July 2019

INFLUENCE OF P FERTILITY ON SWEETPOTATO ROOTING DURING CONTAINERIZED TRANSPLANT PRODUCTION

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A Thesis

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirement for the degree of
Master of Science

in

The School of Plant, Environmental Management, and Soil Sciences

by
Lee T. Rouse
B. S., Louisiana State University, 2013
August 2019

ACKNOWLEDGEMENTS

I would like to thank God for the strength, knowledge, and ability to have gotten this far in life. I wish to thank my family, especially my wife, Brittany Rouse, for the devotion and encouragement to continue my education and to keep pushing forward when time were tough. Many thanks to Drs. Jeffery Beasley and Jeff Kuehny for their time and dedication from start to finish on this project. I would also like to thank my father Thomas Rouse who watched my sick children many times so I would not fall behind in work, school and study. Thank you to both of my children for understanding when Dad had to study instead of play.

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ABSTRACT

A market for edible landscape transplants continues to increase for vegetable production in the home landscape. A method for extending the salability of sweetpotato transplants in retail outlets is needed because containerized transplants can develop spiraling roots and deformed storage roots. Implementing traditional techniques to ameliorate container-bound roots before planting in the landscape is not advisable. Altering P fertility is a non-chemical and non-mechanical method for slowing sweetpotato rooting. Therefore, sweetpotato cuttings were planted in 100% sand-filled containers and fertilized at 0, 5, 10, 15, 20, and 31 mg L^{-1} using a modified Hoagland solution over a 6-week period. Each week transplant shoots were measured for shoot length, quality, and biomass and roots were analyzed for total root length (TRL), root surface area (RSA), root volume (RV), average root diameter (ARD), and biomass. All sweetpotato transplants fertilized at $\geq$ 5 mg P L^{-1} increased in plant length, quality, and biomass for the first four weeks after planting (WAP) followed by declines in transplant quality. Rooting followed a similar pattern for all architectural parameters but continued to increase throughout the duration of the experiments with the exception of the control. Reducing P fertility from 15 to 5 mg L^{-1} slowed root growth, it was not sufficient to extend the salable period beyond 4 WAP. Therefore, sweetpotato transplants ideally would be established in the landscape within 4 WAP to minimize effects from root spiraling and reduce storage root deformation.

CHAPTER 1. LITERATURE REVIEW

1.1. History of Sweetpotatoes

Sweetpotato [*Ipomea batatas* (L.) Lam.] is a warm-season root vegetable and accounts for one of roughly 500 species in the Convolvuleaceae family. *I. batatas*, commonly referred to as sweetpotato, is also known as sweetpotato vine or yam and is most likely native to the tropical Americas. Sweetpotatoes are a true perennial, short-day flowering plant (Bailey and Bailey, 1977) but are more often grown as annuals for their edible storage roots (American Horticultural Society, 1999). Sweetpotatoes are widely cultivated and considered to be a pantropical annual with several cultivated varieties (Bailey and Bailey, 1977).

The sweetpotato was originally brought from Central and South America to Spain; where the Spaniards introduced the sweetpotato to the Philippines, and eventually China. Sweetpotatoes were also quickly spread throughout the world by the Portuguese with introductions to various regions in Asia and Africa. Historical records indicate the sweetpotato was introduced into North America, specifically Virginia, as early as 1648 (American Horticulture Society, 1999). In the Southern regions of the United State the term Yam, sometimes Louisiana Yam, is often used to describe *Ipomea batatas*. However, the yam is a high starch containing edible root from the *Dioscorea spp.* (Bailey and Bailey, 1977).

Sweetpotatoes are fast growing, mat forming perennials consisting of running vines and dark green leaves with a slight reddish-purple in some varieties. Sweetpotatoes can be divided into three general categories: early maturing varieties which typically have yellow or orange roots and have a drier flesh; the Louisiana yams are darker in color, contain a higher moisture level and sweeter taste for cooking; and late maturing varieties such as ‘Boniato’ or ‘Camote’ are dry, white-fleshed (Taylor’s Guide to Vegetables and Herbs, 1987).

1.2. Sweetpotato Propagation

Sweetpotatoes are propagated in one of three ways; a) seed, b) storage root or c) root or stem cuttings. Sweetpotato seeds are sown in 20-25 cm diameter pots with an optimum germination temperatures of 23.9 C or 25 to 27.8 C with 70% relative humidity. Storage roots should be harvested between October and November and allowed to dry in the sun for 4-7 days before planting. However, sweetpotatoes are most commonly vegetatively propagated using root and stem cuttings (Jiang et al., 2017) referred to as slips. Slips are prepared by trimming lower leaves from the bottom 2-4 node of the stem cutting with the basal portion of the cuttings, 20-25 cm, placed into the soil (Toogood, 1999).

1.3. Sweetpotato Market

Production of sweetpotatoes in the U.S. increased from 4.2 to 7.5 lbs per capita from 2000 to 2015 for a total production of 3.1 billion lbs(Bond, 2017). Increased production and sales can be tied to greater consumer awareness of sweetpotato nutritional value as a rich source of anti-oxidants, fiber, minerals, and vitamins A, C, and B6 (Roy and Williams, 2008).. However, the major difference between sweetpotatoes versus white potatoes is that sweetpotatoes is a more complex carbohydrate food. Today, consumption of sweetpotatoes includes fresh produce as well as more readily available processed products such as fries, chips, ready-to-cook and heat-and-eat options (Bond, 2017). Not only has sweetpotato consumption increased as a result of greater consumer health conscientiousness and availability, but has also been influenced by changes in consumer preferences for more colorful and unique foods (Bond, 2017).

1.4. Sweetpotatoes in the Home Garden

Sweetpotatoes are traditionally vegetatively propagated (Ma et al., 2015; Belehu et al., 2004; Villordon et al., 2009) and grown in fields for large scale production throughout the southern U.S.. However, sweetpotatoes with attractive foliage have been commercialized for the ornamental nursery industry for use in the home landscape. Cultivars such as 'Margarite', 'Sweet Caroline', and 'Tricolor' are commonly planted as colorful annuals that have aggressive prostrate growth (Bachman, 2014). Current use by home owners and landscapers as well as increased consumption in human diets has led to interest by home gardeners in not only planting sweetpotatoes as ornamentals but also for harvesting the storage root, a market known as edible landscaping (Beck and Quigley, 2014; Brown and Worden, 2013; Geiger, 2018).

The revival in home gardening over the past decade has also led homeowners to include new and unusual plants (Nation Gardening Association, 2014) such as sweetpotatoes. However, unlike sweetpotatoes that are vegetatively propagated in fields, sweetpotato transplants used in home gardens will need to be grown in containers like many other fruits and vegetables transplants available at local retail outlets. The use of containers presents the potential issue of roots spiraling around the container, a condition commonly referred to as a plant being root-bound (Weicherding et al., 2007). Root spiraling is particularly problematic for fast growing species and has negative effects on establishment in the landscape (Costello and Paul, 1975; Flemer, 1980; Gouin, 1983). Root spiraling might also cause changes to shape of storage root formation and development which could affect harvestable storage roots and quality

1.5. Methods to Reduce Root Spiraling

Methods to reduce root spiraling or associated effects have involved coating the inside surfaces of containers with copper sulfate. However, there have been conflicting results. Cooper

sulfate (Cu_2SO_4) was shown to decrease total root length and surface area of Chinese cork oak (*Querus variabilis* Blume.) (Liu et al., 2016). Copper sulfate also reduced root spiraling and seedling height for impatiens (*Impatiens x hybrid* L.) (Armitage and Gross, 1996). However, for Chinese cork oak, copper sulfate was ineffective in reducing root spiraling (Liu et al., 2016). Other methods to counter root spiraling include scoring, butterfly pruning, or teasing roots prior to planting container bound plants into the field (Blessing and Dana, 1987; Weicherding et al., 2007). Although these methods have been shown to have a positive effect on root growth, results are also inconsistent compared to plants roots that have not been disrupted (Weicherding et al., 2007). These methods could also have an adverse effect on storage root growth and development. The most effective method of preventing root spiraling in containers is to limiting the duration from propagation to planting in the landscape. Under normal soil moisture conditions, adventitious and lateral roots of sweetpotato will grow most rapidly in the first four weeks after planting (Pardales and Yamauchi. 2003). This could limit the duration of acceptable transplant quality prior to planting in the landscape.

Another possible method to slow sweetpotato root growth during transplant production could be through the regulation of phosphorus (P) fertility (Villordon et al., 2018). Phosphorus is one of 16 essential nutrients needed by plants (Herrera et al., 2015) and is needed for all major processes and reproduction in plant (Lopez-Arrendondo et al., 2014). However, P is found in much smaller quantities in the plant when compared to nitrogen (N) and potassium (K) (Tisdale and Nelson, 1975). Phosphorus is absorbed by the root surface (Herrera et al., 2015) as phosphate (PO_4^{3-})(Lopez-Arredondo D. L., et al., 2014). Roots absorb two forms of orthophosphate. The primary form of orthophoshate absorbed by the plant is H_2PO_4, while the secondary form is HPO_4^{2-}. These form are absorbed by the plant at 10:1 ratio (Tisdale and

Nelson, 1975). Plant absorption of available inorganic P is due to the jointly arranged actions of many inorganic P transporters (Lopez-Arrendondo et al., 2014); in addition, root ability to increase or decrease the exploratory capacity of the root system is determined by the ability of the root tip to detect local P which also aids in amount of phosphorus absorbed. When high concentrations of P are unevenly distributed in the soil, roots will grow nearer the pockets of phosphorus (Herrera et al., 2015). Inorganic P availability is increased by the efflux of organic acids and phosphatases from the roots which affect P acquisition efficiency (Lopez-Arrendondo et al., 2014). In addition, a concentration of root development can be seen in localized areas where high concentrations of nitrogen and phosphorus are applied such as when field grown crops are fertilized in a band style application (Tisdale and Nelson, 1975). Phosphorus availability in soil has been shown to govern root growth for many agronomic and horticultural crops (Lynch and Deikman, 1998). Nutritional regulation of root development plays an important role in root type and quantity produced in low P concentrations and the nutrient solutions may affect root architecture by reducing growth of primary roots while increasing the number and length of lateral roots as well as roost hairs (Herrera et al., 2015). Svistoonoff et al. (2007) showed that within hours of transferring *arabidopsis thaliana* growing in a relatively high to low soluble P medium, cell elongation of the primary roots was greatly reduced. Cell division was then reduced by when P concentrations were reduced to < 5 μmol P followed by an increase in root-hair formation which furthered the ability of the plant roots' absorptive capacity (Svistoonoff et al., 2007). A similar response has been noted for sweetpotatoes grown in low P concentrations. Jiang et al. (2017) reported sweetpotato rooting increased more at lower P fertility than sweetpotatoes growing in fertile conditions.

1.6. Effect of Phosphorus Fertility on Sweetpotatoe

Phosphorus can affect plant root:shoot with greater rooting occurring as P fertility decreases (Hansen and Lynch, 1998). Foliage growth is more vigorous when the proper addition of N and P are applied (Tisdale and Nelson, 1975). However, when in P fertility is increased to ≥3 μmol for several tropical legumes, the root:shoot ratio decreased (First and Edwards, 1987).

Phosphorus is a primary nutrient element for plant growth and development and is often over-applied in a greenhouse setting (Chen et al., 2017). Phosphorus deficiencies occur in approximately 70% of global cultivated land (Lopez-Arrendondo et al., 2014). Many soil types such as acid and alkaline calcareous soils affect P deficient soils worlde-wide. Studying the effects of food crops grown in soils and growing media with low-P or P deficiencies is of great importance. Furthermore, it is predicted that the worlds P supply will be depleted in 50-100 years. On the contrary, the International Fertilizer Development Center has indicated global resources of P rock will supply the agricultural needs for several hundred more years (Van Kauwenbergh, 2017).

The sweetpotato nursery industry is reliant upon the quick propagation of virus-indexed stock plants for production of transplants for field production (Jiang et al., 2017). For nurseries to be able to produce a fast, high quality transplant an effective fertilization guideline is necessary. Proper fertilization of crop species is important for growers to produce a timely and profitable crop (Mills and Jones, 1991). Growers in the U.S. often use fertilizers to meet the N requirements of the species being grown, often relying on commercially available products (Broschat and Moore, 2001) rather than tailoring individual amendments to meet the needs of species being grown. However, it has been reported that U.S. farmers are moving away from mulita-nutrient fertilizers and applying single nutrient fertilizers to administer a more precise

nutrient supply. Fertilizers used for greenhouse production are water soluble and controlled released fertilizers(CRF) that include 15N-6.5P-12.5K [1N-1P_2O_5- 1K_2O ratio] and 21N-3P-11.7K [3N-1P_2O_5- 2K_2O ratio] (Broschat and Moore, 2001). Growers often use 15N-6.5P-12.5K [1N-1P_2O_5- 1K_2O ratio] to produce container grown flowers or fruiting plants as these types of plants are believed to have higher phosphorus requirements than foliage or woody ornamentals (Nelson, 1998).

Greenhouse studies were conducted in 2011 and 2012 evaluating the most common commercially used fertilizer mix, 20N- 10P- 20K at rates of 50, 100, 200, 300, 400 mg/L^{-1} using the varieties ‘Covington’, ‘Beauregard’, and ‘Evangeline’. Nine sequential harvests were conducted and indicated similar effects of fertilizer rates on number of nodes produced. For harvests 7-9 treatments 100-300mg/L^{-1} N resulted in similar number of plant nodes, whereas 50 and 400 mg/L^{-1} N reduced node count. Fifty mg L^{-1} N resulted in undesirable storage root formation. One hundred mg L^{-1} N resulted in the inhibition of storage root formation (Jiang et al., 2017). Villordon et al. (2013) conducted field testing of nitrogen fertilizer rates and reported that rates from 50 to 100 kg/ha^{-1} N increased sweetpotato storage root yield howeveradditional nitrogen at 200kg/ha^{-1} N did not benefit storage root yield. Jiang et al. (2017) and Villordon et al (2013) indicated that low amounts of N had a positive effect on sweetpotato storage root production. The study evaluated different levels of 20N- 10P- 20K. As nitrogen increased or decreased, so did Phosphorus and Potassium. Most greenhouse fertilizer regimens are based solely off of the necessary nitrogen rate in order to grow a heathy crop, while P, highly important macro-nutrient, is often over looked. Phosphorus application rates are frequently at the expense of the N recommendation.

When phosphorus deficient soils, whether acid or alkaline, plant roots have been shown to modify their root architecture in order to improve phosphorus acquisition. Specifically, roots proliferate to explore the soil for higher concentrations by increasing the number and length of lateral roots and root hairs (Herrera et al., 2015). Svistoonoff et al.(2007) showed that within hours of transferring plants growing in high to low P concentrations led a reduction in cell elongation of primary roots. Cell division was then reduced by low P followed by an increase in root-hair formation which furthered the ability of the plant roots' absorptive capacity (Svistoonoff et al., 2007). This study supports the findings of Jiang et al. (2017) and Villordon et al. (2013) showing that low nutrient concentrations regularly produces disproportionately more roots than higher nutrient concentrations.

Greenhouse grown crops grown in soilless substrate are often fertilized with excessive nutrients (Chen et al., 2017). Two studies were conducted to evaluate growth responses of 6 coleus varieties at 0, 70, 140, 280 and 420 mg L^{-1} N and 0, 6.2, 12.4, 24.8, and 49.6 mg/L^{-1} P to determine optimum constant liquid feed rates. It was shown when N concentrationincreased plants had a positive growth response while P concentrations had no effect on plant growth or quality of 5 out of 6 cultivars. Phosphorus applied at 12.4mg L^{-1} P yielded a larger dry weight for two of the cultivars than those treated with 0 mg L^{-1} P. Thus lower concentrations of P increased plant height and width and dry weight of plant material than the higher concentrations. It was also concluded that when P treatment concentrations increased the P foliar concentration iincreased. There were no visual signs of P deficiency even at 0mg/L^{-1} P. Phosphorus can be readily mobilized in plantsand is transferred from older tissues to areas of active meristematic tissues (Tisdale and Nelson, 1975). It was concluded in the study by Chen et al. (2017) that

concentration of P older plant tissue was translocated to tissues deficient in P and continue to grow with no visual deficiency (Chen et al., 2017).

Roots and root quantity are responsible for water uptake in plants. Results of previous studies have shown that low levels or phosphorus can have a great impact on root development of many plants. Previous studies have shown improvement of drought stress of marigolds due to an increased root proliferation via long main roots and less densely distributed lateral roots. In addition, the more fibrous a root system is the more plant growth and health is increased (Borch et al., 2003). When phosphorus rates were applied at optimum levels using a solid-phase buffered-phosphorus fertilizer, the drought tolerance enhanced due to the reduction of transcription and increasing the plants ability to take up water from the medium (Borch et al., 2003).

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CHAPTER 2. INFLUENCE OF PHOSPHORUS FERTILITY ON SWEETPOTATO ROOTING DURING CONTAINERIZED TRANSPLANT PRODUCTION

2.1. Abstract

A market for new and unusual plants, such as those used in edible landscaping, continues to be a rising market sector for vegetable production in the home landscape. A method for extending the salability of sweetpotato transplants in retail outlets is needed because containerized transplants can develop spiraling roots and deformed storage roots if the plant continues to grow the limited space provided by the container. Implementing techniques to ameliorate container-bound roots before planting in the landscape is not advisable. Altering P fertility is a non-chemical and non-mechanical method for slowing sweetpotato rooting, allowing additional time before root-spiraling occurs. . Therefore, sweetpotato cuttings were planted in 100% sand-filled containers and fertilized at 0, 5, 10, 15, 20, and 31 mg L^{-1} P using a modified Hoagland solution over a 6-week period. Each week transplant shoots were measured for shoot length, quality, and biomass and roots were analyzed for total root length (TRL), root surface area (RSA), root volume (RV), average root diameter (ARD), and biomass. All sweetpotato transplants fertilized at $\geq$ 5 mg P L^{-1} increased in plant length, quality, and biomass for the first four weeks after planting (WAP) followed by declines in transplant quality. Rooting followed a similar pattern for all architectural parameters. However, the rooting continued to increase throughout the duration of the experiments with the exception of the control. At 6 WAP ARD increased, indicating storage root formation. Reducing P fertility from 15 to 5 mg L^{-1} slowed root growth, it was not sufficient to extend the salable period beyond 4 WAP. Therefore, sweetpotato transplants ideally would be established in the landscape within 4 WAP to minimize the detrimental effects caused by root spiraling, thus reducing possibility of storage root deformation due to time.

2.2. Introduction

A resurgence in gardening over the past decade has resulted in new and unique plants (Nation Gardening Association, 2014), such as ornamental sweetpotatoes, being grown in home landscapes. The most commonly planted ornamental sweetpotato cultivars include 'Margarite', 'Sweet Caroline', and 'Tricolor', and are known for their colorful foliage and aggressive prostrate growth as annual groundcovers (Bachman, 2014). These ornamental cultivars, however, were not originally bred to produce high-quality, edible sweetpotatoes. New breeding efforts have improved cultivars for both desirable foliage and production of high-quality, edible sweetpotatoes. The breeding of sweetpotatoes as well as other fruit and vegetable species for both aesthetics and production has led to the development of a new category - edible landscaping (Beck and Quigley, 2014; Brown and Worden, 2013).

In large-scale field production, sweetpotatoes are vegetatively propagated using stem cuttings (Ma et al., 2015; Belehu et al., 2004; Villordon et al., 2009), however, in the home landscape transplants are the preferred establishment method for many vegetable crops. As a result, edible ornamental sweetpotato transplants will need to be available for purchase at local retail outlets. One drawback to transplant production is the tendency of transplants to develop roots that spiral around the container, a condition commonly referred to as being root-bound (Weicherding et al., 2007). Root-bound plants often exhibit moisture stress which limits photosynthesis (Kramer, 1983), leading to yellowing and necrotic foliage. Root spiraling is particularly problematic for vigorous growing species because it reduces the period of salability (Costello and Paul, 1975; Flemer, 1980; Gouin, 1983). For root crops such as sweetpotatoes, root spiraling not only negatively affects establishment in the landscape but can lead to deformation of storage roots.

Chemical methods to reduce root spiraling have involved growth retardants, such as copper sulfate, but have produced inconsistent results (Armitage and Gross, 1996; Liu et al., 2016) and may not be appropriate for edible crops. Non-chemical, post-transplant production techniques to ameliorate root spiraling prior to planting including scoring, butterfly pruning, and teasing of roots, can have positive effects on root growth depending on species and environmental factors (Weicherding et al., 2007). Ninety percent of storage roots develop from adventitious roots that are formed within seven days after planting (Villordon et al., 2009), thus implementing mechanical root disruption practices during sweetpotato planting would have an adverse effect on storage root shape and quality. A more effective practice to prevent root spiraling for sweetpotato transplants would be to slow growth to extend the duration between propagation and installation in the landscape.

Initiation and development of adventitious and lateral roots on sweetpotato stem cuttings are rapid during the first four weeks after planting (Pardales and Yamauchi, 2003; Villordon et al., 2009). Regulating P fertility may be an alternative, non-chemical method to slow containerized sweetpotato rooting. Available P influences rooting of many agronomic and horticultural crops in soil (Borch et al., 2003). Plants growing in low P environments reduce the production of primary root growth and allocate energy resources to increasing the number and length of lateral roots and root hairs (Herrera et al., 2015). For example, *Arabidopsis thaliana* (L.) Heynh. grown in high P environments and then exposed to low P environments, responded with changes in cell elongation of primary roots followed by accelerated root-hair formation to increase root surface area for greater nutrient absorption capacity (Svistoonoff et al., 2007). Similarly, altering P fertilization and uptake have significant effects on root proliferation and storage root production in field grown sweetpotatoes (Jones et al., 1991).

Architectural rooting response of sweetpotato to low P fertility has not been documented during transplant production; and extrapolating trends between studies which have evaluated sweetpotatoes in controlled environments versus field-based experiments have had mixed results (Villordon et al., 2018). Field grown sweetpotato fertilizer recommendations were developed to maximize sweetpotato storage root production but may not be applicable during transplant production. The objective of this research was to evaluate the effects of P fertility on sweetpotato transplant production.

2.3. Materials and Methods

2.3.1. 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 stem cuttings were selected for uniformity for 15.2 to 17.8 cm in shoot length, 4 to 5 nodes, and plants containing fully expanded leaves. Stem cuttings were transported to the LSU AgCenter Botanic Gardens in Baton Rouge, LA (30.405707N; 91.103358W) and grown 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 plants wilting and no nutrients were applied.

Containers (N=180) for propagating sweetpotato transplants were constructed from 10.2 cm diameter polyvinyl chloride pipe (Schedule 40, Charlotte Pipe and Foundry Company, Charlotte, NC) at 12.7 cm heights with detachable plastic bases. Each plastic bases had five drain holes (2 mm in diameter). In addition, each polyvinyl chloride container had four rows of side drain holes (2 mm in diameter; 3 cm apart within row) that were located diametrically opposite

each other to prevent the formation of a perched water table (Bilderback and Fonteno, 1987; Villordon et al., 2018). Each container was filled with 1247.4 g of non-amended sand for a bulk density of 0.337 g m^{-3}. Sand had a pH 5.3 and fertility of P = 3.5 mg L^{-1} and K = 14.3 mg L^{-1} according to analyses performed by the LSU AgCenter Soil Testing and Plant Analysis Laboratory (STPAL; Baton Rouge, LA). The majority of the sand (89%) used in this study ranged in diameter from 1.00 mm to 0.010 mm (5.43% >1.00 mm; 30.39% 1.00 mm to >0.500 mm; 57.95% .500 mm to >0.025 mm; 4.75% .025 to > 0.010 mm). Stem cuttings growing in the greenhouse were excised and immediately planted into containers. Containers were randomly arranged on a greenhouse bench.

All sweetpotato transplants were fertilized with modified Hoagland solutions (Hoagland and Arnon, 1950) that varied in P concentrations from 0, to 5, 10, 15, 20, or 31 mg L^{-1}. Nutrient concentrations for each solution were analyzed to confirm concentrations using inductively coupled plasma (ICP) optical emission spectroscopy (ICP SPECTRO ACRCOS Model FH E12, Kleve, Germany) by the STPAL before application to plants. Nutrient solutions were delivered using non-recirculating systems for each nutrient solution. Each nutrient delivery system was composed of a 56.8 L container (Fimco Inc., North Sioux, SD) fitted with an electrical pump. The exterior of the container was painted with two coats of black paint followed by two coats of silver paint to exclude light. Pumps delivered nutrient solution through 1.27 cm diameter irrigation lines that ran the distance of the greenhouse bench. Micro-irrigation drippers (WPCJ drippers; Netafilm, Tel Aviv, Israel) delivered 150 mL of nutrient solution per application at a rate of 1.89 L hr^{-1} to each container. Nutrient solutions were applied every other day for the first five weeks of the experiments followed by 75 mL per day the final week to prevent plant wilting.

To ensure the proper volume of each treatment was delivered, nutrient solution from each treatment was captured into a beaker for measurement.

2.3.2. Sweetpotato Transplant Growth

Transplant leaf quality was assessed weekly for six weeks using the Soil Plant Analysis Development meter (SPAD-502, Konica Minolta, Tokyo, Japan) meter on the three youngest fully expanded leaves. Transplant shoot length was measured and then excised at the shoot-soil interface with shoot foliage and stem tissues dried at 65 C for 48 h before biomass was determined gravimetrically. Roots were rinsed under a gentle stream of water to minimize root damage to remove sand particles for analysis of total root length (TRL), root surface area (RSA), root volume (RV), and average root diameter (ARD) using root architecture software (WinRhizo System, Regent Instruments Inc., Quebec, Canada). The methods for root preparation and architectural analysis followed the procedures outlined by Villordon et al. (2013) with the modification of using a 30 cm by 40 cm scanner (Epson Expression 12000 XL, Long Beach, CA) at a resolution of 600 dpi. Roots were then dried at 65 C for 48 h and biomass determined gravimetrically. Dried sweetpotato shoot and root samples were submitted to the SPTAL for tissue nutritional concentration analysis using ICP optical emission spectroscopy.

2.3.3. Statistical Analysis

The design of the study was a complete randomized design that used repeated measures for analysis of sweetpotato shoot length, biomass, plant quality, and root architectural parameters for TRL, RSA, and RV for the two 6-week experiments. The fixed treatment effect was P fertility with experimental run as a random effect. Using the MIXED procedure in the statistical software of SAS 9.4 (SAS Institute, Cary, NC) all data were analyzed with means separated following least significant differences post-hoc procedure at $P \leq 0.05$.

2.4. Results and Discussion

Consumers focus primarily on the above ground tissue qualities such as dark green foliage, evidence of new growth, and the absence of discolored or unhealthy foliage (Brand and Leonard, 2001) when purchasing containerized plants. In this study, all sweetpotato transplants maintained higher leaf quality, increased shoot length, and accumulated greater shoot and root biomass the first 4 WAP (Table 1). The response of transplants to increasing P fertility did not result in higher quality, longer shoot lengths, or more biomass for sweetpotatoes fertilized ≥5 mg P L^{-1}over the 6-week period. Only transplants that received no P had shorter shoot lengths and less shoot biomass as noted with average shoot lengths of 17.5 cm and biomass of 1.64 g compared to 31.1 to 33.9 cm and 2.48 to 2.91 g, respectively, for transplant receiving ≥ 5 mg P L^{-1} during the 6-week production period.

Adequate P fertility is necessary during establishment of many plant species (Boulanger-Pelletier and Lapointe, 2017; Svistoonoff et al., 2007) because of its role in root growth (Svistoonoff et al., 2007), but is extremely important in the development and shape of sweetpotato storage roots (Villordon et al., 2018). Root growth and root system architecture are important factors influencing plant performance and survival (Wright and Wright, 2004). Deficient P can lead to stunted shoot growth and leaf discoloration; characteristics that would decrease containerized plant salability. But increasing P fertility above plant needs, in this case 5 mg P L^{-1}, while maintaining high fertility levels of other essential nutrients did not result in more rapid growth even as P uptake increased congruently with higher P fertilities (data for other

Table 1. Influence of P (phosphorus) fertility on sweetpotato quality, growth, and P tissue concentration for containerized transplants produced over a six-week period.

P fertility	SPAD[b]	Shoot Length	Shoot Biomass	Root Biomass	P uptake	ARD[c]
- mg L^{-1} -	--- unitless ---	---- cm ----	---- g ----	---- g ----	---- % ----	---- mm ----
0	34.4 AB[a]	17.50 B	1.64 B	1.39 B	0.10 D	0.47 B
5	35.9 A	31.10 A	2.48 A	1.87 A	0.14 CD	0.63 A
10	34.2 AB	31.70 A	2.59 A	1.96 A	0.21 BC	0.57 A
15	34.1 AB	34.00 A	2.72 A	1.85 A	0.26 B	0.61 A
20	34.8 AB	33.50 A	2.69 A	2.08 A	0.30 AB	0.58 A
31	32.7 B	33.90 A	2.91 A	1.86 A	0.38 A	0.57 A
Week						
1	36.9 BC	17.50 D	2.13 BC	1.53 C	0.19 A	0.54 BC
2	42.4 A	22.00 CD	2.03 C	1.79 BC	0.27 A	0.51 C
3	38.3 BC	27.10 CD	2.63 B	1.74 BC	0.28 A	0.44 D
4	35.0 C	35.60 B	3.28 A	2.22 A	0.24 A	0.59 BC
5	26.3 D	37.70 AB	3.24 A	1.97 AB	0.21 A	0.66 A
6	27.2 D	42.00 A	1.72 C	1.76 BC	0.20 A	0.68 A

[a] Means within a column followed by a different letter are statistically different according a LSD ($P<0.05$)

[b] SPAD = soil plant analysis development

[c] ARD = average root diameter

nutrients not shown). Application of P above plant requirements has also failed to correlate to increased shoot production of other containerized plants including coleus (*Solenostemon scutellarioides* (L.) Codd) (Chen et al., 2017), *Hydrangea macrophyllaI* (Thunb.) Ser. and *Ilex crenata* (Thunb.) (Shreckhise et al., 2018); and is leading to revisions regarding P fertility requirements of these species. In this study, sweetpotato transplant shoot tissue concentrations were below the reported sufficiency range of 0.23 to 0.5 % P (Jones et al., 1991) for transplants fertilized at 5 and 10 mg P L^{-1}. However, no deleterious effects on shoot growth were observed relative to transplants fertilized at >10 mg P L^{-1} that were within the sufficient P range. It may be that altering N relative to other nutrients is a more significant factor in accelerating transplant shoot growth for transplants (Chen et al., 2017) including sweetpotatoes (Villordon et al., 2013); or that the range between 0 and 5 mg P L^{-1} warrants further study to characterize effects on sweetpotato shoot growth. Fertilization below 5 mg P L^{-1} may be impractical for application by nursery producers.

In the final two weeks of the 6-week production period, transplant quality decreased in conjunction with slight declines in plant biomass. Shoot and root biomass declined 48 and 21%, respectively, at 6 WAP compared to biomasses at 4 WAP. During this period, transplants across all P fertilities were observed to have elongated shoots, smaller leaves, greater leaf discoloration, and increased leaf abscission. The observed morphological changes and measured declines in sweetpotato transplant quality and growth are common symptoms exhibited when container volumes are limited (Latimer, 1991). Over time, container-bound plants develop deformed or spiraling roots, a condition that leads to declining transplant health and aesthetics (Armitage and Gross, 1996) that can negatively affect establishment within the landscape (Ponchia et al., 2010).

The vigorous growth of sweetpotatoes roots presents a challenge when container grown even though sweetpotatoes are easily propagated from cuttings with low mortality (Hartmann, 2014). Little evidence exists that consumers consider roots of a containerized plants when purchasing plant material (Brand and Leonard, 2001). However, the duration from propagation to purchase is a particularly important period for maintaining transplant health and salability. For example, root growth of sweetpotato transplants described architecturally using the parameters TRL, RSA, and RV followed similar positive growth patterns measured for transplant quality, shoot length, and plant biomass during the first four WAP (Figure 1). Only transplants subjected to 0 mg P L^{-1} ceased increases in root growth beyond 3 WAP. However, unlike stagnant or slight declines in root and shoot biomasses that occurred 5 and 6 WAP, all sweetpotato transplants fertilized ≥ 5 mg L^{-1} continued to increase in TRL, RSA, and RV with increasing P fertility from 5 to 15 mg L^{-1} incrementally enhancing root growth. Application of P above 15 mg L^{-1} did not provide any additional benefit to transplants and caused ion imbalances in Mn and Mo (Tisdale and Nelson) (Table 2).

Table 2. Concentration of macronutrients and micronutrients at6 WAP for all P fertilities

Shoot Tissue Concentration

P fertility	Al	B	Cu	Fe	Mn	Mo	Na	Zn
- mg L^{-1} -	- mg L^{-1} -	- mg L^{-1} -	- mg L^{-1} -	- mg L^{-1} -	- mg L^{-1} -	- mg L^{-1} -	- mg L^{-1} -	- mg L^{-1} -
0	45.29	74.21	2.61	60.26	78.09	3.44	1147.56	12.35
5	53.52	146.37	4.12	77.32	123.11	5.23	1928.97	9.91
10	66.91	177.55	5.60	71.55	123.31	4.11	2884.33	10.62
15	66.69	172.52	5.69	69.18	123.36	4.88	3057.41	8.34
20	56.05	166.34	5.65	86.80	117.74	3.72	2482.23	9.64
31	22.33	125.53	4.74	73.41	87.61	3.34	2259.52	9.25
LSD	38.52	35.50	1.96	27.89	56.21	1.45	2.08	2.82

(Table Cont'd)

P fertility	Ca	Mg	N	P	K	S
- mg L^{-1} -	- % -	- % -	- % -	- % -	- % -	- % -
0	1.19	0.37	3.80	0.05	3.23	0.23
5	2.17	0.66	4.54	0.11	3.92	0.30
10	2.74	0.88	4.66	0.17	3.93	0.35
15	2.89	0.93	5.28	0.25	4.67	0.39
20	2.74	0.92	5.08	0.28	4.38	0.41
31	2.29	0.83	4.62	0.35	4.03	0.34
LSD	0.55	0.16	0.80	0.13	0.65	0.09

Root Tissue Concentration

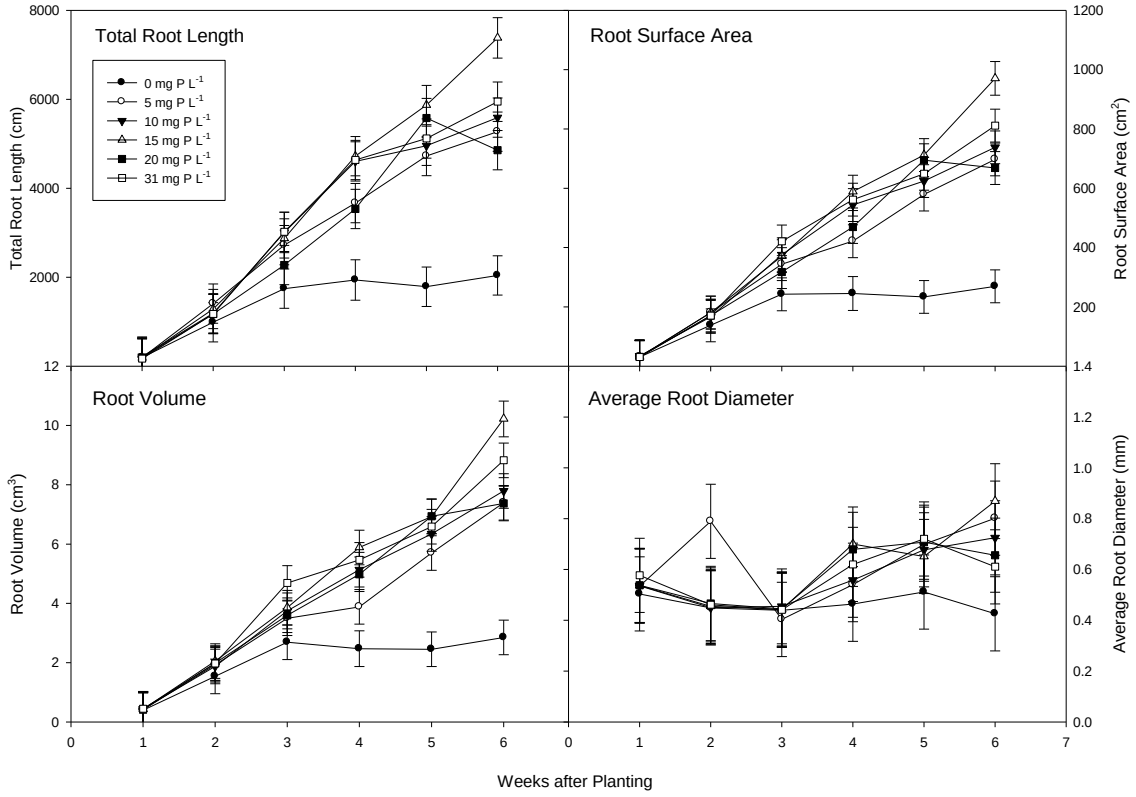
P fertility	Al	B	Cu	Fe	Mn	Mo	Na	Zn
- mg L^{-1} -	- mg L^{-1} -	- mg L^{-1} -	- mg L^{-1} -	- mg L^{-1} -	- mg L^{-1} -	- mg L^{-1} -	- mg L^{-1} -	- mg L^{-1} -
0	177.70	16.90	4.41	289.10	103.60	2.01	3650.43	15.89
5	134.92	19.33	5.61	160.57	55.71	1.61	5222.25	10.31
10	118.95	18.86	5.30	161.50	38.36	1.58	4600.48	8.62
15	142.76	24.62	6.80	184.42	55.82	1.64	7258.70	10.94
20	232.41	16.88	5.11	225.80	35.23	1.52	4816.07	8.44
31	150.79	20.95	4.27	206.76	60.14	1.57	5342.79	14.36
LSD	116.96	5.66	4.45	122.52	45.77	0.33	143.36	6.09

P fertility	Ca	Mg	N	P	K	S
- mg L^{-1} -	- % -	- % -	- % -	- % -	- % -	- % -
0	0.36	0.57	4.66	0.04	2.83	0.15
5	0.50	0.71	4.15	0.09	4.13	0.19
10	0.50	0.67	4.07	0.13	4.58	0.23
15	0.64	0.97	4.82	0.19	6.13	0.32
20	0.50	0.59	3.85	0.18	4.50	0.22
31	0.63	0.81	4.70	0.27	5.30	0.29
LSD	0.19	0.36	0.64	0.06	1.39	0.07

It is important to characterize changes in rooting during sweetpotato transplant development because transplants will not only be grown in home gardens for their aesthetics but also for storage roots. The use of root biomass, as a single measurement, fails to properly characterize sweetpotato rooting, as noted through continued root growth of TRL, SA, and RV, for describing root spiraling. Root growth and development of transplants that occurred 4 WAP, marks a period of transition toward the transplant becoming root-bound. Root-bound plants typically exhibit moisture stress which limits photosynthesis (Kramer, 1983) leading to yellowing and necrotic foliage. This is consistent with the deleterious shoot growth and declining quality observed during the final two weeks of the production period as well as the need to shorten the irrigation interval the final week of the study to maintain plant turgor. In this case, roots continued to grow by altering form even as container volume negatively affected overall plant growth and quality.

It is common for maturing roots to increase radial growth over time (Struve and Moser, 1984; Struve, 1990; Weicherding et al., 2007). In the initial weeks after planting, sweetpotato RSA and RV increases were primarily driven through longer root lengths that maintained ARD of 0.44 to 0.58 mm; whereas in the latter weeks RSA and RV continued to increase as ARD become increasingly wider and the rate of TRL growth slowed (Figure 1).

Fig 1. Influence of P (phosphorus) fertility on sweetpotato total root length, root surface area, root volume, and average root diameter over a six-week period.



The only exceptions to this were transplants fertilized at 5 mg L^{-1} that exhibited an ARD of 0.79 mm at 2 WAP and transplants fertilized at 15 mg L^{-1} that maintained strong TRL growth in conjunction with increasing ARD. Over time, root growth and maturation leads to root-bound plants. Root-bound plants often exhibit moisture stress which limits photosynthesis (Kramer, 1983) leading to yellowing and necrotic foliage that alters nutrient and water uptake efficiency (Kramer, 1983). However, for a root crop, such as sweetpotato, this increase in ARD also indicates the initiation of storage root formation, a period in which deformation of storage roots becomes more likely if transplants are not established within the landscape. The majority of studies examining root spiraling have focused primarily on chemical methods (Liu, 2016; Armitage, 1996; Sword Sawyer et al.) during production or planting techniques post-transplant production (Blessing and Dana, 1987; Ponchia et al., 2010; Weicherding et al., 2007). This study

indicates adjusting fertility affects rooting architecture and thus root spiraling; and may be a method worth investigating for other transplant species to extend the duration of salability.

2.5. Conclusion

In a container volume of 4118.5 cm^3, sweetpotato transplants grew and maintained acceptable quality for 4 WAP for all transplants fertilized at ≥ 5 mg P L^{-1}. However, decreasing P fertility did not slow sweetpotato rooting sufficiently to extend the period of salability. In fact, as root biomass growth declined over the production period, root growth continued to increase architecturally through longer roots and increased diameters. This type of growth led to root spiraling that negatively affected transplant shoot growth and quality. Therefore, there is no advantage in reducing P fertility between 5 and 31 mg L^{-1} for the purpose of extending the period of transplant salability. Failure to establish transplants in the landscape within 4 WAP would increase the potential for poor establishment and/or deformed storage root development. Other practices such as removing the shoot terminal or increasing container size may be more effective in limiting rooting effects when producing edible landscape material such as sweetpotato transplants for homeowner purchase.

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APPENDIX. Leaf macro nutrient tissue concentrations

Leaf macro nutrient tissue concentrations of sweetpotato transplants fertilized using a modified Hoagland solution with differing P concentrations.

P fertility	N		P		K		Ca		Mg		S	
- mg L^{-1} -	---------- % ----------											
0	3.43	B	0.1	D	3.15	C	1.11	B	0.39	C	0.24	C
5	4.01	A	0.14	CD	3.52	AB	1.25	B	0.47	BC	0.25	BC
10	4.34	A	0.21	BC	3.47	AB	1.69	A	0.56	AB	0.27	ABC
15	4.49	A	0.26	BC	3.64	B	1.72	A	0.58	A	0.27	ABC
20	4.31	A	0.3	AB	3.99	B	1.71	A	0.62	A	0.31	A
31	4.28	A	0.38	A	3.99	A	1.69	A	0.63	A	0.29	AB
Week												
1	2.43	B	0.19	A	2.72	B	0.72	D	0.27	D	0.19	D
2	4.37	A	0.27	A	3.94	AB	1.42	BC	0.48	C	0.29	BC
3	4.7	A	0.28	A	3.97	AB	1.73	B	0.58	BC	0.3	AB
4	4.44	A	0.24	A	3.57	AB	1.2	C	0.56	BC	0.25	C
5	4.27	A	0.21	A	3.53	A	1.76	B	0.6	B	0.26	BC
6	4.66	A	0.2	A	4.03	A	2.33	A	0.76	A	0.34	A

VITA

Lee Rouse is currently the East Baton Rouge Parish Horticulture agent for the LSU AgCenter. Previously, Lee work as the Agriculture Extension Agent in Orleans Parish. In 2013 Lee graduated LSU with a Bachelor's of Science from the college of Agriculture. While working for the AgCenter, Lee has worked extensively with urban farmer while conducting Master Gardener Training classes. He has had more than 150 people go through his program. He has participated in the development of the annual Farm to Table conference in New Orleans since 2014, while aiding in the expansion of urban farming and community gardening in South Louisiana. Currently, you can ready Rouse's gardening columns in the Baton Rouge Advocate every Friday, and list to his radio show, Bayou Gardens on WRKF on Saturday Mornings.

Rouse plans to start his doctorate work in the fall on 2019. He intends to study new and innovated methods of growing more food with less resources and in less space. His hopes are to increase the production of food within urban areas.