Horizontal Planting Orientation Can Improve Yield in Organically Grown Sweetpotato

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Keywords. harvest time, *Ipomoea batatas*, 'Monaco', nodes, plant length, storage root number

Abstract. **Sweetpotato [*Ipomoea batatas* (L.) Lam.] is one of North Carolina's (USA) most important organic commodity crops; however, yields tend to be less when compared with conventionally produced sweetpotato. Standard field establishment uses unrooted stem cuttings that are transplanted vertically in the soil. Producers in other countries typically use other planting orientations, including cuttings transplanted horizontally. Empirical evidence from North Carolina, USA, sweetpotato producers suggests that a horizontal orientation may improve yields. An organically managed field study using 'Monaco' sweetpotato was conducted in 2020 and 2021 in Bailey, NC, USA. The study evaluated stem cutting planting orientations (vertical, sleeve, horizontal), stem cutting length (25 cm and 38 cm), and harvest time (early or late) in a full-factorial randomized complete block design. In 2020, marketable yields were 16% greater for the horizontal orientation compared with the vertical orientation, with intermediate yields using the sleeve attachment. However, in 2021, there were no differences in marketable yield among planting orientations. In both years, US No. 1–grade yields were significantly greater when cuttings were planted horizontally compared with vertically, with an average increase of 18%. 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 premium root yields and improve land-use efficiency for organically produced sweetpotatoes.**

The organic sweetpotato market has seen rapid growth in recent years, with the national value of sales growing from $26.6 million to more than $77.1 million from 2011 to 2019 (US Department of Agriculture, National Agricultural Statistics Service 2012, 2020). This industry has also expanded in North Carolina, USA. In 2011, only 11 farms harvested and sold organic sweetpotatoes, whereas in 2019, 40 farms sold organic sweetpotatoes, with sales valuing more than $16.4 million (US Department of Agriculture, National Agricultural Statistics Service 2012, 2020). Organic sweetpotato systems, on average, yield less than conventional systems (Nwosisi et al. 2021). Improved production efficiency is needed for organic systems to meet the increasing demand for organic commodities.

Traditional field establishment of sweetpotato in the United States uses unrooted stem cuttings that are transplanted vertically into the soil (Hall 1986). However, in other countries, other planting orientations are typical, and cuttings may be oriented at an angle or horizontally (Coleman et al. 2006; Low et al. 2009; Yan et al. 2022; Zhang et al. 2009). Empirical evidence from North Carolina, USA, sweetpotato producers suggest that horizontal orientation may improve yields (Jones J, personal communication, 2020).

Most studies comparing planting orientations only analyze data collected from a single site-year, and results from these publications are inconsistent. Some researchers observed no difference between horizontal and vertical orientations (Dlamini et al. 2021; du Plooy et al. 1992), others observed greater yields with horizontal orientation (Belehu and Hammes 2010; Pakkies et al. 2019), or greater yields with vertical orientation compared with horizontal (Dayal and Sharma 1993). Results from these studies are limited to their applicability outside of the specific conditions of that site-year and appear highly influenced by environmental conditions. Moreover, these studies arise from varied production systems, which differ in growing conditions (i.e., ridge/mound planting, climate, irrigation) and their definitions of marketable roots. Therefore, results from one system may apply directly to another system. In the United States, there are only a handful of publications that address planting orientation. Monks (1981) reported no difference in yield between vertical and horizontal orientations. Most publications reported yield responses differed depending on the cultivar (Chen et al. 1982; Hall 1986; Levett 1993). Cultivar-specific responses may contribute to the inconsistency of results from previous research, and therefore highlight the importance of evaluating cultivars that are currently being grown in North Carolina, USA. Furthermore, nearly all published sweetpotato planting orientation studies were hand-planted without the aid of a mechanical planter. The one exception was the study by Chen et al. (1982), who adapted a mechanical transplanter for horizontal orientation. Our study is unique in using a transplanter designed for horizontal planting. The majority of growers in the United States rely on mechanical transplanters; therefore, it is important to evaluate a mechanized planter so that the results are directly applicable for them to adapt the best planting practice.

Two new developments regarding mechanical sweetpotato planters have occurred in recent years. One development is a sleeve adapter, which involves the attachment of the sleeve on the standard vertical transplanter (B & S Enterprises, Inc., Elizabeth City, NC, USA) (Supplemental Fig. 1). There is great interest in the sleeve attachment because it is promoted to increase yields, and it would be a relatively low-cost investment for a grower, rather than a completely new planter. The other key development is the construction of a horizontal transplanter (Jones Family Farms, Bailey, NC, USA) (Supplemental Fig. 1). Our study evaluates these developments compared with a standard planter.

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 1974; Scott and Bouwkamp 1975; Villordon et al. 2009b). However, many different environmental factors influence root bulking, including rainfall and soil temperature (Kays 1985). Given favorable environmental conditions, sweetpotato roots will continue to increase in size, and therefore delaying harvest can increase yields (US Department of Agriculture 2016). Thus, the ideal harvest time would maximize the storage roots that are US No. 1 grade, as this is the most profitable grade.

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 on this understanding, it is theorized that the more nodes buried would permit greater sweetpotato storage root yields. Southeastern US extension publications generally recommend burying more nodes when planting to increase yields (Boudreaux 2009; Granberry et al. 2007; Shankle and Reddy

Received for publication 25 Jul 2023. Accepted for publication 2 Nov 2023.
Published online 15 Dec 2023.
This research was supported by the National Institute of Food and Agriculture – Organic Agriculture Research and Extension Initiative. Grant no. 2019-51300-30247.
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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 greater yields at a 15-cm planting depth compared with a 5-cm depth. Hall (1986) reported no effect on marketable root yields when five or six nodes were buried instead of two or three nodes, but found the effects on US No. 1 yields to be cultivar dependent. Rós (2017) found that the number of buried nodes had no effect on number or yield of roots using 'Uruguaina' in a 1-year study.

For our study, we used the cultivar Monaco because of its beneficial attributes for organic production. This cultivar has resistance to *Fusarium* wilt and southern root-knot nematodes, and moderate resistance to *Streptomyces* soil rot, flea beetle, and the wireworm–*Diabrotica–Systena* complex (Jennings et al. 2019). In addition, it has an upright growth habit, which may contribute to tolerance of weed interference and allow for prolonged cultivations (Smith et al. 2022). However, this cultivar typically has lower yields than 'Covington' (Yencho and Pecota 2022), the most commonly grown cultivar in North Carolina, USA, which may limit its adoption by growers.

Our study had three main objectives: 1) evaluate whether the planting orientation of stem cuttings affects yield, 2) evaluate two stem cutting lengths (25 and 38 cm) to investigate how cutting length influences yield, and 3) harvest at two different dates [$\sim$107 and $\sim$126 d after planting (DAP)] to evaluate whether altering orientation delays storage root bulking.

Materials and Methods

Experiments were conducted in 2020 and 2021 at Jones Family Farms, in Bailey, NC, USA (lat. 35°49'31.1"N, long. 78°07'30.4"W). The soil is a Norfolk loamy sand (fine-loamy, kaolinitic, thermic Typic Kandiudults) and Gritney sandy loam (fine, mixed, semiactive, thermic Aquic Hapludults). Fields used in the experiment were managed organically for at least 7 years. The preceding crop for both years was soybean [*Glycine max* (L.) Merr]. In June, before sweetpotato planting, poultry litter was applied and incorporated at a rate of $\sim$6.7 $Mg{\cdot}ha^{-1}$. An exact nutrient analysis of the litter applied was not obtained. Litter nutrient composition varies depending on the source, with average nutrient compositions ranging from 24 to 29 $kg{\cdot}Mg^{-1}$ nitrogen (N), 20 to 22 $kg{\cdot}Mg^{-1}$ phosphorus (P), and 20 to 24 $kg{\cdot}Mg^{-1}$ potassium (K) of litter (Nutrient Management Team 2022a). According to standard nutrient management guidelines for poultry litter in North Carolina, USA, it is assumed that 60% of the N, and 100% of the P and K is plant available when incorporated (Nutrient Management Team 2022b). Therefore, we estimate that 96 to 116 $kg{\cdot}ha^{-1}$ N, 134 to 150 $kg{\cdot}ha^{-1}$ P, and 133 to 163 $kg{\cdot}ha^{-1}$ K were applied each year.

Three transplant orientation treatments were investigated: vertical, vertical transplanter with a sleeve attachment (portion of stem/transplant cutting horizontal; referred to as "sleeve"), and a horizontal transplanter (Supplemental Fig. 1). Two stem cutting lengths (25 and 38 cm from cut end to growth tip) were evaluated as well as two harvest times, early (104 DAP in 2020 and 111 DAP in 2021) and late (127 DAP in 2020 and 125 DAP in 2021). The resulting experimental structure was a 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 Jun 2020 and 9 Jun 2021. Treatment plots contained two rows spaced 1.1 m apart and were 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. A standard commercial two-row bare-root transplanter (B & S Enterprises, Inc.) was used for the vertical and sleeve orientations. The vertical transplant orientation was achieved by normal operation of the transplanter. The mechanism is driven by a drive wheel, which moves the chains to rotate the clips. Coulter blades followed by row openers create a 10- to 15-cm–deep furrow. The cuttings are placed into spring-loaded rotating clips, which release the cutting into the furrow. Packing wheels follow to close the furrow around the stem cutting. Sleeve attachments were mounted onto the transplanter for the sleeve treatment. The sleeve surrounds the stem cutting after it is in the clip, and guides and bends the bottom of the cutting so that a portion of it has a horizontal orientation when it is released into the furrow. A separate transplanter was used to achieve horizontal stem cutting placement. In 2020, a four-row horizontal transplanter constructed by Jones Family Farms was used. In 2021, a two-row horizontal transplanter constructed by Jones Family Farms was used. The row openers create a furrow $\sim$13 cm deep. 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. After placement of the cutting, the furrow is closed around the stem cutting.

Standard organic management practices were followed throughout the season (Jennings et al. 2019) (Table 1). Management practices include the previously mentioned application of poultry litter as a soil amendment. Plots were managed for weeds by cultivation approximately every 10 days until canopy closure, and weekly hand removal throughout the growing season. There was sufficient moisture throughout the growing season (Supplemental Fig. 2). During the cropping season, average air temperatures were normal for both years, and precipitation exceeded the historical average by more than 19 cm in 2020 and 14 cm in 2021 (Supplemental Table 1).

Data collection. Before transplant, nodes were counted on 12 stem cuttings per plot. Stand counts were collected 12 and 6 DAP in 2020 and 2021, respectively. On the same date, the number of nodes above the soil line was recorded for 12 plants per plot to calculate an estimate of the average 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, USA). Only one row per plot was harvested for data collection. Roots were graded using US Department of Agriculture standards (US Department of Agriculture 2005) into canners (diameter, 2.5–4.4 cm), US No. 1 (diameter, 4.4–8.9 cm; length, 7.6–22.9 cm), jumbos (diameter, $>$ 8.9 cm), and culls (any root containing rot or that was severely misshapen). The weight and number of roots for each grade were recorded. Marketable yield was calculated as the sum of canners, US No. 1s, and jumbos (Yencho and Pecota 2022). In addition, the length of 10 representative US No. 1 roots per plot were recorded.

Data were analyzed using the GLIMMIX procedure in SAS version 9.4 (SAS Institute, Cary, NC, USA). For the analysis of total nodes, stem cutting length and year were treated as fixed effects. For all other analyses, transplant orientation, stem length, harvest time, and year were treated as fixed effects, and block within harvest × year was treated as a random effect. Because of the non-normal nature of the proportion data, a beta distribution was used when analyzing the proportion of marketable yields made up by individual grades. Least square mean separation was completed using Tukey's honestly significant difference adjustment at a significance of $P < 0.05$.

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 per 7.6-m row in 2020 and 26.5 plants per 7.6-m row in 2021.

Nodes. Total nodes were affected by the interaction of stem cutting length and year ($P = 0.0003$; Fig. 1A). In both years, 38-cm cuttings had more nodes than 25-cm cuttings; however, in 2021, there was a greater difference in the number of nodes than in the prior year. An interaction ($P = 0.0030$) of stem cutting length and year affected the number of nodes buried (Fig. 1B). 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, an interaction ($P = 0.0064$) of stem cutting length and orientation affected the number of nodes buried. The average number of nodes buried differed with orientation for only the 25-cm-length cuttings, with more nodes buried for the horizontal orientation than the vertical and sleeve orientations (Fig. 2).

Significant, but minimal, positive correlations were found between the average number of nodes buried and marketable yield ($r = 0.23297$; $P = 0.0246$), the number of nodes buried and number of marketable roots ($r = 0.30193$; $P = 0.0033$), the number of nodes buried and US No. 1 yield ($r = 0.23521$; $P = 0.0232$), and the

Table 1. Timing of cultural practices and data collection.

Cultural practice	Date of activity									
2020										
Poultry litter application	Early June									
Planting	10 Jun									
Stand counts	22 Jun									
Cultivation	22 Jun	8 Jul	16 Jul	26 Jul						
Hand-weed removal	22 Jun	2 Jul	9 Jul	16 Jul	23 Jul	30 Jul	7 Aug	14 Aug	21 Aug	
Harvest	22 Sep	15 Oct								
2021										
Poultry litter application	Early June									
Planting	9 Jun									
Stand counts	15 Jun									
Cultivation	12 Jun	14 Jun	18 Jun	27 Jun	17 Jul					
Hand-weed removal	15 Jun	21 Jun	28 Jun	13 Jul	16 Jul	26 Jul	5 Aug	10 Aug	19 Aug	2 Sep
Harvest	28 Sep	12 Oct								

number of nodes buried and the number of US No. 1 roots (r = 0.24897; P = 0.0161).

US No. 1 root dimensions. Main effects of stem cutting length (P = 0.0125), orientation (P < 0.0001), and harvest time (P = 0.0002) influenced US No. 1 root length (Fig. 3A–C). Roots from 38 cm stem cuttings were 0.5 cm longer than roots from 25 cm cuttings. Roots from stem cuttings planted horizontally were 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.

US No. 1 yield. Stem cutting length had no impact on US No. 1 yields or counts (P > 0.05; data not shown). US No. 1 root weights and counts increased when harvest was delayed, but the magnitude of these increases varied by study year (harvest by year interaction, P = 0.0239 and P = 0.0237, respectively). In 2020, the total weight of US No. 1 roots increased by 74%, whereas in 2021, yield only increased by 22% (Table 2). Similarly, in 2020, late-harvested plants produced 0.8 more US No. 1 roots per plant; but, in 2021, late-harvested plants only yielded 0.4 more roots per plant (Table 3). US No. 1 yield was greater with the horizontal orientation treatment than the sleeve and vertical orientations (P = 0.0008; Table 2). Yield with the horizontal orientation was 18% greater than the vertical orientation. A main effect of planting orientation also affected US No. 1 root counts. The horizontal orientation (2.4 roots per plant) was significantly greater than the vertical orientation (2.1 roots per plant), and the sleeve was intermediate (2.2 roots per plant; P = 0.0167).

Marketable yield. Yields were typical of ‘Monaco’ for this region (average marketable yield, ∼37,000 kg·ha^{-1}) (Yencho and Pecota 2022). Stem cutting length had no impact on marketable weights (P > 0.05; data not shown). However, the number of marketable roots was affected by the interaction of stem cutting length and year (P = 0.0002; Table 3). In 2021 only, plants grown from 38-cm stem cuttings averaged more roots per plant than those grown from 25-cm cuttings. A main effect of harvest time influenced both marketable weights (P < 0.0001; Table 2) and marketable counts (P = 0.0004; data not shown). Marketable yields increased 49% when harvest was delayed. Marketable counts increased from 4.8 roots per plant at early harvest to 5.5 roots per plant at late harvest. The interaction between planting orientation and year also affected marketable yields. The horizontal planting orientation had greater marketable yields than the vertical orientation in 2020, but all orientations had similar yields in 2021 (P = 0.0126; Table 2). However, planting orientation had no effect on the number of marketable roots (P > 0.05; data not shown).

US No. 1–grade roots made up a significantly greater proportion of the marketable weight with the horizontal orientation (63%) than either the sleeve (59%) or vertical orientations (56%) when accounting for stem cutting length, harvest time, and year (P = 0.0018).

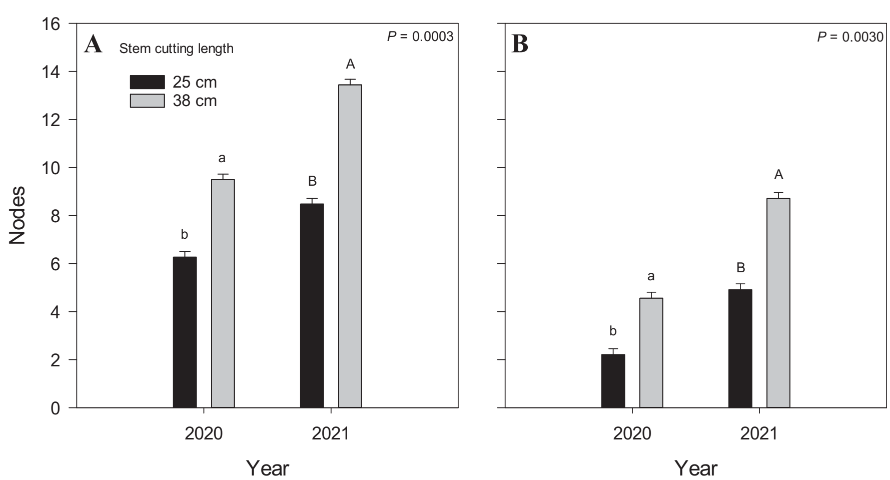

Fig. 1. Interaction of stem cutting length and year on the average total nodes (**A**) and the average nodes buried (**B**) of sweetpotato stem cuttings. Means are compared using Tukey’s honestly significant difference sliced by year (α = 0.05). Lowercase letters are used to compare means in 2020; uppercase 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 plant for each plot.

Discussion

One main objective of this study was to investigate whether planting orientation affected sweetpotato yield. We observed that a horizontal orientation maintained or increased yields compared with the standard vertical planting method, in terms of weight and root count, regardless of stem cutting length or harvest time (Table 2). Most notably, we observed an increased weight and root count of US No. 1–grade roots, which is the premium grade marketed (Table 2). Our work supports findings by Belehu and Hammes (2010) and Pakkies et al. (2019), who found greater yields with a horizontal orientation compared with a vertical one in their single-year studies. Others have also observed comparable yields with plants oriented either horizontally or vertically, including Monks (1981), who found no difference for ‘Jewel’ and ‘Centennial’; du Plooy et al. (1992), who demonstrated similar storage root counts in a 1-year study; and Dlamini et al. (2021), who observed similar root counts and yields for three varieties in a 1-year study. We also observed that the distribution of grades in the marketable yields is preferable with a horizontal orientation, with an increased proportion of US No. 1s and a decreased proportion of jumbos (data not shown). This favorable distribution of root sizes with horizontal planting for some cultivars was observed as either an increased proportion of US No. 1 roots (Hall 1986) or a decrease in the proportion of nonmarketable roots (Levett 1993).

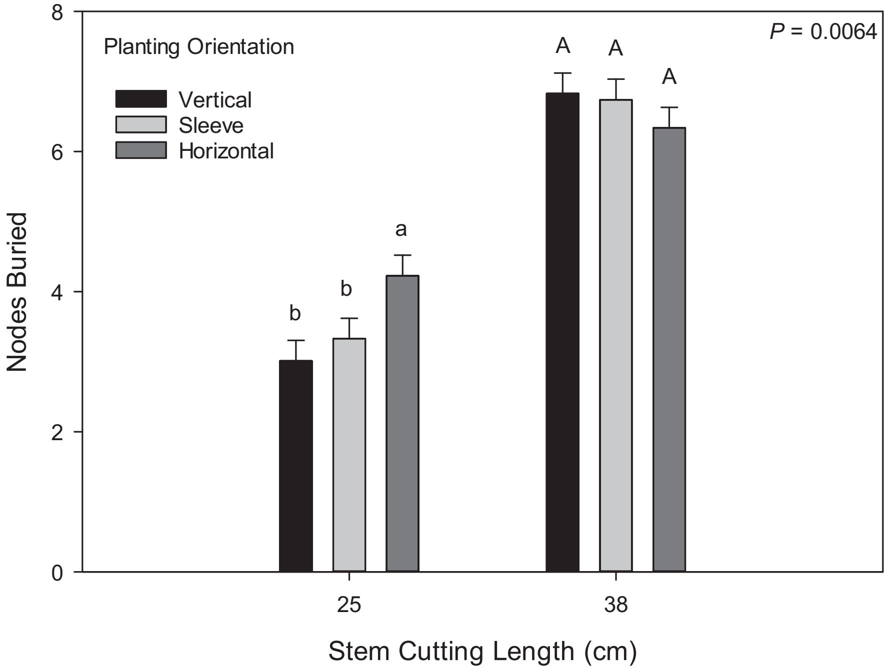

Fig. 2 Interaction of stem cutting length and planting orientation on the average number of sweetpotato stem cutting nodes buried. The number of nodes buried was calculated by subtracting the average number of nodes above the soil line after planting from the average number of total nodes on a plant on a per-plot basis. Means are compared within stem cutting length using Tukey's honestly significant difference sliced by cutting length ($\alpha = 0.05$). Lowercase letters are used to compare means of the 25-cm cuttings; uppercase letters are used to compare means of the 38-cm cuttings. Means with the same letter are not different.

We did not see significant yield gains by using the sleeve attachment on the standard planter (sleeve orientation) compared with the standard planter alone (vertical orientation). Therefore, the results of our study do not support the added investment in the sleeve treatment when planting 'Monaco'. Additional research is needed to evaluate other popular cultivars. One possible reason we may have seen little to no difference between the vertical and sleeve treatments is that the stem cuttings are likely bending and dragging along the bottom of the furrow for the vertical orientation instead of orienting entirely vertically. This has been observed by others who used the same equipment as that used in our study (Parker B, personal communication, 2020). The transplanter only creates a furrow ~10 to 13 cm deep. As a result, the cutting is likely forming an "L" shape to accommodate the extra length belowground, and thus the standard planter would plant in an orientation similar to the sleeve attachment.

We found the longest US No. 1 roots with the horizontal orientation (Fig. 3B) and saw no difference in root diameter among planting orientations (data not shown). Our work builds on evidence provided by a study in Nigeria that observed a horizontal orientation had longer roots than when stem cuttings were planted in a loop or on an angle (Idoko et al. 2018). However, our results differ from conclusions by others, including Dlamini et al. (2021), who found no difference in root length when comparing vertical and horizontal; and Parwada et al. (2011), who found no difference in root length among horizontal, inclined (45°), and vertical orientations. Our results may not be directly comparable to the aforementioned studies because they compared the average dimensions of all storage roots and we only measured US No. 1 roots. Our results suggest that horizontal planting may improve shapes of US No. 1 roots, meeting grower preferences to optimize US No. 1–grade roots and maximize profits. Short and round roots may not meet these requirements, and risk being sorted as an off grade by the packinghouse.

Longer stem cuttings had more nodes and more nodes buried (Fig. 1). We found that more nodes buried correlated with greater marketable and US No. 1 yields; however, the correlations were very weak and thus we cannot make a definitive conclusion regarding this relationship. Prior research regarding buried nodes and yield has indicated mixed results. Thompson et al. (2017) attributed greater yields of 'Covington' planted at deeper depths to more nodes buried, Hall (1986) identified different effects depending on cultivar, and Rós (2017) found no influence of the number of nodes buried on the number or yield of roots using 'Uruguaina' in a 1-year study. It is important to consider that we estimated the number of nodes buried by counting the number of nodes above the soil line to avoid sampling destructively. Implementation of this estimation should be timed with other cultural management practices. For example, in the first year,

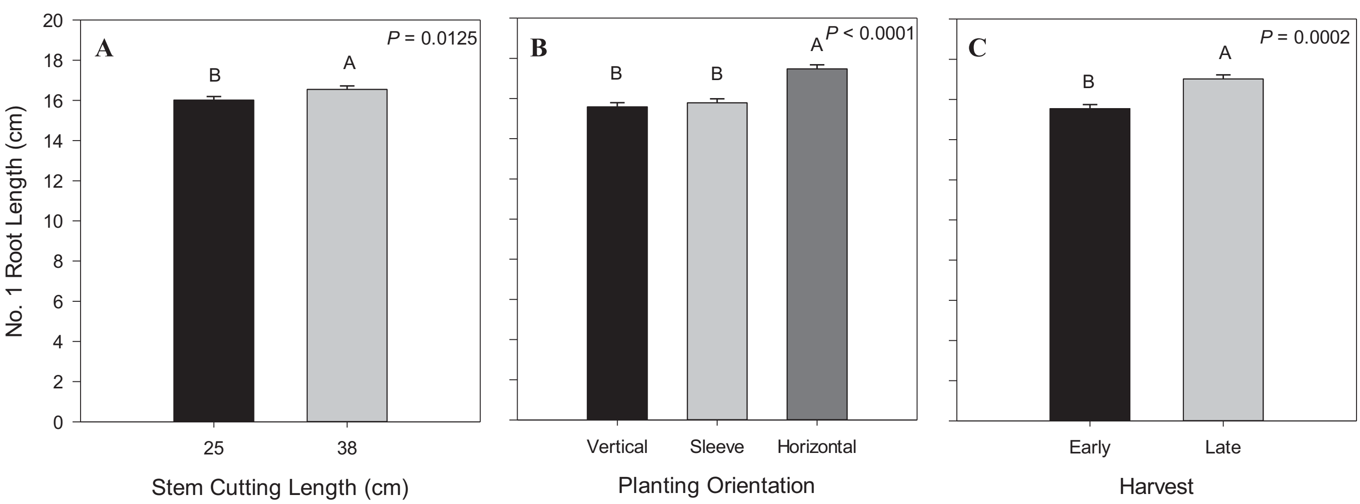

Fig. 3 Main effects of stem cutting length (**A**), orientation (**B**), and harvest time (**C**) on average US No. 1 sweetpotato root length. US No. 1–grade roots were defined as 4.4 to 8.9 cm in diameter and 7.6 to 22.9 cm in length (US Department of Agriculture 2005). Means with the same letter are not different (Tukey's honestly significant difference, $\alpha = 0.05$). Early harvest was 104 d after planting in 2020 and 111 d after planting in 2021. Late harvest was 127 d after planting in 2020 and 125 d after planting in 2021.

Table 2. Effects of stem-cutting orientation, harvest time, year, and their interactions on sweetpotato root yield.

	Sweetpotato grade (kg·ha^{-1})[i]	
Treatment	US No. 1	Marketable
Orientation		
Vertical	20,948 b[ii]	—[iii]
Sleeve	21,779 b	—
Horizontal	24,871 a	—
P value	0.0008	>0.05
Harvest		
Early	—	30,677 b
Late	—	45,584 a
P value	<0.0001	<0.0001
Year		
2020	—	—
2021	—	—
P value	0.0019	0.0002
Orientation × year		
Vertical, 2020	—	30,972 b
Sleeve, 2020	—	32,487 ab
Horizontal, 2020	—	36,065 a
Vertical, 2021	—	44,481 A
Sleeve, 2021	—	42,484 A
Horizontal, 2021	—	42,292 A
P value	>0.05	0.0126
Harvest × year		
Early, 2020	14,776 b	—
Late, 2020	25,651 a	—
Early, 2021	22,410 B	—
Late, 2021	27,293 A	—
P value	0.0239	>0.05

[i] Sweetpotato grades are based on US Department of Agriculture standards. US No. 1s were defined as 4.4 to 8.9 cm in diameter and 7.6 to 22.9 cm in length, canners were defined as roots with a 2.5 to 4.4 cm diameter, and jumbos were roots greater than 8.9 cm in diameter (US Department of Agriculture 2005). Marketable yield is the sum of US No. 1, jumbo, and canner grades.

[ii] Means followed by the same letter within a grade and response are not different (Tukey's honestly significant difference, α = 0.05). Interactions are sliced by year. Lowercase letters are used to compare means in 2020; uppercase letters are used to compare means in 2021. All other first-order interactions and all higher order interactions among model terms are not significant and therefore are not presented.

[iii] Means for nonsignificant effects are not replaced with —.

the node counts were taken before cultivation; in the second year, we were not able to count until after the grower's second cultivation event, which resulted in more nodes buried in the second year compared with the first year of the study. Additional research is needed to investigate further the effect of buried nodes on yield.

Table 3. Selected interactions of stem cutting length, harvest, and year on sweetpotato root counts per plant.

	Sweetpotato grade (no. of roots/plant)[i]	
Treatment	US No. 1	Marketable
Stem cutting length × year		
25 cm, 2020	—[ii]	5.0 a[iii]
38 cm, 2020	—	4.7 a
25 cm, 2021	—	5.1 B
38 cm, 2021	—	5.8 A
P value	>0.05	0.0002
Harvest × year		
Early, 2020	1.6 b	—
Late, 2020	2.4 a	—
Early, 2021	2.3 B	—
Late, 2021	2.7 A	—
P value	0.0237	>0.05

[i] Sweetpotato grades are based on US Department of Agriculture standards. US No. 1s were defined as 4.4 to 8.9 cm in diameter and 7.6 to 22.9 cm in length, canners were defined as roots with a 2.5 to 4.4 cm diameter, and jumbos were roots greater than 8.9 cm in diameter (US Department of Agriculture 2005). Marketable yield is the sum of US No. 1, jumbo, and canner grades.

[ii] Means for nonsignificant effects are not replaced with —.

[iii] Means followed by the same letter within a grade and response are not different (Tukey's honestly significant difference, α = 0.05). Interactions are sliced by year. Lowercase letters are used to compare means in 2020; uppercase letters are used to compare means in 2021. All other first-order interactions and all higher order interactions among model terms are not significant and therefore are not presented.

We anticipated that a horizontal planting orientation would increase yields as a result of burying more nodes than the vertical orientation. Our results do not suggest this simple relationship. We observed more nodes buried with the horizontal orientation only with the 25-cm cutting length; the longer stem cuttings had similar nodes buried among all orientations (Fig. 2). However, we saw greater US No. 1 yields with the horizontal orientation (Table 2) regardless of stem length. This suggests that the number of nodes buried is not the only factor by which yield may be improved with the horizontal orientation.

Although not tested directly in our study or by others, many researchers hypothesize that horizontal orientation has better yields and shapes as a result of the spatial arrangement of the subterranean nodes reducing the competition for space (Chagonda et al. 2014; Gregorie and Villordon 2019; Park et al. 1953) and nutrients (Gregorie and Villordon 2019) among developing roots at each node. With a vertical orientation, nodes are stacked on top of each other, and storage roots grow down and interfere with the roots at the node below, whereas with a horizontal orientation, this interference among nodes could be reduced.

Our results indicate that using 25-cm and 38-cm–long cuttings has no effect on marketable weights or US No. 1 weight or counts (Tables 2 and 3). It is possible that we do not have a clear trend with our study because the cutting lengths were too similar in size to detect differences with the power of our study. Coleman et al. (2006) and Godfrey-Sam-Aggrey (1974) both reported differences in yield when comparing stem cutting lengths that had at least a 20-cm difference in length. However, longer cutting lengths may not have been compatible with all of our planting equipment. Another consideration is that environmental conditions play a critical role in plant response. Conditions in terms of moisture and temperature were favorable for sweetpotato production for the 2 years we conducted these studies. Perhaps a different response might have been elicited under more stressful growing conditions.

We did not observe a difference in marketable root counts among planting orientations (data not shown). In addition, the lack of any significant planting orientation by harvest time interaction with regard to yield metrics suggests that planting with the horizontal orientation does not delay the maturity of the crop. Regardless of planting orientation, delaying harvest until ~126 d increased marketable and US No. 1. yields compared with harvests at 104 or 111 d (Table 2).

We observed harvest-by-year interactions for US No. 1 weights and counts (Tables 2 and 3). In 2021, there were nine fewer days between harvests times, which may have contributed to smaller differences between harvests in this year. Inconsistency in yield response to harvest delay has been observed by others who speculated that insufficient moisture (Hartman and Gaylord 1943) or cool air temperatures (Arancibia et al. 2014; Reynolds et al. 1994) during the period of season extension limited yield gains in some years. In our study, we had adequate moisture throughout the entire growing season (Supplemental Fig. 2). Using growing degree day (GDD) models may help to account for the variability of growing conditions across years. However, published models use different model terms and calculate varied GDD accumulation requirements. For example, Villordon et al. (2009a) used a base temperature of 15.5 °C and a ceiling temperature of 32.2 °C, and calculated 2600 GDDs. Duque et al. (2022) used two models without setting a ceiling temperature. For a base temperature of 15.5 °C, they calculated 700 GDDs; for a base temperature of 10 °C, they calculated 1300 GDDs.

This increase in both weight and proportion of US No. 1 roots when using the horizontal planter is important because growers receive the best financial return for this grade. In addition, increased yields, particularly of the premium grade, equate to improved land-use efficiency, which is important from financial and ecological perspectives. 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). On average, organic sweetpotato systems yield 2% less than conventional ones (Nwosisi et al. 2021). Planting horizontally may be one tool to improve productivity in organic systems. Additional research is needed to evaluate whether an increase in premium-grade roots is also seen with conventional systems.

One potential barrier to the adoption of horizontal planting equipment is the lack of commercial production of this transplanter in the region. Engineers in China have made progress in designing a horizontal transplanter and have recently published results from its field test (Yan et al. 2022). In the United States, horizontal transplanter production currently requires custom requests to equipment manufacturers. For example, the grower partner for this study had custom units created, and then modified them as he saw fit to improve their usability. Although an exact cost cannot be provided, pricing for a horizontal planter is estimated to be less than the cost of a new mechanical transplanter. An economic analysis of this investment for horizontal equipment should be considered to evaluate costs for equipment and labor. For example, adoption of a new planting technique requires training and could increase labor costs if planting is slower. Thus, the returns from increased US No. 1 yields would need to outweigh any potential costs associated with the adoption of a horizontal transplanter.

Conclusion

Potential strategies to increase yields of organically grown 'Monaco' include planting stem cuttings horizontally and delaying harvest until late in the season. Use of a horizontal planter maintained or improved marketable yields compared with the standard planter, and improved the distribution of root grades, favoring a greater percentage of the premium grade (US No. 1). Increased yields, specifically of US No. 1 roots, can increase grower profits and improve land-use efficiency. Additional research is needed to determine whether horizontal planting equipment is cost-effective for sweetpotatoes.

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