Decreasing Phosphorus Fertility to Reduce Sweetpotato Root Growth During Container-grown Transplant Production[1]

L. Rouse, J. Beasley, D. LaBonte, and J. Kuehny[2]

Abstract

Sweetpotato [*Ipomoea batatas* (L.) Lam.], grown as an edible ornamental, is propagated in home gardens using locally purchased transplants. However, vigorous growth of sweetpotato limits the period of transplant salability due to root confinement. The objective of the experiment was to evaluate reductions in phosphorus (P) fertility to slow transplant root growth and extend the period of salability. Cuttings were planted into containers and fertilized at 0, 5 (0.0007), 10 (0.0012), 15 (0.0020), 20 (0.0024), and 31 mg $P{\cdot}L^{-1}$ (0.0040 oz $P{\cdot}gal^{-1}$) using a modified Hoagland solution. All transplants fertilized at ≥5 mg $P{\cdot}L^{-1}$ increased in shoot length, color, and biomass during the first four weeks after planting (WAP) but declined thereafter. Transplant roots fertilized at ≥5 mg $P{\cdot}L^{-1}$ (0.0007 oz $P{\cdot}gal^{-1}$) increased in total length, surface area, and volume throughout the six-week production cycle. However, P fertility <15 mg $mg{\cdot}L^{-1}$ (0.0020 oz $P{\cdot}gal^{-1}$) resulted in narrower storage roots with lower root volumes. Reducing P fertility from 31 (0.0040 oz $P{\cdot}gal^{-1}$) to 5 mg L^{-1} (0.0007 oz $P{\cdot}gal^{-1}$) did not sufficiently slow transplant rooting to prevent roots from reaching container walls to extend the period of salability.

Index words: root length, root diameter, root biomass, and root architecture.

Species used in this study: Sweetpotato [*Ipomoea batatas* (L.) Lam.].

Significance to the Horticulture Industry

The expanding home garden market has led to greater consumer demand for edible ornamental crops such as sweetpotato (*Ipomoea batatas*). Many homeowners purchase transplants from local nurseries rather than planting stem cuttings, which are used in production horticulture. This has led to anecdotal concerns of fertilized sweetpotato transplants quickly developing elongated roots that reach container walls, becoming root bound. Excess container root mass reduces transplant vigor and quality, shortening the period of salability. Common mechanical or chemical methods implemented on many ornamental species to counter or prevent excess root mass are not appropriate for edible root crops. An alternative method to slow sweetpotato rooting during transplant production may be reducing phosphorus (P) fertility. Lowering P fertility modified sweetpotato root architecture, i.e., reduced length and more branching, in greenhouse studies (Villordon, personal communication, 2021). Sweetpotato shoot and root growth were evaluated over a six-week transplant production cycle. Reducing P fertility from 31 (0.0040 oz $P{\cdot}gal^{-1}$) to 5 $mg{\cdot}L^{-1}$ (0.0007 oz $P{\cdot}gal^{-1}$) did not sufficiently slow transplant rooting to prevent root bound conditions and thus did not extend the period of salability beyond 4 weeks. Alternative practices such as reducing N fertility or periodic manual defoliation should be examined to slow transplant rooting to increase the duration of salability.

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[2]School of Plant, Environmental, and Soil Sciences, Louisiana State University Agricultural Center, 137 Sturgis Hall, Baton Rouge, LA 70803. Corresponding author jbeasley@agcenter.lsu.edu.

Introduction

Resurgence in gardening over the past decade has resulted in greater consumer demand for new and unique plants (National Gardening Association 2014). This has encouraged plant breeding programs, which have traditionally focused on species grown for field production (Beck and Quigley 2014, Brown and Worden 2013), to release edible ornamental cultivars such as sweetpotato for home landscapes (Owings 2009). However, movement into the home gardening sector does present different challenges than those associated with field production practices. For example, home gardeners commonly establish vegetables species using transplants purchased from local nurseries compared to large-scale sweetpotato producers that plant vegetative stem cuttings (Belehu et al. 2004, Ma et al. 2015, Villordon et al. 2009). A concern with using container-grown transplants rather than vegetative stem cuttings for sweetpotato establishment is the potential for container-grown transplants to develop root-bound conditions (Weicherding et al. 2007) within limited container volumes. This is more commonly referred to as a plant being root-bound. Root-bound plants often exhibit moisture stress that limits photosynthesis (Kramer 1983), leading to yellowing, necrotic foliage, and an overall decline in aesthetic quality. Root-bound conditions are particularly problematic (Costello and Paul 1975, Flemer 1980, Gouin 1983) for vigorous growing root crop species such as sweetpotatoes because it not only reduces the period of transplant salability but could also deform storage roots.

Implementing commonly used, post-transplant production, mechanical techniques such as scoring to ameliorate root bound conditions prior to planting has been shown to have positive effects on root growth depending on species and environmental factors (Weicherding et al. 2007). However, in the case of sweetpotatoes, adventitious roots

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formed within seven days after planting account for almost 90% of storage root development (Villordon et al. 2009) and implementing mechanical root disruption practices would physically damage storage roots. Alternatively, application of chemical growth retardants such as copper sulfate to reduce root bound conditions has provided inconsistent results across species (Armitage and Gross 1996, Liu et al. 2016) and may not be appropriate for edible crops, especially if non-chemical methods of production are preferred.

A more effective practice to prevent root bound conditions of sweetpotato transplants and extend the duration between propagation and landscape installation would be to reduce fertility to slow transplant growth. Regulating P fertility has been shown to affect root production of many agronomic and horticultural crops (Borch et al. 2003, Boulanger-Pelletier and Lapointe 2017, Lynch and Brown 2001, Miller et al, 2003) as well as sweetpotato during field production (Jones et al. 1991). Observational studies involving plants grown in low P environments have shown arrested root growth (Svistoonoff et al. 2007). To date, response of sweetpotato transplants to low P fertility as a technique to limit negative effects associated with root bound conditions has not been documented. The objective of this research was to evaluate the effects of decreasing P fertility on container-grown sweetpotato root growth as a method to extend the period of transplant salability.

Materials and Methods

Sweetpotato transplant setup and nutrient delivery system. Virus-free stem cuttings of 'Beauregard' sweetpotatoes were obtained from the Louisiana State University Agricultural Center (LSU AgCenter) Sweetpotato Research Center in Chase, LA (32.138935 N; 91.691899 W) for experiments conducted March 2018 and May 2018. All terminal stem cuttings were selected for uniformity and varied from 15.2 to 17.8 cm (6 to 7 in) in shoot length, 4 to 5 nodes, and plants containing 3-4 fully expanded leaves. Stem cuttings were transported to the LSU AgCenter Botanic Gardens in Baton Rouge, LA (30.405707N; 91.103358W) and rooted in sand for 14 d under greenhouse conditions prior to initiating the experiments. During this period, stem cuttings were irrigated with deionized water as needed to prevent plant wilting, but no nutrients were applied.

Containers (N=180) for propagating sweetpotato transplants were constructed from 10.2 cm (4.02 in) diameter polyvinyl chloride pipe (PVC) (Schedule 40, Charlotte Pipe and Foundry Company, Charlotte, NC) at 12.7 cm (5 in) heights with detachable PVC bases. The size of the container selected represents the small volumes often associated with containers used in transplant production. Each container base had five drain holes [2 mm (.079 in) in diameter]. In addition, each container had four rows of side drain holes [2 mm (0.079 in) in diameter; 3 cm (1.181 in) apart within a row] that were located diametrically opposite to one another to prevent the formation of a perched water table (Bilderback and Fonteno 1987, Villordon et al. 2018). Each container was filled with 1,247.4 g (44 oz) of non-amended sand for a bulk density of 0.337 $g \cdot m^{-3}$ (0.00033 $oz \cdot ft^{-3}$). The sand had a pH 5.3 and fertility of P = 3.5 $mg \cdot L^{-1}$ (0.0005 oz $P \cdot gal^{-1}$) and K = 14.3 $mg \cdot L^{-1}$ (0.0019 oz $P \cdot gal^{-1}$) according to Mehlich III extraction and inductively coupled plasma (ICP) optical emission spectroscopy (ICP SPECTRO ACRCOS Model FH E12, Kleve, Germany) analyses performed by the LSU AgCenter Soil Testing and Plant Analysis Laboratory (STPAL, Baton Rouge, LA). The majority of sand particles (89%) ranged in diameter from 1.0 mm to 0.10 mm, with 5.43% >1.0 mm (0.039 in), 30.39% 1.0 mm to 0.5 mm (0.019 in), 57.95% 0.5 mm to 0.25 mm (0.0098 in), and 4.75% 0.25 to 0.10 mm (0.004 in). One terminal stem cutting 15.2 to 17.8 cm (6 to 7 in) grown in the greenhouse was planted in each container with one node below the surface of the sand. All containers were randomly arranged on a single greenhouse bench.

All sweetpotato transplants were fertilized with modified Hoagland solutions (Hoagland and Arnon 1950) that varied in P concentrations from 0 to 5 (0.0007 $oz \cdot gal^{-1}$), 10 (0.0014 $oz.gal^{-1}$), 15 (0.0021 $oz \cdot gal^{-1}$), 20 (0.0028 $oz \cdot gal^{-1}$), or 31 (0.0041 $oz \cdot gal^{-1}$) $mg \cdot L^{-1}$. Nutrient concentrations for each solution were analyzed to confirm the concentrations using inductively coupled plasma (ICP) optical emission spectroscopy by the STPAL before treatment application. Nutrient solutions were delivered to each container using non-recirculating systems for each P concentration. Each nutrient delivery system was composed of a 56.8 L (15 gal) container (Fimco Inc., North Sioux, SD) painted with two coats of black paint followed by two coats of silver paint to exclude light and fitted with an electrical pump. Pumps delivered nutrient solution through 1.27 cm (0.472 in) diameter irrigation lines that ran the distance of the greenhouse bench. Micro-irrigation drippers (WPCJ drippers, Netafilm, Tel Aviv, Israel) delivered 150 mL (5.07 oz) of nutrient solution per application at a rate of 1.89 $L \cdot hr^{-1}$ (63.91 $oz \cdot hr^{-1}$) to each container. Nutrient solutions were applied every other day for the first five weeks of the experiments followed by 75 $ml \cdot d^{-1}$ (2.54 $oz \cdot d^{-1}$) the final week to prevent plant wilting. Nutrient solution was captured into empty beakers by treatment to ensure proper volumes were applied to the transplants.

Sweetpotato transplant growth. Transplant leaf color was assessed weekly for six weeks using a Soil Plant Analysis Development Meter (SPAD-502, Konica Minolta, Tokyo, Japan) on the three youngest, fully expanded leaves. In addition, transplant shoot length was measured weekly before shoots were excised at the shoot-soil interface with shoot foliage and stem tissues dried at 65 C (149 F) for 48 h for dry biomass determined gravimetrically. Roots were rinsed under a gentle stream of water to minimize root damage when removing sand particles for root analyses. The root parameters of total root length (TRL), root surface area (RSA), root volume (RV), and average root diameter (ARD) were measured using root architecture software (WinRhizo System Pro, Regent Instruments Inc., Quebec, Canada). In addition, the number of adventitious roots developing into storage roots was recorded and TRL, RV, and ARD were measured separately at 6 WAP by isolating images within the original root scans for analysis. The methods for root preparation and architectural analysis followed the procedures outlined by Villordon et al. (2013) with the

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Table 1. Influence of P fertility on container-grown sweetpotato transplant leaf color, shoot length, shoot biomass, and leaf P tissue concentration over a 6-week production cycle in 2018. One cm = 0.394 in; 1 g = 0.0353 oz; 1 mg·L^{-1} = 0.00012 oz·gal^{-1}.

Effects								
Fertility treatment	Leaf Color		Shoot length		Shoot biomass		Leaf P tissue concentration	
mg P·L^{-1}	SPAD units[z]		cm		g		%	
0	34.4[y]	ab	17.5[a]	b	1.64	b	0.10	d
5	35.9	a	31.1	a	2.48	a	0.14	cd
10	34.2	ab	31.7	a	2.59	a	0.21	bc
15	34.1	ab	34.0	a	2.72	a	0.26	b
20	34.8	ab	33.5	a	2.69	a	0.30	ab
31	32.7	b	33.9	a	2.91	a	0.38	a
Weeks after planting								
1	36.9	bc	17.5	d	2.13	bc	0.19	a
2	42.4	a	22.0	cd	2.03	c	0.27	a
3	38.3	bc	27.1	c	2.63	b	0.28	a
4	35.0	c	35.6	b	3.28	a	0.24	a
5	26.3	d	37.7	ab	3.24	a	0.21	a
6	27.2	d	42.0	a	1.72	c	0.20	a

[z]Soil Plant Analysis Development meter (SPAD).

[y]Means within a column followed by a different letter are statistically different according to Fisher's LSD (P<0.05).

Table 2. Influence of P fertility on container-grown sweetpotato transplant root biomass and average root diameter over a 6-week production cycle in 2018. One cm = 0.394 in; 1 mm = 0.0393 in; 1 mg P·L^{-1} = 0.00012 oz P·gal^{-1}.

Effects				
Fertility treatment	Root biomass		Average root diameter	
mg P·L^{-1}	cm		mm	
0	1.4[z]	b	0.47	b
5	1.9	a	0.63	a
10	2.0	a	0.57	a
15	1.8	a	0.61	a
20	2.1	a	0.58	a
31	1.9	a	0.57	a
Weeks after planting				
1	1.5	c	0.54	bc
2	1.8	bc	0.51	c
3	1.7	bc	0.44	d
4	2.2	a	0.59	bc
5	2.0	ab	0.66	a
6	1.8	bc	0.68	a

[z]Means within a column followed by a different letter are statistically different according to Fisher's LSD (P<0.05).

modification of using a 30 cm (11.81 in) by 40 cm (15.75 in) scanner (Epson Expression 12000 XL, Long Beach, CA) at a resolution of 23.62 pixel·mm^{-2} (600 dpi). Roots were then dried at 65 C (149 F) for 48 h and dry biomass determined gravimetrically. Dried sweetpotato shoot samples were submitted to the STPAL for P tissue concentration analysis using ICP optical emission spectroscopy.

Statistical analysis. Experimental units composed of single-transplant cuttings per container and destructive harvest date (1 to 6 WAP) were arranged as a completely randomized design with three replications. Data for the fixed treatment effects of P fertility and harvest date were analyzed using repeated measures for sweetpotato shoot length, biomass, leaf color, and root architectural parameters over a 6-week experimental period. The two experimental runs were considered a random effect. Using the MIXED procedure in statistical software (SAS 9.4, SAS Institute, Cary, NC), all data were analyzed. Means were separated following Fisher's least significant differences post-hoc procedure at $P \leq 0.05$. Root data were graphed over the six-week production cycle and standard error bars at $P \leq 0.05$ applied.

Results and Discussion

Sweetpotato transplant shoot growth and leaf color. Consumers tend to assess plant quality based on dark-green color, new growth, and the absence of discolored or unhealthy leaves when selecting container-grown plants for purchase (Brand and Leonard 2001). In this study, sweetpotato transplants for all P treatments maintained acceptable leaf color, increased in shoot length, and accumulated shoot biomass during the first 4 WAP (Table 1). Only transplants that received no P exhibited shorter shoot lengths and lower shoot biomasses of 17.5 cm (5.89 in) and 1.64 g (0.057 oz), respectively, compared to 31.1 (12.24 in) to 34.0 cm (13.39 in) and 2.48 (0.087 oz) to 2.91 g (0.103 oz) for transplants receiving $\geq$ 5 mg P·L^{-1} (.0007 oz P·gal^{-1}) during the transplant production cycle.

Decreasing P fertility, while maintaining sufficient concentrations of other essential nutrients, did not slow shoot growth even as P leaf tissue uptake decreased congruently with lower P fertilities. Poor correlation between P fertility and shoot production has also been reported for other container-grown plants when following current fertility practices for *Solenostemon scutellarioides* (L.) Codd (Chen et al. 2017), *Hydrangea macrophylla* (Thunb.) Ser. and *Ilex crenata* (Thunb.) (Shreckhise et al. 2019) and has led to questions regarding P fertility practices for many container-grown plants. In the final two weeks of the 6-week production cycle, symptoms associated with the plant becoming root-bound (Latimer 1991) resulted in an overall decline in transplant leaf color from 35.0 to 27.2 SPAD units accompanied with an average 48% decrease in shoot biomass. Transplants across all P fertilities were measured or observed to have elongated shoots, smaller leaves, greater leaf discoloration, and increased leaf abscission.

Sweetpotato transplant root architecture. Little evidence exists that consumers consider roots of container-grown plants when purchasing plants (Brand and Leonard 2001). However, rooting affects transplant health, leaf color, salability, and duration from propagation to purchase (Armitage and Gross, 1996, Costello and Paul 1975, Flemer 1980). The pattern observed for sweetpotato transplant root biomass was similar to that measured for shoot biomass (Table 2). Root biomass increased the first four WAP among all P fertilities before declining 18% from 2.2 g (0.071 oz) to 1.8 g (0.063 oz) during the last two weeks of the six-week production cycle. Decreasing P fertility from 31 (0.004 oz) to 5 mg·L^{-1} (0.0006 oz·gal^{-1})

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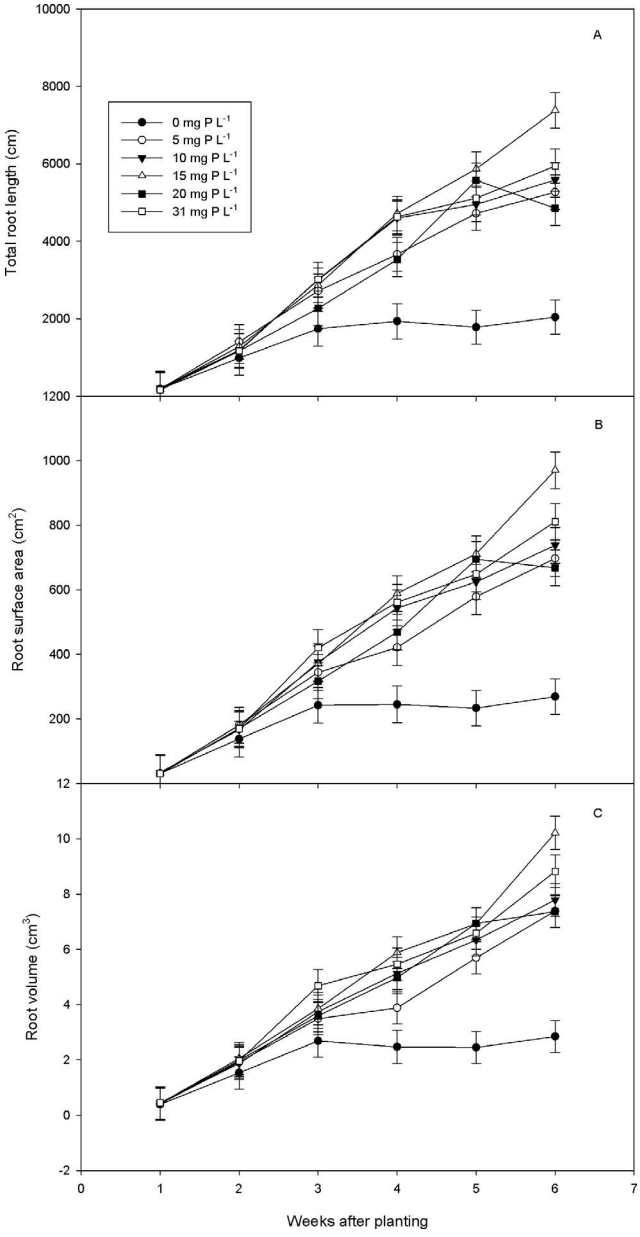

Fig. 1. Sweetpotato root growth of container-grown transplants fertilized at 0, 5, 10, 15, 20, or 31 mg P·L^{-1} during a six-week production period in 2018. Root parameters were measured for A) total root length (cm); B) root surface area (cm^2); and C) root volume (cm^3) through digital analysis of root scans. Bars around each mean represent standard error at P=0.05. One mg P·L^{-1} = 0.00012 oz P·gal^{-1}.

did not result in slower root biomass accumulation. In contrast, transplant rooting described architecturally using the parameters TRL, RSA, and RV followed an increasing pattern of growth throughout the six-week production cycle for all transplants fertilized at ≥5 mg P·L^{-1} (0.0006 oz P·gal^{-1}) (Fig. 1). Only transplants subjected to 0 mg P·L^{-1} (0 oz·gal^{-1}) stagnated in root growth beyond 3 WAP. Decreasing P fertility from 15 (0.0018) to 5 mg·L^{-1} (0.0006 oz gal^{-1}) incrementally decreased transplant rooting with transplants fertilized at 15 mg L^{-1} (0.0018 oz·gal^{-1}) having the highest TRL, RSA, RV. No additional root growth occurred for transplants receiving >15 mg P·L^{-1} (0.0018 oz·gal^{-1}) indicating P fertility of 15 mg P·L^{-1} (0.0018 oz·gal^{-1}) is sufficient. Excessive P soil concentrations do not generally lead to increased adventitious rooting, as has been noted in previous research evaluating P fertility rate effects on sweetpotato (Ichikawa et al. 2019).

The continuous architectural root growth of transplants during a period of declining shoot leaf color and shoot and root biomasses beyond 4 WAP marks the transition of the transplant becoming root-bound (Gouin 1983, Latimer 1991, Weicherding et al. 2007). Decreasing P fertility from 31 (0.004) to 5 mg·L^{-1} (0.0006 oz·gal^{-1}) did not sufficiently decelerate overall root growth to avoid root bound conditions nor effectively slow transplant shoot growth as a mechanism to limit root growth. Alterations in root architecture as shoot biomass decreased indicate photosynthate reallocation occurred within the plant to support root substrate exploration even as shoot and root biomass declined. For example, during the first four WAP, transplants fertilized at ≥5 mg P·L^{-1} (0.0006 oz P·gal^{-1}) increased in RSA and RV as a direct result of transplants rooting deeper into the substrate, whereas, in the latter weeks of the study, increases in RSA and RV were directly affected by root radial expansion, a common occurrence for maturing roots (Struve and Moser 1984, Struve 1990, Weicherding et al. 2007). Similar patterns of root expansion have been characterized for *Arabidopsis* and other plant species when placed into P-deficient growing conditions (Herrera et al. 2015, Jiang et al. 2017, Svistoonoof 2007). Increasing overall transplant ARD more importantly signaled the initiation of storage root formation (Villordon et al. 2009) and thus a period for potential storage root-bound conditions.

Phosphorus is a particularly important nutrient in sweetpotato growth because it affects the shape and quality of storage roots (Villordon et al. 2018). Research evaluating several sweetpotato cultivars indicates adventitious roots initiated within seven days after planting account for almost 90% of total storage root development (Villordon et al. 2009). Because homeowners will establish sweetpotatoes to harvest storage roots for consumption as well as for ornamental purposes, developing storage roots were examined to measure the effects of declining P fertility on storage root length, ARD, and volume (Fig. 2).

Adventitious root initiation occurred rapidly for all transplants with P fertility having no effect on the number of developing storage roots per transplant (P treatment effect, P>0.5121). However, decreasing P fertility affected storage root development with regards to ARD and volume but not length. Decreasing P fertility below 15 mg·L^{-1} led to developing storage roots with narrower ARD (<1 mm) (0.039 in) compared to 1.30 (0.051), 1.52 (0.069), and 1.37 mm (0.054 in) for corresponding P fertilities of 15 (.002), 20 (.0024), and 31 mg·L^{-1}(.004 oz·gal^{-1}). Declining radial root expansion was accompanied with a pattern of decreasing storage root volume as P fertility decreased from 20 (0.0024) to 0 mg·L^{-1} (0 oz·gal^{-1}), whereas, decreasing P fertility did not consistently hinder storage root length. In fact, fertilization treatments ≥5 mg P·L^{-1} (0.0007 oz P·gal^{-1}) resulted in developing storage roots with lengths >20 cm (7.87 in), a length that exceeded

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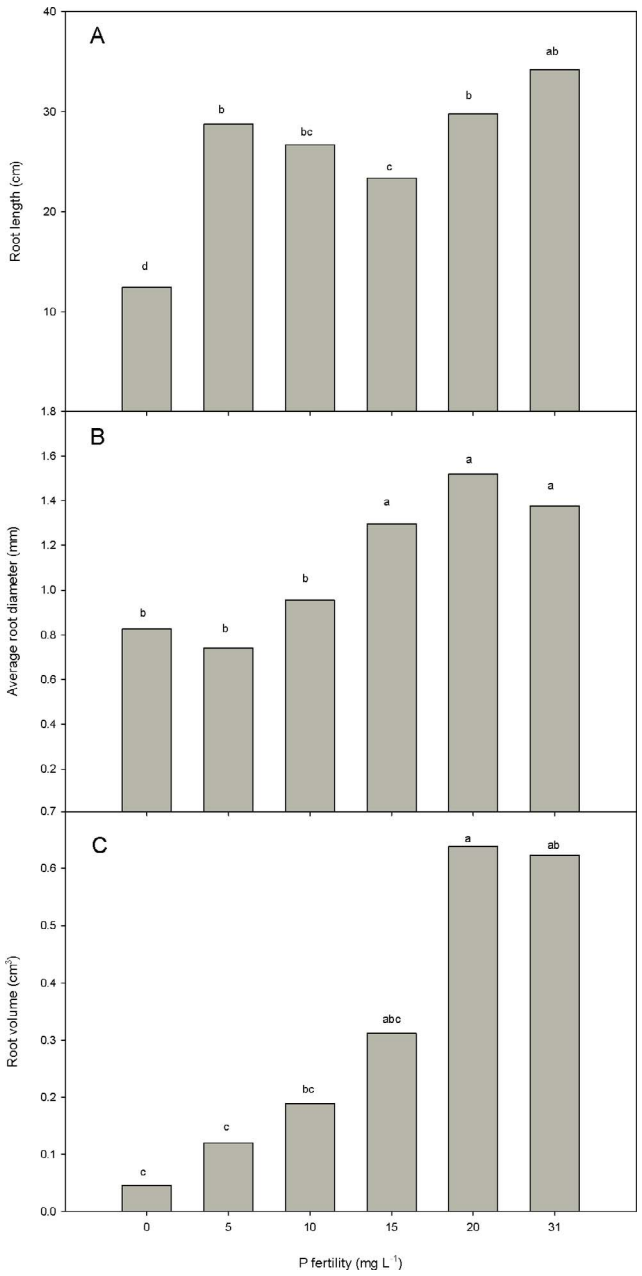

Fig. 2. Developing sweetpotato storage roots of container-grown transplants fertilized at 0, 5, 10, 15, 20, or 31 mg P·L^{-1} after six-weeks in 2018. Storage root parameters were measured for A) total root length (cm); B) average root diameter (mm); and C) root volume (cm^3) through digital analysis of root scans. Bars around each mean represent standard error at P=0.05. One mg P·L^{-1} = 0.00012 oz P·gal^{-1}.

container depth (12.5 cm) (4.92 in) and resulted in right-angle orientation of storage roots upon contact with the container base (Fig 3).

In conclusion, characterizing changes in rooting during container-grown, edible, ornamental sweetpotato transplant production is significant because transplants will not only be grown in home gardens for their aesthetics but also consumption of storage roots. Many studies examining root-bound conditions have either focused on chemical methods (Liu 2016, Armitage 1996, Sword et al. 2009) during production or planting techniques post-

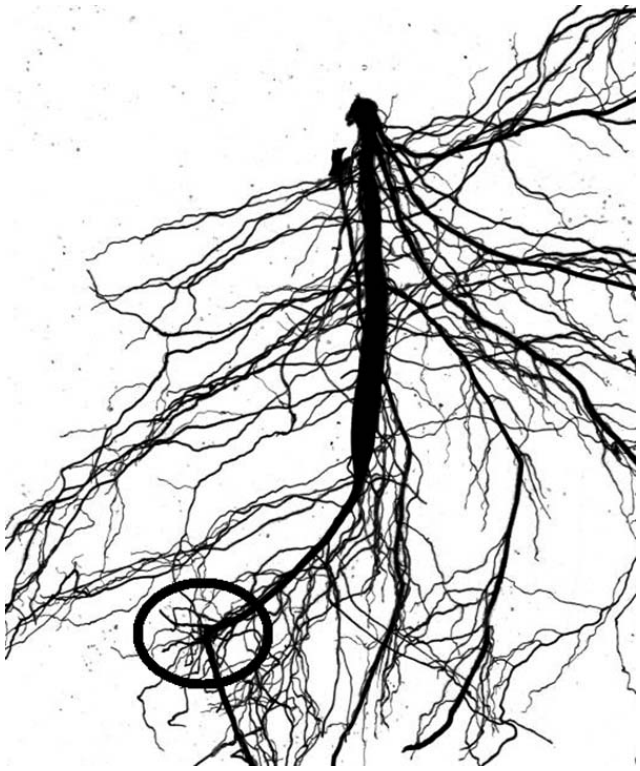

Fig. 3. An example of a developing sweetpotato storage root being deformed from contact with the container base. The circled area of the photo shows the right-angle orientation of the storage root.

transplant production (Blessing and Dana 1987, Ponchia et al. 2010, Weicherding et al. 2007). This experiment showed adjusting P fertility from 31 (0.004) to 5 mg· L^{-1} (0.0007 oz·gal^{-1}) was insufficient to slow sweetpotato rooting to prevent container-grown transplants roots from experiencing root-bound conditions, and thus did not extend transplant salability beyond four weeks. Reductions in P fertility between 5 (0.0007) and 0 mg·L^{-1} (0 oz·gal^{-1}) would theoretically slow transplant rooting, but it would also be expected to exacerbate the negative effects associated with decreasing P fertility, including narrower storage roots with lower RV and potential root-bound conditions. If one wants a longer sweetpotato transplant saleable period, reducing N application or periodic manual defoliation should be examined. It is important to state the trends resulting from this study are limited to the 6-week period of observation. Therefore, guidelines for P fertility once transplants are established in the landscape should follow previous research findings until research is conducted to examine the long-term effects of P fertility post-transplant production.

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