High Tunnel Propagation Systems for Organic Sweetpotato

by

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Abstract

Sweetpotatoes [*Ipomoea batatas* (L.) Lam.] are nutritious, easily stored and marketed, well-adapted to organic production, and fit large or small farming operations. Commercial production of propagules for sweetpotato, vine cuttings known as slips, is concentrated among a few coastal states. Consequently, growers in the Central United States have limited access to planting material. Considering the crop's sensitivity to cold climates and the increasing use of high tunnels (HTs) in the region, the implementation of HT production systems could be a viable mechanism for increasing the distribution of sweetpotato nurseries across the US. The goal of this project was to investigate the production of slip propagation beds in HT systems at two research stations in Northeast and South Central Kansas. Trials were conducted in 2016 and 2017 to compare yield and quality of organic slips grown in HTs and the open-field (OF). Additionally, a split-plot design was utilized inside the HT to compare slip yields for three planting densities (45, 65 and 85-seed roots/m^2). Slips grown in the two systems (HT and OF) were field-planted to elucidate the impact of the system on subsequent root tuber yields and grade. HT enterprise budgets were developed to determine what the potential economic impact is for growers that wish to implement this system and to identify the appropriate planting density based on cost and return. In 2016, the HT plots produced more slips than in the OF ($P < 0.05$), and the overall average slip number was 226.7 in the HT and 147.8 in the OF across both years. However, slips grown in the HT had significantly fewer nodes, less foliage and compactness ($P < .001$). The field performance study showed slightly greater average marketable storage root yield from slips produced in the OF (P = NS), but the quantity and distribution of graded storage roots were similar between slips grown in the HT and OF treatments. Increased planting density treatment corresponded with greater average slip yield across all harvests, but was only

statistically significant during 1st harvest of 2016. The positive correlation between slip yield and planting densities plateaued between 65 and 85-seed roots/m^2. When using foundation seed roots the optimum profit for enterprise budgets was achieved at the 65-seed root planting density. The use of 25% foundation and 75% on-farm produced seed roots at 85-seed root density generated $\$1.05/\text{ft}^2$ profit in HT—using the more manual cultural practices and equipment of two case studies. The results of these trials suggest that slip production in HTs may provide growers in the Central and Northern regions of the U.S. a viable technology for developing their own sweetpotato propagation schedule, without compromising plant yield or storage root production. When compared to other common HT crop budgets, our data suggest that HT slip production is an economically-viable system for growers who wish to incorporate slip propagation beds into their HT rotations.

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Chapter 1 - Literature Review

Sweetpotato Crop Significance

Sweetpotato [*Ipomoea batatas* (L.) Lam.] is a widely cultivated tropical dicotyledeonous vegetable crop from the morning glory family (Convolvulaceae). Within this plant family there are over 1000 species, of which *I. batatas* is the only major global food crop with a broad range of culinary uses and consumption in the United States. The storage roots of the sweetpotato are its most commercially-important and commonly consumed plant part (Padmaja, 2009). Fresh storage roots can be consumed raw, boiled, baked or fried, among other preparations. However, the sweetpotato stems and leaves are edible, consumed by humans and used for animal feed throughout the world—especially in Asia (Woolfe, 1992). The green shoots of water spinach (*Ipomoea aquatic*) are also consumed extensively in Asia. Furthermore, *I. balatas* cultivars are often bred for attractive foliage traits for use within ornamental horticulture (Smith et al., 2009). The sweetpotato is typically grown for fresh market, but in many countries sweetpotatoes are increasingly processed to make products like noodles, chips, sodas, flour and alcohol (Thottappilly, 2009). Moreover, sweetpotato can be converted for industrial applications like biofuels and starch additives (Carpena, 2009; Lareo et al., 2013).

With regard to its origins, the sweetpotato is thought to be one of the oldest cultivated crops in the world, as some remains date back approximately ten thousand years (Austin, 1988). Sweetpotato is a hexaploid cultigen species (2n=6x=90) with several thousand known varieties. Researchers have identified wild relatives but no direct ancestor (Woolfe, 1992). Efforts to determine the exact center of origin have been extensive and the subject of much debate. Based on the use of archeological, linguistic, and more recent genetic analysis of wild plant relatives and domesticates, most researchers consider Central and South America to be the most likely centers of diversity (Roullier et al., 2013; Woolfe, 1992). Roullier et al. (2013) concluded in their research that there may have been two separate domestication events in the Central and Southern American zones. Furthermore, they reported Pre-Columbian diffusion of domesticated sweetpotato from South America into Oceania; however, Portuguese and Spanish trading expeditions are thought to have discovered the crop by the 15th century and initiated its spread throughout Europe, Asia and Africa (Roullier et al., 2013).

Roots of the sweetpotato develop beneath soil or growing media and on average produce 4-10 edible storage roots per plant (Thottapilly 2009). However, yield is variable and largely dependent on specific cultivar, propagule, and other factors like soil type (Lowe and Wilson, 1974; Togari, 1950). The photosynthetic canopy of vines and foliage make up the above-ground portion of the plant. Photoassimilates are exported largely from leaves through the stem to the root system of the plant and induce formation of fleshy edible storage roots (Keutgen et al., 2002). Although the sweetpotato is cultivated commercially as an annual crop, the enlarged storage roots are perennating storage organs which use their accumulated starch reserves to survive cold periods and support perennial vine regrowth in tropic regions—typically cold sensitive but winter hardy to USDA Zones 9-11 (Bouwkamp, 1985; Missouri Botanical Garden, n.d.). One of the greatest advantages of sweetpotato is that it is adaptive to a range of climates, soil types and inputs (Bouwkamp, 1985; Jansson and Raman, 1991), given its genetic diversity.

Global Production, Application, and Consumption

The sweetpotato is grown and consumed throughout at least 100 independent world nations (Woolfe, 1992). Sweetpotato is integral to global food security and the world economy (Thottappilly, 2009). On a global scale, the consumption and use of sweetpotato is more expansive than most realize. The most recent annual report from the International Potato Center

(CIP) characterized sweetpotato as the "sixth most important food crop" worldwide, behind only rice, wheat, potato, maize and cassava (CIP, 2017). Annually, there are more than 8.5 million ha of harvested territory and 105 million metric tons of sweetpotato produced worldwide, driven mostly by developing countries in Asia and Africa (FAO, n.d.). Further, worldwide production is valued at over eight billion dollars making sweetpotato not just an important food source but also a significant economic contributor (FAO, 2017).

Sweetpotatoes are extremely variable in color, form and texture, and the genetic diversity of known sweetpotato cultivars contributes to its robust global production—widespread across more than seventy degrees of latitude from northern through southern temperate zones (CIP, 1987; Woolfe, 1992). Counting all the germplasm accessions, including "landraces, breeding lines and advanced cultivars," held by the International Potato Center's gene bank, one of the largest for *I. batatas*, there are at least 6000 known varieties of sweetpotato (Carpena, 2009). The sweetpotato is grown throughout the Andes Mountains, the deserts of Southern Israel, across various climatic regions of Sub-Saharan Africa and most of temperate and tropical Asia (Woolfe, 1992). Most global sweetpotato agriculture is undertaken by smallholder producers around the world in minimal input systems and with marginal soils (Abidin et al., 2017; Woolfe, 1992). The crop's notable adaptability to variable environmental conditions is one of many factors that contributes to the its widespread culture and production. Moreover, a study of rice and sweetpotato production in Fiji showed that sweetpotato was relatively less labor intensive based on the crops' respective energy output/input relationship (Norman et al., 1984).

The storage root crop is considered a staple food, defined as a crop that constitutes a dominant portion of diet by supplying large concentration of one or more macronutrient, for many countries, particularly in the developing world. It is a vital nutrition source, especially in developing countries, due to its large supply of energy rich carbohydrates and complementary health-promoting vitamins (Loebenstein et al., 2009). Similarly, sweetpotato has relatively high concentration of carbohydrates, 80-90% of total dry matter, make it an effective high-energy food (Padmaja, 2009). Compared to grain crops like wheat and maize, sweetpotato provides more than 120 percent of the calories over the same acreage (Scott, 2000). Even more notable is the carotenoid composition in orange flesh sweetpotato varieties which has proved an effective tool for combating extensive Vitamin A deficiency and related cases of childhood blindness in developing regions like Sub-Saharan Africa (Abidin et al., 2013; Padmaja, 2009). These attributes, along with other macro- and micronutrients found in sweetpotato, have been extensively studied by international agriculture research centers, like CIP and the recently formed Consultative Group on International Agricultural Research (CGIAR) research program on Roots Tubers and Bananas (RTB), for their potential to address food insecurity and improve public health in Sub-Saharan Africa and other developing nations.

However, training materials released by CIP show that despite the adaptability of sweetpotato cultivars and their widespread production, the access to quality, disease free, planting material is one of the major challenges to successful sweetpotato plantings in the global south (Stathers et al., 2013). For that reason, the first phase of the CGIAR Research Program on RTB initiative is aimed at improving the “management, collection, characterization, and use” of plant genetic resources (RTB, n.d.). Both CIP and RTB are working towards an integrated systems approach to resolve the issue and improve local access to better propagules by improving germplasm collection ex-situ in their network of partner gene banks, while managing in-situ landraces and promoting local seed systems and on-farm conservation. With more widespread access to quality, disease free, planting material, countries around the world could see significant impacts. CIP states that yields can be increased by 30-60 percent with use of "healthy planting material" (Stathers et al., 2013).

U.S. Market, Organic and Conventional

Sweetpotato production and consumption in the United States is smaller than that of other nations, accounting for less than one percent of global production; however, the sweetpotato is still one of the country's ten most widely consumed fresh vegetables (FAO, 2017; USDA ERS, 2015). Despite evidence of crop origin in areas as close as modern day Mexico, the historical study of Pre-Columbian agriculture shows little evidence that sweetpotato was widely cultivated by the indigenous communities of the continental U.S. (Edmond, 1971). Through the introduction by European settlers and New World explorers, sweetpotato farming was first reported in Virginia during 1648; however, the crop is not thought to have been adopted extensively in U.S. until the 18th century (O'Brien, 1972; Smith et al., 2009).

The fluctuating trends of sweetpotato production and consumption in the United States over the last century have generally been tied to larger historical events. Throughout the colonial period, the sweetpotato was most commonly farmed in the Southeastern U.S. where it was considered an especially important food crop used for making bread, beer, molasses, vinegar and even fodder for livestock (Gray et al., 1933). During the Great Depression of the 20th century, when access to staple foods was extremely limited, U.S. total sweetpotato production peaked to more than 900,000 planted acres and per capita consumption of more than 25 lb annually (Smith et al., 2009; USDA ERS, n.d.). Production was spread throughout many regions in the country, and in 1938 the sweetpotato was one of the most highly-produced vegetable crops in the state of Kansas, second only to Irish potato (Elmer, 1938).

Nevertheless, following World War II, U.S. production and consumption of sweetpotato experienced a downward trend lasting well into the later part of the century (USDA ERS, 1994). As agriculture became more industrialized, and the food system trended more globally, consumer preferences evolved and sweetpotato fell out of fashion. There were several decades of idled consumption and production with on average just 101,000 planted acres and per capita consumption of 4.5lb annually from 1970-2007 (Smith et al., 2009; USDA ERS, n.d.).

Over the last decade, however, there has been a shift in habits as consumers and society have become more concerned with the importance of wellness and a balanced diet. Increased reporting in scientific, industry and consumer-facing publications has underscored the substantial nutritional benefits of sweetpotato - and food producers and manufacturers have followed suit. The crop is considered a superfood and a “powerhouse” vegetable, based on its well-rounded provision of nutritionally-important macronutrients, vitamins and minerals (Di Noia, 2014; Smith et al., 2009). The concentration of dietary fiber contained in sweetpotato is highly regarded for its potential to mitigate diabetes, colon cancer, obesity and certain forms of heart disease (Padmaja, 2009). These nutritional properties make sweetpotato an important part of healthy diets; not to mention, that certain phytochemical constituents in sweetpotato are being studied for their potential to combat forms of chronic illness. Investigators in the U.S., including those at Kansas State University, have reported extensively on the benefits of the concentration of antioxidant anthocyanin compounds, particularly in purple flesh cultivars (CIP, n.d.; Sun et al., 2014). The dietary value that has motivated campaigns for increased consumption of sweetpotato in the developing world is also likely responsible for a renewed interest across geo-socio-economic lines with consumers in the Global North (AgMRC, 2017).

These increased publicity efforts, combined with national health food trends, have likely contributed to the significant increase in U.S. production and availability of sweetpotato over the last decade (Bond, 2017). Domestic availability, an indicator of consumption trends, has increased from 4.2 lb in 2000 to 7.5 lb in 2014 (Bond, 2017; USDA ERS, n.d.). The USDA's National Agriculture Statistics Service estimated that in 2016 there were 3.1 billion lb of sweetpotato in production, with a gross revenue of more than $705 million (USDA NASS, 2017). Moreover, national sweetpotato production in 2017 was 35.6 million cwt, which was a 13% increase from the year before (USDA NASS, 2018). The sweetpotato is now more than just a staple for traditional holiday dinners in the U.S. The increasing popularity of sweetpotato is seen across many regions and demographics in the U.S. and the variety of recipes and processed goods showcasing this naturally sweet root crop are ever expanding (Severson, 2010).

As the consumption habits of sweetpotato have evolved, so have the production systems. Despite being widely produced throughout many states during the first half of the 20th century, today U.S. sweetpotato production is largely concentrated among four states: North Carolina, Louisiana, Mississippi, and California (Bond, 2017; Estes, 2009.). In fact, more than 50% of domestic sweetpotato farming takes place in North Carolina alone—89,000 acres and 1.9 billion lb worth (Bond, 2017; USDA NASS, 2018). These key production states, each recognized for their proximity to key shipping ports, are not only the largest drivers of domestic supply, but they are also responsible for the export markets to Canada and the United Kingdom, which account for the largest shares of U.S. fresh and dried sweet potatoes exports.

Today, U.S. vegetable production is largely conventional (i.e. agriculture employing use of synthetic agrochemicals) and not compliant with eco-labels like USDA's National Organic Program (NOP). However, organic production and consumption is becoming increasingly popular as producers, consumers, and international organizations like the FAO endorse organic farming for its capacity to achieve improved environmental and economic impacts in comparison with more industrial and conventional systems (Nemes, 2009).

Estimates from the Nutrition Business Journal show that U.S. retail sales of organic food products increased by double digit percentages from 2005 through 2014, when sales hit $35 billion in annual revenue (USDA ERS, n.d.). This represents an 8.4% increase from the year previous, compared to just a 3.3% increase in the overall non-organic produce sector. In 2016, the total annual organic food market was valued at nearly $45 billion, of which almost 40% came from the sale of fresh fruits and vegetables (OTA, 2017). Currently, organic certified produce makes up 13.6% of all domestic produce sales (OTA, 2017). Strong growth is expected to continue. The global sale of organic produce is projected by market researchers to top $63 billion in revenue by 2020 (Research and Markets, 2015).

The sweetpotato industry has benefited from this trend toward organic foods. In their 2016 producer survey, the USDA's National Agricultural Statistics Service (USDA NASS, 2017) reported that sweetpotato is the 5th most valuable organic vegetable crop in the U.S. amounting to $101 million in annual sales—a dramatic 43% increase from 2015. In contrast with conventional production, where North Carolina dominates, California is the leading producer in organic sweetpotato with 4,400 acres in 2016 (USDA NASS, 2017).

In a 2015 meta-analysis of 44 independent studies comparing organic to conventional agriculture researchers from Washington State University reported organic crops are on average 35% more profitable, and organic systems 22% more profitable, than conventional (Crowder et al., 2015). Likewise, in that same study, it was concluded the average premiums for organic produce ranges between 29% and 32% higher than conventional price points for same crop type.

Depending on the commodity, average price premiums on organic vegetables alone can top 70% increase of retail price compared to conventional alternatives (Greene, 2009). In 2017, organic “terminal” or wholesale pricing across the U.S. for sweetpotato averaged $ 43.76/bu while non-organic averaged $21.81—more than a 100% increase (USDA AMS, 2018). Organic potato (*Solanum tuberosum* L.), like sweetpotato, is another tuber crop with similar processing applications and consumer use. In Greene's (2009) report on the organic industry, it’s noted that organic potato, the third most valuable U.S. organic vegetable, sells on average for more than 160% of conventional potato prices.

Local Market Demand

Starting in 2013 local food labels and designations were expected to be the one of the top factors in consumer preference of fresh produce (Flaccavento et al., 2014). In 2014, the Food Market Institute conducted a survey with U.S. shoppers and found that their top three motivations for purchasing local foods were: freshness, support of the regional economy, and taste (Brain, 2012).

With growing consumer interest comes market expansion. The increase in per capita consumption of locally-produced fruits and vegetables has in turn led to notable increases in sales for the local produce industry (USDA-NASS, 2012). There has been an increase in the number of producers that are active in local food systems, along with the value of local food sales. This includes both direct-to-consumer and intermediate marketing channels (e.g. sales to institutions or regional distributors) (USDA-NASS, 2007). Results from the USDA’s Local Food Marketing Practices Survey show that more than 167,000 U.S. farms produce and sell local food through direct marketing practices, resulting in $8.7 billion in revenue in 2015 (USDA-NASS, 2015). Of this total, farms selling food directly to institutions and intermediates, such as wholesalers or food hubs, were the most profitable with $3.4 billion. The next category, at $3 billion in sales, was from direct-to-consumer sales operations, such as on-farm stores and farmers' markets.

While neither Kansas nor Missouri ranks in the top five states by value of direct local food sales, there is a growing market in the region and especially in populated areas like: Kansas City, Lawrence, Topeka, and Wichita. According to two separate food hub feasibility studies conducted for the Kansas City metro area and Northeast Kansas respectively, the demand for locally-grown fresh produce exceeds the supply nearby producers can provide (Flaccavento et al., 2014; Greater Kansas City Food Hub Working Group, 2015). In the Kansas City regional study, the value of unmet demand for local fruits and vegetables was determined to be more than $150 million. This figure demonstrates one of the greatest challenges of local production – meeting the consumer demand while providing consistent quality and availability. This is especially daunting for small producers who make up the vast amount of direct-to-consumer operations. In an effort to address the concerns and provide the seasonal variability consumers are used to, direct-to-consumer growers are required to diversify production in order to compete with the expansive variability of fresh produce available at major supermarkets year around. The analysis for NE Kansas specifically identified locally-grown sweetpotato as a "core [fresh produce] item" that could compete with imported crops based on its "appearance, flavor, freshness, uniqueness of varieties and good production conditions in the region" (Flaccavento et al., 2014).

From a horticultural perspective, the sweetpotato is an ideal crop for decentralized agricultural models. Although it is considered somewhat labor intensive, sweetpotato thrives in diverse soil types including marginal; it establishes in a wide range of climates, requires little in the way of fertilizer or irrigation, adapts well to organic systems, scales to small and large acreage, and produces storage roots that can be kept fresh for up to 10 months with minimal energy inputs. With the increasing consumer demand for local food and agriculture throughout our country, the sweetpotato is a noteworthy case study that is worthy of closer observation.

Propagation and Commercial Slip Production

The methods by which sweetpotato is reproduced, along with the production and distribution of its propagule, are unique in comparison to other commonly-consumed vegetable crops. The sweetpotato is a genetically complex polyploid with six pairs of chromosomes. Embryotic seed from sexual reproduction, i.e. pollinated flowers, will rarely produce true-to-type and is therefore not suitable for commercial agricultural use (Loebenstein and Thottappilly, 2009). In place of true seed, a new sweetpotato storage root crop is propagated by transplanting stem cuttings, i.e. the adventitious sprouts produced by seed roots harvested in the previous season. Horticulturalists and commercial nurseries refer to the stem cuttings as “slips”. Fresh slips are cut from propagation beds that are planted with storage roots from the previous year. When the slips grow to approximately 1ft in length, they are harvested and directly transplanted on-farm or marketed to other producers. Similar to propagation of the stem tuber *S. tuberosum*, new sweetpotato storage roots can be grown from saved tubers and tuber pieces; although it has been reported that storage root yield and quality when grown from root pieces are poor (George et al., 2011).

Nursery production of slips for sweetpotato production in the US typically occurs by specialty growers and is largely distinct from vegetable production. Most commercial sweetpotato growers rely on annual purchase of propagative material from slip producers. Some growers may produce a large portion of their planting material and purchase supplemental propagules, to incorporate improved cultivars, diversity and cleanliness into their "seed stock." Management of sweetpotato propagation beds is reported as being more labor intensive and requiring specialized equipment and farm infrastructure (e.g. over-winter storage) despite the fact that with the acquisition of equipment the process can become very mechanized (Barkley, 2015).

A substantial amount of the slips available throughout the U.S. are shipped from larger production states like North Carolina and are considered an important portion of state agribusiness. Prices vary depending on whether plants are organic, virus-tested, and how many plantings the stock is removed from micro-propagation (i.e. G1, G2, G3 etc.). As of 2018, organic wholesale prices for three orange flesh varieties can range from $60/1000 (Jones Farm, Bailey, NC) to $120/1000 plants (JCPHC) to $462/1000 (Johnny's Selected Seeds, Fairfield, ME), while retail of exotic or rare heirloom cultivars can sell for more than $1.00/slip (Sandhill Preservation Center, Calamus, IA). The profits from slip production can be considerable, even for a small nursery producer (Sandhill Preservation Center, personal communication). Nonetheless, there is very little information that exists regarding the market value of U.S. nursery slip production, let alone a standard retail or wholesale value for propagule sales. Moreover, enterprise budgets for seedbed production are scarce outside of the four main production states and rarely adapted to smaller scale or diversified production systems.

Slip Production Practices

The majority of transplants sold in the U.S. are sprouted stems cut from bedded seed roots, although some nurseries and clean plant centers will sell multiplied cuttings taken from recently planted slips (Smith et al., 2009). In the U.S., a portion of storage roots harvested in late summer and fall are stored separately for producing the nursery stock in the following spring. On average, approximately 75% of U.S. production is sold for human consumption, while approximately 7-9% is used for seed (USDA ERS, 1994). Other non-food uses might include shrinkage, loss, and animal feed.

Although any size of whole storage roots can be sprouted, major production states typically reserve small to medium sized storage roots, referred to as canners (diameter 1-1.75 inches), for propagation bed planting (Smith et al., 2009; Stoddard, 2013). Small seed roots are preferred because sweetpotato, unlike Irish potato, sprout largely from the proximal end of the storage root and consequently small roots provide greater spouting points/ft² (Coolong et al., 2012). Coolong et al. (2012) is careful to mention that selecting exclusively small roots for slip propagation may promote inferior quality traits in progeny.

Storage root production is typically carried out in the open-field (OF) and raised beds are arranged on 48” row centers. At 12” in-row spacing, sweetpotato growers require 10,890 slips to plant an acre. Based on the 169,000 acres of sweetpotato production in the US in 2016 (AgMRC, 2017), we can conservatively estimate the market at roughly 1.8 billion slips that are currently produced and sold across the country. Commercial nurseries recommend bedding one (40 lb – 50 lb) bushel of seed roots to produce at least 500 slips, and that on average an acre of seedbed production should produce approximately 62 acres of transplants (Jones Farm, personal communication; Stoddard, 2006). Nursery producers in North Carolina reportedly employed anywhere from 24 to 73 bu/1000ft² (50 lb/bu) to plant their seedbeds (Barkley et al., 2017a). Extension publications and commercial production manuals vary in their recommendations for seed root planting density in nursery beds. Some make prescriptions based on seed root weight, volume and/or seed root count. Coolong et al. (2012) recommend seven seed roots averaging 8 oz in weight/ft² in their seedbeds. Large commercial nurseries advocate laying seed as close together as possible without stacking them on top of each other which they say amount to 1.0 bushel of seed/20-30ft² (Jones Farm, personal communication).

The lack of definitive information regarding planting density motivated a replicated field trial by Barkley et al. (2017a) in order to determine the optimum planting density for yield to cost ratio. In their work comparing use of U.S.#1, jumbo, and canners as seed roots, bedded at 49 bu/1000 ft², showed no treatment effect on the seedbed's production of marketable slips in a "once-over harvest system." The same publication trialed the use of canner seed roots planted at seven densities (12, 24, 37, 49, 61, 73, and 85 bu/1000ft²) and found a generally positive correlation between increased planting density and average marketable slip production. In one year of the study, the results show a significantly greater total slip production at the two highest planting density treatments, while in another year slip yields from planting densities 49 bu/1000ft² were on average greater but they were statistically comparable. The study by Barkley et al. (2017a) also revealed a decreasing trend of slip weight as planting density increased. This was attributed to increased competition for physical requirement of plant growth. By assigning a value of $40/1000 slips and accounting for cost of increase and decrease in planting density treatments, they concluded that increased planting density was always positively correlated with increased profit. Barkley et al. (2017a) acknowledges there are many factors that determine the appropriate density for optimal economic benefit and plant quality, including: cultivar, direct variable costs like irrigation and inputs.

In North Carolina and other large production states, seed roots are commonly laid at soil grade or onto shaped ridges a few inches tall. Sweetpotato seed roots are placed in a large hopper and conveyed on a belt into the propagation beds and then covered with 2 in of soil (Wilson et al., 1977). Beds are covered with either black or clear polyethylene mulches, usually 1.5-2ml thick (Smith et al., 2009). In addition to manual labor and hand tools, implements can be pulled behind a tractor to lay plastic and cover edges with soil, securing the mulch. Plastic mulches help maintain adequate soil moisture and raise soil temperature for sprouting (Barkley, 2015; Saglam et al., 2017). Some producers raise temperature in the storage facility to 70-85°F and 75-85% relative humidity to induce pre-sprouting approximately four weeks prior to bedding (Schultheis, 1990; Smith et al., 2009). Pre-sprouting is shown to decrease time to slip harvest and increase slip yield (Schultheis and Wilson, 1998).

Holes may be cut in the plastic mulch shortly after planting to prevent loss of seed roots that may occur due to decay from excessive temperatures and buildup of CO_2. The mulch is later removed from beds when shoots emerge or when outside temperatures become too hot. Once the mulch is removed, slip beds quickly establish themselves and develop a dense canopy of stem and leaf growth. Slip length can vary greatly because the location of the meristem is variable among plants even in the same plot. Nevertheless, once the average distance from the soil to canopy reaches 10-14 in, the vines are cut with hand shears or a mechanized tool (Barkley, 2015).

Slips should be cut at least 1inch above soil line and the cutting tool should be sanitized routinely to reduce transmission of diseases present in soil (Clark et al., 2009). Because the growing point location can vary with respect to the top of the canopy, transplant sizes often vary when cut on the propagation bed (Barkley et al., 2017b). It is possible to repeatedly harvest of viable sprout cuttings from one seedbed, and beds can also be harvested after an approximate four-week re-growth period. However, commercial nurseries in North Carolina and other production states commonly use a “once-over harvest strategy,” which involves taking just one cutting from bedded seed roots (Barkley et al., 2017a). The market for sweetpotato slips reduces significantly after late July as it is too late to plant sweetpotatoes in much of the U.S. (Smith et al., 2009). Throughout the world, farmers often take slip cuttings produced from their own sweetpotato crop to produce successive plantings (Thottappilly, 2009).

California is the leading U.S. organic sweetpotato producer and their seedbed production is distinct from the systems employed by growers in Southeastern states. California is usually the earliest region to begin nursery production; in February seedbeds are planted 8 ft wide and hundreds of feet long (Smith et al., 2009; Stoddard, 2013). Seed roots are often bedded over decomposing cotton gin by-product to achieve appropriate soil temperature in early spring—referred to as “hotbeds”(Stoddard, 2013). Instead of using polyethylene mulch, clear plastic is stretched over metal hoops, creating a low tunnel growing environment (Stoddard, 2013).

Slip Quality and Foundation Seed Programs

There are a number of factors that can affect the quality of propagules and thus the success of transplant and storage root production. Because the vine cuttings used to propagate sweetpotato are genetic clones, viruses and mutations present in mother plants are easily transferred to progeny; quality and marketable storage root yields can diminish greatly, especially over successive plantings and cuttings from afflicted stock (Bryan et al., 2003).

Accumulation of viral pathogens in plant material and its impact on tuber yield and quality are one of the greatest concerns for sweetpotato production. According to the NCPN the four most common virus diseases, collectively known as Sweet Potato Viral Disease (SPVD), are all closely related to the most prevalent sweetpotato viral pathogen—Sweet Potato Feathery Mottle Virus (SPFMV). SPFMV (Genus *Potyvirus*) and other species within the extensive Potyvirideae family produce cracking and internal cork damage, dramatically decreasing yields and marketability.

In 1961, following years of pronounced yield and quality decline from russet crack disease, a subtype of SPFMV, extension agents from UC Davis adapted meristem culture for propagation of clean sweetpotato propagules (Dangler et al., 1994). A form of tissue culture, meristem culture of sweetpotato relies on the *in-vitro* culture of small (0.1mm), virus free, apical meristematic portions dissected from plant shoots. Meristem culture is often coupled with virus indexing, where established mericlones are grafted to an intrageneric indicator species like Brazilian and Japanese morning glory [*I. setosa* Ker Gawl and *I. nil* (L.) Roth] and plants are observed for up to six weeks for infection symptoms (Gaba and Singer, 2009; FPS, n.d.). Following successful absence of visually-observed symptoms during the index process, labs removed leaf samples from the host plant to conduct further testing through use of qPCR and bioassays. At the UC Davis Foundation Plant Center (FPS, n.d.) these molecular tests can effectively identify six known sweetpotato viral pathogens: Sweet Potato Feathery Mottle Virus (SPFMV), Sweet potato virus C (SPVC), Sweet potato virus G (SPVG), Sweet potato virus 2 (SPV2), Sweet potato leaf curl virus (SPLCV) and Sweet potato chlorotic stunt virus (SPCSV).

Sometimes thermotherapy procedures are employed to ensure optimum quarantine of nuclear and breeder stock (Gaba and Singer, 2009). Only after negative results are obtained from all samples throughout all testing procedures are *in-vitro* explant finally transferred to the greenhouse where a process of micropropagation is used to disseminate Generation 0 plants (G0) to slip nurseries and storage root producers. Both vine cuttings (rooted transplants and unrooted slips) and subsequent seed roots are sold as propagative material by specialized producers. Commercial nurseries use terms established by state commission or certifiers like registered and certified or G1, G2, etc. to indicate how many plant cycles or generations a slip or seed root is removed from last meristem culture and virus testing (Clark et al., 2010). The recommendation is that seed roots no older than G5 be used for propagation beds. (Bryan et at., 2003). Moreover, these commercial vine propagators often work in conjunction with laboratories, often times at local colleges of agriculture, to conduct *in-vitro* virus testing on the plant stocks they multiply and distribute. In the U.S., federal funding has recently been allotted for operation of clean plant centers for maintenance and supply of sweetpotato foundation stock. The establishment of the National Clean Plan Network, a collaborative effort of three USDA agencies: Animal Plant Health Inspection Service (APHIS), Agricultural Research Service (ARS) and National Institute of Food and Agriculture (NIFA), are just a few recent examples.

Beyond quality factors that are more cellular in nature, such as accumulation of viral pathogens, there are other morphological factors that can impact the overall transplant quality. Slip length, for example, has been shown to be an important parameter for transplant quality. When sprouts form vines approximately 25 to 35cm in length, they are cut in bunches and individual stems are transplanted directly into the soil (2-3 nodes deep) to grow a new storage root crop (Thompson, 2014). Barkley et al. (2015) report that slips are normally transplanted to a depth of 3-6 inches. The use of undersized slips is especially unsuitable for use with typical mechanical transplanters, as it often results in improper planting depth or inadequate plant tissue above the soil and is usually avoided by large producers (Thompson et al., 2017a). At a typical planting depth of 3-6 inches, slips ≤ 5 inches long are not considered viable because plants are unable to survive when planted completely below soil (Barkley, 2015). In a 2014 study in North Carolina, significantly greater total storage root production at a level of $P \leq 0.10$ was found for slips transplanted at depth of 15.2 cm compared to shallower planting depths (P =.088) for cv. ‘Covington’ (Thompson, 2014). A separate paper from Thompson et al. (2017) showed that slips measuring between 20 cm and 30 cm (from cut end to new growth) had greater survival rates and produced greater storage root yields compared to shorter slips. The authors also reported significantly greater US #1 and total storage roots/plant for slips ≥ 15.9cm (Thompson, 2014). Barkley (2015) report that slips harvested longer than 14 in can be cut to optimal length or cut again into two slips, although some accounts suggest that plants with apical meristems perform better when transplanted (Hossain and Mondal, 1994; Low et al., 2009). Trials with cassava, another tropical tuber species propagated vegetatively, have shown that longer stem cuttings produce higher yields (Thompson, 2014). Moreover, a minimum of three nodes under the soil surface has been recommended (Thompson, 2014). Stem nodes are the site of root primordia where adventitious roots are produced and develop into the desired fleshy storage roots (Firon et al., 2009). Therefore, shorter slips are discarded for their lack of nodes and the number of plant nodes are another quality factor for to be considered for sweetpotato slips.

Local Slip Production and Access

According to many international agriculture organizations and researchers, access to seed and other forms of plant genetic resources is one of the most "crucial elements" for the sustainability and prosperity of farming communities (FAO, 2017; Reuter, 2017). Seed and/or other plant propagules are the basis of production and genetic improvement. Without readily available reproductive material for agriculture, regional food security is weakened (Godfray et al., 2010). Efforts to address this need often revolve around promoting increased seed sovereignty, which has become a pivotal issue for farmers and communities around the world. Seed sovereignty, as defined by Indian scholar and activist Vandana Shiva, addresses "the farmer's rights to save, breed and exchange seeds, to have access to diverse open source seeds which can be saved – and which are not patented, genetically modified, owned or controlled by emerging seed giants"(Shiva, 2016). Local seed systems support access to profitable cultivars that are adapted to local biogeophysical factors and provided increased local revenues with markets for planting material (Coomes et al., 2015).

In his report, Reuter (2017) states all segments of agriculture - from community to industry-based - agree that seed and all forms of plant genetic resources are critical to ensuring a sustainable future food supply for all. In the U.S., supplies of sweetpotato slips, along with most other plant genetic resources for food and agriculture material, are largely consolidated in their production because of the concentration of production regions, commoditization, and subsequent vertical integration. There are propagators, predominately in those dominant production states, who specialize in production both for retail and wholesale markets. These hubs of domestic production, each with their own state sweetpotato commissions and designated research programs, are the paradigms for crop-specific economies of scale. Over the last 50 years, the top producing states have become more and more vertically integrated to manage the germplasm, breeding, inputs, tools, storage infrastructure, processing and distribution for most of the U.S. sweetpotato industry (Smith et al., 2009). With increasing consolidation, availability of sweetpotato is vulnerable to supply shortage due to crop loss caused by extreme weather. In 2016 Hurricane Mathew caused considerable flooding to the main production areas of North Carolina at harvest (Bond, 2017). Likewise, in 2017 the excessive rains from Hurricane Harvey negatively impacted production in Louisiana and Mississippi (USDA NASS, 2018). Isolated difficulties and disasters encountered by large producers pose a widespread risk to national supply of sweetpotato foodstuff and planting stock and therefore food security as a whole.

The increasing concern that regional food systems in the U.S. are overly reliant on consolidated supply chains and outside inputs is a response to potential food insecurity and apparent lost revenues in the local economy (Woods et al., 2013). This is reflected even outside the U.S. in Canada, for example, where nationally funded research is trialing production methods for sweetpotato propagules because of their stated overreliance on supply from U.S.—deemed a “bottleneck” to their regional crop production (Vineland, 2017) and this example highlights a similar situation in the U.S.

Increasing the capacity for local growers to manage their own sweetpotato slips is one way to support both sustainable community and economic development. According to farm enterprise budgets developed by the University of Kentucky Extension in 2012, annual purchase of slips is the number one variable production cost for sweetpotato growers (Coolong et al., 2012). Currently, smaller growers that supply their direct-to-consumer market frequently rely on shipments from distant producers for their planting material. Many local growers in the Central U.S. rely on slip producers and distributors more than 1,000 miles away. A 2017-2018 survey (n=20) conducted by our research team at the Great Plains Growers Conference (St. Joseph, MO) showed that while over 60% of respondents were interested in growing their own slips, challenges such as time, supply and quality prevented them from doing so.

In order to fulfill some of the need of local producers, Kansas State University has operated a wholesale nursery program since 2006 for organic sweetpotato slips at the John C. Pair Horticulture Center in Haysville, KS (JCPHC). Over the last 9 seasons, the JCPHC has successfully grown approximately 250,000 certified organic slips and 30,000 lb of certified organic seed roots annually. The seed program was initially developed to demonstrate the viability of regional sweetpotato production by supplying the propagation material. A decade later, the regional storage root production has increased and the center has recorded annual revenues of $30,000 ($120.00/1000 slip bushel) with sales to 90 farmers and 27 states in 2015. The seedbed production at JCPHC demonstrates the potential market, not only for local storage root production, but also for regional growers who incorporate organic slip crops into their farming systems.

High Tunnel Production Systems for Organic Sweetpotato Slips

Due to their sensitivity to cool climates, sweetpotato production schedules in the northern growing regions of the U.S. are often dictated by a shorter growing season. Producers in these areas must plant slips in earlier in the summer to harvest a fresh tuber crop by the fall compared to the Southeastern U.S. This means typical OF slip production, harvest, shipping, and transplanting is not feasible for creating a local propagations system. In response to some of these challenges, growers may adopt controlled environment production systems such as high tunnels (HTs). HTs are non-permanent, passively-heated, controlled environment growing structures that rely mainly on evenly spaced arch shaped pipe frames, built from bent steel or plastic, covered with tightly fastened greenhouse type polyethylene plastic films (Carey et al., 2009). Similar to other commonly-used technologies in temperate zones, such as greenhouses, HTs are largely coveted for their ability to create microclimates, especially warmer air and soil temperatures (Wells and Loy, 1993). In contrast to greenhouses, HTs rarely use concrete floor pads and crops are often grown in ground (Blomgren and Frisch, 2007).

A regional survey conducted at the Great Plains Growers Conference (2015) (n=265) showed that 82% of participating growers had already adopted HT operations or were planning to do so in the near future (Rivard, 2014). HTs have been reported to accelerate the days to harvest for warm season crops when compared in trials to otherwise identical OF plantings (O’Connell et al., 2012). Both et al. (2007) demonstrated an increase in spring nighttime soil and air temperatures of 0.9°C and 6.7°C respectively when using HTs. Further, HTs provide added barriers to weather elements like wind and rain, and to some extent they may exclude animal and insect pests (Lamont, 2005). Foliar disease may also be reduced given the rainfall protection offered in HTs (O'Connell et al., 2012; Orzolek et al., 2004)

While HTs present a number of benefits for growers, there are some potential obstacles that might deter a farmer from pursuing this production system. Once such obstacle is the initial expense and assembly required for HTs. Three-season HTs are not covered during the winter due to insufficient snow load capacity and may cost anywhere between \$0.75-\$1.25/ft^2 whereas four-season HTs can be utilized 365 days per year and typically cost \$2-\$3/ft^2. However, the added income from greater yield and quality due to HT production generally begins to accumulate by year 1 or 2 (Blomgren and Frisch, 2007; Sydorovych et al., 2012), accounting for much of the initial investment. HT production is typically reliant on drip irrigation systems and consequently access to frost-free water, which may not be readily available (Montri and Biernbaum, 2009). However, given the increasing consumer demand for fresh, locally-produced food, HT production is likely to continue to expand, especially in regions where specialty crop production is low and/or limited by extreme weather (Blomgren and Frisch, 2007).

Sweetpotato Propagation Beds in High Tunnels

There are no reports in the scientific literature that we are aware of, which evaluate the utilization of HTs for propagating sweetpotato slips. The HT system may be a useful tool for facilitating small-scale slip production in the Central and Northern growing regions of the U.S. However, crop types and cultivars that are suitable for OF production systems may not be suitable for HT systems. HT cultivars and varieties must be adaptive to warmer, more humid environments as well as resilient to the pests and diseases that thrive in those conditions. Moreover, intensely cropped systems such as HTs require additional considerations when it comes to crop rotation and selection. Crop rotations, which improve soil quality and mitigate pest and disease pressures, should normally include species that belong to a variety of plant families. (Montri and Biernbaum, 2009). A 2010 survey of HT growers in Missouri, Kansas and Nebraska showed that 50% practiced some form of crop rotation in their HT systems (Knewtson et al., 2010). This ranged from growing different crops in successive years or rotating crops to different areas of the HT. Another less common practice involved moving the HT to cover a different soil location.

Sweetpotato is the only food crop in the *Convolvulaceae* family making it a unique option for growers looking to increase diversity while maintaining productivity in their HT systems. Furthermore, studies have shown all sweetpotato plant parts and residues to be allelopathic. Allelopathy can be beneficial when trying to rid fields of invasive weed species; however, it could potentially interfere with the germination and establishment of successive cash crops (Reinhardt et al., 1992). Some extension publications also contend that sweetpotato prevents nodulation in nitrogen fixing legume crops, which would be also be problematic for increasing amounts of growers that rely on fertility of nitrogen fixing cover crop species (Peoples et al., 2009). However, there is little known in terms of the interaction between sweetpotato and crops more typically grown in HT systems.

Sweetpotato growers in the colder temperate zones of the U.S. and Canada, are reported to use unheated greenhouses and HTs for the production of propagules and storage roots (Coleman, 1995; Sand Hill Preservation Center, personal communication; Vineland, 2017). Regional growers have shown a considerable interest in producing their own sweetpotato slips using HTs, if available. In the 2017-2018 survey (n=20) conducted by our research team, nearly 80% of all respondents indicated an interest in using HTs for sweetpotato slip production. However, research regarding the effects of growing sweetpotato propagation beds under an elevated transparent plastic film such as a low or HT is limited. Recommended production practices for HT sweetpotato propagation beds are equally scarce although a recent report evaluated seed root planting densities in the OF (Barkley et al., 2017a). In the HT production system, growing space is at a premium and therefore production models that optimize planting densities based on economic costs and returns would be valuable.

In a study conducted in the Southeastern U.S., La Bonte et al. (2000) demonstrated greater slip production under a black plastic low tunnel, but subsequent yield from those slips was inconsistent when compared to OF slip production. In the study, La Bonte et al. (2000) constructed 38 cm steel wire hoops over the nursery beds and covered the tunnel with poly immediately following the removal of a black plastic mulch laid over the soil at initial bedding.

In California, nursery production of slips can start as early as February, earlier than most other production recommendations (Stoddard, 2013). Instead of plastic mulch laid over the soil at bedding, metal rod hoops covered with plastic film are used to construct tunnels over the length of commercial seedbeds (Smith et al., 2009; Stoddard, 2013). This process requires approximately 2.5 man hours per acre which could potentially be avoided using a HT structure to modify the microclimate (Stoddard, 2006).

Generally, the references to slip production in HTs using a clear poly is lacking from the scientific literature. Moreover, the aforementioned studies did not compare the physical traits and quality parameters, such as foliage, fresh and dry weight, and compactness, of slips grown under HTs versus OF. Plastic films utilized by HTs are typically UV-blocking and the plants produced can be significantly taller and have thinner leaves in comparison to OF production (Tsormpatsidis et al., 2008). Feedback from a sweetpotato nursery in Iowa (Sand Hill Preservation) using a HT for early season production has indicated that slips grown in protected culture such as a HT or greenhouse are sometime elongated, ‘leggy’, and/or ‘soft’ (overly-succulent) when compared to plants produced in the OF. Similarly, the results obtained from a 2012 study on specialty cut flowers suggest that HT production alters stem length and width of certain cultivars compared to the OF (Ortiz et al., 2012). This is a growing trend in the cut flower industry, where longer stems are preferred (Criley and Paull, 1993).

Research Objectives

Sweetpotato is clearly an important crop around the world, driven in great part by the potential to strengthen food security as well as it’s agronomic adaptability. In the United States, commercial sweetpotato production and propagation is largely concentrated in southern and coastal states. Moreover, a regional supply of organic sweetpotato slips is limited, leaving growers dependent on distant and often costly, outside sources. Wholesale production of regionally-produced slips could help meet the demand for this important crop. Bedding and slip production in HTs may also provide growers the opportunity to control their own planting material (e.g. timing, cultivar, volume), thereby reducing vulnerabilities in their production systems. With the increasing consumer demand for organic, locally-grown vegetables, and the similarly burgeoning use of HT systems in the Central U.S., there is an opportunity for growers in the region to explore sweetpotato propagation as a viable economic activity.

Despite this extensive use of plasticulture and controlled environmental systems, research regarding the effect of growing sweetpotato propagation beds under an elevated plastic film such as a low- or high- tunnel is extremely limited. Moreover, while sweetpotato is the 5th most valuable organic vegetable crop in the U.S., studies regarding economic viability of organic slip production in HTs is generally lacking from published crop enterprise budgets as well as the scientific literature. Even less is known about how HT production might affect slip quality and performance during storage root production, and growers need research that addresses cultural methods such as planting density in order to develop these systems. Therefore, our specific research objectives included the following:

- Determine the utility of growing organic sweetpotato slips in HTs and the subsequent impact on yield in the OF through replicated research station trials.
- Identify the effect of HT slip production on specific slip quality parameters including length, stem diameter, nodes, leaf area, fresh weight and compactness.
- Investigate the optimal planting density of sweetpotato seed root for HT production systems
- Develop HT slip production budgets and determine economic feasibility of propagating organic sweetpotato slips in HTs

Chapter 2 - Yield, Quality, and Performance of Sweetpotato Slips Grown in a High Tunnel Compared to the Open-Field

Abstract

Sweetpotatoes [*Ipomoea batatas* (L.) Lam.] are nutritious, easily stored and well-adapted to fit large or small organic farming operations. This widely consumed root crop is propagated through use of cuttings, known as slips, which are commercially grown primarily in the Southeastern United States. Consequently, growers in the Central U.S. have limited control of and access to local planting material. Production of organic slips in high tunnels (HTs) could be a profitable enterprise for growers in the Central U.S. that would allow them to diversify their operations and encourage the use of crop rotation in HTs. This study evaluated the yield and performance of organic sweetpotato slips grown in HTs as compared to the open-field (OF). Similar trials were conducted in 2016 and 2017 at two research stations in Northeast and South Central Kansas. We utilized a randomized complete block design for all trials, with 4 to 6 replications per treatment. Propagation beds planted with 'Beauregard' seed roots in 2016 and 'Orleans' in 2017 were established in HTs and the OF under identical cultural methods and planting schedule. Slips were harvested from HT and OF plots and transplanted to field plots to investigate the impact of production system (HT vs. OF) on transplant establishment and storage root crop production. Slip yield from HT was significantly greater than OF at two trial locations in 2016 ($P \leq 0.001$) but this trend was inconsistent in 2017. Slips grown in HT were on average 12% less compact (slip dry wt/cm length) with fewer nodes then their OF counterparts in 2016. Nonetheless, neither vine length, stem diameter nor total marketable storage root yield post-transplant was influenced by HT or OF treatments (1.7 and 2.1 lb/plant, respectively). Similarly, the number of marketable storage roots was not affected by the HT or OF treatments (3.4 and 3.8

storage roots/plant, respectively). More research is needed to evaluate the feasibility of sweetpotato slips grown in HT systems and to determine recommendations for seed root planting densities. The results of this study suggest that organic sweetpotato slip production could be a viable alternative to OF production as it relates to slip performance. Local or regionalized propagation systems provide growers with more control over their planting material and this study suggests that HT production could be a useful system for growing sweetpotato slips, which could further promote the adoption of an underutilized vegetable crop that can be grown throughout many parts of the United States.

Introduction

In 2016 sweetpotato was the 5th most valuable organic vegetable crop in the U.S., generating 101 million dollars in annual sales (NASS, 2017). However, U.S. sweetpotato production is largely concentrated among four states: North Carolina, Louisiana, Mississippi, and California (Estes, 2009). More than 50%of domestic sweetpotato farming takes place in North Carolina alone (Bond, 2017; USDA NASS, 2018).

Sweetpotato is tropical crop and doesn’t tolerate frost (Thottappilly, 2009). It is propagated vegetatively using 25cm to 35cm stem cuttings known as slips (Boudreaux, 2005; Schultheis et al., 2008). Sweetpotato growers in the colder temperate zones of the U.S. and Canada, are known to use unheated greenhouses and HTs for the production of propagules and storage roots (Coleman, 1995; Sand Hill Preservation Center, personal communication; Vineland, 2017). Greenhouse production for sweetpotato is widely used by certified seed programs for isolated multiplication of virus-tested foundation plants (Jiang et al., 2017). However, sweetpotato slips are typically grown in the OF in the largest production states. It is a common cultural practice to cover bedded seed roots with plastic mulch to warm the soil and promote early spouting for slip production (Barkley et al., 2017a). The plastic is then removed once slip shoots reach the soil surface. In place of a plastic ground mulch, commercial growers in California use low tunnels that consist of metal wire covered with clear plastic (Smith et al., 2009). Despite this extensive use of plasticulture that is used for sweetpotato slip production, research regarding the effect of propagation beds grown under an elevated polyethylene film such as a low- or HT is lacking.

HTs are impermanent, passively-heated, controlled environment growing structures that typically use evenly-spaced arch shaped pipe frames, built from bent steel or plastic, covered with tightly fastened greenhouse type polyethylene films (Carey et al., 2009). Similar to greenhouses that are used in temperate zones, HTs are largely coveted for their ability to create microclimates, especially those with warmer air and soil temperatures (Wells and Loy, 1993). HT systems allow for season extension and the enclosed growing environment lends itself to organic production, reduced foliar disease, increased crop marketability and higher yields (Black, 2010; O'Connell et al., 2012).

Considering that many growers propagating slips are routinely importing costly tissue-cultured and virus-tested derived seed stock (La Bonte et al., 2000), production systems that promote high yield and consistency would be ideal for sweetpotato slip production. However, there are no reports in the scientific literature that examine the utilization of HT systems for slip production. La Bonte et al. (2000) demonstrated greater and earlier slip production under a low tunnel with black (opaque) poly covering applied after the removal of ground mulch. However, subsequent yield from those slips was inconsistent when compared to slips grown in the OF and ultimately the authors did not recommend the treatment.

La Bonte et al. (2000) removed plastic several days prior to harvest to de-etiolate plants before transplant but still found that slips grown under plastic tunnels weighed less on average than the control. Aside from this study, there is little information available to predict what the effect of HT production would be on the quality of slips that are grown in a HT. Plastic films utilized by HTs are typically UV blocking and the plants produced can be significantly taller and have thinner leaves in comparison to OF production (Tsormpatsidis et al., 2008). Feedback from a sweetpotato nursery in the Midwest (Sand Hill Preservation Center, Calamus, IA) that has used a HT for early season production indicated that slips grown in protected culture such as a HT or greenhouse, are sometime elongated, ‘leggy’, and/or ‘soft’ (overly-succulent) when compared to plants produced in the OF. This is consistent with findings from other studies showing the effect of comparative HT production on crops, like cut flowers, where longer stems are preferred (Ortiz et al., 2012). This influence on plant morphology and composition is the reason why most vegetable transplants are ‘hardened off’ when being transitioned from the greenhouse environment to the OF. This process reduces ‘transplant shock’ when moved outside. Slips are nonrooted cuttings and cannot be acclimated in the same way. Investigating the quality parameters of the slips grown in the HT in similar fashion to Barkley et al. (2017a) will be an important part of this project.

The overall objective of this study was to determine utility of HT production for growing organic sweetpotato slips and we utilized two complementary experiments to address our research questions. The specific research objectives included: (i) to investigate the effect of HT production on slip yield, (ii) to assess the effect of HT production on slip quality, and (iii) determine if HT production of slips affects growth and storage root production in the OF.

Materials and Methods

Trials were conducted in 2016 and 2017 at two research stations operated by Kansas State University: the Olathe Horticulture Research and Extension Center (OHREC) in Olathe, Kansas [Johnson County (lat. 38.884347°N, long. 94.993426°W; USDA Plant Hardiness Zone 6A)] and the John C. Pair Horticultural Center (JCPHC) in Haysville, KS [Sedgwick County (lat. 37.518928°N, long. 97.313328°W; USDA Plant Hardiness Zone 6B)]. The soil type is a Chase silt loam (pH= 6.3) at the OHREC, and at the JCPHC the soil type is a Canadian-Waldeck fine sandy loam (pH = 6.7).

Two complementary experiments were conducted at both sites. A propagation bed study was designed to compare the yield and quality of slips grown in the HT compared to the OF (systems). The slip performance study included slips that were grown in both systems (and at both locations) to determine the impact of HT slip production on their performance in regards to crop productivity. All trial areas at both sites were managed using organic practices. There were no fertilizers or pesticides applied to the field trials in both years and locations, which is typical for slip and storage root production in the region.

In 2016, seed roots that were utilized at both sites were produced at the JCPHC in 2015. In 2016 ‘Beauregard’ seed roots were presprouted for approximately four weeks prior to planting. Presprouting involves storing seed roots at approximately 85°F and 85% RH with use of humidifiers and space heaters. Due to flooding and subsequent crop loss at the JCPHC trial site during the summer of 2016, storage root harvest data for the slip performance study in 2016 could only be collected from OHREC. Additionally, G-1 seed roots were purchased and shipped in from commercial nursery (Jones Farm, Bailey, NC) to plant propagation beds at both locations in 2017. For the 2017 trials, ‘Beauregard’ was not available and therefore ‘Orleans’ was used.

The later delivery of purchased seed roots in 2017 also shortened the length of presprout period to two weeks. ‘Beauregard’ seed roots used to plant propagation beds in 2016, were mainly comprised of USDA grade no. 1 (diameter 1.75 to 3.4 in and length 3 to 9 in) and at the OHREC weighed on average 8.1 oz (no weights recorded for JCPHC site in 2016); however, purchased ‘Orleans’ seed roots used in 2017 were predominantly canner grade (diameter 1 to 1.75 in) and weighed on average 3.5 oz at the JCPHC and 3 oz at the OHREC. ‘Orleans’ was bred to be a similar alternative to ‘Beauregard’; both cultivars used in this study are alike in average propagation bed vigor, canopy biomass, leaf size, days to harvest; storage root yield, appearance and composition (La Bonte et al., 2012).

Propagation Bed Study

The objective of this experiment was to determine the effect of HT production on slip yield as well as physical characteristics of individual slips from propagation beds grown within the HT. Whole seed roots, free of decay, rot and/or other deformity were selected for planting into propagation beds. Beds were planted when soil temperature was consistently above 55°F. In both years and locations except JCPHC in 2016, seed roots for the propagation bed study were planted at 65-seed roots/m² density using a square quadrat frame made from PVC with 1m x 1m interior dimension. Seed roots were laid by hand in all years other than the JCPHC trial in 2016, which was planted mechanically. In all cases, seed roots were laid in an even distribution within the plot dimensions without overlapping or stacking seed roots. Stacking will diminish the sprouting potential of seed roots and can increase likelihood of decay in propagation beds (Barkley, 2015). In both years and locations, the study was conducted in a randomized complete block design (RCBD) with at least four replications per treatment. Plastic mulch was removed from all replications when shoot emergence was observed. Slips were harvested when slip canopy reached approximately 30 cm in length. In both years and locations plots were harvested by laying a 1.0 m² PVC square over the center of the 2.0 m² long beds and manually cutting vine stems approximately 1.0 inch above soil line. All plots within a replication were harvested on the same day. The same plots in each year and location were harvested at twice. Harvest data was occasionally collected over multiple days. Data was collected identically at both sites and is described below.

John C. Pair Horticultural Center

All HT tunnel plots in both years were planted in single three-season (20' x 100') HT, with no end walls and open sidewalls. HT bedding areas were prepared with a disc followed by a spring-tooth harrow prior to planting. In 2016 and 2016 and 2017 bedding soil was irrigated two days prior to laying seed roots. In 2016, seed roots were laid using a tractor pulled hopper and conveyor belt and were placed at soil grade. Planting density in 2016 in both HT and OF plots was solely determined by the amount of seed roots required to fill bedding rows as densely as possible without stacking or layering, which is typical of commercial production at the site. According to random sampling following the laying of seed roots, each meter of row length contained approximately 85-seed roots /m^2. The propagation bed plantings in 2016 OF and HT were contiguous, in a 300 ft and 100 ft long row, respectively. The hopper/seed root layer at JCPHC made a narrower bed width (~74 cm) compared to the plots that were laid by hand at OHREC in 2016 (1m). Once the seed roots were placed on the ground, a tractor-mounted, PTO-driven implement was used to pull soil from the edges to cover roots and build a uniform rectangular raised bed (~25 cm tall). Next, 2.0 mil clear poly mulch (Mid South Extrusion, Monroe, LA) was placed over the beds with a tractor drawn implement. Plastic mulch was not punctured or vented prior to removal. Following the removal of plastic mulch overhead irrigation was applied as needed.

In 2017 all propagation bed plots were planted using a 1.0 m^2 PVC quadrat, and seed roots were weighed and planted manually at 65-seed roots/m^2. The experimental design was a RCBD and each OF and HT plot was replicated four times. There were two rows of propagation bed plantings centrally-located within the HT and there was one meter of space between each row. All replications were centered over the length and width of the tunnel to reduce interference from the edges and ends of the HT. The experimental plots were assigned randomly to the two rows. Each row contained two replications with a meter of space in between the reps. Each plot was 2.0 m long x 1.0 m wide. In the 2017 trial, OF plots were seeded in an adjacent 100 ft section of row that was planted within an approximately 1/4-acre OF planting, 2.0 m long x 1.0 m wide plots were randomly assigned over the length of the row for data collection.

In the 2016 trial, JCPHC HT and OF plots were planted on 15 April. Plastic mulch was removed approximately 14 days after planting (DAP) in both years. In 2016 all HT and OF first harvests were conducted on 31 May (46 DAP). The second harvest for 2016 HT and OF plots were done on 28 June (74 DAP).

In 2017 trial HT and OF were planted on 17 April. In 2017 all HT and OF first harvests were conducted 13 June (57 DAP). The second harvest for 2017 HT and OF plots were done on 10 July (84 DAP).

Olathe Horticulture Research and Extension Center

At the OHREC, the experimental design was a randomized complete block design (RCBD) with two treatments (HT and OF). The treatments were replicated six times. In both years, plots were planted at 65-seed root/m^2 in six identical 20’ x 32’ Quonset-style, four-season

HTs and equivalent OF plots. OF plots had the same orientation, spacing between replicates and cropping history as the HTs.

Soil in HT and OF bedding areas was prepared with a tiller that was driven by a two-wheel tractor (BCS Model 732, BCS America, Portland, OR). Individual plot dimensions in both years, was 2 m long x 1m wide and planted at a 65-seed root/m² planting density. This density was chosen based on the results presented in Chapter 3. Unplanted buffer (0.5 m) was left between the plots as well as the edges and endwalls of the OF and HT plots.

In 2016 seed roots were laid below soil grade in HT and OF plots by manually digging a large trench with shovels, approximately 5 cm deep, throughout the plot area. Conversely, in 2017 seed roots were laid at grade level and were covered with 5 cm of soil that was dug from outside of the plot dimensions. In both years, temperature probes were placed in each plot, beds were irrigated, and polyethylene sheeting was used to cover the propagation beds. A generic 6 mil transparent polyethylene plastic sheeting (HDX, Atlanta, GA, USA) was installed over the plots to stimulate shoot growth. The sheeting was removed at the same time for all plots within a treatment group once shoots were visible. Although the plastic sheeting was not vented prior to its removal in 2016, four 25 cm vents were cut in each main treatment plot in 2017 10 d after planting based on recommendations from Coolong et al. (2012).

In 2016, OHREC HT and OF plots were planted on 11 May and 20 May, respectively. In 2016 OHREC HT plastic sheeting was removed 16 DAP. Although the 2016 OF plots still showed little to no shoot emergence, plastic mulch was finally removed from propagation beds 25 DAP. The first harvest of HT plots and subplots in 2016 took place on 17 June and 20 June (37 and 40 d after planting, respectively). Due to slow shoot emergence, the 2016 OF plots were only harvested once, which occurred on 11, 12 and 13 July (52, 53 and 54 d after planting) and rotting seed roots were observed below the soil line. In 2016 HT second harvest was conducted on 6 and 7 July (56 and 57 d from planting) and there was no data collected for the second harvest of OF treatment.

In 2017, HT and OF plots were planted on 28 April and 8 May. In 2017 HT and OF plastic sheeting was removed on 25 and 15 DAP, respectively. First harvest in 2017 of HT subplots was conducted on 16 June and OF plots on 19 June (49 and 42 DAP). The second HT harvest in 2017 was conducted on 12 and 13 July (75 and 76 DAP) and OF plots were harvested a second time on 17 July (70 DAP).

Propagation Bed Data Collection

Harvesting was performed manually and was similar to on-farm methods at JCHPC. In addition to slip yield, slip quality parameters were measured on 15 individual randomly-selected slip subsamples in 2016 and on 10 subsamples in 2017. Otherwise, all data collection was conducted in the exact same way at both locations and in both years.

All biomass was removed with hedge shears and sorted as described below. Slips were harvested in the morning and subsequent slip measurements were conducted on the same day of harvest. Harvests from HT and OF production systems were sorted and measured to determine the number of marketable slips produced/m^2, total marketable fresh and dry weights as well as total cull fresh and dry weight. Marketability was based upon on-farm standards utilized at JCHPC for commercial production of organic sweetpotato slips. Marketable slips were considered free from visible disease or deformity and were larger than 13 cm. Marketable and total number of slips were recorded for each plot. Slips ≤ 5 in long (~13 cm) are not considered viable because plants are unable to survive when planted completely below soil (Barkley et al., 2017a). Marketable and cull fresh weight were determined and all biomass was dried at 70 degrees C for at least 72 hours in a forced air drying oven (Grieve SC-350 Electric Shelf Oven, Round Lake, IL) prior to being weighed.

Slip quality measurements (length, fresh and dry weight, stem diameter, number of plant nodes, and leaf area) were performed on a randomly selected sub-sample of individual slips. Slip length was determined by measuring from the basal end to the meristem. The length of slip randomly selected from each plot for measurement was not controlled and all measured slips had met the minimum acceptable length of ~13 cm that was categorized as marketable. There is an appropriate length for slips (between 7 and 14 in) preferred by growers and correlated with increased yield (Thompson et al., 2017a); however, for this study the mean comparison of slip length is not considered a treatment effect, treatment groups were planted and harvested at different times in accordance with typical on-farm practices and these variable effects may have more to do with the average length than the fixed effect. Moreover, slips length within the plot is variable. Depending on cultivar the apical meristem, which was used as the end point for length measurement, can range in its distance relative to the top leaves of the bed canopy (Barkley et al., 2017b)—canopy height was the primary indicator for when to harvest in this study. Slip length was not considered a quality parameter but was included to provide context for the other parameters that were normalized over the length of each slip subsample and may be more indicative of a treatment effect. The nodes of each subsample were counted from the cut end to the apex, but did not include the growing point. Slip stem diameter was measured using a caliper tool within 1.0 cm of cut end and nodes were avoided. Leaf area was recorded by separating whole leaf blades from the petiole at their base by hand. Excised leaves were measured using a leaf area meter (LI-3100C; LI-COR, Lincoln, NE) with the adaxial surface laid downwards. Leaf blades were combined with their removed plant stem in small paper bags for drying as previously described.

Slip Performance Study

To further evaluate the effect of the HT system on sweetpotato propagation beds, slips produced in the HT and OF systems at both sites were planted at each trial location to determine treatment effect on transplant performance. Therefore, the four treatments implemented in this experiment included slips that were grown in: JCPHC HT, JCPHC OF, OHREC HT, OHREC OF—a two-way factorial at each trial location of slip origin (JCPHC and OHREC) x treatment (HT and OF). Flooding experienced at JCHPC in 2016 resulted in complete crop loss, therefore, harvest data could only be collected at OHREC during the 2016 season. In 2017 storage root harvests were recorded from both the OHREC and JCPHC. In all year and locations, these trials were planted in a randomized complete block design. Each plot was 25 ft long and had 25 slips, which were transplanted by hand at 12 inch in-row spacing and a planting depth of ~3 nodes (Thompson, 2014). Transplant establishment data was collected by taking plant growth measurements at 3, 4, 5, 6, 7 weeks after transplanting (WAT) from three random subsamples within each treatment and replication.

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Although final harvest data could not be collected in 2016, the JCPHC site was planted in a RCBD with 3 replications using 3 parallel 200 ft rows (~60 in row-centers). In 2017 RCBD was conducted over two parallel, 255 ft rows. Two separate replications were planted per row, with a 25 ft planted buffer area to separate the 100 ft long replications and a minimum 15 ft of buffer plants were at the end of each row. The field was prepared by discing twice and a spring-tooth harrow was used to level the soil. A bed shaper implement was used to build 10 in-tall ridges for transplanting

Slips were watered in by hand immediately following transplanting. Overhead irrigation was applied using a travelling irrigation system (Kifco B-140, Kifco Inc., Havana, IL) as needed following typical commercial production practices. Cultivation was performed as needed to control weeds either manually within rows or with a tractor mounted cultivation assembly between rows. In 2016, HT and OF slips were planted at the JCPHC trial site on 29 June and were harvested from OHREC on 28 June and at JCPHC on 29 June. Due to flooding, harvest data was not collected in 2016. In 2017 HT and OF slips that were planted at the JCPHC trial site on 10 July were harvested from JCPHC and OHREC on the same day as planting. In 2017 the JCPHC slip performance experiment was harvested on 12 October (94 d after planting).

Olathe Horticulture Research and Extension Center

In both years at the OHREC replications consisted of four parallel 100 ft rows (~50 in row-centers). The field was tilled with a 55 hp tractor and a bed shaper implement was used to build 6-8 in-tall ridges for transplanting. The four treatments were randomly assigned to each block/row with at least 25 ft of planted buffer areas on the ends of each row. A single row of low pressure drip tape was run over the length of each row. Beds were irrigated immediately following transplanting and when needed (first 5 cm of soil surface was dry to touch), which was approximately 1.25x/week. Cultivation was performed as needed with hand tools for the first few WAT. In 2016 HT and OF slips that were planted at the OHREC trial site on 30 June, were harvested at JCPHC on 28 June and 30 June at OHREC. In 2016 the storage roots from OHREC slip performance study were harvested on 4 Oct (96 d after planting). In 2017 HT and OF slips planted at the OHREC trial site on 12 June were harvested at JCPHC on 10 July and 12 July at OHREC. In 2017 the trial storage roots were harvested on 20 Oct (100 d after planting).

Slip Performance Trial Data Collection

Each plot was evaluated weekly for plant growth from 3 to 7 WAP. Three subsample plants were selected at random from each plot and measured to determine stem diameter at the soil interface and vine length. Stem diameter and vine length were averaged per plot over the five weekly samples. At harvest, 10 ft of row (10 plants) in the middle of the plot was harvested manually with a spade fork. In all years and locations, excluding the JCPHC site in 2016, a plant survival percent was taken from each 10 ft plot. Vines were cut and storage roots were sorted and weighed. Harvested storage roots from both sites were cleaned to remove excess soil and sorted as either marketable or cull. Storage roots were culled if they were damaged, diseased, irregular shape, malformed, and/or not meeting size requirements of marketable grades. Marketable storage roots were graded according to La Bonte et al. (2012), counted and weighed. Marketable grades consisted of U.S. #1 (5.1 to 8.9 cm in diameter and 7.6 to 22.9 cm long), medium or “canner” (2.5 to 5.1 cm in diameter and 5.1 to 17.8 cm long), and jumbo (larger diameter and/or length but not less than U.S. #1).

Statistical Analysis

Analysis of all collected data was conducted with JMP software (version 13.2.0, SAS Institute, Cary, NC). Standard least squares tests were performed to identify any significant interactions between fixed effects and random effects. Standard least squares test was conducted for slip performance study parameters to show interactions between year, slip origin, and production system. Because site effect was unbalanced with no storage root data collected at JCPHC in 2016, location x system interactions were tested separately for each trial year.

Treatment means were separated conducted using Tukey's honest significant difference test. All data was subject to analysis of variance. Homogeneity of variance and normality were evaluated using Levene's and Shapiro-Wilk's tests respectively. The plot yield data was normalized to standard m^2 plot dimension used in most trial years and locations. All individual slip quality measurements were normalized by slip length. Slip quality parameters were averaged from subsamples and analyzed as one value for each parameter per associated plot and harvest.

Results

Slip Yield

When considering each harvest event, we had an unbalanced factorial design due to having only one harvest in the OF at OHREC in the 2016 trial. Similarly, the regression model for 2017 showed significant three-way interaction location x harvest x system for marketable fresh weight and dry weight, and total fresh weight and dry weight (data not shown). Cumulative yield data from both years showed significant interactions between year and production system (Table 1). Therefore, the results of each year, trial site, and harvest are shown independently in Table 2.

Comparing data from all years, locations, and harvests, the HT plots averaged greater slip number than the OF (HT = 226.7 vs. OF = 147.8). Out of the eight harvests that are shown on Table 2, the HTs produced more slips in six of them, but only two showed significantly higher marketable slip yield. Interestingly, the results of the two years indicate that there was a stronger benefit of utilizing the HT system in 2016 compared to 2017. This is verified by the presence of a significant year x system interaction (Table 1), and there were no significant increases in slip yield seen in 2017 as the result of implementing the HT system (Table 2). Averages for HT and OF marketable slip production in 2017 across all sites and harvests were nearly the same (HT =

120.3 vs. OF = 123.3). In 2016, the utilization of the HT system increased slip number by 49% to 199% and averaged 82% more slips than in the OF. Conversely, in 2017, slip yield increases ranged from -63% to 25% and averaged -8% in the HT as compared to the OF.

Sweetpotato biomass production in the HT followed a similar trend to slip number. In 2016, all the 12 comparisons of marketable and total, fresh and dry weights were higher in the HT plots compared to the OF. All but two were statistically significant ($P < 0.05$; Table 2). In 2017, none of the HT vs. OF comparisons showed a significant benefit of utilizing the HT system as they relate to overall biomass production and plant growth. In contrast to slip number and biomass production, slip marketability (percent by wt.) was consistently higher in the HT as compared to the OF, but it was only statistically significant in the first harvest at JCPHC.

Slip Quality

Least squares regression model testing for interactions of year x system effect on slip quality was significant for all parameters except for fresh weight. The three-way interaction of fixed effect (HT and OF systems) and random effects (year and location) was significant for stem diameter and slip length (Table 3).

Based on the regression model results, data was separated by year and trial location and a second model was run on each year and location combination testing for significant interaction of harvest x system on all slip quality parameters. These tests showed significant interactions for fresh weight, dry weight, and leaf area for the JCPHC trial location in 2016 (data not shown). The same two-way interaction model was significant for nodes and stem diameter at the OHREC in 2017 (data not shown). Based on the presence of significant interactions, the data was further separated to compare HT to OF treatment groups for each year x site x harvest event (Table 4).

Fresh and dry weights, which have been normalized by slip length (mg/cm), are indicators of plant compactness. In only one of the sixteen comparisons of compactness that are shown on Table 4 did the HT system provide a significant benefit. In fact, ten of the sixteen comparisons showed higher compactness from slips grown in the OF and five of these were statistically significant ($P < 0.05$; Table 4). Compactness of slips grown in the OF was on average 25% greater than HT.

In 2016, the leaf area of slips grown in the OF was significantly greater at first harvest in both locations, but was not significant during the second harvest at JCPHC. In 2017, there were no statistically significant effects of the HT system on leaf area, but higher values were found on slips grown in the HT. A similar trend was observed in the number of plant nodes as well. In 2016, there were significantly more nodes on slips grown in the OF than in the HT ($P < 0.05$; Table 5). This contrasts with 2017, when the number of nodes was generally higher for slips grown in the HT and was statistically significant in the second harvest at JCPHC and the first harvest at OHREC. When averaged across all data, the stem diameter of slips grown in the two systems was similar (HT = 0.17 mm vs OF = 0.16 mm). Interestingly, the slips grown in the OF at JCPHC had significantly greater stem diameters than the ones grown in the HT in 2016. This contrasts with 2017, when the stem diameter of slips grown in the HT was generally higher across both locations and was statistically significant in the first harvest at both locations ($P < 0.05$; Table 4). Due to the need for coordinated data collection and the differential growth rate in the HT vs. OF, the slip length for each system is somewhat arbitrary. However, the slip length was statistically greater at JCPHC in 2016 during both harvests and was higher at OHREC during the first harvest. Like slip number, the average length of the slips was greater in the OF in 2017.

Slip Performance

The average plant survival for slips that were grown in the HT and OF was 94 and 96 percent, respectively, and the effect of production system was not significant. Plant growth data was collected from 3-7 weeks after planting (WAP). Least squares regression model tested for significant interaction of year x trial location x slip production location (origin) x slip production treatment (HT and OF) x weeks after planting (WAP) on the transplant establishment parameters (stem diameter and vine length). The model resulted in a significant effect of WAP, year, year x WAP, location x WAP, and year x location x WAP (($P < 0.001$); however, there were no significant main effects for slip production treatment (HT and OF) and no significant interactions that occurred with that factor. The main treatment effect (HT vs. OF) was not statistically significant for stem diameter or vine length. However, the values are reported are reported for each of WAP in order to provide a description of the plant growth in the trial (Table 5).

The data set was unbalanced for analysis of the yield data that was generated in the slip performance study. Flooding prevented storage root harvest at JCPHC site in 2016. Therefore, each individual trial (2016 OHREC, 2017 JCPHC, and 2017 OHREC) was analyzed as a single factor (trial) rather than including separate factors for year and location. The linear regression model testing interactions of trial x origin x treatment on all storage root yield (lb/plant and no. /plant) and marketability parameters was significant for trial ($P < 0.001$), treatment ($P < 0.05$), and trial x origin ($P < 0.05$) but not for any factorial interactions including the (HT vs. OF) treatment effect. Therefore, the mean comparison for treatment storage root yields were combined for all three trials (Tables 6-7).

Based on two years of harvest data from OHREC, and one year from the JCPHC, the OF treatment was on average greater for all storage root yield parameters. The slips grown in the OF produced nearly 20 percent more marketable storage roots by weight than the ones that were grown in the HT. However, the ANOVA means comparison was not significant for any of the yield parameters (Tables 6 and 7).

Discussion

The overall objective of these trials was to evaluate the utility of slip propagation in HTs and compare them to the OF. Previous studies conducted on fruit and vegetable crops have demonstrated that HT systems can achieve higher yields and produce marketability that are significantly greater than OF production (O'Connell et al., 2012). In La Bonte et al. (2000) the yield of propagation beds grown under a black plastic low tunnels varied depending on cultivar and harvest, but were significantly greater than the ones grown in the OF in multiple trial year x location combinations. Similarly, the results from our trials varied over the course of two trial years, locations and repeated harvests. In 2016, we observed significantly greater slip yields from plots grown in the HT. In 2017, however, yields in the HT and OF were similar, other than the second harvest at the JPCHC site, a year x location which provided results that were not consistent with the rest of the findings in our study. The averages for all yield parameters at the JCPHC in 2017 plots were dramatically lower than the three-other site x year combinations (Table 2). During the second harvest at this site in 2017, significant burrowing of the plots was observed from rodents and it is likely that this issue led to confounding effects. Careful review of the trial data across both years and locations suggests that the yield potential of HT slip production may be at least similar to that of the OF, and could be greater depending on cultivar, environment, and management practices.

HTs often provide intangible benefits such as a more consistent growing environment that can lead to more convenient production schedules (Knewtson et al., 2010). In the case of our trials at OHREC, excessive rain and poor growing conditions led to only one harvest in the OF whereas the HT was harvested twice. Shoot emergence under the plastic in the OF was inconsistent and it removed 25 DAP as a last resort. Following the removal of the plastic sheeting, the slip canopy in the OF plots was observed to be patchy and less vigorous. It's likely that by planting seed roots in shallow trenches in combination with the location's higher clay soil content and heavy rain that was received just after planting, the seed roots did not have sufficient gas exchange. The accumulation of CO_2 and largely hypoxic conditions are known to cause tissue decay in propagation beds (NC Sweet Potato Commission, 2018). Because they have a closed roof and due to original grading, that was performed during construction, the HT plots did not experience this situation, which may have allowed for improved slip production and early growth. Spring and early summer rain events can seriously limit OF production in the Central U.S. and the results of our trials reflect the impact of erratic weather on OF production compared to the HT system.

In addition to measuring yield, the propagation bed trials in HT and OF systems sought to compare the individual slip quality of plants grown in the HT to the OF system. HT production has been shown to influence the morphology of plants and certain aesthetic quality parameters in cut flower crops, (e.g. stem length and stem diameter) (Ortiz et al., 2012). There is little known about the impact of the HT production system on the physical characteristics of propagules or nursery plants of horticultural food crops grown for field planting. The methods used by La Bonte et al. (2000) were distinct from typical HT production and black plastic was used to make a low tunnel. Furthermore, there was little data presented in this previous study on the physical characteristics of slips from the tunnel and OF groups.

For sweetpotato slip growers, the physical attributes of the slips that contribute to slip quality in addition to the performance of the slips in the OF is just as valuable as the slip yield data. The HT treatment means were lower on average for all slip quality parameters except stem diameter. It is difficult to determine if the HT had a consistent effect on slip quality due to the variation that we saw across years. In 2016, the plots in the OF generally produced higher quality slips and in 2017, the opposite trend occurred.

Despite the inconsistent differences in physical characteristics, neither plant growth or storage root harvest data were significantly different for transplanted slips grown under the two systems regardless of trial year or location. The mean stem diameter and vine length of transplanted HT and OF slips were very comparable through the first seven weeks of plant growth. The storage root harvest data showed that the OF slips produced greater average storage root yield for all grades as well as percent marketability; however, the mean comparisons were not statistically significant and so it's unclear whether the production treatments and their corresponding slip morphology trends influenced the yield potential. Future slip performance studies comparing transplant potential may benefit from more standardized factors like holding days between propagation bed harvest and slip planting, as was done in Thompson et al. (2017b).

We saw significant differences between slip yields in 2016 and 2017. It is important to note that we were working with different, although similar, cultivars during each trial year. Moreover, the seed root grade and average weight per seed root was dramatically different. The 'Beauregard' seed roots that were planted in 2016, were planted at 33.5 lb per plot, whereas in 2017, the smaller 'Orleans' seed roots averaged 13.1 lb per plot. Furthermore, the 'Orleans' seed roots from 2017 were shipped over a thousand miles via standard freight shipping and likely experienced suboptimal handling and storage conditions. When seed roots arrived in 2017 the presence of what appeared to be Rhizopus soft rot was pronounced and required sorting and culling. The diminished quality of the imported seed roots reduced time for presprouting and required careful sorting of individual seed roots destined for propagation bed plots. Seed roots that were free of decay were utilized. However, it's possible that seed root quality was an influencing factor in the 2017 propagation beds. Due to the nature of our experiment, we needed to import seed roots in 2017. Nonetheless, the phytosanitary issues associated with shipping seed roots long distances is an issue a grower should avoid. Whenever possible, the import of foundation stock should be done with early-generation plants or slips that originate from meristem culture (e.g. G-1 or G-2 slips).

Conclusion

The results of this study suggest that slip production in HTs may be a comparable alternative to the more widely-used OF method. To our knowledge, this is the first report of sweetpotato slips being propagated in HTs and provides data that could be very valuable to growers as they consider adopting HT production systems. Moreover, HT production of sweetpotato slips in the Central and Northern growing regions of the United States may permit sufficient season extension for regional farmers to produce their own slips for on-farm storage root production. This would give producers greater control of their planting schedule(s) without compromising slip yield, quality, or performance. Small-acreage sweetpotato growers might dedicate a small portion of a HT to produce all the slips they need on-farm. Alternatively, a grower could dedicate an entire tunnel to slip production and distribute those slips regionally, providing an alternative source of farm gate revenue and a potential high-value crop while supporting crop diversity in the HT. Clearly, an economic analysis of this production system will be critical to determining its sustainability. However, our data suggests that this system is a viable way to grow sweetpotato slips that perform well in the OF.

Table 2-1- Probability values for total marketable slips, marketable fresh and dry weight, total fresh and dry weight, and marketable percentage by weight for propagation beds grown in Haysville, KS and Olathe, KS in 2016 and 2017.

Interactions[z]	Slip yield parameters[y]					
	Marketable slips	Marketable fresh wt.	Marketable dry wt.	Total fresh wt.	Total dry wt.	Marketable % by wt.
Year (Y)	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	NS[x]
Location (L)[w]	NS	NS	NS	NS	**<0.05**	**<0.05**
System (S)	**<0.001**	**<0.01**	**<0.05**	**<0.01**	**<0.05**	NS
Y x L	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	NS
Y x S	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.05**
L x S	NS	NS	NS	NS	NS	NS
Y x L x S	NS	NS	NS	NS	NS	NS

[z] The experimental design was a randomized complete block design (RCBD) with at least four replications; main effect was HT and OF production (system). Each plot consisted of m^2 sweetpotato propagation bed planted with 65 seed roots. Slips were harvested once canopy reached ~30 cm, two harvest per plot, except for OF at OHREC in 2016, taken from May to July. All cumulative slip yield data was included in the statistical analysis.

[y] Least Squares model to determine which factors and interactions between factors affected the slip yield parameters.

[x] NS indicates non-significant (α=0.05).

[w] Two distinct trial location (JCPHC and OHREC) planted in 2016 and 2017.

Table 2-2- Effects of production system (HT vs. OF) on total plot fresh weight and dry weight, total marketable slips, and marketable percentage of slip harvest for propagation beds grown in Haysville, KS and Olathe, KS in 2016 and 2017.

	Marketable plot yield			Total plot yield		Marketable
Treatment[z]	Slips (plants/m^2)	Fresh weight (g/m^2)	Dry weight (g/m^2)	Fresh Weight (g/m^2)	Dry weight (g/m^2)	(% by wt)
2016 JCPHC 1st Harvest[y]						
HT	395.7	3511	353	5053	479	69.3
OF	138.5	1331	140	3390	366	39.8
P value[x]	**<0.001**	**<0.001**	**<0.01**	**<0.001**	NS[w]	**<0.01**
2016 JCPHC 2nd Harvest						
HT	437.1	6606	603	8055	802	80.8
OF	293.6	3058	343	4150	470	71.5
P value	NS	NS	**<0.05**	**<0.05**	**<0.05**	NS
2016 OHREC 1st Harvest						
HT	414.5	5048	0.434	5912	494	74.0
OF	138.5	1603	0.152	2190	215	73.8
P value	**<0.001**	**<0.001**	**<0.01**	**<0.001**	**<0.01**	NS
2016 OHREC 2nd Harvest						
HT	140.8	1348	94	2635	177	83.2
OF	n/a	n/a	n/a	n/a	n/a	n/a
P value	n/a	n/a	n/a	n/a	n/a	n/a
2017 JCPHC 1st Harvest						
HT	50.0	893	91	1065	110	64.0
OF	40.0	635	84	840	112	71.8
P value	NS	NS	NS	NS	NS	NS
2017 JCPHC 2nd Harvest						
HT	22.8	420	40	0.598	52	75.8
OF	62.0	1660	178	1.798	187	80.5
P value	**<0.01**	**<0.001**	**<0.001**	**<0.01**	**<0.001**	NS
2017 OHREC 1st Harvest						
HT	167.0	2002	130	2462	151	71.5
OF	174.3	2627	208	2885	227	61.8
P value	NS	NS	**<0.01**	NS	**<0.01**	NS
2017 OHREC 2nd Harvest						
HT	185.5	2765	214	3272	252	84.3
OF	168.5	2717	238	3108	269	87.3
P value	NS	NS	NS	NS	NS	NS

[z] The experimental design was a randomized complete block design (RCBD) with at least four replications; fixed treatment effect included the use of either HT or OF production system. Each plot consisted of 1.0 m^2 sweetpotato propagation bed planted with 65-seed roots. Slips were harvested once canopy reached ~30 cm, two harvest per plot, except for OF at OHREC in 2016, taken from May to July.

[y] Data is separated by year, location and harvest for every slip yield main effect because interactions were observed between the treatment (HT and OF) and random effect (year, location, and harvest).

[x] Analysis of variance (ANOVA) to determine which factors and interactions between factors affected the main total and marketable yield effects (weight, average weight), and marketable (percent by wt), data from the entire production season was used for this analysis.

[w] NS indicates non-significant ($\alpha=0.05$).

Table 2-3- Probability values individual slip fresh weight dry weight, leaf area, nodes, stem diameter, and for propagation beds grown in Haysville, KS and Olathe, KS in 2016 and 2017.

Interactions[z]	Main effect[y]					
	Fresh weight	Dry weight	Leaf area	Nodes	Stem diameter	Slip Length
Year (Y)	NS[x]	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Location (L)[w]	NS	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.01**
System (S)	NS	**<0.001**	NS	**<0.001**	NS	NS
Y x L	NS	**<0.001**	**<0.001**	**<0.001**	NS	NS
Y x S	NS	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
L x S	NS	NS	NS	NS	NS	NS
Y x L x S	NS	NS	NS	NS	**<0.001**	**<0.05**

[z] The experimental design was a complete block design (RCBD) with at least four replications; main effect was HT and OF production (system). Each plot consisted of m^2 sweetpotato propagation bed planted with 65-seed roots. Slips were harvested once canopy reached ~30 cm, two harvest per plot, except for OF at OHREC in 2016, taken from May to July. All cumulative slip yield data was included in the statistical analysis.

[y] Least Squares model to determine which factors and interactions between factors affected the slip quality parameters.

[x] NS indicates non-significant (α=0.05).

[w] Two distinct trial location (JCPHC and OHREC) planted in 2016 and 2017.

Table 2-4- Effects of production system (HT vs. OF) on individual slip quality for propagation beds grown in Haysville, KS and Olathe, KS in 2016 and 2017.

	Slip Quality					
Treatment[z]	Fresh wt. (mg/cm)	Dry wt. (mg/cm)	Leaf area (cm^2/cm)	Nodes (#/cm)	Stem diameter (mm/cm)	Slip Length
			2016 JCPHC 1st Harvest[y]			
HT	417.5	33.6	5.4	0.37	0.20	19.1
OF	612.5	63.6	8.1	0.55	0.29	15.8
P value[x]	**<0.01**	**<0.001**	**<0.05**	**<0.001**	**<0.001**	**<0.01**
			2016 JCPHC 2nd Harvest			
HT	557.5	43.8	7.1	0.29	0.14	32.3
OF	545.0	58.1	7.5	0.46	0.22	20.8
P value	NS[w]	**<0.05**	NS	**<0.01**	**<0.01**	**<0.01**
			2016 OHREC 1st Harvest			
HT	505.0	39.3	5.3	0.34	0.16	30.5
OF	548.3	53.8	7.8	0.43	0.15	26.8
P value	NS	**<0.05**	**<0.01**	**<0.01**	NS	NS
			2016 OHREC 2nd Harvest			
HT	475.0	33.7	5.9	0.32	0.16	23.4
OF	n/a	n/a	n/a	n/a	n/a	n/a
P value	n/a	n/a	n/a	n/a	n/a	n/a
			2017 JCPHC 1st Harvest			
HT	712.5	79.0	11.1	0.45	0.24	22.5
OF	550.0	69.6	8.3	0.41	0.14	35.3
P value	**<0.05**	NS	NS	NS	**<0.05**	NS
			2017 JCPHC 2nd Harvest			
HT	545.0	73.1	10.9	0.39	0.18	29.8
OF	485.0	76.5	10.5	0.34	0.15	38.4
P value	NS	NS	NS	**<0.05**	NS	NS
			2017 OHREC 1st Harvest			
HT	618.3	38.1	7.2	0.31	0.16	31.3
OF	696.7	43.7	6.4	0.25	0.12	39.6
P value	NS	**<0.05**	NS	**<0.01**	**<0.01**	**<0.05**
			2017 OHREC 2nd Harvest			
HT	403.3	35.2	6.0	0.22	0.13	37.4
OF	420.0	39.8	5.7	0.23	0.13	35.6
P value	NS	NS	NS	NS	NS	NS

[z] The experimental design was a randomized complete block design (RCBD) with at least four replications; fixed treatment effect included the use of either HT or OF production system. Each plot consisted of m^2 sweetpotato propagation bed planted with 65-seed roots. Slips were harvested once canopy reached ~30 cm, two harvest per plot, except for OF at OHREC in 2016, taken from May to July.

[y] Data is separated by year, location and harvest for every slip quality main effect because interactions were observed between the treatment (HT and OF) and random effect (year, location, and harvest).

[x] Analysis of variance (ANOVA) to determine significant mean difference for the treatment groups (HT and OF) for the main slip quality effects, data from the entire production season was used for this analysis.
[w] NS indicates non-significant (α=0.05).

Table 2-5- Main effects of production system (HT vs. OF) on stem diameter and vine length by week after planting (*P = NS*) for slips transplanted in Haysville, KS and Olathe, KS in 2016 and 2017.

		Weeks after planting[y]				
	Treatment[z]	3	4	5	6	7
Vine length (cm)	HT[x]	36.9	62.5	91.1	115.6	118.6
	OF	35.4	60.8	85.8	108.4	110.3
Stem Diameter (mm)	HT	5.3	6.0	7.4	8.3	9.3
	OF	5.2	6.1	7.4	8.6	9.3

[z] The experimental design was a randomized complete block design (RCBD) with 8 replications; fixed treatment effect included the use of either HT or OF production system. Each plot consisted of 25 ft of row transplanted in July to slips at 12 in spacing from either HT or OF production system. Random subsamples from each plot were measured every week from 3 to 7 WAP.

[y] Data is combined by year (2016 and 2017) and location (JCPHC and OHREC) for every vine length and stem diameter main effects because interactions were not observed between the treatment (HT and OF) and random effect (year, location, and origin).

[x] Analysis of variance (ANOVA) to determine significant mean difference for the treatment groups (HT and OF) for the main effects was *P* = NS (non-significant, α=0.05) for all treatment comparisons.

Table 2-6- Main effects of production system (HT and OF) on storage root yield (all grades by weight and number) for plants grown in Haysville, KS in 2017 and Olathe, KS in 2016 and 2017.

	Yield (lb/plant)[y]			Yield (#/plant)		
Treatment[z]	No. 1	Canner	Jumbo	No. 1	Canner	Jumbo
HT	0.72	0.35	0.20	0.89	2.38	0.16
OF	0.90	0.37	0.27	1.05	2.52	0.21
P value	NS[x]	NS	NS	NS	NS	NS

[z] The experimental design was a randomized complete block design (RCBD) with 8 replications; fixed treatment effect included the use of either HT or OF production system. Each plot consisted of 10 ft of row transplanted in July to slips at 12 in spacing from either HT or OF production system. Seed roots were harvested in October and graded per USDA standards: No. 1 (diameter of 1.75 to 3.5 inches and length of 3 to 9 inches), canner storage roots (diameter 1 to 1.75 inches), and jumbo storage roots (diameter >3.5 inches).

[y] Data is combined by all trial years and locations (2016 OHREC, 2017 JCPHC, and 2017 OHREC) for every storage root grade yield main effects because interactions were not observed between the treatment (HT and OF) and random effect (year, location, and slip origin).

[x] Analysis of variance (ANOVA) to determine significant mean difference for the treatment groups (HT and OF) for the main effects was *P* = NS (non-significant, α=0.05) for all treatment comparisons.

Table 2-7- Main effects of production system (HT vs. OF) on storage root yield (marketable and total by weight and number) for plants grown in Haysville, KS in 2017 and Olathe, KS in 2016 and 2017.

	Yield (lb/plant)[y]			Yield (#/plant)
Treatment[z]	Marketable	Total	% by wt.	Marketable
HT	1.74	2.64	65.3	3.43
OF	2.07	2.81	71.7	3.78
P value	NS[x]	NS	NS	NS

[z] The experimental design was a randomized complete block design (RCBD) with 8 replications; fixed treatment effect included the use of either HT or OF production system. Each plot consisted of 10 ft of row transplanted to slips in July at 12 in spacing from either HT or OF production system. Seed roots were harvested in October.

[y] Data is combined by all trial years and locations (2016 OHREC, 2017 JCPHC, and 2017 OHREC) for every storage root marketable yield and total yield main effects because interactions were not observed between the treatment (HT and OF) and random effect (year, location, and slip origin).

[x] Analysis of variance (ANOVA) to determine significant mean difference for the treatment groups (HT and OF) for the main effects was *P* = NS (non-significant, α=0.05) for all treatment comparisons.

Chapter 3 - Diversifying Crop Rotation in High Tunnels with Sweetpotato Slip Production

Abstract

High Tunnel (HT) production in the U.S. is rapidly growing, particularly in climates where vegetable production is difficult such as the Central United States. The most common crop grown in HTs is tomato (*Solanum lycopersicum*) and many growers find it challenging to implement crop rotations with warm-season crops that can provide similar per square foot profitability. It was reported recently that sweetpotato [*Ipomoea batatas* (L.) Lam.] slips (vegetative propagules) that were grown in the HT performed comparably to slips that were grown in the open-field. However, studies regarding economic viability of organic slip production, especially in HTs, are lacking from published crop enterprise budgets. This study compared three standardized planting densities to identify an optimum density for HT production in regards to slip yield, quality, and profitability. Three similar trials were conducted in 2016 and 2017 at two research stations in Northeast and South Central Kansas. The studies utilized a randomized complete block design (RCBD) with at least four replications. Propagation beds were planted with 'Beauregard' seed roots in 2016 and 'Orleans' in 2017 were established in HTs using three distinct planting densities (45, 65, and 85-seed roots/m^2) under identical cultural methods and planting schedules. Crop enterprise budgets for two different case studies were developed to determine the costs of slip production in HT. Partial budget methodology was utilized to identify the costs and returns of implementing the three planting densities. On average, slip yields from the 85-seed root density averaged 41% more slips than produced by the 45-seed root density, but only 8% more compared to the 65-seed root density. In 2016, the 65 and 85-seed root density yields were significantly greater than the 45-seed root treatment for the first harvest conducted. The results of this study suggest that increasing planting density in HT systems may not always positively correlate with yields and subsequent profits. Average gross revenue for the three planting densities increased as density increased, but so did seed root, harvest, and packaging costs. As the growth in slip yield weakened between 65 and 85-seed root treatments, the profit declined and the highest planting density was not the most profitable. In the only profitable case study of two locations, seed roots planted at the optimal density of 65-seed roots were the greatest input cost at \$97.61/100 ft^2 of HT planting. The added fixed cost of 2.5 months of HT production amounted to \$10/100 ft^2. Total production, fixed and marketing costs for the slip crop was \$235.45/100 ft^2 and the profit was \$56.01/100 ft^2. HT slip production can be an economically-viable system for growers who wish to incorporate slip propagation beds into their HT crop rotations. Increasing planting densities may increase yield but growers must be mindful of the associated input and labor costs. Similar to the results from recent open-field research, there is a risk of plateauing yield and decreased profitability at higher seed root planting densities in HT.

Introduction

Specialty crop production in the Central and Northern growing regions of the U.S. are often dictated by a shorter growing season. In response to this, many fruit and vegetable growers are adopting controlled environment production systems such as HTs. A survey conducted at the Great Plains Growers Conference, St. Joseph, MO (2015) (n=265) showed that 82% of participating growers had already adopted HT operations or were planning to do so (Rivard, 2014). HTs are non-permanent, passively-heated, controlled environment growing structures that use arch-shaped steel or plastic frames covered with tightly fastened greenhouse type polyethylene plastic films (Carey et al., 2009). In contrast to greenhouses, HTs rarely use concrete floor pads and crops are often grown in ground (Grubinger, 2015). However, similar to other controlled environment systems used in temperate zones, HTs are largely coveted for their ability to create microclimates, especially warmer air and soil temperatures (Wells and Loy, 1993). HTs have been reported to accelerate the days to harvest for warm season crops when compared to the OF (O'Connell et al., 2012). Both et al. (2007) demonstrated an increase in spring nighttime soil and air temperatures of 0.9°C and 6.7°C respectively when using HTs. Further, HTs provide added barriers to weather elements like wind and rain, and to some extent they may exclude animal and insect pests (Lamont, 2005). Foliar disease may also be reduced given the rainfall protection offered in HT production systems (O'Connell et al., 2012; Orzolek et al., 2004).

The cost of high tunnel production is greater when compared to open-field ((Blomgren and Frisch, 2007; Galinato and Miles, 2013; Sydorovych et al., 2013), materials and construction of a HT on range from \$2.24/ft^2 \$5.00/ft^2 (Janke et al., 2017). This added cost can encourage intensive production methods and homogenous crop plans that favor short rotations of reliably high-value crops from a few plant families. Asteraceae, Brassicaceae, Cucurbitaceae and Solanaceae. Tomatoes (*Solanum lycopersicum*) are considered the most important HT crops (Lamont, 2009) and the most commonly-grown vegetable crops in HTs by growers in U.S. (Carey et al., 2009; Knewtson et al., 2010). At an optimal fruit marketability percentage and premium price point, tomatoes produced in HTs can bring in a profit of \$4.27/ft^2 (Sydorovych et al., 2013). In contrast, cucumber (*Cucumis sativus*) may only generate \$0.38/ ft^2 in profit (Chase and Naeve, 2012). Cool-season crops like lettuce (*Lactuca sativa*) mixes can generate net revenues of \$1.65/ ft^2 for growers in the Central U.S. and spinach (*Spinacia oleracea*) may only generate \$0.33/ ft^2 (Buller et al., 2016).

Diverse crop rotation has been cited numerous times as a major component in an integrated pest management (IPM) system (Rusch et al., 2013). Crop rotation can also help with soil quality and fertility (Montri and Biernbaum, 2009). Sweetpotato is the only economically-important food crop in the *Convolvulaceae* family making it an ideal option for growers looking to increase diversity while maintaining productivity in their high tunnel systems. Sweetpotato is propagated vegetatively with stem cuttings known as slips. The commercial production of sweetpotato is comprised of two separate components: nursery production of slips (propagation) and storage root production. Nursery production has its own set of production requirements and can be expensive to manage (Smith et al., 2009). Studies regarding economic viability of organic sweetpotato slip production in HTs or the open-field is lacking from published crop enterprise budgets. Anecdotal experience with sweetpotato slip propagation at Kansas State University combined with current slip markets in the U.S. suggest that it is a high-value crop that would benefit from the protection of the HT system and support the cost of the HT structure.

Sweetpotato is the 5th most valuable organic vegetable crop in the U.S. and its domestic production generates $733 million in annual farm-gate revenue (U.S.DA NASS, 2018). According to farm enterprise budgets developed by the University of Kentucky in 2012, annual purchase of slips is the number one variable production cost for sweetpotato growers (Coolong et al., 2012). A substantial amount of the slips available throughout the U.S. are shipped from larger production states such as North Carolina. Sweetpotato growers require anywhere from 9,330 to 17,420 slips to plant an acre (Coolong et al., 2012). Based on the 169,000 acres of sweetpotato production in the U.S. in 2016 (AgMRC, 2017), we can conservatively estimate the market size to include roughly 1.6 billion sweetpotato slips that are currently produced and sold across the country. In the North Central region, Kansas State University has demonstrated the potential market for growers who incorporate organic slip crops into their farming systems for more than a decade. The John C. Pair Horticulture Center in Haysville, KS (JCPHC) ships over 250,000 slips to 90 farmers in 27 states annually (Griffin, unpublished data).

Considering that many sweetpotato propagators are routinely importing costly tissue-cultured and virus-tested derived seed stock (La Bonte et al., 2000), production systems that promote high yield and consistency are ideal for sweetpotato slip production. High tunnels have been shown to increase yield as well as marketability in a number of studies with leafy as well as fruiting vegetables (Janke et al., 2017). A recent report from Kansas showed that slip propagation in high tunnels reduced slip quality due to slips with a lower number of nodes and less compactness. However, the HT production system provided high slip productivity and there were no significant differences in tuber yield from slips grown in the HT as compared to the open-field (Hoppenstedt et al., Ch2). Moreover, the study suggests that HT production systems are a viable approach for growing slips that perform comparably with slips that are propagated in the open-field.

High tunnel growers may be interested in propagating sweetpotato slips for their own use or for sale to local farmers and gardeners. A 2017-2018 survey (n=20) conducted by the research team at the Great Plains Growers Conference showed that over 60% of respondents were interested in growing their own slips, citing challenges such as delayed delivery, lack of supply and poor quality as motivators. However, there are several considerations that need to be addressed including the economic costs and potential benefits of producing this crop.

The only known national production figures that account for sweetpotato slips are reported in aggregate under a variety of “Horticultural Specialty Operation” categories, including annual bedding plants, transplants for commercial vegetable production and tissue culture plantlets—depending on production methods and end-use (USDA National Agricultural Statistics Service (NASS), 2015). Prices vary depending on whether plants are organic or virus-tested, and how many plantings the stock is removed from micro-propagation (i.e. G1, G2, G3 etc.). As of 2018, organic wholesale prices for three orange flesh varieties ranged from $60/1000 (Jones Farm) to $120/1000 plants (JCPHC) to $462/1000 (Johnny's), while retail of exotic or rare heirloom cultivars can sell for more than $1.00/slip (Sandhill Preservation Center). The profits from slip production can be considerable, even for a small nursery producer (Sandhill Preservation Center, 2018). However, enterprise budgets for seedbed production are scarce outside of the four main production states and are rarely adapted to smaller scale or diversified production systems.

In addition to enterprise budgets for regional HT production, growers need information related to the cultural methods that may help ensure success within HT. Based on the finite size of the structure in addition to the cost of HT production, growers are generally focused on maximizing and optimizing their per square foot (or meter) profitability. One way this can be accomplished with sweetpotato slip propagation is by varying seed root planting densities in propagation beds. Commercial nurseries recommend bedding one (40 lb – 50 lb) bushel of seed roots to produce at least 500 slips (Jones Farm, personal communication). On average, an acre of seedbed production should produce approximately 62 acres of transplants (Stoddard, 2006). Nursery producers in North Carolina reportedly employed anywhere from 24 to 73 bu/1000ft^2 (50 lb/bu) of canner grade seed roots to plant their open-field seedbeds (Barkley et al., 2017a). Extension publications and commercial production manuals vary in their recommendations for seed root planting density in nursery beds. Some make prescriptions based on seed root weight, volume and/or root count. Coolong et al. (2012) recommends seven seed roots averaging 8 oz in weight/ft² in their seedbeds. Large commercial nurseries advocate laying seed as close together as possible without stacking them on top of each other which are reported to amount to 1.0 bushel of seed/20-30ft² (Jones Farm, 2014).

Seed roots produced on-farm can be valued for as little as $12/bu in conventional systems (Guidry et al., 2017), to as much as $30/bu for organic foundation seed roots derived from micropropation and tissue culture (Jones Farm, 2017). In their 2017 production budget, Louisiana State University Agricultural Center shows the cost of seed roots are the #1 most costly input for slip propagation, comprising approximately 95% of the production cost—$21,236/acre. Furthermore, the number of sweetpotato slips that are produced in the open-field is affected by planting density (Barkley et al., 2017a). In the study by Barkley et al. (2017a), the authors found a generally positive correlation between increased planting density and average marketable slip production. Based on quadratic response the research team observed ($R^2 = 0.96$), as the density increased, they suspected that slip production would eventually plateau and regress as due to seed root stacking. However, they conclude that increased yields from higher seed root density are eventually restricted by competition for finite resources like space, water, and light, citing research on fodder radish showing decreased stands at increased seeding past optimum density (Oliveira et al., 2011). Although the study by Barkley et al. (2017a) was conducted in the open-field, it can be useful for informing a grower about management practices that could be implemented in the HT production system.

The overall objectives of this study were threefold: (i) to determine if the implementation of sweetpotato production is a viable candidate for diversifying crop rotations in HT production systems; (ii) to report the production costs associated with high tunnel sweetpotato slip production using two case studies; and (iii) to identify the optimum seed root planting density for HT production in regards to: yield, slip quality, and profitability.

Materials and Methods

Planting Density HT trials

HT trials were conducted in 2016 and 2017 at two research stations operated by Kansas State University: the Olathe Horticulture Research and Extension Center (OHREC) in Olathe, Kansas [Johnson County (lat. 38.884347°N, long. 94.993426°W; USDA Plant Hardiness Zone 6A)] and the John C. Pair Horticultural Center (JCPHC) in Haysville, KS [Sedgwick County (lat. 37.518928°N, long. 97.313328°W; USDA Plant Hardiness Zone 6B)]. The soil type is a Chase silt loam (pH= 6.3) at the OHREC. At the JCPHC, the soil type is a Canadian-Waldeck fine sandy loam (pH = 6.7). All trial areas at both sites were managed using organic practices. There were no fertilizers or pesticides applied to the field trials in both years and locations, which is typical for slip production at JCPHC.

In 2016, the planting density study was conducted only at the OHREC and in 2017 trials were located in both locations. Seed roots for trial plots were handled, selected and planted as described in Hoppenstedt et al. (Chapter 2). ‘Beauregard’ seed roots were mainly comprised of USDA grade no. 1 (diameter 1.75 to 3.4 in and length 3 to 9 in) weighing 8.1 oz on average. For the 2017 trials, ‘Beauregard’ was not available and therefore ‘Orleans’ G-1 seed roots had to be purchased and shipped in from a commercial nursery (Jones Farm, Bailey, NC). The 2017 seed roots were predominantly canner grade (diameter 1 to 1.75 in) and weighed on average 3.5 oz at the JCPHC and 3 oz at the OHREC.

The main effect of planting density compared three treatments groups (45, 65, and 85 seed roots/m^2). Albeit in a slight smaller plot (39” long x 39” wide) the JCPHC routinely planted their propagation beds at 85-seed root density. When the treatment densities were chosen in 2016, 85 Beauregard seed roots was typically the maximum that could be evenly distributed in the plot dimension without stacking. The lower densities were chosen to measure effect of increasing space between seed roots on yield and slip quality.

The planting density trials at OHREC in 2016 were nested within a split-plot randomized complete block design (RCBD; n=6) that examined the effects of HT vs. OF (main plots) as well as the three planting density treatments (sub-plots). The main effects are reported in Hoppenstedt et al. (Chapter 2) and only the results of the sub-plots are reported here. At both locations in 2017, the planting density study was arranged in a RCBD (n=4). In 2016, the study at OHREC was conducted in six identical 32 ft-long x 20 ft-wide four-season HTs and each HT served as a replication. In 2017, the experiments were repeated inside of individual, larger high tunnels at each location. Data was collected in the exact same way for both studies and is described below.

Olathe Horticulture Research and Extension Center

At the OHREC in 2016, the planting density study experimental design was an RCBD (n = 6) with two treatments (HT and OF). The treatments were replicated six times. In both years, plots were 2.0 m long x 1.0 m wide. The plots were planted on one half of six identical 20’ x 32’ Quonset-style, four-season HTs. All plots had the same orientation, 1.0 ft spacing between treatments within replications, and previous cropping history. Propagation beds were planted on 11 May in 2016 and harvesting was conducted on 17 June, 20 June (37 and 40 DAP) and 6-7 July (56 and 57 DAP). Additional details for the crop rotation, high tunnel layout, and bed preparation for the 2016 trial are included in Hoppenstedt et al. (Chapter 2).

The 2017 trial was planted within one bay of a 100’ x 200’ multi-bay, three-season HT (Haygrove, Ledbury UK). The experimental design in 2017 was identical to JCPHC. The trial was arranged in an RCBD and there were four replications planted within two rows of propagation beds (2 reps each). The two rows were planted on 2.0 m row centers. The trial was conducted in two centered rows and replications were at least 15’ from the ends of the HT in order to reduce interference from the edges and ends. Each plot was 2.0 m long x 1.0 m wide with 1 ft of spacing between plots and 1.0 m between the replications. In 2017, the plastic sheeting was vented by cutting four 25 cm vents in each replication two weeks after planting based on recommendations from Coolong et al. (2012). The trial was planted on 26 April and in 2017 seed roots were laid at grade level and covered with 5 cm of soil that was dug from outside of the subplot dimensions. Plastic sheeting was removed on 18 May (22 DAP). In 2017, the first slip harvests were conducted on 20 and 23 June (55 and 58 DAP) and 13 and 17 July (78 and 84 DAP).

John C. Pair Horticulture Center

The planting density study at JCPHC was conducted in 2017 in a 20 ft-wide x 100-ft long high tunnel (Stuppy Greenhouse, Kansas City, MO) with no end walls and open sidewalls. The details of the HT production system are shown in Hoppenstedt et al. (Chapter 2). This site has both a high tunnel and equipment that provide the ability to utilize mechanical planting. There were two rows of propagation bed plantings centrally-located within the HT to reduce interference from the edges and ends of the HT and to allow for tall planting equipment to enter the high tunnel. HT bedding areas were prepared with a disc and spring-tooth harrow prior to planting. There was one meter of space between each row. Each row consisted of two replications that were centered over the length of each row and separated by a 1.0 m space. The treatments were randomly assigned to plots with 1.0 ft spacing between treatments within each of the replications. Each plot was 2.0 m long x 1.0 m wide. Once the seed roots were placed on the ground, a tractor-mounted, PTO-driven implement was used to pull soil from the edges to cover seed roots and build a uniform rectangular raised bed (~25 cm tall). Next, 2.0 mil clear poly mulch (Mid South Extrusion, Monroe, LA) was placed over the beds with a tractor drawn plastic mulch layer (AMCO RB4-3, AMCO Division Dynamics Corporation of America, Yazoo City, MS). Plastic mulch was removed upon the visible emergence of slip shoots (14 DAP) and overhead irrigation was applied as needed. Seed roots were planted on 17 April and harvesting occurred on 13 June (57 DAP) and 10 July (84 DAP).

Propagation Bed Data Collection

Harvesting and data collection were described in Hoppenstedt et al. (2018) and were similar to commercial, on-farm methods at JCHPC. In addition to slip yield, slip quality parameters were measured on 15 individual randomly-selected slip subsamples in 2016 and on 10 subsamples in 2017. Otherwise, all data collection was conducted in the exact same way at both locations and in both years. The plot yield was measured for number of marketable slips, marketable fresh and dry weight, total fresh and dry weight, and marketability (percent by wt). The individual slip quality parameters follow Barkley et al. (2017a) methods, i.e. subsamples are measured for length, fresh weight, stem diameter, and nodes, in addition to measurements for leaf area and dry weight.

Statistical Analysis

Analysis of all collected data was conducted with JMP software (version 13.2.0, SAS Institute, Cary, NC). Homogeneity of variance and normality of distribution were evaluated using Levene’s and Shapiro-Wilk’s tests respectively. Standard least squares tests were performed to identify any significant interactions between fixed effects and random effects. Trial year, location and harvest were separated based significant interactions between fixed and random effects. Following any separation, data for main effects was subject to analysis of variance (ANOVA). to compare treatment means. Standard least squares models were performed to identify any significant interactions between fixed effects and random effect. Data was separated in accordance with results from least squares model, and treatment means from fixed effect were subject to ANOVA. Treatment means were separated using Tukey's honest significant difference test at $P \leq 0.05$. Linear regressions were conducted using fit line procedure in JMP graph builder.

Economic Analysis

The two HT trial sites (OHREC and JCPHC) served as case studies to develop enterprise budgets for organic sweetpotato slip production in HTs and at various planting densities. Partial budget methodology was performed to separate the variable costs (and returns) of planting density (e.g. seed root costs, harvest costs) from the fixed and annual production costs that were not affected by this factor (e.g. bed preparation, irrigation, scouting, etc.).

Both enterprise budgets are based on two and half months of production time in HT in addition to 4 weeks of seed root pre-sprouting in a walk-in cooler or other insulated area with humidifier and space heater. Pre-sprouting occurred in late March and the propagation beds were planted in late April with the second and final harvest in mid-July. The budgets for both systems assumed similar activities; however, the associated labor, machinery, and material costs varied depending on the methods and equipment utilized by each site. The second and final harvest occurred an average of 72 DAP in our trials. However, an additional 14 days was provided to allow time for bed preparation and set-up prior to planting, as well as clean-up of the HT production area after the final harvest.

The two case studies represent two distinct methods of HT planting and management– manual at the OHREC and mechanized at JCPHC. The case studies are meant to show how production methods and equipment affect the profitability of HT propagation beds. The JCPHC has been growing sweetpotatoes for more than a decade, and the budget at that site characterizes the costs and revenues of HT slip production using similar equipment and methods to common commercial slip production. Research and production methods at the OHREC are uniquely focused on HT production. The tools and methods employed for this budget are more characteristic of diversified HT producers rather than specific to sweetpotato slip production. There are many potential applications for the information presented in this study. Sweetpotato growers that are interested in producing their own slips in HT can review the costs and profits for each budget to decide which method and corresponding equipment is best suited for their farm. Growers that already produce slips and own corresponding machinery might use the JCPHC budget to evaluate whether HT production is a viable alternative to their open-field production. Lastly, a diversified HT producer can review the OHREC budget to determine whether slip production might be an appropriate addition to their established crop rotation.

Both budgets are based on the respective HT dimensions and cultural practices outlined for each location in the 2017 density study. The amount (ft^2) and layout (bed length x width) of planted areas in the HT corresponds to the maximum possibly allowed in each HT and based on equipment clearance and common methods for field production at each site. Both case studies assume standard costs for activities like venting and removing plastic, pest scouting. Other costs are site specific and reflect the specific practices and equipment employed at each site, e.g. irrigation, cultivation.

The JCPHC production model was developed to utilize a mechanical seed root planting system within a 100 ft long x 20 ft-wide HT. The raised propagation beds are planted on 72 in row centers over the full length of the HT with 30 in planted and 21 in of aisle between rows. The two rows are centered over the width of the tunnel (500 ft^2 of planted area/1200 ft^2 total are occupied by the crop). and seed roots are laid, covered and terminated with attachments mentioned in the density study using a 55 hp tractor (Kioti DK5510, Daedong USA, Wendell, NC). The JCPHC budget assumes the cost of plastic mulching used in the density study. The irrigation system is overhead sourced from ground water with pump. The material cost reflects the equipment necessary to distribute water from main irrigation line, including impact head, tripod stand and hose fittings.

The OHREC budget assumes production in a 50 ft-long x 30 ft-wide section of HT (utilized for density study in 2017) with 7 x 30 in wide beds planted on 48 in row centers (875 ft^2 of planted area/1500 ft^2 total). Soil is prepared with 11 hp walk behind tractor (BCS Model 732, BCS America, Portland, OR) and hiller-furrower attachment is used to bring soil out of footpaths for covering seed roots. The OHREC production budget assumes the cost of plastic sheeting described in the density study. The irrigation system was a high-pressure drip system, sourced from surface water with water pump and there were three lines of tape running the length of each row. The material cost reflects the equipment necessary to distribute water from main irrigation line, including header pipe, drip tape and fittings.

Assumptions of the Economic Model

One of the primary goals of this report was to develop enterprise budgets for HT slip production that are useful for existing HT growers. Therefore, although we included fixed HT costs in both enterprise budgets, we did not assess the actual structural costs at either site. In both case studies, the tunnels had been built for at least 5 years and were a regularly-used piece of production equipment. Therefore, a standard fixed cost for high tunnel materials and construction was assumed and based on the HT study by Sydorovych et al. (2013). The useful life of the 30’ X 96’ long HT from Sydorovych et al. (2013) is assumed to be 10 years and amounts to an annual fixed cost of $1,410.07 per 2,880 ft^2 HT ($0.49/ft^2) and a monthly cost of 117.51 per 2,880 ft^2 HT ($0.04/ft^2). The HT fixed costs are included in each budget based on the time required for propagation bed production cycle as well as the square footage occupied.

Other than the HT itself, the enterprise budgets do not include any fixed infrastructure, machinery or equipment costs that could be used for other on-farm duties or crop production such as an enclosed structure for pre-sprouting seed roots, tractor and attachments, utility vehicle/cart, etc. The budgets assume 3 months of marketing costs based on a standard monthly rate for marketing farm produce outlined in HT crops budgets from the Kansas Rural Center (Buller et al., 2016), otherwise the economic models do not include indirect costs (e.g. depreciation, utilities, administrative costs, etc.).

The price of materials and other inputs came from production records at both trial locations in addition to vendors that regularly supply growers in our region. The cost of organic seed roots was $30.00/bushel, based on the price of virus-tested G-1 seed roots ‘Orleans’ in 2017. Production costs assume the purchase of virus-tested foundation seed roots for 100% of total seed requirements. Following the methods outlined in the LSU budget for sweetpotato production (Guidry et al., 2017), the labor cost is assumed $13.79/hr, charged according to 2017 adverse wage rate for the state of Kansas (U.S. Department of Labor, 2017) plus an additional 26.75% for social security, workman’s compensation and Medicare. The variable costs for machinery (e.g. tractors, irrigation/water pump, etc.) adapted from standard rates in Guidry et al.

(2017), includes the costs of fuel and maintenance. The expected yield for each planting density was the same for enterprise budgets and was calculated by using average yield data from the three trials that were conducted in 2016 and 2017. It is assumed that harvest cost includes labor hours required to field pack 1000 slips/bu with each box costing $2.50. The labor time required to harvest and pack 1000 slips was assumed to be 1hr (Stoddard et al., 2006). The budgets do not account for the cost of transport, storage, shipping and handling that may occur, and can vary highly depending on market that is utilized for off-farm sales.

Gross revenue assumed for organic slips was $0.14/slip. This pricing is based on the current price at the JCPHC ($140.00/1000 slips). There are many ways that slips can be marketed and the sale price can vary. The budgets assume two harvests, although it may be viable to conduct more or fewer depending on the production methods and the market.

Results

Effect of Planting Density on Slip Yield

When considering each trial year, we had an unbalanced factorial design due to having only one location in 2016 trial (OHREC) and two locations in 2017 (JCPHC and OHREC). The regression model for the cumulative yield data showed significant two-way interaction of year x planting density on propagation beds yield parameters (marketable slips, fresh weight and dry weight; total fresh weight, dry weight and percent marketability). Least squares model showed significant interactions of harvest x density in 2016 and location x density x harvest in 2017 for trials conducted at JCPHC and OHREC. Consequently, the results of each year, trial site, and harvest are shown independently in Table 1. Comparing data from all years, locations, and harvests, the 85-seed root planting density averaged greater slip number (178.9 slips/m^2) than 45 and 65 density treatments (126.0 and 165.2 slips/m^2, respectively). However, out of the six harvests that are shown on Table 1, the 85-seed root treatment mean for slip yield number was greater in four, but only one showed significantly higher marketable slip yield (2016 OHREC Harvest 1). Moreover, the 85-seed root planting density was not significantly greater than the 65-seed root treatment for slip yield in any of our trials. Interestingly, the results of the two years indicate that there was a stronger benefit of utilizing the increased planting density in 2016 compared to 2017. This was verified by the presence of significant year x density interaction that we observed (data not shown), and there were no significant increases in slip yield seen in 2017 as the result of increasing planting density in the HT system (Table 1). Average slip production for 45, 65, and 85-seed root density plots in 2016 for all sites and harvests was distinct for each treatment (194.8, 227.7, and 308.1, slips/m^2, respectively). On average the utilization of the planting density increased slip number by -38% to 57% compared to the 45-seed roots/m^2. When combined across all years, locations and harvests, the plots with 85-seed roots/m^2 averaged 41% more slips than those that had the 45-seed roots/m^2, but only 8% more than the plots planted at 65-seed roots/m^2. Average slip production for 45, 65, and 85-seed root density plots in 2017 across all sites and harvests was similar (74.5, 80.9, and 82 slips/m^2 respectively). In 2017, combined locations and harvests the 85-seed root treatment averaged just 1% and 10% increased slip yield with the 65 and 45-seed root density, respectively.

Sweetpotato biomass production for the 85-seed root density followed a similar trend to slip number. In all years, locations and harvests, the 85-seed root planting density was on average greater for marketable and total, fresh and dry weights. However, the treatment means for biomass were only significantly different consistently for the first harvest at the OHREC in 2016 ($P < 0.05$; Table 1). Furthermore, the 85-seed root was never significantly greater in biomass than the 65-seed root treatment using Tukey's honest significant difference test ($P <$

0.05). In 2017, none of the density comparisons showed a significant difference of utilizing the higher planting densities system as they relate to overall biomass production and plant growth. Although only slightly, slip marketability (percent by wt.) was greater on average for the 45-seed root density treatment than the 65 and 85-seed root treatment (74.4%, 73.0%, and 72.1% respectively).

Linear regression was conducted to determine the relationship between seed root density by number (Figure 1) and by weight (Figure 2). During the first harvest of 2016, linear regression showed the strongest positive covariance between increasing seed root number and slip yield ($R^2 = 0.674$) and the greatest positive slope ($y = 300.8 + 80.5x$) ($P < 0.001$). The quadratic regression shown in Fig. 1 demonstrated even greater fit ($R^2 = 0.760$) with increasing density treatment ($y = 284.2 + 180.2x - 49.83x^2$)—the quadratic relationship between plot weight and slip yield was similarly strong for harvest one at OHREC in 2016 (Fig. 2). However, the relationship between slip yield and increasing planting density (by wt and lb) in subsequent years, location and harvests had a lower R^2 value (Fig. 1-2). In 2016 the average 45, 65, and 85-seed root plot weighed 23.6, 34.7, and 46.9 lb/m^2 respectively. In 2017 the average 45, 65, and 85-seed root plot weighed 9.4, 12.7, and 16.2 lb/m^2 respectively. The coefficient of determination for linear regression testing the correlation of seed root weight to number of slips/m^2 for cumulative data set (both years and locations) was higher ($R^2 = 0.449$) than seed root number ($R^2 = 0.026$).

Effect of Planting Density on Slip Quality

Least squares regression model testing for interactions of year x density effect on slip quality was significant for the cumulative data set. Therefore, data was separated by year and subsequent tests for interaction of fixed effect (density) x random effects (location and harvest) was significant for slip quality parameters in 2017. Based on the regression model results, the data was further separated to compare means for 45, 65, and 85-seed root treatment groups for each year x site x harvest event (Table 2).

When fresh or dry weight is normalized by slip length (mg/cm), these values are indicators of plant compactness. In 2016 fresh and dry slip weight was inversely correlated with increasing planting density. For combined years, locations and harvests fresh and dry slip weight for plots planted at 65-seed root density was slightly greater than the 45 and 85-seed root treatments. However, this was not a consistently significant trend; the 65-seed root treatment was only significantly greater than the 85-seed root treatment for fresh weight at two of the comparisons presented in Table 2. A linear regression testing for correlation between plot seed root weight and slip fresh weight showed negative covariance ($R^2 = 0.201$). The leaf area of slips grown at 65-seed root density was on average 10% and 4% greater than 85 and 45-seed root treatments, respectively, but ANOVA was not significant for any of the comparisons in Table 2. The length for individual slips harvested from propagation beds was on average 3 cm greater for plants from the 45-seed root density treatment. The lowest planting density resulted in significantly longer slips compared to the other treatment groups in both harvests at JCPHC in 2017. Although the treatment groups were largely similar on average for number of nodes and stem diameter, the 65-seed root treatment group was greater on average for both parameters. The same treatment was significantly greater than other treatments for both quality parameter in consecutive harvests at JCPHC in 2017.

Enterprise Budgets

In accordance with partial budget methodology, separate enterprise budgets were developed for costs that were not affected by seed root planting density (Tables 3-4) and combined with those that were (Table 5) to determine the profit from both case studies (Table 6). Separate variable production budgets are presented for the JCPHC (Table 3) and OHREC (Table 4) trial locations.

At OHREC, a larger proportion of the space (62.5%) was dedicated to planted propagation beds (Table 5) and there were no equipment limitations. The variable production costs of the OHREC case study (excluding seed roots and marketing) was \$59.82 per 100 ft^2 (Table 3). Labor costs accounted for a much higher proportion of the total costs at OHREC (Table 3) than at JCPHC (Table 4) and were 65% of the total variable costs. The total production costs, including fixed HT cost and marketing, were \$1347.33 per 100 ft^2 and made up 41% of total annual costs reported in Table 6. Like JCPHC, the net revenue from the various planting densities was highest at 65-seed roots/m^2. However, in contrast to JCPHC, the case study from OHREC produced a profit for the season of \$56.01 per 100 ft^2 (Table 6). It is interesting to note that the normalized seed costs (per 100 ft^2) were higher at OHREC than at JCPHC (Table 6). This is because 62.5% of the dedicated HT space was planted in seed roots compared to 41.7% in the JCPHC case study. At OHREC, seed roots comprised 41% of the total costs and the fixed costs of the HT structure were 4% of the total cost (Table 6).

The production costs of the JCPHC location were \$56.68 100 ft^2 and took place between March and July (Table 4). Amongst the three categories of variable production costs shown in Table 4 (labor, machinery, and materials), labor was the highest and accounted for nearly 50% of the production costs, excluding seed roots. The total production costs, including the HT structure and marketing costs, was \$97.52 per 100 ft^2. The combined fixed cost of the HT and marketing was 42% percent of the total annual costs (Table 4). At JCPHC, the net revenue was greatest at the 65-seed roots/m^2 planting density (Table 5). The gross revenue for assumed slip yields per

100 ft^2 at each of the three planting densities ranged from $145.92 to $211.40 (Table 5). Due to the high cost of planting material, the medium density of 65-roots/m^2 provided 6% greater revenue than the highest seed root treatment 85-roots/m^2 and 27% greater revenue than the lowest at 45-roots/m^2. The planted bed space in the case study comprised of 500 ft^2 out of the 1200 ft^2 of dedicated space in the HT, which means that 58.3% of the dedicated space was lost in walkways and room needed for mechanical planting equipment. Slip yield is based upon combined averaged data from the two locations and is scaled based on the amount of planted bed space in each system (Table 5).

The values in Table 6 show the production categories with seed root and harvest costs included at the most profitable planting density (65-seed roots/m^2). In this case study, the implementation of slip production in the HT at JCPHC was marginally profitable with profit of $3.99 per 100 ft^2 (Table 6). At $780.87, seed root costs were the highest category at 34 % of the total cost (Table 6). Conversely, the fixed costs of the HT structure were only 5% and marketing was 16% of the total costs (Table 6).

In both case studies, seed roots were the highest annual variable cost and 100% G-1 foundation seed was utilized to build the enterprise budgets. Therefore, a sensitivity analysis was conducted for both case studies to determine how the proportion of foundational seed affected profitability at the three planting densities (Table 7). This analysis included all production costs in addition to seed root, fixed, and marketing costs. The vast difference in foundation seed root costs compared to the cost of saving seed roots from the previous year provides a dramatic range in profitability (Table 7). Profit (per 100 feet^2) ranged from -$25.45 to $102.04. Commercial producers growing slips for use on farm will typically only employ 25% foundation seed

(Stoddard et al., 2006). At this rate, the lowest planting density was not profitable, but the medium and higher planting densities provided \$20.21 to \$82.89 in profit per 100 feet^2.

Discussion

The overall objective of this report was to investigate the economic feasibility of sweetpotato slip propagation in a HT production system as well as to identify the optimum seed root planting density in regards to slip yield, quality and profitability The positive results of high tunnel production, such as added income from greater yield and quality, generally begin to accumulate by year 1 or 2 (Blomgren and Frisch, 2007; Sydorovych et al., 2012); however, high tunnel growers must account for upfront production costs associated with the construction and maintenance of the structure (Sydorovych et al., 2013).

One of the challenges to incorporating crop rotation in HTs is competing with the per ft^2 revenue generation and overall profitability of tomato and others. Although it is difficult to quantify numerically, the production value of crop rotation has been cited in numerous studies (Montri and Biernbaum, 2009; Rusch et al., 2013). Tomatoes grown in high tunnels are reported to generate \$3.66 per ft^2 in gross revenue and \$2.31 per ft^2 in profitability. Similarly, bell peppers can generate \$2.30 per ft^2 and \$0.83 per ft^2 in profitability (Buller et al., 2016). In our case studies, the projected gross revenue ranged from \$1.46 per ft^2 at the lowest planting density at JCPHC to \$3.17 per ft^2 at the highest density in the OHREC case study. These values for gross revenue indicate that sweetpotato production is a viable candidate for diversifying crop rotations in HT production systems, comparable to solanaceous crops and higher than bell pepper. The OHREC enterprise budget provided a profit of \$0.56 per ft^2 when using 100% G-1 foundation seed. In the report by Buller et al., (2016), spinach provided a profit of \$0.33, and cucumber \$0.69, suggesting that growers may consider utilizing sweetpotato propagation beds as an alternative to these somewhat lower-value crops when rotating with tomatoes. More importantly, these findings emphasize the importance of seed root costs in the profitability of slip production.

For growers who primarily intend to use slips produced for on farm transplanting, recommended rate of replacement for foundation seed roots is 25% and our results indicate that profitability of slip propagation dramatically improves when using lower proportions of foundation seed. Even at the JCPHC site, which was less profitable than in the OHREC case study, our results showed a profit of \$0.50 per ft^2 at the highest planting density using 100% on-farm produced seed roots, which is comparable to tomato (Buller et al., 2016). In the OHREC case study, profits are projected to range from \$0.27 to \$1.02 per ft^2, which is higher than any crop enterprise budget that has been reported for HT systems. Like many growers that would be entering into production, we chose to purchase 100% G-1 seed roots for our initial planting. This resulted in a significant cost that ranged from 25% to 48% of the total costs. Growers producing slips for on-farm planting may more commonly elect to use 25% of foundation seed and plant remaining propagation beds with seed roots grown on-farm (Stoddard et al., 2006). Guidry et al. (2017) reports that the cost of seed roots makes up approximately 93% of the production budget for open-field propagation beds, which comes out to be \$0.52 per ft2. Clearly, growers that are interested in starting a slip propagation enterprise would need to consider their initial planting material. G-1 slips are commercially-available to growers and could be used to propagate seed roots for the following spring. By purchasing G-1 slips and growing seed roots, a slip propagator could have more control over the size and quality of seed roots, potentially increasing the likelihood of maximum yields.

Regardless of the seed root costs, the case study from OHREC was more profitable than the one at JCPHC. The JCPHC site utilized a more mechanized approach by using a small tractor and attachments common to open-field slip production to preparing soil, laying and covering seed roots, laying plastic mulch and cultivation. This contributed to only a slightly greater cost associated with machinery for this case-study. There were more than 20 additional required hours of labor to produce slips at the OHREC site and cost of labor was 67% more than JCPHC. Although the proportion of total cost that was accounted for by labor was much higher at OHREC, the overall production costs were very similar. It is likely that the difference in profitability was due to the amount of space that could be planted in the HT using the walk-behind tractor and hand tools compared to the mechanized planting system utilized at JCPHC.

The OHREC case study utilized 63% of the of designated production space whereas the JCPHC case study utilized 42% of the dedicated space for slip production. Therefore, our results suggest that developing propagation bed systems for HTs with wider propagation beds and fewer aisles might allow for more efficient use of space and increased profit. In California, slip propagation beds are planted 8 ft wide; although aisles are often 10ft (Stoddard, 2006) which amounts to 44% space planted within the row. Future work with similar systems may be advantageous for HT growers.

The average weight/seed root for all density treatments in all years and locations was 5.5 oz and therefore the enterprise budgets assume each bushel contains 116 seed roots. The seed roots ‘Orleans’ purchased from a commercial nursery (Jones Farm, Bailey, NC) in 2017 weighed 3.1 oz and it is worth noting that seed count per bushel may vary.

The lack of definitive information regarding planting density in commercial open-field production motivated a replicated open-field trial by Barkley et al. (2017a). That study trialed the use of canner seed roots ‘Evangeline’ and ‘Covington’ weighing 3.4 oz and 6.3 oz on average respectively, planted at seven densities based on weight (6.5, 12.9, 19.9, 26.4, 32.8, 39.3, 45.7

lb/m²). The study found a positive correlation between increased planting density and average marketable slip production (Barkley et al., 2017a). In one year of the study, the results showed a significantly greater total slip production at the two highest planting density treatments whereas in the second year, slip yield was more influenced by cultivar (Barkley et al., 2017a). The conclusions from this open-field study demonstrated that slip production would eventually plateau as density increased. In our 2016 trial with 'Beauregard', we observed a similar quadratic relationship between increased seed root density and slip yield, reaching a plateau between the 65 and 85-seed root treatment. During the second harvest, slip yield was generally lower and the relationship between density and slip yield was not as pronounced. In the study by Barkley et al. (2017a), only one harvest was conducted so comparisons cannot be made.

In our 2017 trials, the 'Orleans' seed roots weighed almost the same as the 'Evangeline' seed roots used by Barkley et al. (2017a). However, the average seed root weight/plot used in our study were only comparable to the three lowest treatments from their open-field study. Similar to the lowest treatments used by Barkley et al. (2017a) slip yields increased with increasing density treatments, but 45, 65 and 85-seed root treatments were not significantly different from one another.

In the Barkley et al. (2017a) study which compared the use of no.1 (8.3 oz), jumbo (23 oz), and canners (6.3 oz) as seed roots, there were no significant effects on the production of marketable slips when it was harvested one time. Although previous research has demonstrated a proximal dominance of seed root sprouting (George et al., 2011), these findings suggest that the number of planted seed roots is not as important as the weight in regards to planting density. In our study, we utilized two different cultivars due to unexpected flooding that occurred in 2016. The 'Beauregard' seed roots utilized in 2016 were 149% larger than the 'Orleans' seed roots that were used in 2017. Therefore, it is difficult to predict if the dramatic difference in yield was an effect of variety or seed root size.

This study also assessed the relationship between planting density and physical slip characteristics, like those defined as quality parameters by Barkley et al. (2017a), e.g. fresh weight, nodes, stem diameter and slip length, in addition to leaf area and dry weight. Although the results were inconsistent, the lower densities exhibited greater quality attributes on average. However, like the results of Barkley et al. (2017a) they were rarely significant. Barkley et al. (2017a) also revealed a negative correlation between increasing planting density and average slip fresh weight for ‘Covington’ and ‘Evangeline’ ($R^2 = 0.98$ and 0.96, respectively). We found that the fresh weight of slips grown from the lower planting densities were significantly greater than highest density in only two of the six comparisons. Future studies should evaluate how slips grown at different planting densities produce when transplanted to the field for storage root production.

Like our study, Barkley et al. (2017a) included an economic analysis to evaluate corresponding cost and revenue for various seed root planting densities. There were stark differences in the report compared to this one and the cost of G-2 seed roots was estimated to be $7 per 50 lb bushel compared to $30 for 40 lb bushel of organic G-1 seed roots utilized in this study. Furthermore, the enterprise budget in Barkley et al. (2017a) projected an expected revenue of $40 per 1000 slips produced, which is only 31% of the $140 per 1000 slips that we estimated. They concluded that increased planting density was positively correlated with increased profit up to the second highest density treatment. The same overall effect was demonstrated in the enterprise budgets reported here and the optimum planting density was found to be 65-seed roots per m^2. This finding was influenced by the high cost of G-1 seed roots and our sensitivity analysis showed that slightly higher profitability was found at the highest planting density when 25% G-1 seed roots were utilized. Growers should consider that there are many factors which determine the appropriate density for optimal economic benefit including: plant quality, cultivar, seed root costs, and the market value of slips.

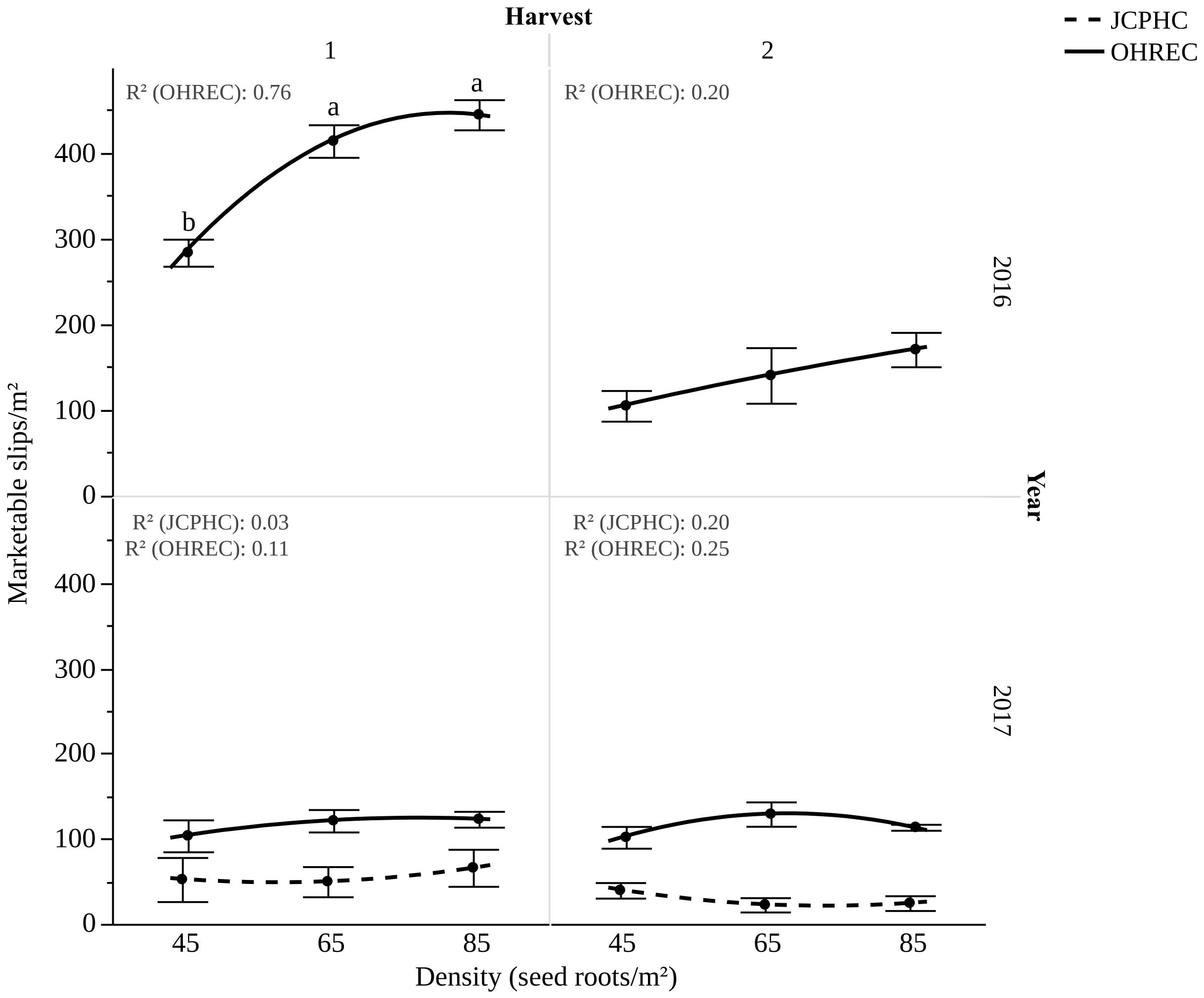
Future studies that investigate the use of sweetpotato slip propagation in HT crop rotations should also consider the negative impacts that may occur. In our 2016 trials at OHREC, the seed roots were not fully removed and attracted rodents that were detrimental to winter crops. More importantly, several studies have shown that all sweetpotato plant parts and residues are allelopathic to future crops. Allelopathy can interfere with the germination and establishment of successive cash crops (Reinhardt et al., 1992). Some extension publications also claim that sweetpotato plant residues prevent nodulation in nitrogen fixing legume crops (Peoples et al., 2009). Due to the crop rotation(s) employed in our studies, we were not able to assess the allelopathic characteristics of this highly-valuable crop.

Conclusion

The results of this study suggest that sweetpotato slip production could be a highly profitable crop rotation option for growers that wish to diversify their HT production systems. However, we found that the cost of seed roots can be prohibitive and should be carefully considered when developing enterprise budgets. To our knowledge, this is the first report of an enterprise budget for sweetpotato slip production in HTs. Furthermore, we found that increasing planting density in HTs may not always correspond with increasing slip yields. The economic analysis conducted in this study reinforces that seed root costs can be the greatest input cost for production which has been shown in the open-field. Moreover, the study illustrates how seed root costs can influence the profitability of slips grown at various planting densities. To our knowledge, this is the first report addressing optimal seed root density in regards to yield, quality, and profitability for HT production.

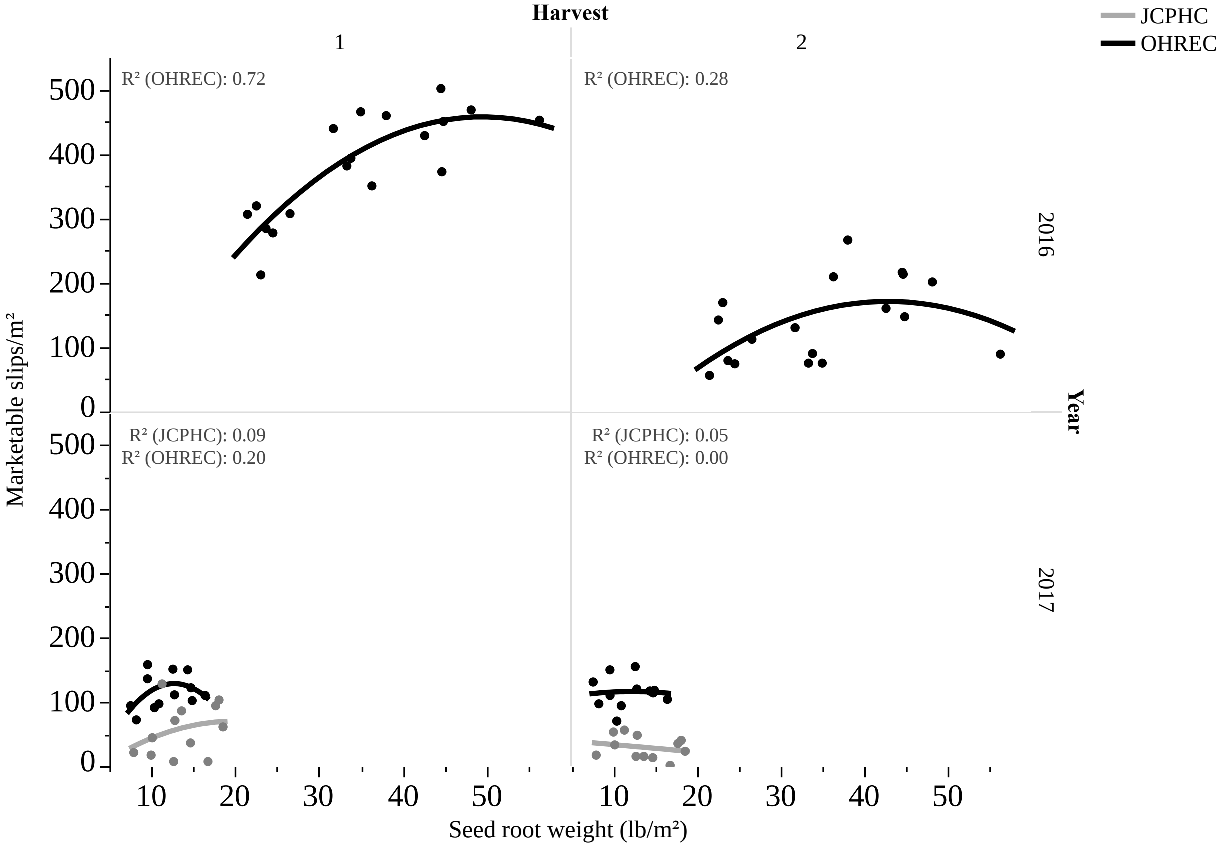
The results of this study provide data that could be valuable to growers as they consider adopting HT production systems. HT production of sweetpotato slips in the Central and Northern growing regions of the United States may permit sufficient season extension for regional farmers to produce their own slips for on-farm storage root production or off-farm sale to other regional growers. This would give producers greater control of their planting schedule(s) without compromising slip yield, quality, or transplant performance. Small-acreage sweetpotato growers may consider dedicating a small portion of their HT to produce the slips they need for on-farm storage root production. Alternatively, a grower could dedicate an entire tunnel to slip production and distribute those slips regionally, providing an alternative source of revenue with a high-value crop. Furthermore, HT slip production may support improved local access to planting materials while facilitating greater crop diversity in the HT. Clearly, further economic analysis of slip production systems, regional foundation plant production systems, and appropriate marketing strategies will be critical to determining the sustainability of HT sweetpotato nurseries.

Figure 3-1 The influence of planting density (by number of seed roots) on marketable slip production for propagation beds grown in HT systems in Haysville, KS and Olathe, KS in 2016 and 2017.



Different letters between density groups indicate a statistically significant difference in mean slip yield based on Tukey's HSD at $P \leq 0.05$. Quadratic lines without letters are not significant. The seed roots in 2016 trial were 'Beauregard' and in 2017 'Orleans'. OHREC 2016 1st harvest yield: $y = 284.2 + 180.2x - 49.83x^2$. OHREC 2016 2nd harvest yield: $y = 105.3 + 38.17x - 2.667x^2$. JCPHC 2017 1st harvest yield: $y = 52.5 - 11.87x + 9.375x^2$. JCPHC 2017 2nd harvest yield: $y = 39.75 - 26.5x + 9.5x^2$. OHREC 2017 1st harvest yield: $y = 103.8 + 25.75x - 8x^2$. OHREC 2017 2nd harvest yield: $y = 102 + 48.63x - 21.38x^2$.

Figure 3-2 The influence of planting density (by weight of seed roots) on marketable slip production for propagation beds grown in HT systems in Haysville, KS and Olathe, KS in 2016 and 2017.



Data points are for weight per plot and correspond to one of the three density treatments by seed root number (45, 65, or 85-seed roots/m^2). The seed roots in 2016 trial were ‘Beauregard’ and in 2017 ‘Orleans’. In 2016 the average 45, 65, and 85-seed root plot weighed 23.6, 34.7, and 46.9 lb/m^2 respectively. In 2017 the average 45, 65, and 85-seed root plot weighed 9.4, 12.7, and 16.2 lb/m^2 respectively. OHREC 2016 1st harvest yield: $y = -147.4 + 24.42x – 0.2466x^2$. OHREC 2016 2nd harvest yield: $y = -194.9 + 17.08x – 0.1995x^2$. JCPHC 2017 1st harvest yield: $y = -37.46 + 10.79x + 0.2714x^2$. JCPHC 2017 2nd harvest yield: $y = 44.85 – 1.145x – 0.000576x^2$. OHREC 2017 1st harvest yield: $y = -108.4 + 37.25x – 1.464x^2$. OHREC 2017 2nd harvest yield: $y = 95.17 + 3.425x – 0.1402x^2$.

Table 3-1 Effects of planting density on marketable slip yield, biomass production, and percent marketability by weight for propagation beds grown in Haysville, KS and Olathe, KS in 2016 and 2017.

	Marketable plot yield			Total plot yield		Marketable
Treatment[z]	Slips (plants/m^2)	Fresh wt. (g/m^2)	Dry wt. (g/m^2)	Fresh wt. (g/m^2)	Dry wt. (g/m^2)	(% by wt)
			2016 OHREC 1st Harvest[y]			
45	284.2 b[v]	3358 b	262 b	3961 b	304 b	84.7
65	414.5 a	5048 a	434 a	5912 a	493 a	85.3
85	445.2 a	5312 a	431 a	6047 a	479 ab	87.7
P value[x]	**<0.001**	**<0.001**	**<0.05**	**<0.001**	**<0.05**	NS
			2016 OHREC 2nd Harvest			
45	105.3	898	74	1727	142 b	50.2
65	140.8	1348	94	2635	177 ab	49.5
85	171.0	1507	111	2713	196 a	54.1
P value	NS	NS	NS	NS[w]	**<0.01**	NS
			2017 OHREC 1st Harvest			
45	103.8	1732	141	2040	160	84.4
65	121.5	1947	166	2400	203	81.4
85	123.3	1875	156	2275	184	82.7
P value	NS	NS	NS	NS	NS	NS
			2017 OHREC 2nd Harvest			
45	102.0	1695	118	2153	161	76.5
65	129.3	2063	152	2535	188	80.9
85	113.8	1803	137	2185	171	82.3
P value	NS	NS	NS	NS	NS	NS
			2017 JCPHC 1st Harvest			
45	52.5	1243	126	1438	149	78.9
65	50.0	893	91	1065	111	78.4
85	66.3	1263	128	1561	160	80.7
P value	NS	NS	NS	NS	NS	NS
			2017 JCPHC 2nd Harvest			
45	39.8	732	69	945	86	78.8 a
65	22.8	420	40	598	52	67.9 ab
85	24.8	370	38	690	7	46.3 b
P value	NS	NS	NS	NS	NS	NS

[z] The experimental design was a randomized complete block design (RCBD) with at least four replications; fixed treatment effect included the use of three planting density treatments (45, 65, and 85-seed roots/m^2). Each plot harvest consisted of 1.0 m^2 sweetpotato propagation bed planted at one of the three densities. Slips were harvested once canopy reached ~30 cm, taken from May to July.

[y] Data is separated by year, location and harvest for every slip yield main effect because interactions were observed between the treatment (planting density) and random effect (year, location, and harvest).
[x] Analysis of variance (ANOVA) to determine which factors and interactions between factors affected the main total and marketable yield, total yield and marketability (percent by wt), data from the entire production season was used for this analysis.
[w] NS indicates non-significant (α=0.05).
[v] Values representing the means separated within a column within a year, location, and harvest marked with the same letter do not differ (α=0.05), Tukey's HSD procedure.

Table 3-2 Effects of seed root planting density (by number) on individual slip quality for propagation beds grown in Haysville, KS and Olathe, KS in 2016 and 2017.

	Slip Quality[u]					
Treatment[z]	Fresh wt (mg/cm)	Dry wt (mg/cm)	Leaf area (cm^2/cm)	Nodes (#/cm)	Stem diameter (mm/cm)	Slip Length (cm)
			2016 OHREC 1st Harvest[y]			
45	503.3	42.9	6.0	0.38	0.16	26.0
65	505.0	39.3	5.3	0.34	0.16	30.5
85	393.3	42.0	5.5	0.33	0.16	29.1
P value[x]	NS	NS	NS	NS	NS[w]	NS
			2016 OHREC 2nd Harvest			
45	491.7 a[v]	33.6	6.2	0.34	0.16	22.8
65	475.0 a	33.7	5.9	0.32	0.16	23.4
85	338.3 b	28.7	5.0	0.30	0.16	23.8
P value	**<0.01**	NS	NS	NS	NS	NS
			2017 OHREC 1st Harvest			
45	487.5 b	49.7	7.6	0.27	0.14	38.0
65	687.5 a	47.2	6.8	0.27	0.14	38.6
85	432.5 b	50.1	7.2	0.25	0.14	36.2
P value	**<0.001**	NS	NS	NS	NS	NS
			2017 OHREC 2nd Harvest			
45	465.0	34.8	6.1	0.24	0.11	42.8
65	415.0	37.5	6.5	0.24	0.13	36.8
85	425.0	36.1	6.2	0.25	0.13	37.1
P value	NS	NS	NS	NS	NS	NS
			2017 JCPHC 1st Harvest			
45	632.5	74.9	9.5	0.34 b	0.15 b	40.1 a
65	712.5	79.0	11.1	0.45 a	0.24 a	22.5 b
85	562.5	66.8	8.4	0.32 b	0.15 b	35.8 a
P value	NS	NS	NS	**<0.05**	**<0.05**	**<0.05**
			2017 JCPHC 2nd Harvest			
45	672.5	63.7 b	8.8	0.32 b	0.14 b	41.7 a
65	545.0	73.1 ab	10.9	0.39 ab	0.18 ab	29.8 ab
85	485.0	82.6 a	10.1	0.44 a	0.20 a	24.9 b
P value	NS	**<0.05**	NS	**<0.01**	**<0.01**	**<0.05**

[z] The experimental design was a randomized complete block design (RCBD) with at least four replications; fixed treatment effect included the use of three planting density treatments (45, 65, and 85-seed roots/m^2). Each plot harvest consisted of 1.0 m^2 sweetpotato propagation bed planted at one of the three densities. Slips were harvested once canopy reached ~30 cm, taken from May to July.

[y] Data is separated by year, location and harvest for every slip yield main effect because interactions were observed between the treatment (planting density) and random effect (year, location, and harvest).

[x] Analysis of variance (ANOVA) to determine which factors and interactions between factors affected the main total and marketable yield, total yield and marketability (percent by wt), data from the entire production season was used for this analysis.

[w] NS indicates non-significant (α=0.05).

[v] Values representing the means separated within a column within a year, location, and harvest marked with the same letter do not differ (α=0.05), Tukey's HSD procedure.

[u] All slip quality parameters (fresh and dry wt, nodes, stem diameter and leaf area) are normalized by slip length (cm)

Table 3-3 Estimated annual variable costs to produce organic sweetpotato slips in 1400 ft^2 section of high tunnel growing area in Olathe, KS (harvest and seed cost excluded).

Production operation[z]	Labor ($/plot)[y]	Machinery ($/plot)[x]	Materials ($/plot)	Total ($/plot)	$/100 ft^2
March					
Receive seed roots	3.50	1.70	0.00	5.20	0.37
Presprout seed roots (4 weeks)	52.44	0.00	0.00	52.44	3.75
Space Heater - 1,500 W (85°F)	0.00	105.84	18.32	124.16	8.87
Humidifier - 177 W (85% RH)	0.00	12.49	16.67	29.16	2.08
Total March costs	55.94	120.03	34.98	210.95	15.07
April					
Rototill bedding rows	10.49	2.10	0.00	12.59	0.90
Assemble drip irrigation	34.96	0.00	30.36	65.31	4.67
Preplant irrigation (2 h)	5.82	0.72	0.00	6.54	0.47
Load and transport seed roots	10.49	5.09	0.00	15.58	1.11
Plant seed roots	26.22	1.20	0.00	27.42	1.96
Cover seed roots	17.48	2.52	0.00	20.00	1.43
Lay Plastic	58.26	0.00	0.00	58.26	4.16
6 mil. sheeting (10' x 100') - 1.5 rolls @ $54.98	0.00	0.00	82.47	82.47	5.89
Inter-row cultivation (0.25 h/week)	17.48	0.00	0.00	17.48	1.25
Total April costs	181.19	11.63	112.83	305.64	21.83
May					
Make vents in plastic	4.37	0.00	0.00	4.37	0.31
Remove and dispose plastic	24.46	0.67	0.00	25.13	1.79
Drip irrigation (2.5 h/week)	29.13	4.32	0.00	33.45	2.39
Inter-row and in-row cultivation (0.75 h/week)	52.44	0.00	0.00	52.44	3.75
Pest scouting (15 min/week)	17.48	0.00	0.00	17.48	1.25
Total May costs	127.88	4.99	0.00	132.87	9.49
June					
(1st harvest)					
Drip Irrigation (2.5 h/week)	7.28	0.90	0.00	8.18	0.58
Inter-row and in-row cultivation (0.75 h/week)	52.44	0.00	0.00	52.44	3.75
Pest scouting (30 min/week)	17.48	0.00	0.00	17.48	1.25
Total June costs	77.20	0.90	0.00	78.10	5.58
July					
(2nd harvest)					
Postharvest cleaning and disposal	99.59	10.30	0.00	109.88	7.85
Total July costs	99.59	10.30	0.00	109.88	7.85
Production costs (harvest and seed roots not included)	541.79	147.84	147.81	837.44	59.82
HT fixed cost - 1400 ft^2 x 2.5 months @ $0.04/ft^2				140.00	10.00
Marketing costs – 3 months @ $123.33/month				369.99	26.43
Total				1347.43	96.25

[z] Includes all activities between March-July, excluding harvest and packaging

[y] Labor cost $17.88/hr per adverse wage rate by U.S. Dept. of Labor

[x] The variable costs for machinery, e.g. tractors, irrigation/water pump and other self-propelled tools, includes the costs of fuel, lubrication, and repair.

Table 3-4 Estimated annual variable costs to produce organic sweetpotato slips in 1200ft^2 section of high tunnel growing area in Haysville, KS (harvest and seed cost excluded).

Production operation[z]	Labor ($/plot)[y]	Machinery ($/plot)[x]	Materials ($/plot)	Total ($/plot)	$/100 ft^2
March					
Receive seed roots	3.50	1.70	0.00	5.20	0.43
Presprout seed roots (4 weeks)	52.44	0.00	0.00	52.44	4.37
Space Heater - 1,500 W (85°F)	0.00	105.84	18.32	124.16	10.35
Humidifier - 177 W (85% RH)	0.00	12.49	16.67	29.16	2.43
Total March costs	55.94	120.03	34.98	210.95	17.58
April					
Disc bedding rows	10.49	3.41	0.00	13.89	1.16
Assemble overhead irrigation	17.48	0.00	119.99	137.47	11.46
Preplant irrigation (2 h)	5.82	0.63	0.00	6.45	0.54
Load and transport seed roots	20.97	6.81	0.00	27.78	2.32
Plant seed roots w/ hopper	17.48	3.41	0.00	20.88	1.74
Cover seed roots w/ bed shaper	10.49	3.41	0.00	13.89	1.16
Lay Plastic	15.73	5.11	0.00	20.84	1.74
2 mil mulch (8' x 4000') - 0.05 rolls @ $198.00	0.00	0.00	9.93	9.93	0.83
Inter-row cultivation (0.25 h/week)	20.97	6.81	0.00	27.78	2.32
Total April costs	119.43	29.57	129.91	278.92	23.24
May					
Make vents in plastic	4.37	0.00	0.00	4.37	0.36
Remove and dispose plastic	24.46	0.67	0.00	25.13	2.09
Overhead irrigation (2.5 h/week)	17.48	3.78	0.00	21.26	1.77
Inter-row and in-row cultivation (0.25 h/week)	20.97	6.81	0.00	27.78	2.32
Pest scouting (15 min/week)	17.48	0.00	0.00	17.48	1.46
Total May costs	84.77	11.26	0.00	96.02	8.00
June					
(1st harvest)					
Overhead irrigation (2.5 h/week)	17.48	3.78	0.00	21.26	1.77
Inter-row and in-row cultivation (0.25 h/week)	20.97	6.81	0.00	27.78	2.32
Pest scouting (30 min/week)	17.48	0.00	0.00	17.48	1.46
Total June costs	55.93	10.59	0.00	66.52	5.54
July					
(2nd harvest)					
Destroy seed roots (disk twice)	20.97	6.81	0.00	27.78	2.32
Total July costs	20.97	6.81	0.00	27.78	2.32
Production costs (harvest and seed roots not included)	337.04	178.26	164.90	680.20	56.68
HT fixed cost - 1200 ft^2 x 2.5 months @ $0.04/ft^2				120.00	10.00
Marketing costs – 3 months @ $123.33/month				369.99	30.83
Total				1170.19	97.52

[z] Includes all activities between March-July, excluding harvest and packaging

[y] Labor cost $17.88/hr per adverse wage rate by U.S. Dept. of Labor

[x] The variable costs for machinery, e.g. tractors, irrigation/water pump and other self-propelled tools, includes the costs of fuel and repair.

Table 3-5 Seed and harvest cost compared with projected slip revenue for HT organic sweetpotato propagation beds (normalized per 100 ft^2) planted at three densities and grown in Haysville, KS and Olathe, KS.

	Planting density (seed roots/m^2)		
OHREC (48 in row centers)[z]	45	65	85
Bushels[y]	2.3	3.3	4.3
Seed root cost ($)[x]	67.57	97.61	127.64
1st harvest slip yield	1052	1452	1567
Cost of 1st harvest and pack	21.02	29.02	31.32
2nd harvest slip yield	512	630	697
Cost of 2nd harvest and pack	10.22	12.58	13.94
Gross slip revenue[w]	218.87	291.46	317.10
Seed root and harvest cost	98.81	139.20	172.90
Net revenue[v]	120.06	152.26	144.20
JCPHC (72 in row centers)			
Bushels	1.5	2.2	2.8
Seed root cost ($)	45.05	65.07	85.09
1st harvest yield (slips/plot)	701	968	1045
Cost of 1st harvest and pack	14.01	19.35	20.88
2nd harvest yield (slips/plot)	341	420	465
Cost of 2nd harvest and pack	6.81	8.39	9.29
Gross slip revenue	145.92	194.31	211.40
Seed root and harvest cost	65.87	92.80	115.26
Net revenue	80.04	101.50	96.14

[z] OHREC beds are planted on 48 in row centers with 30 in of planted row and 18 in of aisle (62.5 per 100 ft^2 planted) JCPHC beds are planted on 72 in row centers with 30 in of planted row and 42 in of aisle (41.7 ft^2 per 100 ft^2 planted)

[y] 1 40-lb bushel = 116 seed roots

[x] Organic G-1 seed root cost = $30/bushel.

[w] 1 box of slips costs $140/1000slips; marketable slips are longer than 5 inches (12.7 cm).

[v] Net revenue = gross slip revenue less total seed root, harvest and pack cost. Net revenue/100 ft^2 is based on 1200 ft^2 HT production area at JCPHC and 1400ft^2 at the OHREC.

Table 3-6 Total production costs at optimal planting density and projected slip revenue for HT organic sweetpotato propagation beds grown in Haysville, KS and Olathe, KS in 2017.

OHREC	Labor (\$/plot)	Machinery (\$/plot)	Materials (\$/plot)	Total (\$/plot)	\$/100ft^2
Seed root cost			1366.52	1366.52	97.61
Production costs - 100 days	541.79	147.84	147.81	837.44	59.82
Harvest and pack costs	509.47		72.86	582.33	41.60
HT fixed cost - 2.5 months				140.00	10.00
Marketing costs - 3 months				369.99	26.43
Total cost				3296.28	235.45
Projected gross revenue				4080.43	291.46
Profit				784.14	56.01

JCPHC	Labor (\$/plot)	Machinery (\$/plot)	Materials (\$/plot)	Total (\$/plot)	\$/100ft^2
Seed root cost			780.87	780.87	65.07
Production costs - 100 days	337.04	178.26	164.90	680.20	56.68
Harvest and pack costs	291.13		41.64	332.76	27.73
HT fixed cost - 2.5 months				120.00	10.00
Marketing costs - 3 months				369.99	30.83
Total costs				2283.81	190.32
Projected gross revenue				2331.67	194.31
Profit				47.86	3.99

[z] 500ft^2 planted/1200 ft^2 HT production area at JCPHC and 875ft^2/1400ft^2 at the OHREC, values/100ft^2 are based on the total HT production area.

[y] Includes all activities between March-July,

[x] Labor cost \$17.88/hr per adverse wage rate by U.S. Dept. of Labor

[w] The variable costs for machinery, e.g. tractors, irrigation/water pump and other self-propelled tools, includes the costs of fuel, lubrication, and repair.

Table 3-7 Normalized (per 100 ft^2) seed root costs and total slip sales profit (including all production, HT fixed costs, marketing, harvest, and packaging costs) at four proportions of G1 foundation seed roots for organic sweetpotato slips

		Planting density					
		45 seed roots/m^2		65 seed roots/m^2		85 seed roots/m^2	
OHREC[w]	Percent (%) Foundation Seed Roots[y]	Seed Root Cost ($)[z]	Profit ($)[x]	Seed Root Cost ($)	Profit ($)	Seed Root Cost ($)	Profit ($)
	100	67.57	23.82	97.61	56.01	127.64	47.96
	75	57.44	33.95	82.97	70.65	108.50	67.10
	50	47.30	44.09	68.33	85.29	89.35	86.25
	25	37.17	54.23	53.68	99.93	70.20	105.40
	0	27.03	64.36	39.04	114.58	51.06	124.54
JCPHC							
	100	45.05	-17.47	65.07	3.99	85.09	-1.38
	75	38.29	-10.72	55.31	13.75	72.33	11.38
	50	31.53	-3.96	45.55	23.51	59.57	24.15
	25	24.78	2.80	35.79	33.27	46.80	36.91
	0	18.02	9.56	26.03	43.03	34.04	49.68

[z] 1 40-lb bushel = 116 seed roots/bushel,

[y] Organic Foundation G-1 seed root cost = $30/bushel, seed root produced on farm = $12/bushel

[x] 1 box of slips valued at $140/1000 slips; marketable slips are longer than 5 inches (12.7 cm). Profit = gross revenue minus all production, fixed, marketing, seed root, harvest and packaging cost/100 ft^2 planted (all other production costs excluded).

[w] JCPHC site were planted on 72 in row centers (30 in planted and 21 in aisles) and planted 500ft^2/1200ft^2 of HT production area. OHREC propagation beds were planted on 48 in row centers (30 in planted and 18 in aisles) and planted 875ft^2/1400ft^2 of HT production area. Normalization per 100ft^2 is based off the total HT production area.

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