeper depths to more nodes buried. Contrasting this, Hall (1986) found that the effect of the number of nodes buried on No. 1 yields was cultivar dependent and Rós (2017) found no influence of number of nodes buried on number or yield of roots using ‘Uruguaina’ in a one-year study.

We hypothesized that a horizontal planting orientation would increase yields due to it burying more nodes than the vertical planter. We saw similar or higher marketable and No. 1 yields with horizontal orientation (Table 2.3). However, we only had more nodes buried with the horizontal orientation with the 25 cm cutting length (Fig. 2.4). The longer stem cuttings had similar nodes buried with all orientations, and still had the yield increase with horizontal. This suggests that the number of nodes buried is not the only mechanism by which yield may be improved with the horizontal orientation.

Although beyond the scope of the current study, other researchers have hypothesized that horizontal orientation has better yields and shapes due to the spatial arrangement of the subterranean nodes, which may reduce competition for water, nutrients, and space among developing roots at each node. One of the earliest documented observations of differences in root set arrangement was from test plots in South Carolina in 1950. Roots were uncovered from horizontally and vertically planted cuttings, and it was observed that for plants laid horizontally, “the sweet potatoes are set in a linear manner instead of in the usual clusters” (Park et al., 1953). They speculated the better root shape was due to less competition for space because the roots were set along the entire vine. Chagonda et al. (2014) attributed the higher mean root diameter found with horizontal planting compared to looped (cutting looped and buried with both ends above the surface) to increased competition for space affecting storage root expansion with the looped orientation. In an abstract presented in 2019, Gregorie and Villordon also hypothesized that horizontal would potentially have more nodes buried, less competition for space, and greater nutrient acquisition, which could be factors potentially increasing yields and uniformity.

Root shape is important because growers for the fresh market want roots within the No. 1 grade dimensions to maximize profits. Short and round roots may not meet these requirements, and therefore be graded as an off grade by the packinghouse, which reduces grower profits. Thus a longer root may help to optimize the number and weight of roots that fall within the No. 1 grade.

Sweetpotatoes are indeterminate so under favorable growing conditions, roots will continue to enlarge (USDA, 2016). Lowe and Wilson (1974a) observed stabilization of storage root number by 8 weeks [56 days] after planting in 5 of the 6 cultivars they studied. Throughout the remainder of the season they observed growth of these established storage roots. Specifically, they observed high rates of expansion of storage root width during the 16 to 24 week period after planting (Lowe and Wilson, 1974b).

With this developmental process in mind, we expected that delayed harvest would increase root dimensions. The diameter of No. 1 roots could increase when harvest is delayed because small No. 1 roots would be able to continue to expand with extra time in the field. We only observed this harvest timing effect in 2020 (Fig. 2.6), which may be due to more time between harvests in this year compared to 2021; in 2020 there were 23 days between harvests, but only 11 days between harvests in 2021. No. 1 roots were also longer when harvest was delayed (Fig. 2.7c). Again, the additional 12 days in the field may have allowed further starch accumulation and root expansion. We also observed that No. 1 roots from 38 cm stem cuttings were longer than roots from 25 cm cuttings (Fig. 2.7a). The average internode distance was similar for both stem cutting lengths, therefore differences in spatial separation between nodes cannot explain this difference in root length (data not shown).

Most studies comparing root dimensions among planting orientations have averaged lengths and widths across all grades. In regards to root length, many found no difference among orientations. Chagonda et al. (2014) found no difference in root length between horizontal, looped (cuttings tied in a loop that was buried with ends above the soil surface) and folded (cuttings folded in half with folded end buried with cut ends above the soil surface). Dlamini et al. (2021) found no difference when comparing vertical and horizontal and Parwada et al., (2011) found no difference among horizontal, inclined (45°), and vertical orientations. Conversely, a two year study in Nigeria observed that the horizontal orientation had longer roots than inclined or loop (Idoko et al., 2018). In regards to root widths, Parwada et al., (2011) and Monks (1981) both recorded wider roots with the horizontal orientations than vertical. However, Dlamini et al. (2021) documented no difference in root diameter between horizontal and vertical plantings.

In our study we found the longest roots with the horizontal orientation (Fig. 2.7b) and saw no difference in root diameter among planting orientations (data not shown). However, we focused specifically on the dimensions of No. 1 roots and therefore our results may not be directly comparable to the aforementioned studies that compared the average dimensions of all storage roots. Our results suggest that horizontal planting may improve shapes of No. 1 roots, meeting grower preferences. Additional research is warranted to determine if transplant length and planting method affect root shape, which could potentially improve root quality.

Delaying harvest until approximately 126 days increased marketable, No. 1, and jumbo yields compared to harvests around 104 or 111 days (Table 2.3). Average root weights also increased at the late harvest for No. 1, jumbo, and marketable roots in both years and canners in 2020 (Table 2.5). Delaying harvest also reduced the proportion of marketable weights that were canners (Fig. 2.10). Azevedo et al. (2014) also saw an increase in the average weight of commercial roots, defined as roots weighing between 100 and 800 g, when harvest was delayed from 120 days to 150 and/or 180 days. Scott and Bouwkamp (1975) tracked roots biweekly throughout the growing season and observed root size and yield increase with time. Increased yield with delayed harvest also fits in with the physiological understanding we have of the crop, in which the majority of the number of storage roots per plant are determined early in the season and then expand in size throughout the remainder of the season (Lowe and Wilson, 1974b; Scott and Bouwkamp, 1975; Villordon et al., 2009b).

Other researchers have also looked into delayed harvest, but with varying results, some of which can be attributed to unfavorable environmental conditions during the extension of the season. Light intensity, temperature, and soil moisture have all been shown to influence sweetpotato yields (Kays, 1985). For example, Hartman and Gaylord (1943) saw increased marketable and No. 1 yields with ~20 day season extension in some years but not others, attributing insufficient moisture as a reason for lack of response in some years. Reynolds et al. (1994) saw increases in total yield and table grade yield (roots 5 to 9 cm in diameter) between their early and middle harvest dates with ‘Georgia Jet’ and ‘Jewel.’ These harvest dates ranged between 87 and 107 DAT for early harvest and 104 and 121 DAT for middle harvest, with dates ranging from late August to late September. However, they did not see further increases when harvests were delayed until October, and speculated that this was due to cooler temperatures. Arancibia et al. (2014) also attributed inconsistent results to cooler temperatures later in the growing season, seeing yield increases in one year but not the other with their work in Mississippi. They also investigated early and late harvests for early and late season planted cuttings and found a net benefit in delaying harvest for early plantings.

It is also likely that some cultivars are impacted more by season extension. Extension publications classify varieties by early-, mid-, and late-season harvests (Jennings et al., 2019). In addition, in a study of sweetpotato grown in black plastic, researchers observed that ‘Georgia Jet’ benefited from delaying harvest one or two additional weeks with increases to No. 1 yield, total yield, and/or average storage root weight depending on the study year (Wees et al., 2016). However, ‘Beauregard’ did not appear to benefit as much from the delay, having less consistent increases in root weight and yield. A study in Brazil found lower total and marketable yields when some of the 8 cultivars they studied were harvested at 120 days instead of 150 or 180 days (Azevedo et al., 2014).

Some researchers have suggested deviating from predicting harvest based off of the number of calendar days from planting (Duque et al., 2022; Villordon et al., 2009a), proposing models of growing degree days. A model for ‘Beauregard’ in Louisiana estimated ~2600 GDD with a ceiling of 90°F [32.2°C] and daily min of 60°F [15.5°C] to gauge harvest (Villordon et al., 2009a). Seem et al. (2003) used a base 21.1°C model in North Carolina to compare plant growth of cuttings planted early and late. Most recently, Duque et al. (2022) predicted harvest for No. 1 and petite grades at the accumulation of ~1300 GDD and ~700 GDD modeled at 10°C and 15.5°C, respectively, for plants grown in black plastic in Pennsylvania. Since there is variation in accumulated GDD to estimate harvest and since current models do not agree on the same base and ceiling temperatures, more research is needed to improve this tool. However, if predicting harvest date by calendar days, growers should anticipate a growing season of at least 126 days in order to maximize yield for ‘Monaco’.

The results of this study are inconclusive regarding the impact of stem cutting length on sweetpotato yield. Stem cutting length had no effect on marketable weights and counts and weights of No. 1 roots (Table 2.3 and 2.4). In addition, we observed no effect of cutting length on No. 1, jumbo, or canner average root sizes (data not shown). In both years, the 25 cm cuttings had an increase number and weights of jumbo roots than the 38 cm cutting treatment (Table 2.3 and 2.4). But jumbos only made up a larger percentage of the marketable weights with the 25 cm cuttings compared to the 38 cm cuttings at the early harvest (Fig. 2.9). In 2021, the 38 cutting treatment had increased weights and counts of canner roots (Table 2.3 and 2.4). This increased number of canner roots likely contributed to the increase number of marketable roots and decreased average size of marketable roots in that year with the 38 cm treatment (Table 2.4; Fig. 2.12). Thus, there may be a tendency for the 38 cm cuttings to have more, smaller roots (canners), and for the 25 cm cutting to have more, larger roots (jumbos), but since the effects vary depending on the harvest or year, a clear conclusion cannot be formed from the results of this study.

The tendency for longer cuttings to produce more, smaller roots was also seen in work by Belehu and Hammes (2010). They observed an increase only in the number and yield of small roots (between 100 and 200 g), when 30 cm cuttings were used compared to 20 cm. In some studies, it was observed that there was an increase in yield when longer stem cuttings were used. Godfrey-Sam-Aggrey (1974) saw an increase in yield in two cultivars when 46 cm and 61 cm cuttings were used in place of the 23 cm standard length. Parker and Schultheis (in press) found the best yields with 14 inch [35 cm] cuttings compared to 6, 10, and 18 in [15 cm, 25 cm, and 46 cm] cuttings. Similar research that focused on the total number of nodes per cutting, and therefore inferred increased cutting length, found that the number of nodes on the cutting (4, 5, or 6) did not have an effect on the number of marketable roots, root length, root diameter, or unmarketable root weight (Essilfie et al., 2016). Hall (1986) found that for ‘Georgia Jet’, more nodes buried had no influence on total marketable yields, but decreased the yield of No. 1’s and therefore the percent of marketable yields that were No. 1. They found no effect of stem cutting length on yields for this cultivar. However, for ‘Red Jewel’, more nodes buried had no effect on No. 1 or marketable yields. But longer stem cuttings yielded higher marketable yields with this cultivar, and longer stem cuttings had higher No. 1 yields when planted horizontally.

Coleman et al. (2006) and Godfrey-Sam-Aggrey (1974) both reported differences in yield when comparing stem cutting lengths that had at least 20 cm difference in length. It is possible that we may not have seen a clear trend with the current study because the cutting lengths were too similar to detect differences. However, using stem cutting lengths that are larger than 40 cm may be inappropriate for vertical planting methods in the United States. In the Southeast Vegetable Handbook, it is recommended that stem cuttings should be 8 to 12 inches [20 to 30 cm] in length (Kemble, 2022) and with the equipment used for the vertical and sleeve plantings, longer slips can be unwieldy. In some cases the 38 cm cuttings were difficult to handle during this study, with the cuttings getting caught in the planting mechanism. The sleeve attachment was a guide for the cuttings and was helpful in reducing this problem. The horizontal planter could accommodate larger stem cutting lengths, which could allow for longer lengths to be investigated. However, the production of larger cuttings would need to be facilitated in propagation beds and could require changes in plant production methods that might increase production costs. The trailing nature of sweetpotato vines would warrant some type of system to maintain upright growth of plants to produce long cuttings without trailing along the ground. In addition, extra costs could arise from the additional time it would take to grow cuttings out to long lengths. A thorough analysis would be necessary to determine if longer cutting lengths increase yield and if their adoption would outweigh any increase costs.

Root yields were not impacted by the interaction of stem cutting length and planting orientation (data not shown). This suggests that growers may use cuttings that are the current standard length and do not necessarily need to invest in longer stem cuttings to see increased yields with a different planting orientation. However, we only used a single cultivar in this study and similar studies using different sweetpotato cultivars are warranted. Coleman et al. (2006)

concluded that planting orientation had the potential to improve yield with longer stem cuttings of ‘Beauregard’ than with shorter cuttings. Hall (1986) observed longer stem cuttings of ‘Red Jewel’ set horizontally had an increased proportion of No. 1 roots compared to the vertical orientation, but cutting length did not have an effect on yield in ‘Georgia Jet’.

Horizontal orientation maintained or increased yields compared to the standard vertical planting method, in terms of weight and root counts (Tables 2.3 and 2.4). The horizontal orientation also increased counts and weights of No. 1’s, and had similar or lower weights and counts of jumbo roots. Our work supports findings by Belehu and Hammes (2010) and Pakkies et al. (2019), who found higher yields with horizontal orientation compared to vertical. Belehu and Hammes had higher counts of medium, large, and oversized roots, and higher weights of marketable, small, medium, and large roots. In their study, marketable roots included small (100 to 200g), medium (200 to 350g), and large (350 to 500g) roots. Pakkies et al. found higher total yields with horizontal. Yields were maintained with the horizontal treatment in other studies as well. Monks (1981) found no difference for ‘Jewel’ and ‘Centennial’ (1981), du Plooy et al. (1992) had similar storage root counts with vertical and horizontal, and Dlamini et al. (2021) found similar root counts and yields in three varieties in their comparison of vertical and horizontal plantings. As also seen in the proportion of marketable weight analysis, the distribution of grades within marketable yield is preferable with horizontal orientation, with increased No. 1’s and decreased jumbos (Fig. 2.8). Other researchers have also seen favorable distribution of roots with horizontal planting for some cultivars; either seeing an increased proportion of No. 1 roots (Hall, 1986) or a decrease in the proportion of nonmarketable roots (Levett, 1993).

This increase of both weight and yield proportion of No. 1 roots is important because growers receive a premium for this grade and should see increased profits. In addition, increased yields, particularly of the premium grade, equates to increased land-use efficiency. This is important for a grower financially as they can maintain profits by farming less area or increase revenue by farming the same area. This is also important from an environmental perspective as we aim to increase agronomic production without increasing the amount of land being farmed. Land-use efficiency is of particular interest to the organic sector because organic production typically has lower yields than conventional systems (de Ponti et al.; 2012; Reganold and Wachter, 2016; Seufert et al., 2012; Smith et al., 2019). However, this discrepancy may not be as large in sweetpotato production. In a meta-analysis of sweetpotato studies in the Southeastern United States from 2005 through 2017, Nwosisi et al. (2021) determined that organic systems yield on average 2% lower than conventional. But discussions with organic growers in the region have indicated variability in yields, with some seeing lower yields and others seeing yields comparable to conventional systems.

We did not observe a difference in marketable root counts between planting orientations (Table 2.4). In addition, the lack of any significant planting orientation by harvest time interaction in regards to yield measurements suggests that planting with the horizontal orientation does not delay the maturity of the crop. Regardless of planting orientation, delaying harvest until approximately 126 days increased yields (Table 2.3).

In the Southeastern United States commercial production of horizontal planting equipment is not common and requires custom requests to equipment manufacturers. The grower partner for this study had custom units created for his use and has adapted the equipment as he saw fit throughout its use to improve usability. Although an exact cost cannot be estimated due to the custom nature of our partner's equipment, pricing for a horizontal planter is estimated to be lower than the cost of a new mechanical transplanter (J. Jones, personal communication). Costs will be lower especially when using parts (toolbar, cultivators, etc.) that one already has on hand or can acquire at auction. Equipment companies may charge approximately $18,000 to cut, weld, and assemble the units if all components are supplied (J. Jones, personal communication). However, a full economic analysis of this investment for horizontal equipment has not been executed.

We did not see significant yield gains by using the sleeve attachment on the standard planter compared to the standard planter alone (Table 2.3 and 2.4). With investment typically $375 per row unit, the results of this study do not support the added investment in this technology for planting 'Monaco'. No benefit of the sleeve attachment was observed in 'Covington' cuttings when using a wide range of stem cutting lengths (Parker and Schultheis, in press). One possible reason we may have saw little to no difference between the vertical and sleeve treatments is that the stem cuttings are likely dragging along the bottom of the furrow in the vertical orientation instead of being entirely vertically orientated. This was observed by Parker and Schultheis in their trial, which used the same equipment as the present study. Since the transplanter only creates a furrow approximately 10 to 13 cm deep, the cutting is likely forming an "L" shape to accommodate the extra length below ground. This results in the standard planter planting in a similar orientation to the sleeve attachment. The extra length is not being accommodated above the soil line due to the mechanism of the planter. When placing the plant in the clip, the top of the cutting is justified to the top of the clip, therefore any excess length protrudes into the portion of the cutting placed below the soil line. However, the sleeve may be useful for growers who choose to use longer stem cuttings, as it guided the cuttings while they were in the clips and prevented them from getting caught in the planter mechanism as they entered the furrow.

CONCLUSION

Potential strategies to increase yields of organically grown ‘Monaco’ include planting stem cuttings horizontally and delaying harvest until late in the season. Planting horizontally maintained or improved marketable yields compared to the standard planter and improved the distribution of root grades, favoring a higher percentage of the premium grade (No. 1). Increased yields, specifically of No. 1 roots, can increase grower profits and improve land-use efficiency. With a growing demand for organically grown foods and a persisting yield gap between organic and conventionally produced commodities, improving land-use efficiency is of the upmost importance.

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Table 2.1 Timing of cultural practices and data collection.

Cultural Practice										
2020										
Poultry Litter Application	June									
Planting	10 June									
Stand Counts	22 June									
Cultivation	22 June	8 July	16 July	26 July						
Hand Weed Removal	22 June	2 July	9 July	16 July	23 July	30 July	7 Aug	14 Aug	21 Aug	
Harvest	22 Sept	15 Oct								
2021										
Poultry Litter Application	June									
Planting	9 June									
Stand Counts	15 June									
Cultivation	12 June	14 June	18 June	27 June	17 July					
Hand Weed Removal	15 June	21 June	28 June	13 July	16 July	26 July	5 Aug	10 Aug	19 Aug	2 Sept
Harvest	28 Sept	12 Oct								

Table 2.2 Cumulative rainfall and average temperature by month at Rocky Mount-Wilson Regional Airport, Nash County, NC.

Year	**June**		**July**		**August**		**September**		**October**	
	Rainfall (cm)	Temp. (°C)	Rainfall (cm)	Temp. (°C)	Rainfall (cm)	Temp. (°C)	Rainfall (cm)	Temp. (°C)	Rainfall (cm)	Temp. (°C)
2020	16.03	24.0	6.71	27.3	20.15	25.6	19.44	21.4	5.77	17.7
2021	21.04	24.6	14.74	26.2	9.66	26.5	7.47	22.8	10.72	19.0

Data taken from the State Climate Office of North Carolina station closest to field site.

Table 2.3 Effects of year, stem cutting orientation, length, harvest time, and their interactions on sweetpotato root yield.

Treatments				Sweetpotato grade[z]			
Year	Orientation	Stem cutting length	Harvest	No. 1	Jumbo	Canner	Marketable
					$kg\ ha^{-1}$		
2020				20,213	5,001	7,968	33,175
2021				24,852	10,790	7,452	43,086
P-Value				0.0019	0.0002	0.0457	0.0002
	Vertical			20,948 b[y]	9,139	7,669	37,727
	Sleeve			21,779 b	8,050	7,649	37,485
	Horizontal			24,871 a	6,597	7,812	39,179
P-Value				0.0008	0.0026	NS	NS
		25 cm		22,595	8,926 a	7,030	38,540
		38 cm		22,470	6,865 b	8,390	37,721
P-Value				NS	0.0011	0.0007	NS
			Early	18,593	4,392 b	7,702	30,677 b
			Late	26,472	11,398 a	7,718	45,584 a
P-Value				<.0001	<.0001	NS	<.0001
2020	Vertical			17,860	5,518 a	7,629	30,972 b
	Sleeve			19,398	4,788 a	8,288	32,487 ab
	Horizontal			23,382	4,698 a	7,986	36,065 a
2021	Vertical			24,035	12,761 A	7,709	44,481 A
	Sleeve			24,161	11,313 A	7,010	42,484 A
	Horizontal			26,359	8,295 B	7,638	42,292 A
P-Value				NS	0.0360	NS	0.0126
2020		25 cm		20,800	5,632	7,755 a	34,164
		38 cm		19,626	4,371	8,180 a	32,185
2021		25 cm		24,389	12,221	6,306 B	42,915
		38 cm		25,314	9,358	8,599 A	43,256
P-Value				NS	NS	0.0171	NS

Table 2.3 (continued).

2020	Early	14,776 b	1,853	8,030	24,637
	Late	25,651 a	8,149	7,905	41,713
2021	Early	22,410 B	6,932	7,375	36,716
	Late	27,293 A	14,647	7,530	49,455
P-Value		0.0239	NS	NS	NS

[Z] Sweetpotato grades are based on USDA standards. Canners were defined as roots with 2.5 cm to 4.4 cm diameter, No. 1's were defined as 4.4 cm to 8.9 cm diameter and 7.6 cm to 22.9 cm length, and jumbos were roots greater than 8.9 cm diameter (USDA, 2005). Marketable yield is the sum of No. 1, jumbo and canner grades.

[Y] Means followed by the same letter within a grade and response are not different (Tukey's honest significant difference; α=0.05). Interactions were sliced by year. Lowercase letters are used to compare means in 2020 and uppercase letters are used to compare means in 2021.

[X] All other first-order interactions and all higher order interactions among model terms were not significant and therefore are not presented.

Table 2.4 Effects of year, stem cutting orientation, length, harvest time, and their interactions on sweetpotato root counts.

Treatments				Sweetpotato grade^z			
Year	Orientation	Stem cutting length	Harvest	No. 1	Jumbo	Canner	Marketable
				roots plant^{-1}			
2020				2.0	0.2 b^y	2.7	4.9
2021				2.5	0.4 a	2.6	5.4
P-Value				0.0003	0.0008	NS	0.0009
	Vertical			2.1 b	0.3 a	2.6	5.0
	Sleeve			2.2 ab	0.3 ab	2.6	5.1
	Horizontal			2.4 a	0.2 b	2.6	5.3
P-Value				0.0167	0.0050	NS	NS
		25 cm		2.3	0.3 a	2.4	5.0
		38 cm		2.2	0.2 b	2.8	5.3
P-Value				NS	0.0002	0.0032	NS
			Early	1.9	0.2 b	2.7	4.8 b
			Late	2.5	0.4 a	2.5	5.5 a
P-Value				<.0001	<.0001	0.0283	0.0004
2020	Vertical			1.8	0.2	2.6	4.6
	Sleeve			2.0	0.2	2.7	4.9
	Horizontal			2.2	0.2	2.7	5.1
2021	Vertical			2.4	0.4	2.6	5.5
	Sleeve			2.4	0.4	2.6	5.4
	Horizontal			2.6	0.3	2.5	5.4
P-Value				NS	NS	NS	NS
2020		25 cm		2.1	0.2	2.7 a	5.0 a
		38 cm		1.9	0.2	2.7 a	4.7 a
2021		25 cm		2.5	0.4	2.2 B	5.1 B
		38 cm		2.4	0.3	2.9 A	5.8 A
P-Value				NS	NS	0.0017	0.0002

Table 2.4 (continued).

2020	Early	1.6 b	0.1	2.9 a	4.6
	Late	2.4 a	0.3	2.4 b	5.2
2021	Early	2.3 B	0.3	2.5 A	5.1
	Late	2.7 A	0.5	2.6 A	5.8
P-Value		0.0237	NS	0.0115	NS

[Z] Sweetpotato grades are based on USDA standards. Canners were defined as roots with 2.5 cm to 4.4 cm diameter, No. 1's were defined as 4.4 cm to 8.9 cm diameter and 7.6 cm to 22.9 cm length, and jumbos were roots greater than 8.9 cm diameter (USDA, 2005). Marketable yield is the sum of No. 1, jumbo and canner grades.

[Y] Means followed by the same letter within a grade and response are not different (Tukey's honest significant difference; α=0.05). Interactions were sliced by year. Lowercase letters are used to compare means in 2020 and uppercase letters are used to compare means in 2021.

[X] All other first-order interactions and all higher order interactions among model terms were not significant and therefore are not presented.

Table 2.5 Effects of year and harvest time and their interaction on average size of sweetpotato roots.

Treatments		Sweetpotato grade^{z}			
Year	Harvest	No. 1	Jumbo	Canner	Marketable
		Grams root^{-1}			
2020		294	745 b^{y}	90	201
2021		298	825 a	86	237
P-Value		NS	0.0097	NS	0.0010
	Early	282 b	755 b	84	188
	Late	310 a	816 a	92	249
P-Value		0.0034	0.0372	0.0038	<.0001
2020	Early	274	700	82 b	161 b
2020	Late	315	790	98 a	241 a
2021	Early	291	810	86 A	216 B
2021	Late	306	841	87 A	258 A
P-Value		NS	NS	0.0043	0.0420

[Z] Sweetpotato grades are based on USDA standards. Canners were defined as roots with 2.5 cm to 4.4 cm diameter, No. 1's were defined as 4.4 cm to 8.9 cm diameter and 7.6 cm to 22.9 cm length, and jumbos were roots greater than 8.9 cm diameter (USDA, 2005). Marketable yield is the sum of No. 1, jumbo and canner grades.

[Y] Means followed by the same letter within a grade and response are not different (Tukey's honest significant difference; α=0.05). Interactions were sliced by year. Lowercase letters are used to compare means in 2020 and uppercase letters are used to compare means in 2021.

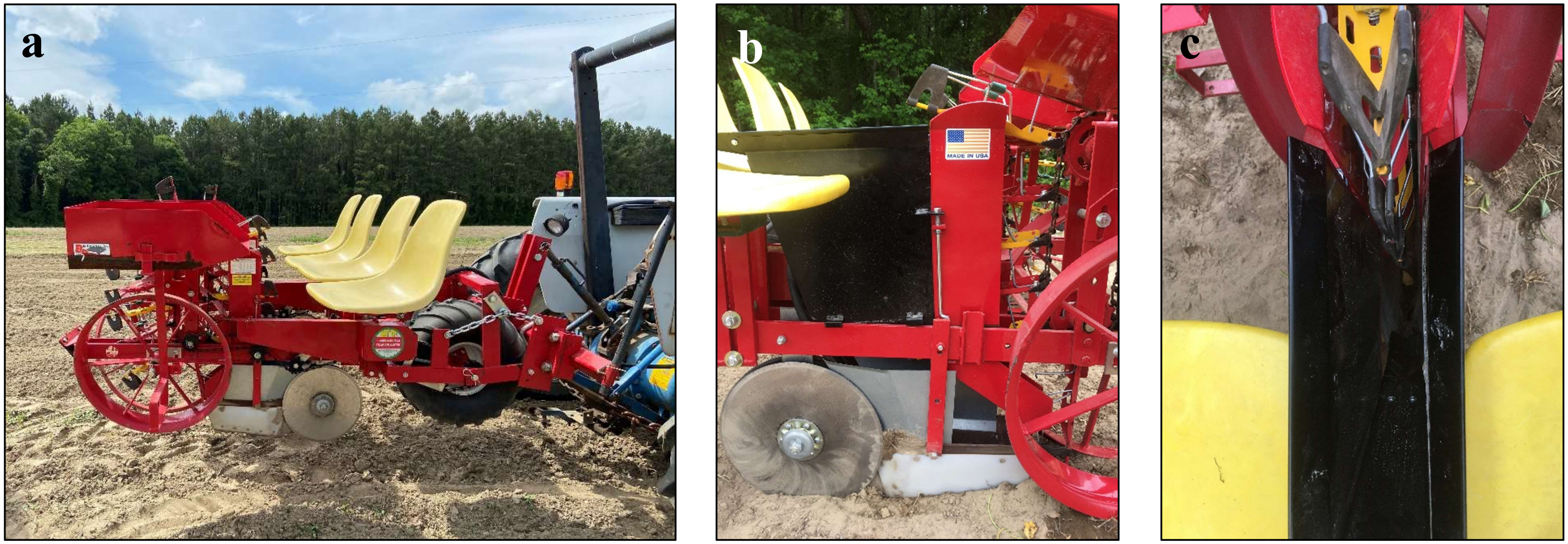

Figure 2.1 Standard planter (a) and standard planter equipped with sleeve attachment used for the angled planting orientation (b and c).

Figure 2.2 Two-row horizontal planter used to plant the horizontal treatment in 2021 (a) and close up of the planting apparatus for the horizontal planters (b).

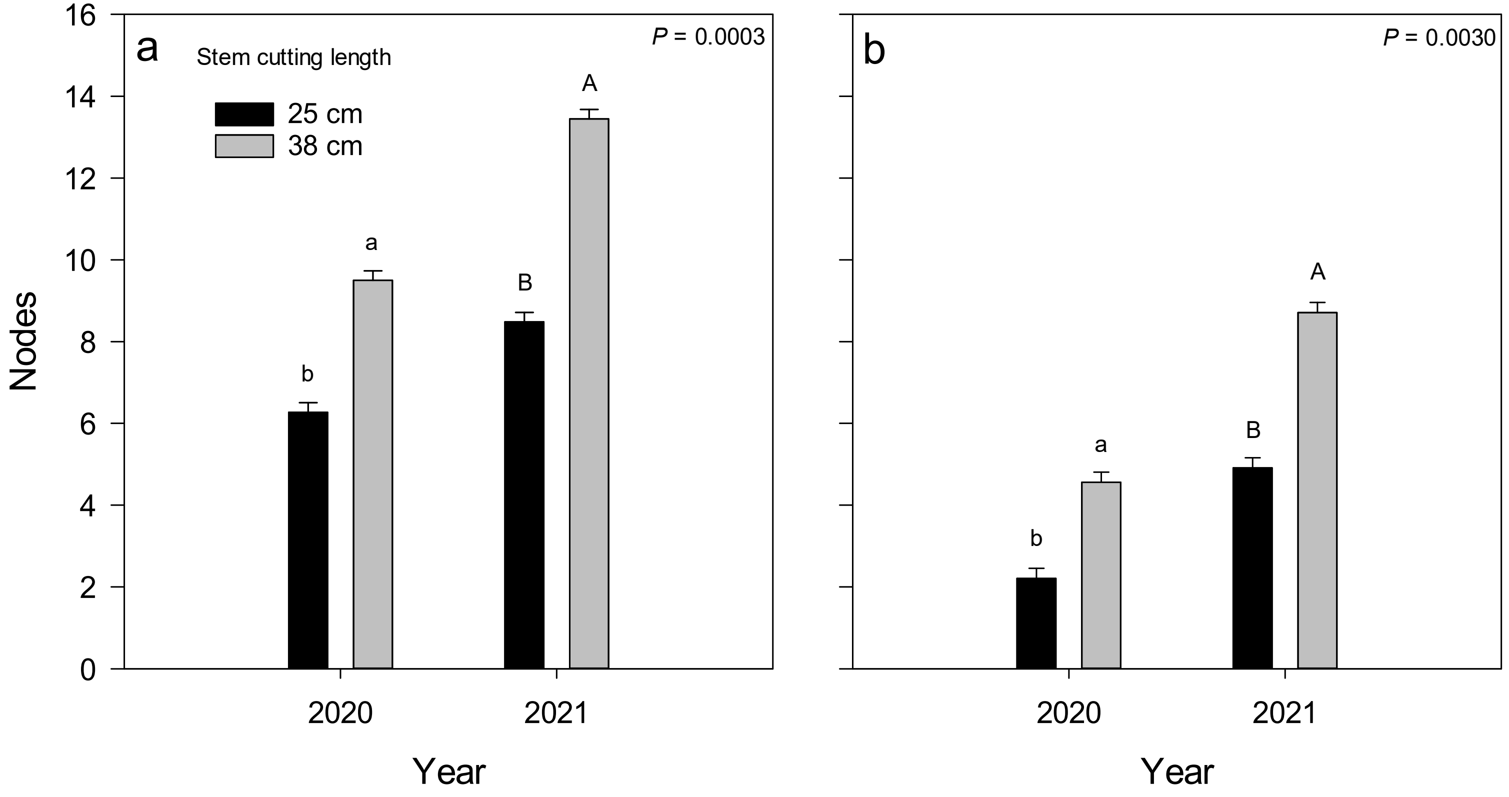

Figure 2.3 Interaction of stem cutting length and year on average total nodes (a) and average nodes buried (b). Means are compared within year using Tukey's honest significant difference (α=0.05), lowercase letters are used to compare means in 2020 and uppercase letters are used to compare means in 2021. Means with the same letter are not different. The number of nodes buried was calculated by subtracting the average number of nodes above the soil line after planting from the average number of total nodes on a per plot basis.

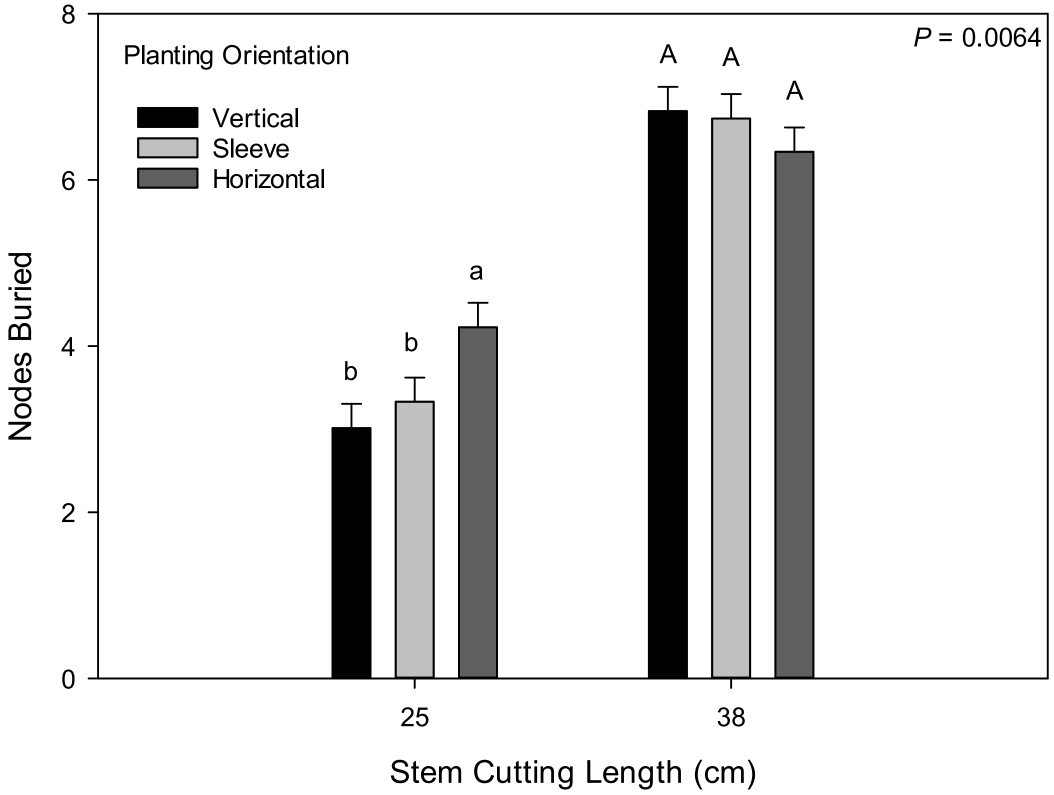

Figure 2.4 Interaction of stem cutting length and planting orientation on average number of nodes buried. The number of nodes buried was calculated by subtracting the average number of nodes above the soil line after planting from the average number of total nodes on a per plot basis. Means are compared within stem cutting length using Tukey's honest significant difference (α=0.05), lowercase letters are used to compare means of the 25 cm cuttings and uppercase letters are used to compare means of the 28 cm cuttings. Means with the same letter are not different.

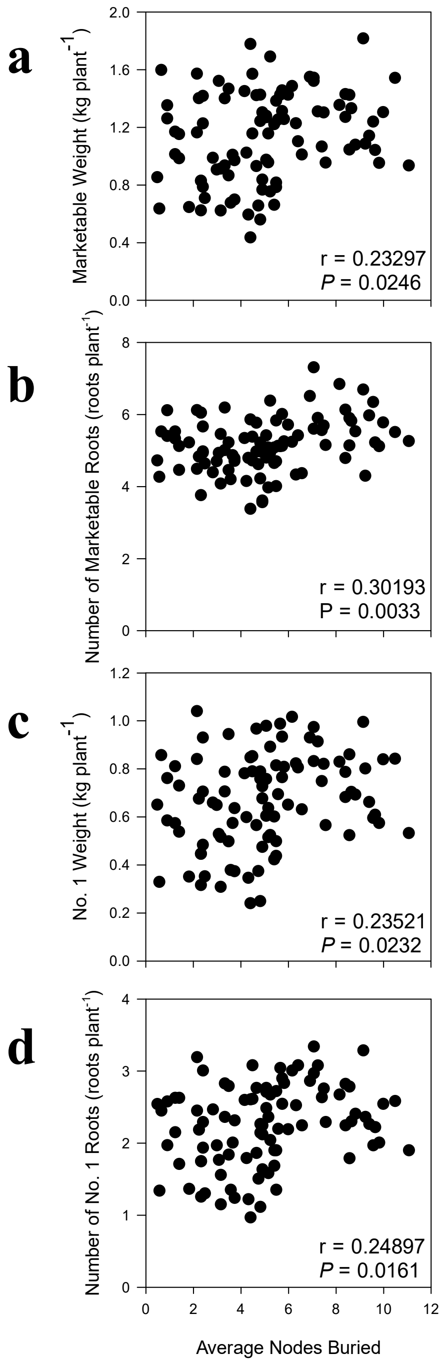

Figure 2.5 Correlations between average nodes buried with marketable yield (a), number of marketable roots (b), No. 1 root yield (c), and the number of No. 1 roots (d), presented as Pearson correlation coefficients. The number of nodes buried was calculated by subtracting the average number of nodes above the soil line after planting from the average number of total nodes for each plot. Sweetpotato grades are based on USDA standards. Canners were defined as roots with 2.5 cm to 4.4 cm diameter, No. 1's were defined as 4.4 cm to 8.9 cm diameter and 7.6 cm to 22.9 cm length, and jumbos were roots greater than 8.9 cm diameter (USDA, 2005). Marketable yield is the sum of No. 1, jumbo and canner grades.

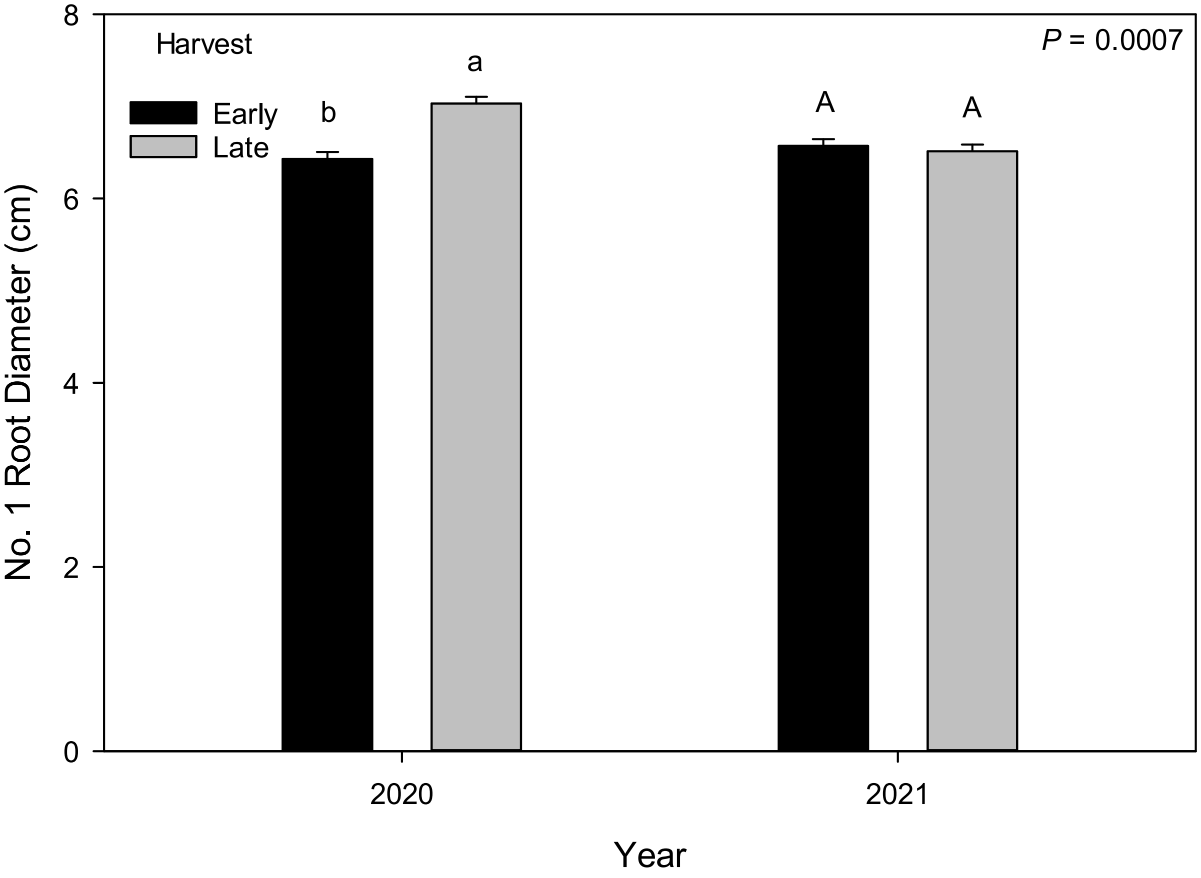

Figure 2.6 Interaction of harvest time by year on No. 1 root diameter. No. 1 grade roots were defined as 4.4 cm to 8.9 cm diameter and 7.6 cm to 22.9 cm length (USDA, 2005). Means are compared within year using Tukey's honest significant difference (α=0.05), lowercase letters are used to compare means in 2020 and uppercase letters are used to compare means in 2021. Means with the same letter are not different. Early harvest was 104 days after planting in 2020 and 111 days after planting in 2021. Late harvest was 127 days after planting in 2020 and 125 days after planting in 2021. Root diameter was calculated from measurements of the maximum circumference of 10 representative roots per plot.

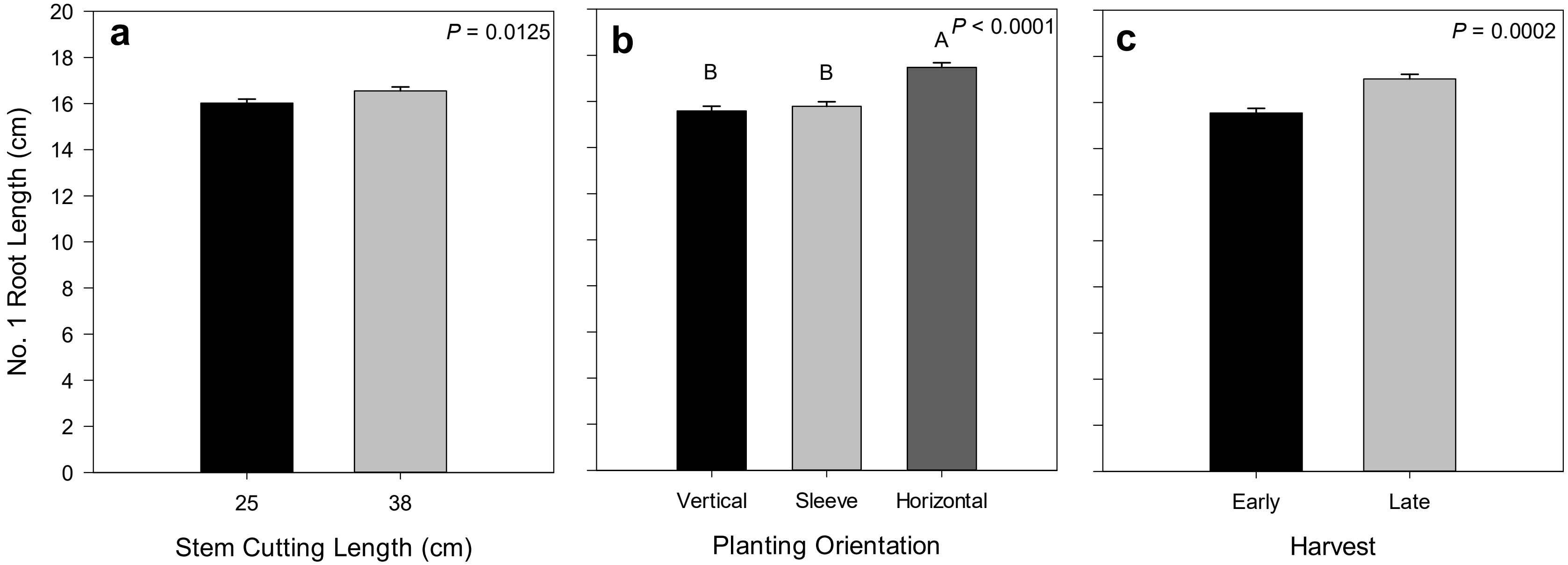

Figure 2.7 Main effects of stem cutting length (a), orientation (b) and harvest time (c) on average No. 1 root length. No. 1 grade roots were defined as 4.4 cm to 8.9 cm diameter and 7.6 cm to 22.9 cm length (USDA, 2005). Means with the same letter are not different (Tukey's honest significant difference; α=0.05). Early harvest was 104 days after planting in 2020 and 111 days after planting in 2021. Late harvest was 127 days after planting in 2020 and 125 days after planting in 2021.

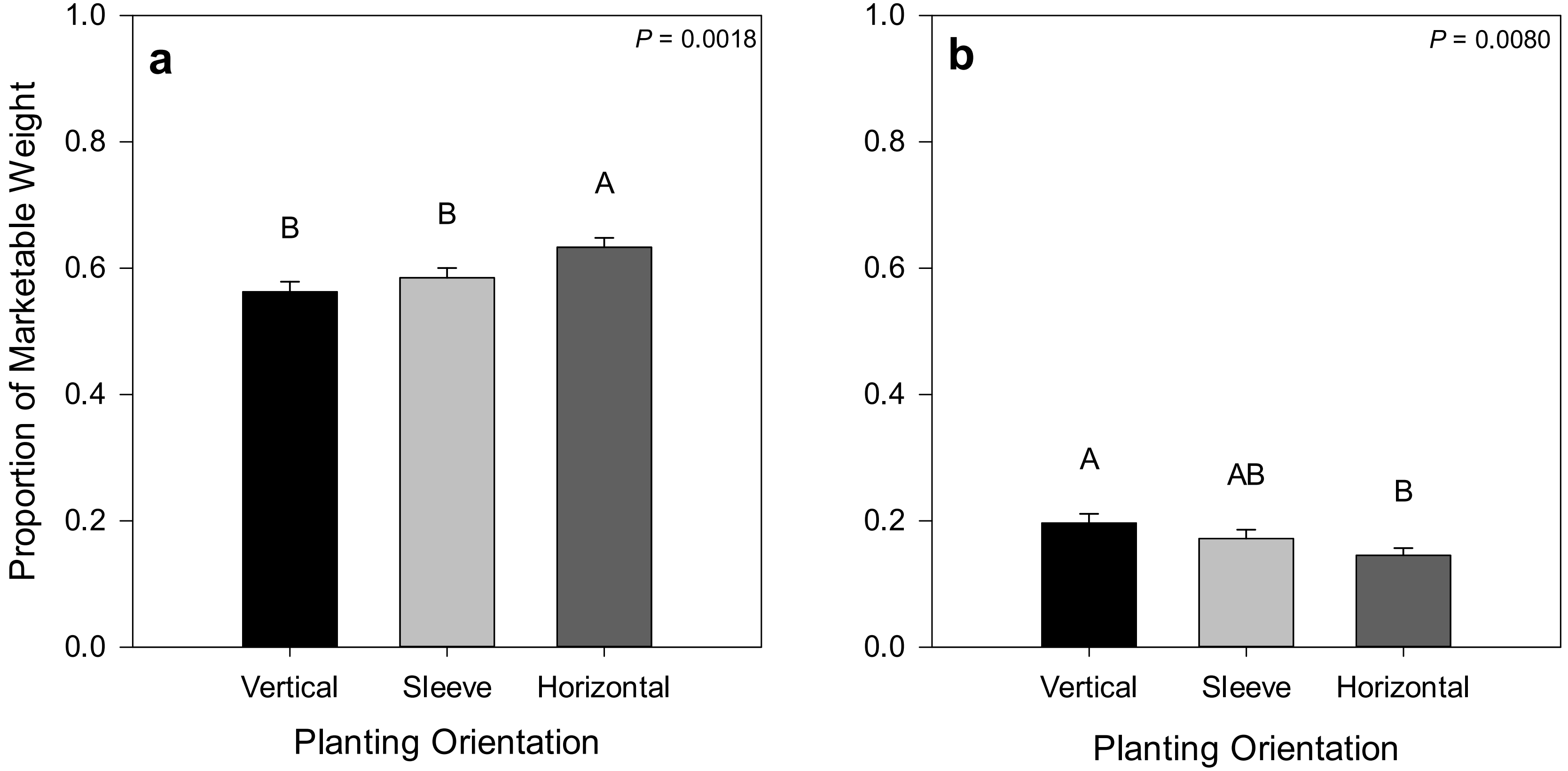

Figure 2.8 Main effect of orientation on proportion of marketable yield for No. 1 (a) and jumbo grades (b). Data is pooled over both years of the study. Sweetpotato grades are based on USDA standards. Canners were defined as roots with 2.5 cm to 4.4 cm diameter, No. 1's were defined as 4.4 cm to 8.9 cm diameter and 7.6 cm to 22.9 cm length, and jumbos were roots greater than 8.9 cm diameter (USDA, 2005). Marketable yield is the sum of No. 1, jumbo and canner grades. Means with the same letter are not different (Tukey's honest significant difference; α=0.05).

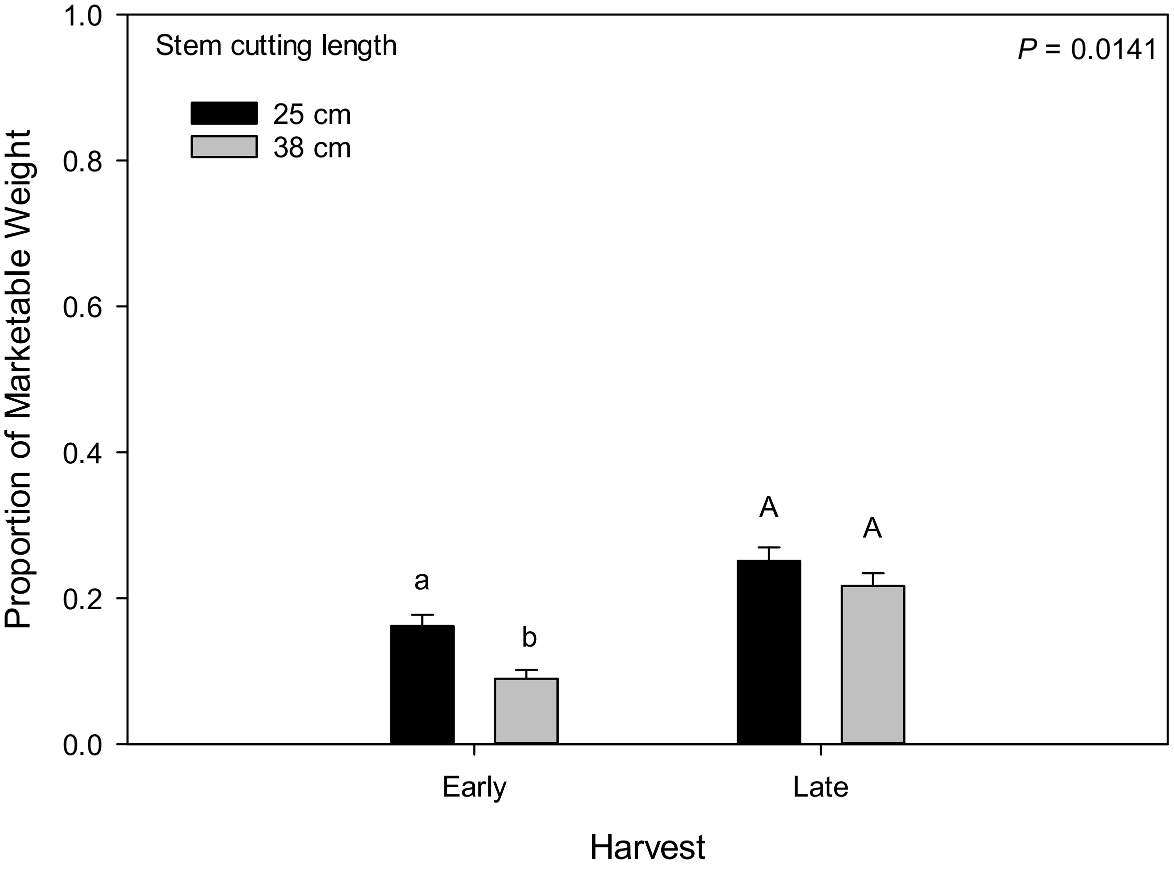

Figure 2.9 Interaction of stem cutting length and harvest time on the proportion of marketable yield comprised of jumbo grade roots. Data is pooled over both years of the study. Sweetpotato grades are based on USDA standards. Canners were defined as roots with 2.5 cm to 4.4 cm diameter, No. 1's were defined as 4.4 cm to 8.9 cm diameter and 7.6 cm to 22.9 cm length, and jumbos were roots greater than 8.9 cm diameter (USDA, 2005). Marketable yield is the sum of No. 1, jumbo and canner grades. Means are compared within harvest time, using Tukey's honest significant difference (α=0.05). Lowercase letters are used to compare means within early harvest and uppercase letters are used to compare means within late harvest. Means with the same letter are not different.

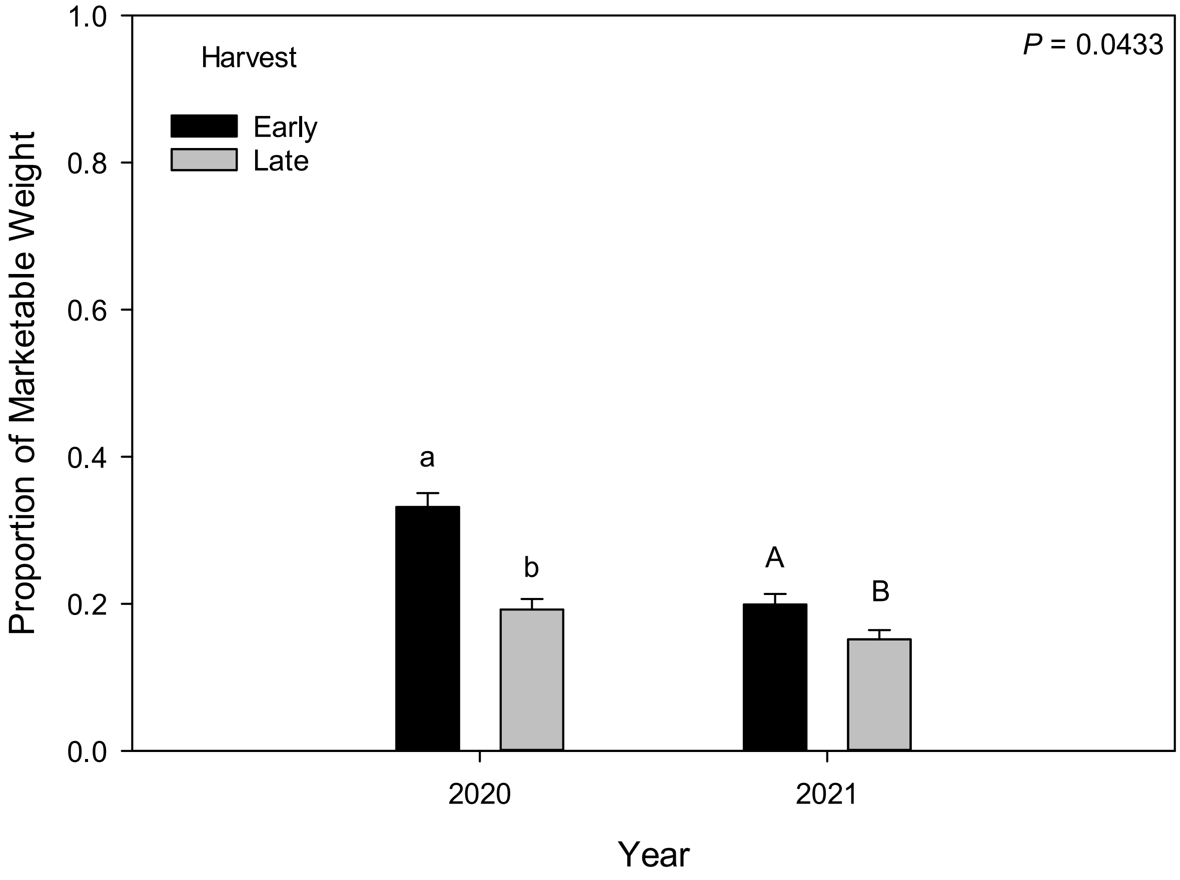

Figure 2.10 Interaction of harvest time and year on the proportion of marketable yield comprised of canner grade roots. Sweetpotato grades are based on USDA standards. Canners were defined as roots with 2.5 cm to 4.4 cm diameter, No. 1's were defined as 4.4 cm to 8.9 cm diameter and 7.6 cm to 22.9 cm length, and jumbos were roots greater than 8.9 cm diameter (USDA, 2005). Marketable yield is the sum of No. 1, jumbo and canner grades. Means are compared within year, using Tukey's honest significant difference (α=0.05). Lowercase letters are used to compare means in 2020 and uppercase letters are used to compare means in 2021. Means with the same letter are not different.

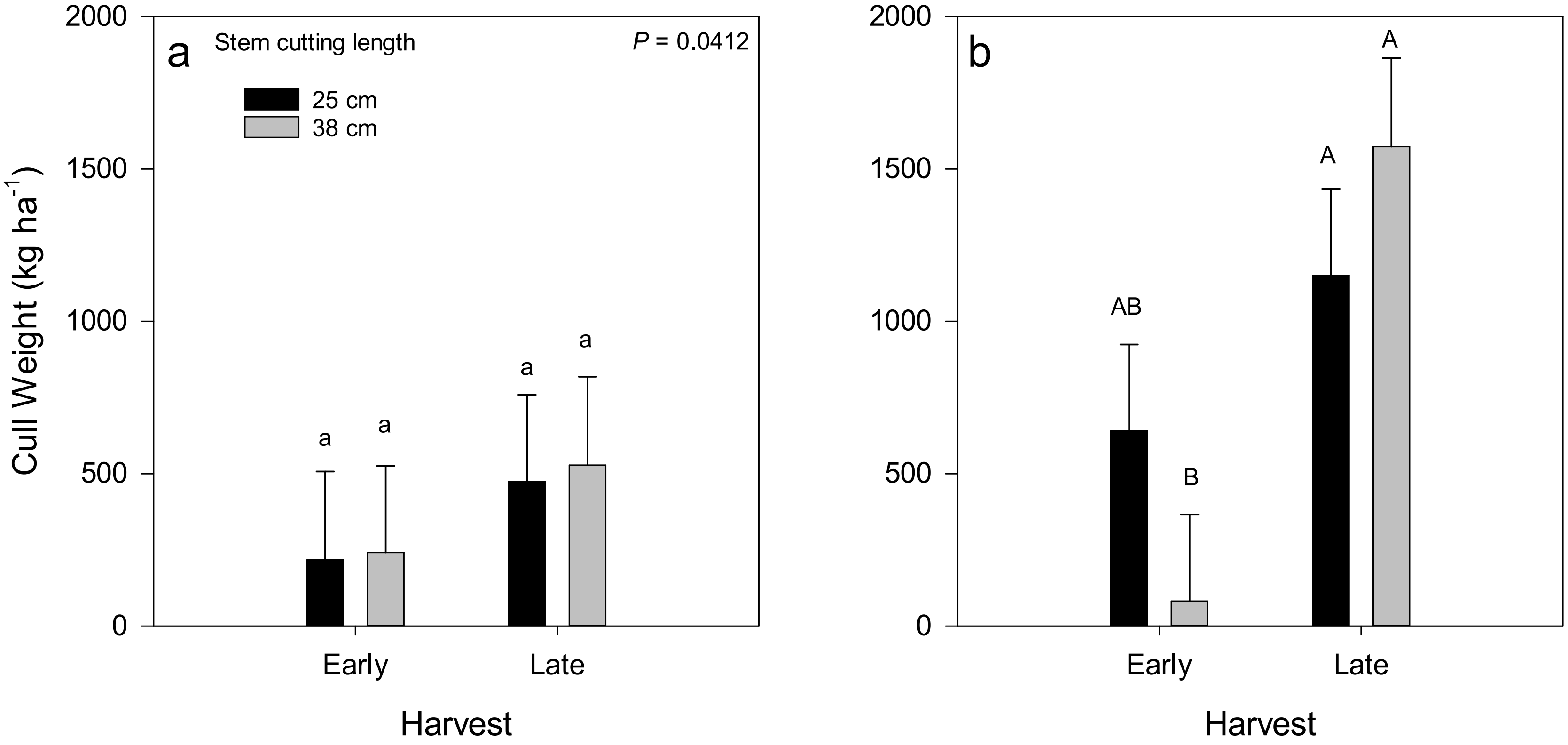

Figure 2.11 Interaction of stem cutting length, harvest, and year on cull yield, sliced by year. Results from 2020 (a) and 2021 (b) are presented. Culls were defined as any root containing rot, severely misshapen, or rendered otherwise unmarketable. Means are compared within each year, using Tukey's honest significant difference (α=0.05). Lowercase letters are used to compare means in 2020 and uppercase letters are used to compare means in 2021. Means with the same letter are not different.

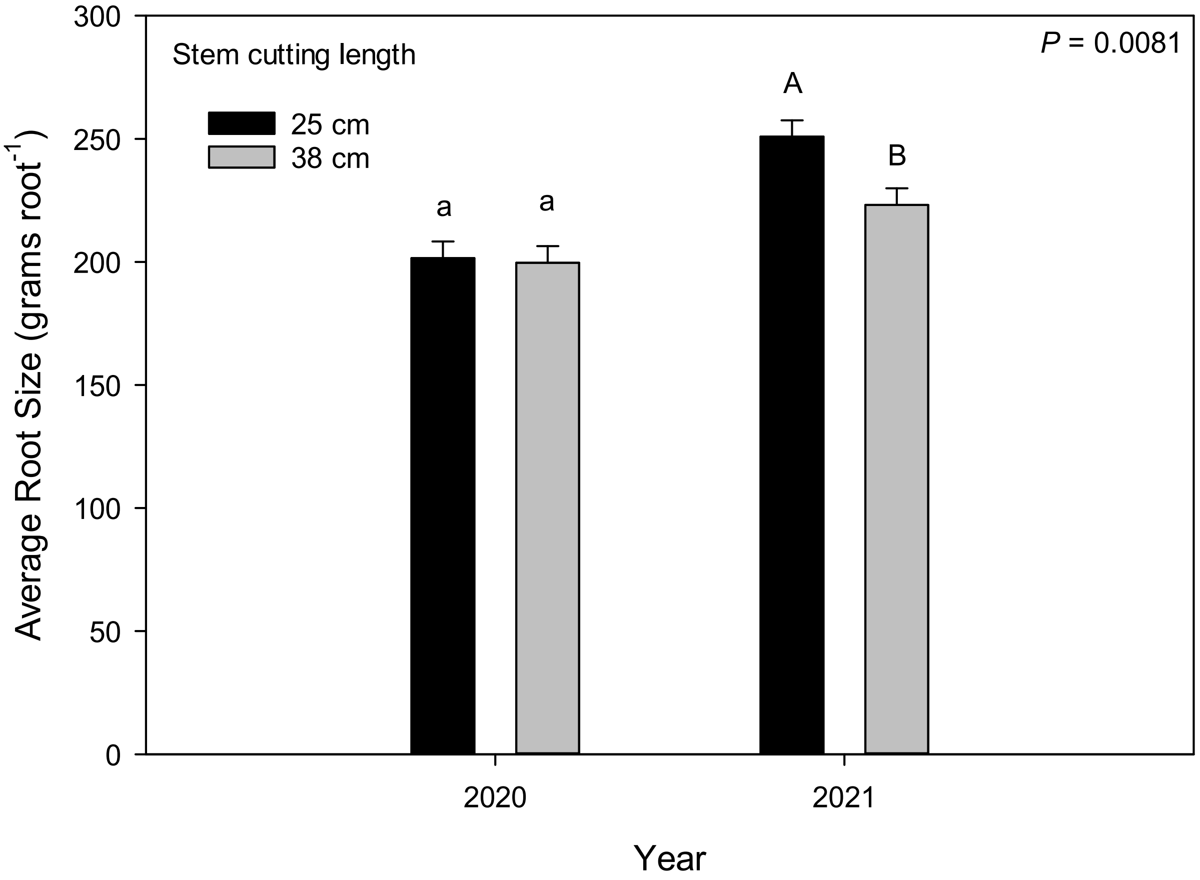

Figure 2.12 Interaction of stem cutting length and year on the average weight of marketable roots. Sweetpotato grades are based on USDA standards. Canners were defined as roots with 2.5 cm to 4.4 cm diameter, No. 1's were defined as 4.4 cm to 8.9 cm diameter and 7.6 cm to 22.9 cm length, and jumbos were roots greater than 8.9 cm diameter (USDA, 2005). Marketable yield is the sum of No. 1, jumbo and canner grades. Means are compared within year, using Tukey's honest significant difference (α=0.05). Lowercase letters are used to compare means in 2020 and uppercase letters are used to compare means in 2021. Means with the same letter are not different.

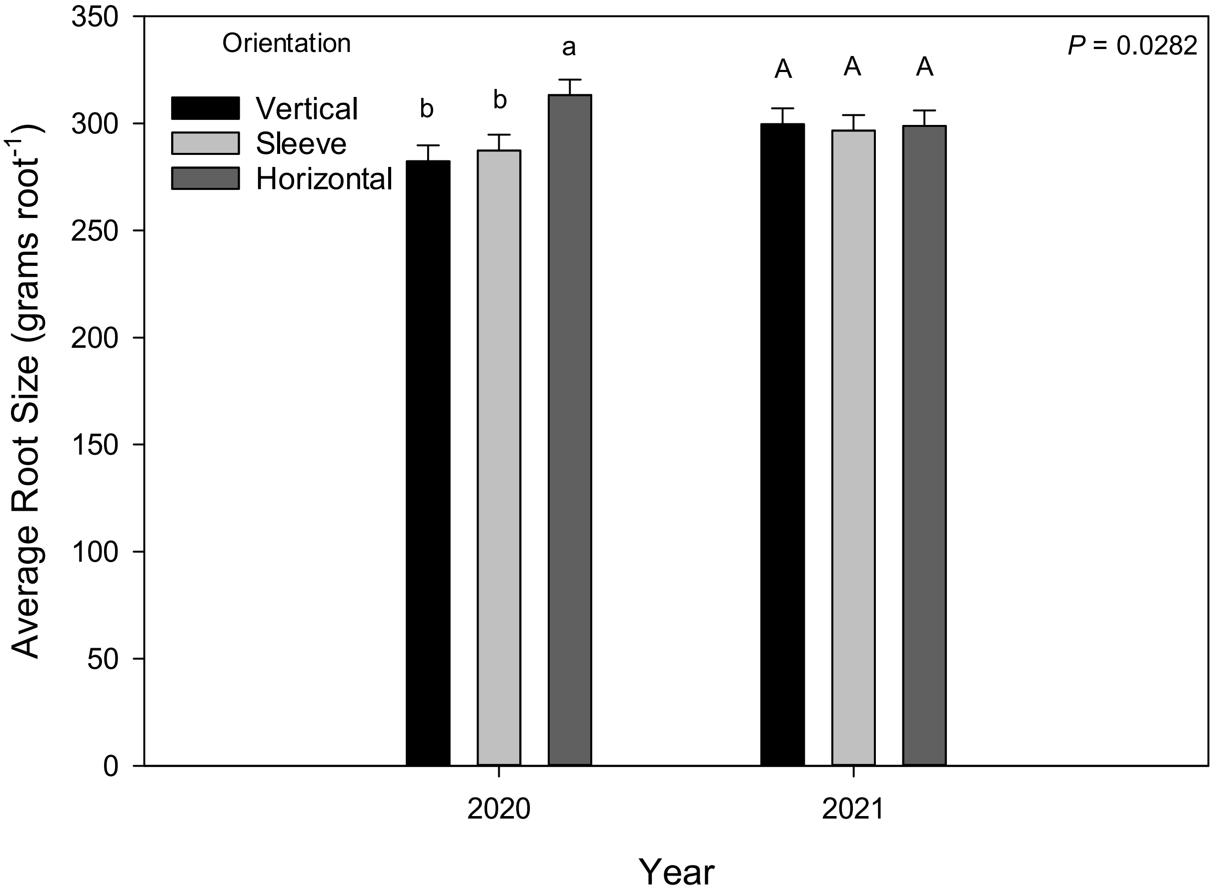

Figure 2.13 Interaction of orientation and year on the average weight of No. 1 roots. No. 1 roots were defined as 4.4 cm to 8.9 cm diameter and 7.6 cm to 22.9 cm length (USDA, 2005). Means are compared within year, using Tukey's honest significant difference (α=0.05). Lowercase letters are used to compare means in 2020 and uppercase letters are used to compare means in 2021. Means with the same letter are not different.