ABSTRACT

THOMPSON, WILLIAM BRADFRED. Sweetpotato Transplant Considerations to Optimize Root Set, Yield, and Plant Stand of Sweetpotato. (Under the direction of Dr. Jonathan R. Schultheis and Dr. David W. Monks).

Sweetpotato (*Ipomea batatas*) is one of the most important crops grown in North Carolina. The variety 'Covington' is the most commonly grown cultivar in North Carolina and is a very economically important cultivar for growers within the state. 'Covington' transplants can be inconsistent in size within a sweetpotato bed. In order to produce a quality crop of sweetpotatoes, a quality transplant is needed. Certain practices were investigated to help define a quality transplant. Two experiments were conducted. One evaluated holding time durations, the other transplant size and transplant depth. The goal of these experiments that were conducted were to determine the optimal holding time, plant size, and planting depth of sweetpotato transplants to achieve maximum root set, yield, and plant stand. The use of irrigation was also explored to determine if water availability benefited additional root set and plant survival among transplants that had been held for certain durations of time or transplants that were of different sizes and planted at different depths.

The first test of the transplant holding study were conducted in 2010 and 2011 at an on farm location in Bailey, NC and at a research station located in Kinston, NC. Subsequent studies included an irrigation treatment. These studies were conducted at the Horticulture Crops Research Station in Clinton, NC. The data that are represented were taken from each location for yields (MT ha^{-1}) as well as plant stand. Data from 2012 and 2013 are combined and the interaction effects of irrigation and transplant holding on yields and plant stand were determined. The holding durations that were investigated included holding plants 7 days

before planting (DBP), 5 DBP, 3 DBP, 1 DBP, and Day of planting (DOP). The results indicate that transplants held for 1 DBP and up to 3 DBP consistently had higher yields and plant stands than transplants held up to 7 DBP. The results also indicate that available soil moisture can minimize the differences among holding treatments as locations that had relatively high soil moisture during the establishment phase of growth had few differences among yields and plants stands among the different holding durations. However, when moisture was limited, the holding of transplants longer (> 3 DBP) proved to be detrimental to plant stand and overall yields. The use of irrigation proved to be a non factor among the holding treatments when relatively high soil moisture levels were present at planting. Even with the use of irrigation, yields were only influenced by holding treatment with transplants held for 7 DBP producing the lowest yield compared to the other holding treatments.

The study of which evaluated transplant size and planting depth was completed in 2013 at the Horticulture Crops Research Station in Clinton, NC. The data that are represented is from the three years this study was conducted in 2011, 2012, and 2013. The transplant holding sizes that were utilized included 9.5 cm, 15.9 cm, 21.6 cm, and 27.2 cm. The two planting depths were 5.1 cm and 15.2 cm. Irrigation was also applied to determine any interactions among plant size and planting depth with available soil moisture. Results from all years indicated that transplants ≥ 15.9cm and planted 15.2 cm deep provided the most consistent root set and plant stand when compared to the smallest treatment of 9.5 cm regardless if irrigation applied.

Sweetpotato Transplant Establishment Considerations for Sweetpotato Production in North Carolina

by
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For:

Melody, Bethany, Caitlyn, and Corbin

BIOGRAPHY

William Bradfred Thompson was born on May 12, 1980 to Bruce and Linda Thompson. Brad grew up in a small community called Windblow where his father worked at the Sandhills Research Station and his mother stayed at home for a number of years before going back to school to complete her degree in teaching and became a 5th grade teacher. Brad's family also farmed tobacco, sweetpotatoes, and other various vegetable crops. Brad's interest in agriculture, especially horticulture crops, began at an early age as he helped his family on the family farm, though it was not an avenue that he considered doing his entire life nor wanted to study in school.

Brad's interest in weather brought him to North Carolina State University where he majored in Meteorology in 2003. During his undergraduate studies, Brad had the privilege to work with Dr. Denny Werner in Horticulture Science as a work study student. This experience reopened the door into horticulture that Brad had tried to close when coming to North Carolina State University. However, the connections that had been made over the years between his father and the researchers within the department made the work study job feel less like a job and more like working with family. Upon graduating in 2003 with a B.S. in Meteorology, a Research Technician position opened up within the Department of Horticultural Science under the direction of Dr. Jonathan Schultheis. Brad applied for this position and began working full time for Dr. Schultheis on June 1, 2003. Brad has been employed in the department for 11 years since graduating. After many years of thinking about what do next, Brad decided to begin working on a Master of Science degree in Horticultural Science. Brad's Master research focuses on transplant establishment of sweetpotato utilizing plant size and planting depths as well as holding durations to determine yield and plant survival effects. After graduating with his Master's Degree, Brad plans on continuing to work with Dr. Jonathan Schultheis and the cultural management research that is being conducted on various vegetable crops.

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CHAPTER 1

CHAPTER I. ‘COVINGTON’ SWEETPOTATO YIELD AND ROOT QUALITY RESPONSE TO VARIOUS TRANSPLANT SIZES AND PLANTING DEPTHS.

W. Bradfred Thompson, Jonathan R. Schultheis, David W. Monks, Katie M. Jennings, and Garry L. Grabow.

The influence of transplant size and planting depth on the sweetpotato, *Ipomea batatas* (L.) Lam., variety ‘Covington’ has not been fully researched. Sweetpotato is a very important staple crop for North Carolina as well as the United States as there were 23,000 hectares planted in 2013 in North Carolina and a total of 48,000 hectares in the United States in 2013. The key to a quality crop of sweetpotatoes begins with quality transplants. The main objectives of this study are to determine how plant size affects root yield and plant survival; determine how planting depth affects root and crop development; and determine how soil moisture at planting impacts plant stand and storage root set. The study was conducted in 2011, 2012, and 2013. The plant sizes that were studied were 7.6-11.4 cm, 14.0-17.8 cm, 20.3-22.9 cm, and 24.1-30.5 cm. Two planting depths (5.1 cm and 15.2 cm) were evaluated for each plant size and in 2012 and 2013, 2 irrigation components were added (irrigated and non-irrigated). Plant sizes ranging from 20.3-30.5 cm planted at 15.2 cm planting depth produced the most storage roots per hill, had the highest overall storage root production per plot, and the best plant survival over both irrigation treatments. The use of plants smaller than 14.0 cm or planting at a depth of 5.1 cm resulted in reduced root numbers, root set per hill, and plant stands. Irrigation applied at planting was beneficial for plant survival and storage root set per plant except for plant sizes ranging from 7.6-11.4 cm planted 15.2 cm deep. The use of irrigation had an overall positive impact on yields except when abundant moisture was readily available. When moisture is readily available, yields nor plant stands were not impacted by the application of irrigation.

Introduction

Sweetpotato transplant size and planting depth in production fields are important considerations because sweetpotatoes are vegetatively propagated by using cuttings or slips for commercial production. Size of sweetpotato transplants can vary considerably in sweetpotato propagation beds (A. Thornton, Extension Associate, Department of Horticultural Science, NC State University, personal communication). Size of transplants can impact yield and quality of sweetpotato storage roots, with most growers transplanting 25 to 36 cm long transplants to production fields (Barkley et al., 2013). Certain varieties of sweetpotato such as 'Beauregard', 'Evangeline' or 'Orleans' have a growth habit that typically results in uniform transplant sizes as the growing points in these varieties are located near the canopy leaves at the time transplants are cut from propogation beds for planting into production fields. However, the variety 'Covington' is unlike most other commercial varieties as it has a growth habit in which the top canopy leaves are mostly at the same height, but location of growing points can vary from being close to the top of the leaf canopy to several cm below. 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., 2013).   'Covington' is grown on 90% of the sweetpotato hectacreage in North Carolina (North Carolina Crop Improvement, 2014), and farmers in this state grew 46.8 % of the sweetpotato hectareage in the United States in 2012 (NCDA, 2013). When transplants are ready to be cut on the propagation beds for planting into the production fields, they are cut from plant beds by hand or by mechanical plant cutters and then boxed by hand (Smith el al., 2009). Thus,'Covington' transplants often vary in plant size. This variation within plant size can lead to planting difficulties in the field. Extreme variation in plant size can lead to skips as laborers have challenges in handling and placing transplants into the fingers of a transplanter (Figure 1). Another important factor in having variation in plant size is achieving a uniform planting depth of sweetpotato transplants.

Transplant planting depth can vary depending on positioning of the transplant within the fingers on a mechanical transplanter (Figure 1). Laborers follow the mechanical transplanter to replant transplants by hand since laborers on the mechanical transplanter periodically fail to place a good quality plant in the fingers. The planting depth can also affect transplant survival and overall yields due to the number of nodes located beneath the soil surface or lack thereof. Sweetpotato transplants should be set deep, with a portion of the plant above the soil surface but with at least three nodes below the soil surface (Granberry et al., 1986). Other reports have shown that sweetpotato transplants are typically planted at a depth of 7.6 to 10.2 cm and several nodes are placed underground to maximize potential root set (Boudreaux, 2005). Thus, sweetpotato growers have some knowledge about the plant size that should be used to maximize plant stands, but documentation as to the interaction of plant size and planting depth and the resulting storage root quality and yield is limited (Gurnah, 1974). Thus, a study was conducted to determine the effect of transplant size and planting depth with and without irrigation at planting on transplant survivability, storage root set, and yield of 'Covington' sweetpotato.

Materials and Methods

Studies were conducted in 2011, 2012, and 2013 at the Horticulture Crops Research Station, Clinton, NC (Lat: 35° 00' 30.602", Long: -78° 19' 08). All studies were randomized complete block designs with 4 replications. The study was not irrigated in 2011, but in 2012 and 2013 a complete set of transplant size and planting depth treatments were arranged in a randomized complete block design in non-irrigated and irrigated plots. Irrigation plots were placed on opposite sides within the same field with a border area of ten rows between the plantings to ensure no water overspray between irrigation treatments. The planting date in 2011 was 23 June and the harvest date was 24 October (123 days after planting (DAP)). The planting dates in 2012 was 20 and 21 June and the harvest dates were 11-12 October (114 DAP). The planting date in 2013 was 17 June and the harvest date was 18 October (123 DAP). The reason for the day of separation in irrigation and planting in 2012 dealt with irrigating the field prior to planting to achieve optimal soil moisture levels before planting the irrigated section of the study. In 2011, soil moisture levels were ideal for planting as 8 mm rainfall occurred the day before planting and 3 mm rainfall occurred on the day of planting, (Figure 2). In order to mimic the environmental condition in 2011, (Figure 2), overhead irrigation was applied in 2012. To ensure optimal soil moisture levels, the irrigated portion of the field was irrigated before planting could occur. Due to irrigation scheduling issues on the research station, the non-irrigated portion of the field could only be planted on 20 June. On 21 June, irrigation of 13 mm was applied to the irrigated portion of the field using a linear move system. Once the irrigation had been applied, plots were planted within 1.5 hours while soil moisture appeared optimum. Soil for each study was a Norfolk fine sandy loam (fine-loamy, kaolinitic, thermic Typic Kandiudults). All studies were culturally managed according to North Carolina recommendations (Kemble et al., 2013). Fertilizers were applied each year to the studies based on soil test recommendations provided by the North Carolina Department of Agriculture and Consumer Services Agronomic Department; Raleigh, NC. Nitrogen fertilization consisted of 76.2 kg ha^{-1} of ammonium nitrate applied at lay-by. Lay-by refers to a time during the growing season when the sweetpotato vines reach a point where cultivation equipment can no longer cultivate the crop without damaging the plants. The time for lay-by is usually 21 to 30 DAP, depending on growing conditions. Nitrogen was applied on 21 July 2011; 20 July 2012; and 17 July 2013. In addition, 44.8 kg ha^{-1} phosphorus was applied in 2011 and 2012 while 40.3 kg ha^{-1} phosphorus was applied in 2013 before planting occurred. Potash, (K_2O) at 136.6 kg ha^{-1} (2011, 2012) and 170.2 kg ha^{-1} (2013) was also applied preplant and a supplemental application of 100.2 kg ha^{-1} potash was applied at lay-by for each study.

Weed control consisted of two herbicides that are routinely used in commercial sweetpotato production in North Carolina. In 2011 and 2012, clomazone (Command®3ME, HELENA Chemical Company, 225 Schilling Blvd., Suite 300, Collierville, TN 38017) at 0.84 kg ai ha^{-1} was applied preplant on 23 May 2011 and 24 May 2012 and flumioxazin, (Valor®, Valent U.S.A Corporation, P.O. Box 8025, Walnut Creek, CA 94596-8025) at 0.107 kg ai ha^{-1} was applied 7 days before planting on the 16 June 2011 and 18 June 2012. In 2013, again 0.84 kg ai ha^{-1} clomazone plus 0.107 kg ai ha^{-1} flumioxazin was applied on 13 June prior to planting. For insect control, 0.053 kg ai ha^{-1} bifenthrin (Sniper®, Loveland Products, Inc., P.O. Box 1286, Greeley, CO. 80632-1286) was applied in 2011 and 2013 on

28 July 2011 and 8 July 2013. In 2012, 2.2 kg ai ha^{-1} chlorpyrifos (Lorsban®, DOW AgroSciences LLC, 9330 Zionsville Rd., Indianapolis, IN, 46268) was applied pre-plant with clomazone herbicide on 24 May.

Plant size treatments ranged from 7.6 to 11.4 cm (designated as the 9.5 cm size treatment), 14.0 to 17.8 cm (designated as the 15.9 cm size treatment, 20.3 to 22.9 cm (designated as the 21.6 cm size treatment), and 24.1 to 30.5 cm (designated as the 27.2 cm size treatment). Plants were measured from the base of the cut plant to the tip of the growing point. The planting depths of the plants were 5.1 cm and 15.2 cm beneath the soil surface with 5.1 cm representing shallow commercial planting depth and 15.2 being the average planting depth of mechanical transplanters used by growers (A. Thornton, Extension Associate, Department of Horticultural Science, NC State University, personal communication). Transplants were established in the plots with a wooden dowel that was marked at 5.1 cm and 15.2 cm. A stake was attached to the dowel in a manner that allowed for the stake to remain stationary when making the holes; therefore ensuring that the soil depths were exactly 5.1 cm or 15.2 cm. In 2011, there were no difficulties with planting the transplants as the soil was wet from rainfall the previous day that allowed for the planting holes to be made without soil collapsing back into the hole after retracting the dowel. In 2012 and 2013, the soil was drier and it was very difficult to make holes in the non-irrigated portion of the field without the holes falling in before getting the transplants planted. To alleviate this problem, a mechanical transplanter was run over the top of the rows with the transplant water running continuously but no transplants placed in fingers for planting. The transplant water firmed up the soil enough to make the planting holes with out having soil fall back into the hole. This soil firmness allowed for proper planting of the transplants at 5.1 cm or 15.2 cm depending on treatment. Once plants had been established, plant stands were recorded for all treatments two to three weeks after planting. Storage roots were dug with a shovel by hand so that they could be counted by grade on a per hill basis. Storage root yields that were determined included storage root number per plant, total storage root number per plot, and total storage root weight by grade according to the United States Standards for Grades of Sweetpotatoes; U.S. Number 1, canner, jumbo, and culls or misshapen roots (USDA, 2005) per plot.

To determine the statistical significances of independent variables within this experiment, the PROC ANOVA procedure was conducted using SAS 9.3 (SAS Institute Inc.100 SAS Campus Drive; Cary, NC 27513-2414, USA). To evaluate the effects of plant size and irrigation when significant on root number per plot, root number per hill, and stands, the PROC GLM procedure was conducted using SAS 9.3. The results are presented separately for 2011, 2012, and 2013 due to variations in environment among each year.

Results

2011. Plant stands were similar for all transplant size and planting depth treatments (Table 1). When comparing transplants of similar size, US number 1 root numbers within 4.6 m of linear row were consistently higher when transplants were set deeper in the soil than those planted shallow (Table 2). The smallest size plant (9.5 cm) which was only established at the 5.1 cm depth, always had lower production of US number 1 roots than plants, regardless of plant length, transplanted 15.2 cm deep. At 5.1 cm planting depth, number 1 root production did not differ due to transplant size. Jumbo, canner, and cull root production were similar among all planting treatments (Table 2). No difference between planting depth or plant size was observed with respect to total and total marketable yields. However, the longest transplants established at the deepest depth tended to yield more than the shortest plants planted at the shallow depth. When evaluating storage root set on a per hill basis, there was an average of one additional U.S. number 1 root set per hill when plants were set at the deep (15.2 cm) planting depth compared to the shallow (5.1 cm) planting depth (Table 1). However, the number of storage roots produced per hill were similar for the canner, jumbo, and cull grades. Total number of storage roots produced per hill was also similar regardless of the planting depth or plant size treatment. The shallow planting depth by shortest plant size treatment tended to produce fewer roots per hill than the longest plant size by deeper plant depth treatment, which was similar to what occurred on a per plot basis (Table 2).

2012. There were no three way interactions between irrigation, plant depth, and plant size for any of the measured variables (Table 3). U.S. number 1, canner, jumbo, cull total marketable, and total root production within the 4.6 m linear plot row was influenced by planting depth and transplant size as a significant interaction effect occurred among all measured variables (Table 3). In terms of storage root production within the 4.6m linear plot row, U.S. number 1 root production was greater among the plant size treatments that were at least 21.6 cm and planted at the 15.2 cm depth compared to the 5.1 cm depth (Table 4). The smallest transplant (9.5 cm) planted 15.2 cm deep produced fewer U.S. number 1 roots than all other transplant size treatments (Table 4). As with U.S. number 1 roots, deeper planted transplants that were at least 14.0 cm long (15.9 cm treatment) produced more total and total marketable roots per plot than similar size transplants at 5.1 cm depth (Table 4). Total marketable root numbers per linear plot row show that the largest transplants (21.6 and 27.2 cm) planted 15.2 cm deep produced more marketable roots than similar plant size treatments at the shallow planting depth (Table 4). Transplants planted 5.1 cm deep produced the same number of U.S. number 1, total, and total marketable roots regardless of plant size (Table 4). Jumbo root production within the plot was influenced by the interaction of planting depth and transplant size. The smallest transplant planted at the deeper planting depth produced few jumbo roots (1.3) compared to all other transplant size and depth treatments. The transplants that produced the most total roots were the larger transplants (21.6 and 27.2 cm) planted at the deeper planting depth. In most cases, the 21.6 cm size transplants produced the most U.S. number 1, canner, total, and total marketable roots per plot when planted at the 15.2 cm planting depth.

Irrigation influenced the response of U.S. number 1, culls, total, and total marketable root number of roots produced per plot (Table 3). No significant interactions were observed for the irrigation by planting depth for any of the root grades and for total and total marketable number of roots produced per plot. However, there were interactions for irrigation and plant size for U.S. number 1, total, and total marketable roots per plot. Root production for the 4.6 m plot for U.S. number 1, total, and total marketable root number was greatest among the 15.9, 21.6, and 27.2 cm transplant size when irrigation was applied while root production was low with the smallest transplant size (9.5 cm), regardless of whether there was no irrigation or an irrigation treatment was applied (Table 5). The smallest plant size always had the lowest storage root production compared with all other plant sizes for U.S. number 1, total, and total marketable root numbers within the non-irrigated portion of the study (Table 5). The 15.9 and 21.6 cm plant sizes consistently produced the highest storage root numbers within the irrigated portion of the study; however, the 15.9 cm plant size treatment without irrigation produced only marginal root numbers per plot that were slightly greater than root numbers produced by the smallest plant size (9.5 cm). Larger transplants (21.6 and 27.2 cm) produced the most storage roots among treatments that had not been irrigated for total and total marketable root numbers (Table 5).

Irrigation and plant size also influenced the number of jumbo roots produced on a per hill basis (Table 3). Transplants that were 15.9 and 27.2 cm long produced more jumbo roots per hill within the non-irrigated portion of the study when compared to corresponding plant sizes in the irrigated portion of the study (Table 5). All other interactions for each yield or stand variable were not significant (Table 3).

The main effect of planting depth was significant for the canner and total number of roots at the $P = 0.088$ level. Canner production among transplants planted at the deeper planting depth of 15.2 cm increased on average by 10 roots per plot row with the deeper planting depth producing on average 25 canners per plot compared to 15 canner roots per plot for transplants planted at the shallow depth of 5.1 cm (Table 6).

The main effect of plant size had a significant effect on the number of U.S. number 1, jumbo, and total roots produced per plant. U.S. number 1 root production was greatest among transplants that were ≥ 15.9 cm while transplants that were shorter had significantly lower U.S. number 1 root production. This same result occurred for jumbo roots and total roots produced on a per plant basis. For all measured variables compared within the main effect of plant size; the longest transplants consistently produced the most roots across both planting depths (Table 6).

Irrigation influenced the number of U.S. number 1 and jumbo roots produced per hill. The use of irrigation proved to be beneficial to U.S. number 1 production as irrigated plots produced on average 29 U.S. number 1 roots while the non-irrigated plots produced on average only 18 U.S. number 1 roots (Table 6). Jumbo root production per plant however was not positively influenced by irrigation as plants within non-irrigated plots produced on average 0.8 jumbo roots per plant compared to 0.5 jumbo roots per plant for plants within irrigated plots (Table 6).

Percent plant stand was influenced by the main effect of plant size as well as the interaction between planting depth and transplant size and irrigation and transplant size (Table 3). Plant stands were greatest among the largest size transplants planted at the 15.2 cm planting depth (Table 4). The 15.9 cm transplant size had the same percentage stand, regardless of planting depth. The smallest transplant (9.5 cm) had stands comparable to the 15.9 cm size transplant at the 5.1 cm planting depth, but had the lowest plant stand (19.2%)

at the 15.2 cm planting depth (Table 4). Transplants within the 21.6 and 27.2 cm size treatments had statistically lower stands when planted at the shallow planting depth than the corresponding treatments planted at the deeper planting depth (Table 4).

The size of transplants when placed within either an irrigated or non-irrigated setting had percent stands that varied depending upon combination of plant size and irrigation (Table 3). Plant stands were greatest when transplants were larger (>9.5 cm) and irrigated (Table 5). All plant sizes that were irrigated had greater percent stands than the corresponding plant size treatments within the non-irrigated portion of the study. The smallest transplant size (9.5 cm) had the lowest percent plant stands for both irrigated (56.7 %) and non-irrigated (38.3%) settings.

2013. Transplant size had a significant effect on U.S. number 1, canner, jumbo, total, and total marketable root production while planting depth significantly affected U.S. number 1 root production (Table 7). There was no interaction of planting depth and transplant size for any of the root number per plot variables (Table 7). The most influential factor affecting root production was transplant size. Transplants that were in the 15.9 cm or larger size category produced the most roots for U.S. number 1, jumbo, total, and total marketable roots, while the 9.5 cm size transplants consistently produced the lowest number of roots for all these variables (Table 8). Jumbo root production tended to increase as transplant size increased, with the the largest transplant size (27.2 cm) producing more jumbo roots than the smallest transplant size (9.5 cm). The greatest number of canner roots was produced with the 15.9 cm transplant size and the smallest number was produced with the 9.5 cm size transplant.

The interaction of planting depth and transplant size showed significant response among canner and total roots per hill (Table 7). More canner grade roots were produced per hill with the 21.6 cm size transplants when planted 15.2 cm versus 5.1 cm deep (Table 9). Planting depth had no effect on canner root number for the other transplant size treatments. More total roots were produced per hill when transplants were set at the deep than the shallow planting depth with the exception of the 15.9 cm size transplant. Similar to the results in 2011 and 2012, transplants that were planted at the deeper planting depth produced approximately one more root per hill when compared to transplants that were planted at the shallow planting depth (Table 9).

Irrigation was not as influential in 2013 (Table 7) as it was in 2012 (Table 3). U.S. number 1 and canner roots per 4.6 m plot were the only measured variables that were influenced by irrigation (Table 7). The interaction of irrigation and planting depth showed only a response among cull roots per plot and per hill (Table 7). The interaction of irrigation and transplant size showed a response among canner roots produced per plot and total roots produced per hill. The transplants within the 21.6 cm size treatment that were irrigated produced significantly more roots than all other plant size treatments regardless of whether irrigation was applied (data not shown).

Plant stand among treatments was influenced by the main effect of transplant size as well as the interactions of planting size by planting depth and irrigation by planting depth (Table 7). Percent plant stand was the lowest for the smallest transplants size (9.5 cm), planted at the deeper planting depth (15.2 cm) (Table 9). All other transplant sizes and planting depths were similar in regards to plant stand. The role of irrigation on percent plant stand was only significant by its interaction with planting depth. The irrigated treatments at the deeper planting depth had lower percent stands of 79.2% while plant stands for all other combinations (irrigated at shallow planting depth, no irrigation at shallow planting depth, and no irrigation at deep planting depth) ranged from 92 to 93% (Appendix A: Table 1).

Discussion

Based on these studies, transplant size and planting depths are linked to overall sweetpotato storage root set and ultimately transplant survival. Environmental conditions such as precipitation and initial soil moisture have also been shown to be key components to transplant survival and root set in sweetpotato (Gajanayake et al., 2013). The main challenge of this study was determining why there were common and differing results between growing seasons. Each growing season presented a challenge that every sweetpotato grower faces. In all studies across years, root production and plant stands increased as transplant size increased. The smallest transplant size category ranging from 7.6-11.4 cm (9.5 cm) consistently produced the fewest number of roots per plant except when soil moisture was excessive in 2013 (Figure 3). Transplants that ranged from 21.6 and 27.2 cm in length consistently produced the highest yield and root set which correlates to the results of previous work where transplants that ranged from 20.3 to 30.5 cm produced higher yields and root set (Gurnah, 1974; Schultheis et al., 2008). The larger transplant size produced more roots due to the increase in the number of nodes planted beneath the soil surface. Nodes were counted in this study for the transplants within each plant size treatment and are represented in Table 10. The more nodes that were beneath the soil due to larger plant sizes (21.6 and 27.2 cm) increased the yield potential as each node is a source of adventitious root development and potential storage root formation (Boudreaux, 2005). The relationship between plant size and total storage root set were positive for each year the study was conducted. Since the relationship was positive, use of larger transplant sizes that are not too large as to interfere with the transplant process of planting using a mechanical transplanter should maximize the total root set among plants as well increase plant stand. Plant stand was shown to be influenced by plant size as larger plant sizes had improved stands when compared to the smallest plant size (9.5 cm). Plant stands, excluding planting depth and irrigation treatment, for the smallest plant size treatment averaged 75.8% over all years while plant stands for the remaining treatments of 15.9 cm, 21.6 cm, and 27.2 cm averaged 94.6, 92.9, and 93.8% respectively (Table 8).

The interaction between plant size and planting depth as well as the interaction of irrigation by plant size were the most important factors for overall storage root set and plant stand of sweetpotato in 2012. However, in 2011 and 2013 this was not the case. When moisture was available prior to planting (2011) and constantly available after planting (2013) (Figures 2 and 4), there was less root set response among the plant size treatments regardless of planting depth or irrigation application. The interaction among plant size and planting depth in 2012 demonstrated that transplants planted at the deeper planting depth of 15.2 cm showed a beneficial response for root set and percent stand among the larger plant sizes (≥ 15.9 cm). The only treatment where the deeper planting depth was detrimental to root set and plant stand was for the 9.5 cm plant size. This result reasserts the importance of the number of nodes located beneath the soil surface to plant stand and yield. The larger transplants planted at 15.2 cm beneath the soil surface allowed for the most nodes to be buried resulting in higher storage root sets and plant stands which agrees with previous research (Boudreaux, 2005). Selection of transplant size is an important consideration in order to consistently achieve high plant stands and yields. In this study, 9.5 cm transplants at the 15.2 cm planting depth, resulted in too many environmental and physiological stresses which reduced plant stands and yields. The use of transplants that were too small and planted too deep resulted in stunted transplant growth/slowed development or ultimately killed the plant. These results were consistent all years and highlight the importance selecting an appropriate plant size and planting at the proper planting depth. The smallest transplant size planted at the deeper planting depth had consistently lower storage root sets and plant stands when compared to the same treatment's shallow planting depth treatment. Planting the larger size transplants at the shallow depth of 5.1 cm beneath the soil surface allowed fewer nodes to be buried and total root set was reduced. However, for the 15.9 cm size treatment, root set was comparable among size grades of sweetpotatoes between the planting depths. This observation suggests that the transplants within this treatment were neither too long nor too short for either planting depth. The deeper planting depth allowed for the maximum amount of nodes to be planted without burying the plant and the shallow planting depth also allowed for more than 3 nodes to be planted which allowed for root production and yields to be similar among the planting depths. The importance of planting transplants deeper, especially transplants that range from 15.9 to 27.2 cm, is emphasized in 2012 and 2013. By increasing the planting depth, U.S. number 1 roots per hill are increased on average by one-half root per plant. Total root numbers are increased by one root per plant by planting transplants deeper rather than at the shallow depth. An increase in one U.S. number 1 root for every two plants can lead to yield increases of nearly 4,670 kg per hectare as well as approximately 6,000 roots per hectare, which can lead to substantially more financial return to the producer.

Deeper planting likely provided slips (transplants) with a more stable environment. Soil temperature and volumetric water content nearer the soil surface can be highly variable while those at greater depths are more consistent. (Meyers, 2013). When soil moisture was available from rainfall in 2011 initially, (Figure 2), and the soil was allowed to stay at or near field capacity for about 1 week after planting, no statistical differences were observed among the transplant sizes and planting depths for total yields and percent plant stands. The application of irrigation in 2012 and 2013 was intended to mimic the soil environment that was present in 2011. However, due to various weather patterns between both years, there were differing results. In 2012, the application of irrigation provided a statistical beneficial response for root set among U.S. number 1, total, and total marketable root numbers per plot area as well percent plant stand. The beneficial response of root set was likely due to the environmental conditions being less favorable at the time of planting as measurable rainfall did not occur until 5 days after planting (Figure 2). Root sets among the measured variables among all plant sizes increased by an average of 73.9% for U.S. number 1, 54% for total (U.S. number 1, canner, jumbo, and cull), and 52% for total marketable (U.S. number 1, canner, and jumbo) roots per plot. These results confirms previous research conducted by Lana and Peterson (1956) and Bowers et al. (1956) where they found that yields of sweetpotatoes were increased by irrigation by up to 67%. The primary difference between their studies and this study was that irrigation was applied through out the entire growing season, while the irrigation treatment in this study was only applied during plant establishment. The 2013 study showed that irrigation did not play as much of a role in root set and stand as rainfall was constant through a majority of the plant establishment and root initiation period for sweetpotato that extends approximately 13 days after planting (Villordon et al., 2009) (Figure 3). Due to the excessive rainfall, there was limited response to irrigation treatment with respect to root numbers per plot area or per hill (Table 7). There were differences in canners per plot and total root numbers per hill, that showed that irrigation increased canner root production and slightly increased total roots produced per hill. However, the results were similar among all plant sizes and irrigation treatments. This similar response to irrigation treatment can likely be attributed to the rainfall that occurred during establishment and during the 2013 growing season. Previous research has concluded that excessive irrigation should be avoided because poor soil aeration may cause poor storage root induction and or development (Chua and Kays, 1981). Other research has found that when soil moisture is high the development of the storage roots in sweetpotato is inhibited (Watanabe, 1979). Though this research does not show root development being inhibited by excessive moisture, it does show that using irrigation in a drier year is beneficial, but within a wet year the results were neither beneficial or problematic. Percent stand was influenced by the interaction of irrigation and planting depth in 2013. The interesting result was transplants that were irrigated at the deeper planting depth had the lowest plant stand while transplants that were non-irrigated and planted at the deeper planting depth had higher plant stands. The reasoning behind this result is that a majority of the transplants within the smallest plant size (9.5 cm), once buried at the deeper planting depth were not able to survive due to excessive soil moisture being applied through irrigation before and after planting and then with excessive amounts of rainfall soon after planting. This excessive moisture likely stressed the transplants to the point of suffocation and plant death.

The results of this study show that plant size and planting depth are very important factors to consider when growing sweetpotatoes. Increasing transplant size and increasing planting depth up to 15.2 cm increase storage root numbers per plot, per plant, and improves plant stand. The use of plants smaller than 15.9 cm and planting at depths of 15.2 cm can be detrimental to root set and reduce plant stand causing a reduction in overall yields. Though the yields and stands were not always different among the planting depths and various transplant sizes, these results show that if planting depth is a major challenge to regulate, then by planting larger transplants that range from 15.9-27.2 cm in length, farmers can overcome the stand and root set loss associated with shallow planting depths. Previous studies found that farmers commonly use larger transplants ranging from 25.4-35.6 cm in length for planting. (Schultheis et al., 2008). Studies for other vegetatively propagated crops such as cassava have also found that longer cuttings give better stands and higher yields than shorter ones (Ekandem, 1962; Rodrigues and Sanchez de Bustamante, 1963). The results of this study confirm that longer transplants planted at deeper depth produce greater numbers of roots and have improved plant stands. The use of irrigation can be beneficial for overall yields and improving plants stands, especially if it is very and hot and dry when planting is occurring. The use of irrigation when soil moisture is optimal may not be necessary initially, but to improve yields, the use of any type of irrigation within the root initiation phase of plant establishment or when there are long periods of no rainfall would be beneficial to overall yields. In general, the use of irrigation is left completely to the discretion of the grower as every year, location, and soil type can be different.

The objective of this experiment was to investigate how plant size and planting depth of sweetpotato transplants affects the plants stands, yield, and quality of the variety 'Covington'. The results show that planting transplants that are 20.3-30.5cm in length at a planting depth of 15.2 cm provides the greatest consistency for achieving high plant stands and yields for 'Covington'. Transplants that range from 14.0-17.8 cm in length would also be acceptable for planting if soil moisture is near optimal levels. However stands may not be as good when soil moisture is not optimal which would impact overall yields, if dry conditions are encountered at planting and during plant establishment. Planting transplants less than 14.0 cm and at either a shallow or deep planting depth would not be advised as yield and plant stands would be likely be reduced. The use of irrigation, especially within the establishment phase extending to 13 DAP, would be beneficial to maximize root set and plant stands, however may not be necessary if rainfall occurs soon after planting or within a few days after planting.

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Table 1. Transplant size and planting depth effects on number of roots per plant for various size grades and total and percent stand, 2011.

Plant size (cm)	Planting depth	U.S. No. 1	Canner	Jumbo	Cull	Total Number	% Stand
9.5	5.1 cm	3.5 d [z]	3.3	0.6	0.0	7.3	95.0
15.9	5.1 cm	3.3 d	3.8	0.7	0.0	7.8	98.3
	15.2 cm	4.6 ab	3.6	0.4	0.1	8.7	98.3
21.6	5.1 cm	3.8 cd	3.8	0.7	0.0	8.3	98.3
	15.2 cm	4.5 a-c	3.9	0.6	0.0	8.9	98.3
27.2	5.1 cm	4.0 b-d	3.9	0.5	0.0	8.4	96.7
	15.2 cm	5.1 a	3.7	0.4	0.0	9.2	98.3
Pr>F (Treat)		0.0023	0.9865	0.4112	0.2232	0.4347	0.7400

[z] Means followed by the same letter within column are not significantly different according to least significant difference test in PROC ANOVA ($P \leq 0.05$)

Table 2. Average number of roots based upon 4.6m linear plot row and appropriate size grade in 2011.

Plant size (cm)	Planting depth	U.S. No. 1	Canner	Jumbo	Cull	Total	Total Mkt.
9.5	5.1 cm	49.3 c [z]	45.8	8.5	0.3	103.8	103.5
15.9	5.1 cm	49.0 c	56.5	10.0	0.0	115.5	115.5
	15.2 cm	68.3 ab	52.8	6.5	0.8	128.3	127.5
21.6	5.1 cm	55.8 bc	56.0	9.8	0.5	122.0	121.5
	15.2 cm	66.5 ab	56.8	8.3	0.0	131.5	131.5
27.2	5.1 cm	58.0 bc	56.5	7.5	0.0	122.0	122.0
	15.2 cm	75.3 a	55.0	6.3	0.0	136.5	136.5
Pr>F (Treat)		0.0026	0.9616	0.4616	0.2264	0.3313	0.3403

[z] Means followed by the same letter within columns are not significantly different according to calculated least significant difference means using PROC ANOVA ($P \leq 0.05$).

Table 3. P-values for total storage root numbers produced per plot and per plant among root grades including percent plant stand, 2012.

Dependent Variable	Irr.	Depth	Size	Depth x Size	Irr*Depth	Irr* Size	Irr*D*S
				Per Plot			
U.S. No. 1	0.0029	0.0570	0.0004	<0.0001	0.9380	0.0465	0.9079
Canner	0.0608	0.0003	0.0020	0.0003	0.1227	0.0681	0.8173
Jumbo	0.1540	0.5207	0.0004	0.0091	0.3601	0.0850	0.6082
Cull	0.0424	0.2270	0.0352	0.0244	0.0872	0.1165	0.0605
% Stand	0.1539	1.0000	<0.0001	<0.0001	0.2190	0.0253	0.6976
Tot. Mkt.	0.0060	0.0001	<0.0001	<0.0001	0.1950	0.0047	0.7944
Total	0.0056	<0.0001	<0.0001	<0.0001	0.2158	0.0032	0.7045
				Per Plant			
No.1	0.0002	0.2363	0.0232	0.2687	0.1582	0.2528	0.1648
Canner	0.5041	0.0018	0.3185	0.4446	0.2070	0.4104	0.7916
Jumbo	0.0073	0.0887	0.0142	0.3632	0.6565	0.0483	0.4225
Cull	0.1872	0.9922	0.3200	0.3245	0.0840	0.4780	0.4417
Total	0.0809	0.0036	0.0015	0.0674	0.9952	0.1215	0.2753

Table 4. Average number of storage roots pooled over irrigation within 4.6m linear plot row by appropriate size grades and percent stand; HCRS, Clinton, NC; 2012.

Plant size	Planting depth	U.S. # 1	Canner	Jumbo	Cull	Total	Total Mkt.	% Stand
9.5 cm	5.1 cm	22.1 cd[z]	16.3 bc	5.9 a	1.6 ab	45.9 c	44.3 c	75.8 b
	15.2 cm	5.4 e	5.8 c	1.3 b	0.4 b	12.8 d	12.4 d	19.2 d
15.9 cm	5.1 cm	24.8 b-d	16.0 c	6.8 a	1.6 ab	49.1 c	47.5 c	76.7 b
	15.2 cm	29.3 a-c	26.9 ab	7.1 a	2.1 a	65.4 b	63.3 b	76.7 b
21.6 cm	5.1 cm	19.1 d	15.4 c	6.8 a	2.3 a	43.5 c	41.3 c	60.8 c
	15.2 cm	35.3 a	36.1 a	8.1 a	2.8 a	82.4 a	79.6 a	92.5 a
27.2 cm	5.1 cm	19.3 d	12.3 c	6.8 a	0.5 b	38.8 c	38.3 c	59.2 c
	15.2 cm	34.0 ab	32.8 a	7.9 a	2.5 a	77.1 ab	74.6 ab	84.2 ab
Pr>F(Depth)		0.0570	0.0003	0.5207	0.2270	<0.0001	0.0001	1.0000
Pr>F(Size)		0.0004	0.0020	0.0004	0.0352	<0.0001	<0.0001	<0.0001
Pr>F(Depth*Size)		<0.0001	0.0003	0.0091	0.0244	<0.0001	<0.0001	<0.0001

[z] Means followed by the same letter within column are not significantly different according to calculated least significant difference means using PROC ANOVA (P≤0.05).

Table 5. Irrigation and plant size effects on number of roots per 4.6m plot for U.S. No. 1, total, total marketable number of well as roots as jumbo per plant and percent plant stand in 2012.

	U.S. No. 1		Total		Total Mkt.		Jumbo/plant		% Plant Stand	
Plant Size	Irr	NI	Irr	NI	Irr	NI	Irr	NI	Irr	NI
9.5	17.5 de	10.0 e	37.6 c	21.0 d	36.3 c	20.4 d	0.4 c	0.3 c	56.7 e	38.3 f
15.9	38.8 a	15.25 de	77.7 a	36.8 c	74.8 a	36.0 c	0.4 c	0.9 a	92.5 a	60.8 de
21.6	30.0 a-c	24.5 b-d	66.6 ab	59.3 b	62.7 ab	58.1 b	0.6 bc	0.8 ab	81.7 ab	71.7 cd
27.2	31.5 ab	21.8 cd	61.8 b	54.1 b	59.9 b	53.0 b	0.5 bc	1.0 a	75.0 bc	68.3 c-e

[z] Means followed by the same letter within category for non-irrigated and irrigated are not significantly different according to calculated least significant difference means using PROC ANOVA ($P \leq 0.05$).

Table 6. Number of roots for main effects [z] for U.S. number 1, canner, jumbo, and total per plot as well as jumbo and total roots per plant; HCRS, Clinton, NC; 2012.

Variable	Planting Depth		Plant Size				Irrigation	
	5.1 cm	15.2 cm	9.5	15.9	21.6	27.2	Irr.	NI
U.S. #1	X [y]	X	13.8 b	27.0 a	27.3 a	26.6 a	29.4a	17.9 b
Canner	25.4 a	15.0 b	X	X	X	X	X	X
Jumbo	X	X	3.6 b	6.9 a	7.4 a	7.3 a	X	X
Total	59.4 a	44.3 b	X	X	X	X	X	X
Total/plant	X	X	3.7 b	4.9 a	5.4 a	5.4 a	X	X
Jumbo/plant	X	X	X	X	X	X	0.5 b	0.8 a

[z] Means followed by the same letter within rows are not significantly different according to calculated least significant difference means using PROC ANOVA ($P \leq 0.05$).
[y] "X" denotes values not given due to no significance difference among main effect for certain measured variables.

Table 7. P-values for total root numbers produced per plot and per hill among root grades including percent plant stand, 2013.

Dependent Variable	Irr.	Depth	Size	Depth x Size	Irr*Depth	Irr* Size	Irr*D*S
				Per Plot			
No. 1	0.0464	0.0289	0.0529	0.6106	0.3863	0.8305	0.1014
Canner	0.0366	0.1813	0.0057	0.0673	0.8505	0.0258	0.0379
Jumbo	0.2360	0.1637	0.0424	0.8290	0.5119	0.7953	0.7650
Cull	0.2667	0.9423	0.7130	0.8031	0.0207	0.6935	0.1722
% Stand	0.1785	0.06000	0.0012	0.0414	0.0466	0.0812	0.3378
Tot. Mkt.	0.9855	0.0783	0.0008	0.1157	0.3458	0.1030	0.2913
Total	0.8929	0.0766	0.0006	0.1008	0.2234	0.0807	0.1972
				Per hill			
No.1	0.1319	<0.0001	0.4981	0.3743	0.3504	0.1658	0.0372
Canner	0.0073	0.0106	0.1206	0.0357	0.2772	0.0698	0.0234
Jumbo	0.3019	0.2756	0.2195	0.9119	0.8240	0.8419	0.7742
Cull	0.2894	0.7739	0.8145	0.8043	0.0214	0.6252	0.1544
Total	0.1281	<0.0001	0.1942	0.0138	0.2931	0.0258	0.0737

Table 8. Number of roots per plot and per plant by transplant size and planting depth by category; HCRS, Clinton, NC; 2013.

	Number of roots within 4.6m plot row					
Transplant Size	U.S. #1	Canner	Jumbo	Total	Total Marketable	% Plant Stand
9.5 cm	30.3 b[z]	14.7 c	12.1 b	57.9 b	57.1 b	75.8 b
15.9 cm	39.0 a	24.6 a	13.9 ab	78.9 a	77.4 a	94.6 a
21.6 cm	39.6 a	21.9 ab	15.4 ab	78.3 a	76.9 a	92.9 a
27.2 cm	36.0 ab	18.1 bc	17.5 a	72.8 a	71.6 a	93.8 a

	Roots per hill		
Planting Depth	U.S. # 1	Canner	Total
5.1 cm	2.4 b	1.3 b	4.9 b
15.2 cm	3.1 a	1.7 a	5.9 a

[z] Means followed by the same letter within category are not significantly different according to calculated least significant difference means using PROC ANOVA ($P \leq 0.05$).

Table 9. Average number of roots per hill based upon size grade and percent plant stand by plant size and planting depth; HCRS, Clinton, NC; 2013.

Plant size (cm)	Planting depth	Canner	Total Number	% Plant Stand
9.5 cm	5.1 cm	1.2 b[z]	4.6 d	88.3 a
	15.2 cm	1.6 ab	5.9 ab	63.3 b
15.9 cm	5.1 cm	1.9 a	5.5 bc	93.3 a
	15.2 cm	1.6 ab	5.5 bc	95.8 a
21.6 cm	5.1 cm	1.2 b	4.8 cd	94.2 a
	15.2 cm	2.0 a	6.5 a	91.7 a
27.2 cm	5.1 cm	1.1 b	4.7 d	95.0 a
	15.2 cm	1.5 ab	5.6 b	92.5 a

[z] Means followed by the same letter within column are not significantly different according to calculated least significant difference means using PROC ANOVA ($P \leq 0.05$).

Table 10. Average number of nodes per transplant between plant size treatments.

Plant size	Nodes/plant
9.5 cm	4.9
15.9 cm	7.0
21.6 cm	8.2
27.2 cm	9.8

Figure 1. Sweetpotato transplant being set within transplanter clip. Note the length of the plant extending beyond the clip. This distance beyond the clip controls planting depth.

(https://www.jbgorganic.com/blog/2013/05/sweet-potato-tranplanting/)

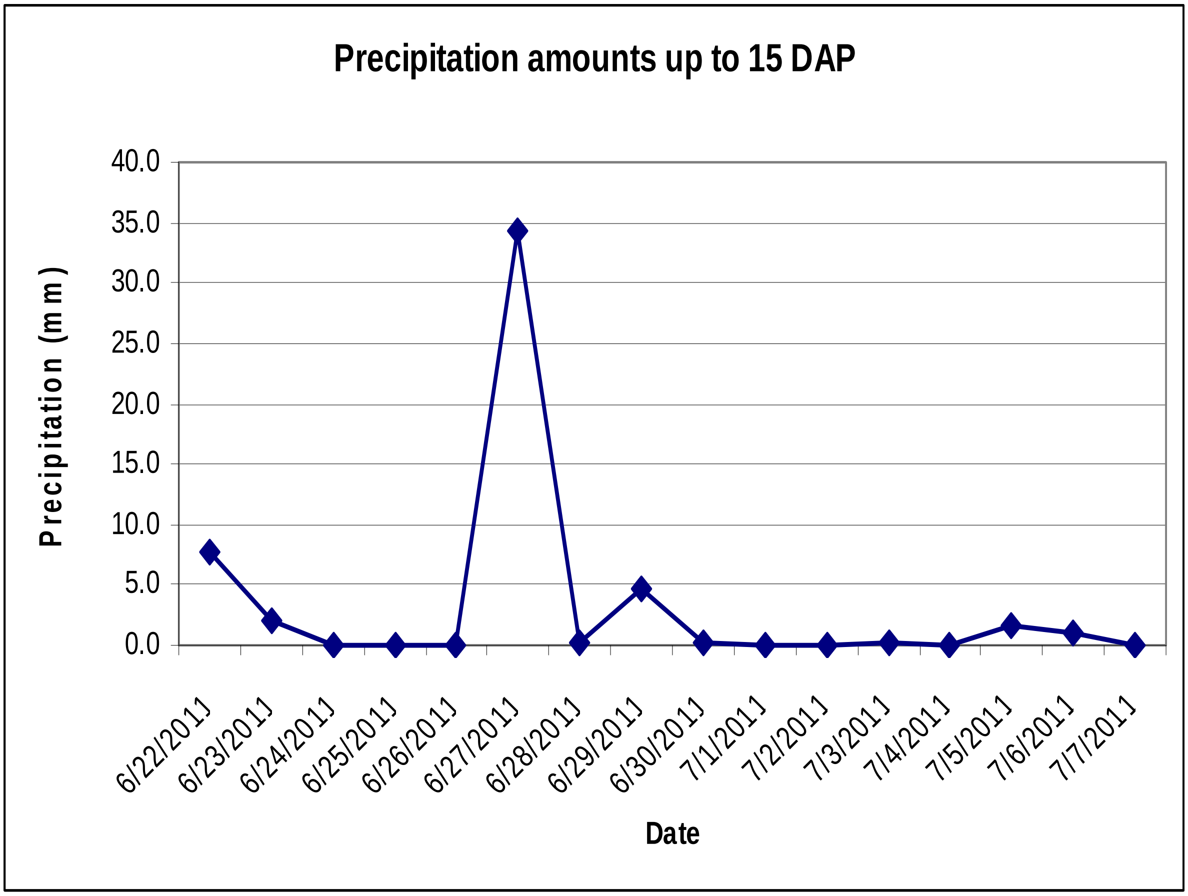

Figure 2. Daily precipitation (mm) recorded the day before planting and up to 15 days after planting (DAP) in 2011.

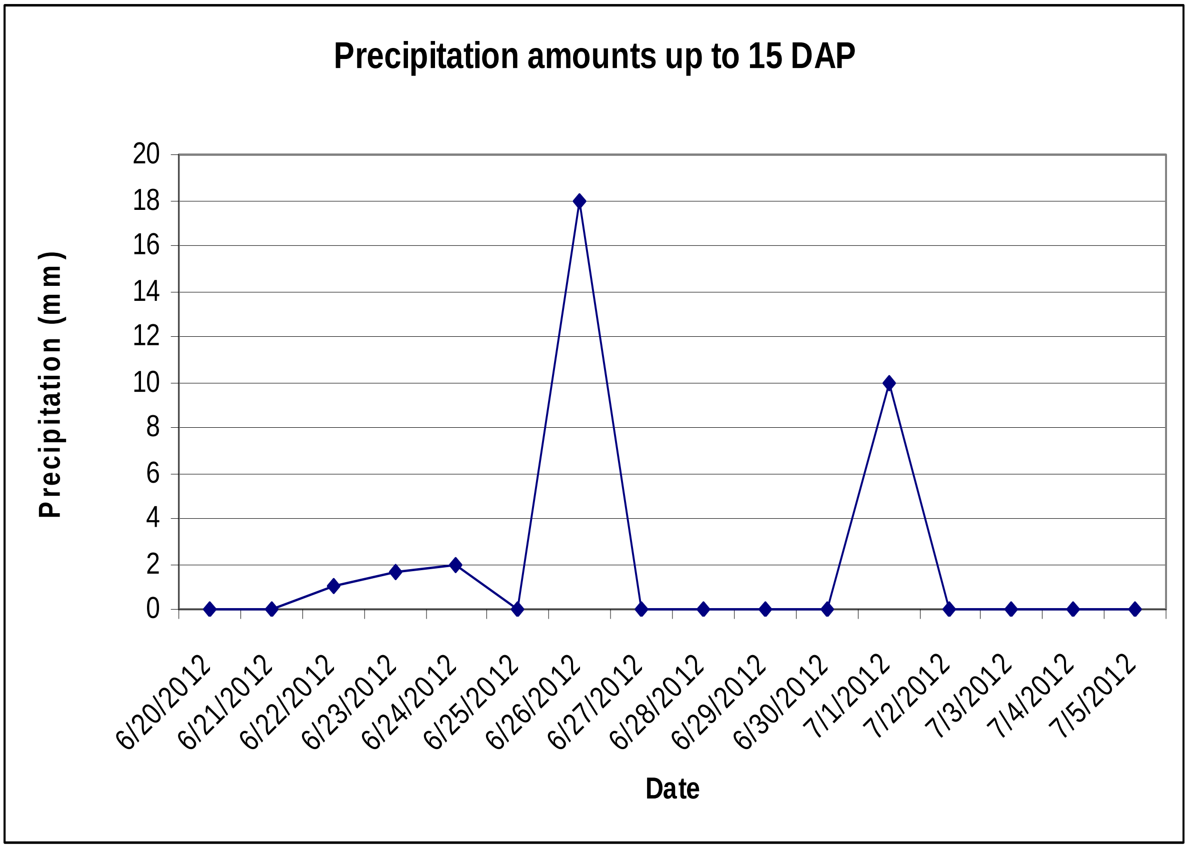

Figure 3. Daily precipitation (mm) recorded the day prior to transplanting and up to 15 days after planting (DAP) in 2012.

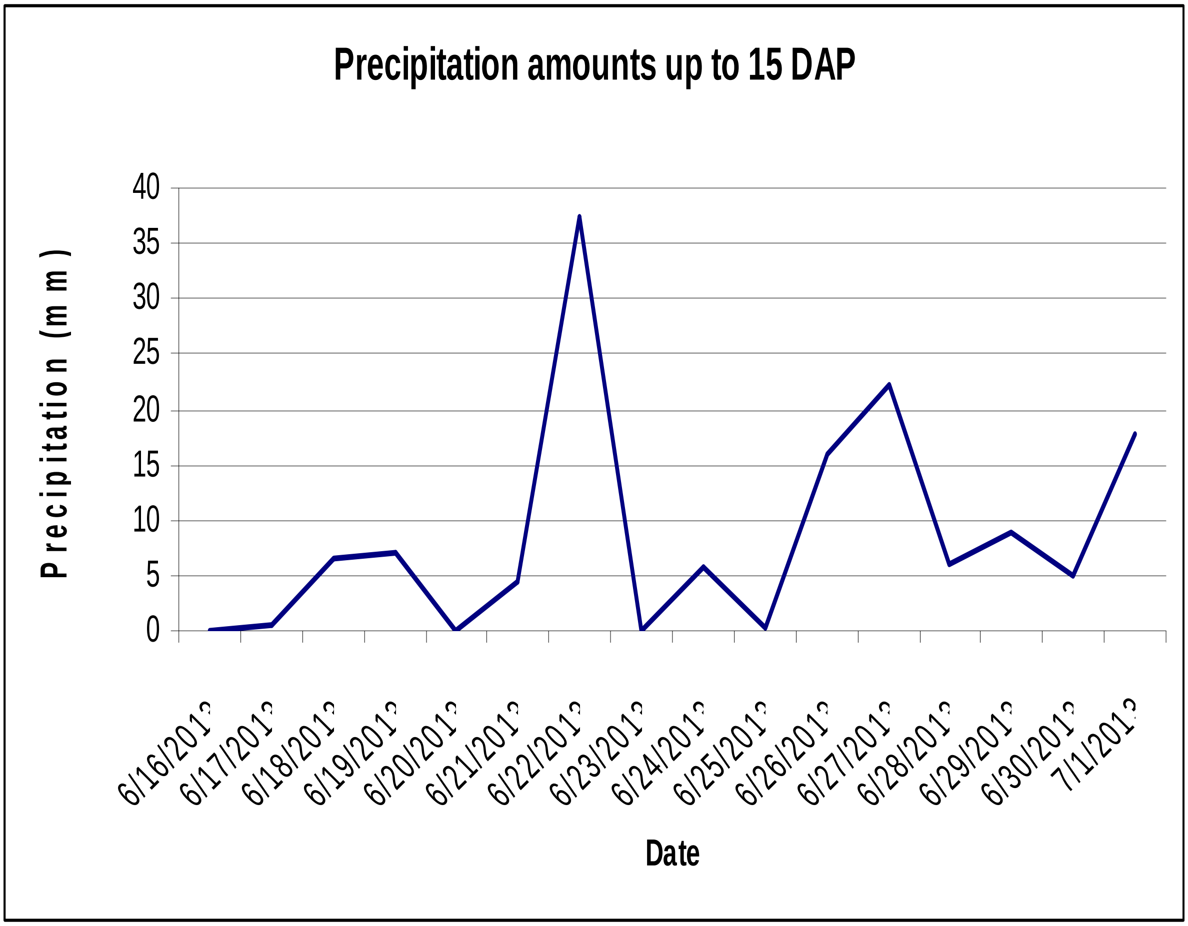

Figure 4. Daily precipitation (mm) recorded the day before planting and up to 15 days after planting (DAP) in 2013.

CHAPTER II

CHAPTER II. RESPONSE OF 'COVINGTON' SWEETPOTATO STAND AND STORAGE ROOT YIELD TO TRANSPLANT HOLDING DURATIONS.

W. Bradfred Thompson, Jonathan R. Schultheis, David W. Monks, Katie M. Jennings, and Garry L. Grabow

Studies were conducted in North Carolina to determine the effect of holding times [7 days before planting (DBP), 5 DBP, 3 DBP, 1 DBP, and day of planting (DOP)] of 'Covington' sweetpotato transplant cuttings with and without irrigation on plant stand and storage root yield in production fields. Transplants cut 7 DBP did not survive as well (lower plant stands) as the other treatments and had lower U.S. number 1, total, and total marketable yields compared to other holding treatments. All holding treatments except 7 DBP produced similar plant stands and storage root yields. However, holding cuttings 1 or 3 DBP, resulted in higher plant stands and storage root yields if transplants were cut and planted the same day, 5 DBP, or 7 DBP. Based on these studies it appears that transplant cuttings held for at least 1 day, is optimum for stand establishment and storage root yield. However, by holding transplant cuttings for 7 days, stand establishment and storage root yield may be negatively influenced. Soil moisture at planting plays a key role in sweetpotato plant establishment and achieving good yield, while holding transplants for 1 to 3 DBP can improve stand establishment and yields when dry conditions prevail.

Introduction

'Covington' sweetpotato, *Ipomea batata* (L.) is the most commonly grown cultivar in North Carolina (North Carolina Crop Improvement, 2014). This cultivar is also grown in other states such as California and other countries such as Canada. A key reason this cultivar is the primary cultivar grown in North Carolina is that it produces consistently higher yields and greater storage root set resulting in a high percentage "pack out" of U.S. number 1 sweetpotatoes and greater economic return. For high storage root yield and quality, growers must closely follow recommended growing practices in the production field (Kemble et. al, 2014). However, production practices in the propagation bed and transplant cutting practices are often overlooked both in research and in practice within production fields. Specifically, with the handling of transplant cuttings, it is not known if there is any benefit in holding transplants for a period of time prior to planting. If holding transplants is beneficial the optimum holding time is not known and likewise the effect of varying holding times on sweetpotato production is unknown. The practice of holding transplant cuttings is thought by many North Carolina growers to allow for cuttings to produce adventitious roots before transplanting in the production field. These growers believe that transplant cuttings that have been held and have begun to initiate adventitious roots prior to transplanting in the production field will establish more successfully than those that are cut from propagation beds and transplanted the same day.

Since sweetpotatoes are vegetatively propagated, all initial roots produced are adventitious in derivation (Esau, 1977). The role of adventitious root formation is critical to storage root formation. The initial adventitious roots originate from pre-formed root primordia that are commonly visible on the aerial stem at the time of cutting (Hahn and Hozyo, 1983; Belehu et. al, 2004). These root primordia typically form in pairs on either side of the stem just below the node or leaf (Togari, 1950). Adventitious rooting can also develop within the callus tissue that forms on the buried end of a transplanted sweetpotato stem cutting. However, swollen edible storage roots develop from the initial adventitious roots, primarily those pre-formed at nodes prior to transplanting rather than those initiated later in the stem end callus (Lewthwaite and Triggs, 2009). Storage roots are the principal carbohydrate storage organ in sweetpotato and are a length of adventitious root that forms a localized carbohydrate storage structure and is defined by its distinctive lateral growth (Lewthwaite and Triggs, 2009). The swollen edible storage roots are the roots that need to be maximized on a per plant and per hectare basis in order to have a good yield of sweetpotatoes. Conditions may occur that reduces storage root formation. Any event that limits carbohydrate deposition, or the cambial activity associated with development of a fully formed storage root will temporarily or permanently obstruct the progress of a root along the developmental series (Togari, 1950; Kays, 1985). These conditions include water logged soils that expose roots to prolonged periods of oxygen deficiency or long periods of drought that can lead to the formation of pencil roots. Pencil roots are roots that have limited carbohydrate storage function as the stele may be only partially lignified which allows for some lateral thickening to occur (Wilson, 1970). Storage root development, as mentioned earlier, commences with the formation of adventitious roots that begin forming prior to planting which explains why many growers hold their transplants before planting them in the field. However, the amount of time the transplants are held before planting has not been investigated to determine if this practice is beneficial.

An irrigation treatment was included in this study to determine its influence on plant survival and yields. Villordon et al. (2009) reported that available soil moisture at the time of planting through 21 days after planting (DAP) was critical in influencing whether adventitious roots became storage or pencil roots. One of the most significant factors that affects the development of the plant's root system is soil moisture content (Morita and Abe, 1996). Sweetpotato is considered a relatively drought tolerant crop (Pardales et al., 2000) and fairly good yields have been reported in production systems suffering drought stress (Bouwkamp, 1985). Previous studies have demonstrated high yields in drought conditions, however it has also been demonstrated that yields benefit from supplemental irrigation when rainfall is not adequate or where moisture distribution is erratic and unpredictable (Bouwkamp, 1985). Rainfall can be sporadic in North Carolina during typical sweetpotato growing periods and after planting. The use of additional irrigation after planting and through the growing season is not usually practiced by growers in North Carolina. However, in California, 100% of the sweetpotato crop is irrigated through the use of drip irrigation or furrow irrigation (Stoddard et al., 2013). The use of irrigation could possibly not only maximize plant stand and storage root yield, but also allow cuttings that have been held for long periods of time to have the ability to survive and produce quality sweetpotatoes.

The objectives of this study were to determine the effect of various holding times of sweetpotato transplant cuttings on the establishment and storage root production on a per plant and per area basis. The effects of various holding times with and without irrigation during plant establishment was also investigated.

Materials and Methods

Studies. Studies were conducted in 2010, 2011, 2012, and 2013 at the Horticulture Crops Research Station (HCRS), Clinton (34.9979 N, -78.3233 W); the Cunningham Research Station (CRS), Kinston (35.2917027N, -77.5590597W); and at the Jones Farm; Bailey, NC (35.824721N, -78.125067 W). In 2010, tests were conducted at the Jones Farm and at CRS. In 2011, the studies were also conducted at the HCRS. Studies conducted in 2012 and 2013 were only conducted at the HCRS.

Treatments included in all studies were; holding transplant cuttings 7 days before planting (DBP), 5 DBP, 3 DBP, 1 DBP, and DOP (day of planting). In 2010 and 2011 after planting, fields were not irrigated however, in 2012 and 2013, studies included a non-irrigated and irrigated study. Holding treatments at each study location were arranged in a randomized complete block design. Treatments within the irrigation treatment blocks were arranged in a randomized complete block design with four replications. The irrigation treatment block and the non-irrigation treatment block were placed within the same field but separated by ten rows between the blocks to prevent irrigation drift into the non-irrigated plots. Irrigation (1.3 cm) was applied to the irrigated portion of the field the day before and then again the day after planting at the Horticulture Crops Research Station in 2012 and 2013 to ensure optimal soil moisture availability at planting (Figures 1 and 2). Planting dates varied among test locations and years and are reported in Table 1.

Generation 2 transplants (Averre et. al., 2008) were obtained from either Jones Farm (2010 and 2011) or from Scott Farm; Lucama, NC, USA (2012 and 2013) (Table 1). Transplants were held within a storage shed at Jones Farm in 2010, but were transported to the North Carolina State University campus and placed under an equipment shelter for the duration of the specified treatment in 2011, 2012, and 2013. A environmental data logger; HOBO U12 (Onset Headquarters Onset Computer Corporation, 470 MacArthur Blvd., Bourne, MA 02532), was placed next to the boxes of transplant cuttings to record hourly ambient air temperature as well as hourly relative humidity during the duration the transplants were held. In 2012, a HOBO unit was placed with the boxes, but failed to record the correct environmental parameters of temperature and relative humidity that were programmed into the logger prior to it being placed among the transplants. The remaining data logger results are presented for each year and each test that the transplants were held (Appendix B-Table 1). Once the transplants had been cut and held for the duration of the designated treatment, they were taken to their respective location and planted. Transplant cuttings were planted and simultaneously watered using a mechanical transplanter, which is standard commercial practice (Kemble et. Al., 2013). In all studies, plots for each treatment consisted of four rows, with each plot 9.1 m long except in 2010 at the Cunningham Research Station location plots were 7.6 m. Transplants were spaced approximately 31cm apart in row. At the Cunningham Research Station in 2010 the number of transplants was 25 per row rather than 30 transplants planted per treatment row. The between row spacing varied between locations as Jones Farm had a between row spacing of 1.1 m while the between row spacing at the research station locations were 1.06 m.

Soil Classification and Fertilization. Soils where the studies were conducted were a Norfolk fine sandy loam soil (North Carolina AgStats, 2014). Table 2 indicates the soils for each study location. Studies were fertilized according to North Carolina Cooperative Extension recommendations (Kemble et al, 2014) and soil test recommendations provided by the North Carolina Department of Agriculture and Consumer Services Agronomic Department Raleigh, NC. Total season fertilization rates are provided for each test location and year (Table 3). Fertilization rates varied slightly among tests due to differing soil types and nutrient content within the soil (Table 2). The manner fertilizer was applied also varied. Among the research station locations, a base application of fertilizer was initially applied prior to planting. This base application included mainly the applications of phosphorous and potassium. Total nitrogen application and additional potassium amounts were applied during cultivation just prior to when the sweetpotato vines would sustain little or no damage as the equipment passed through the field (referred to as lay-by). Initial nitrogen application at the Jones Farm location occurred 7 to 10 days after planting and the remaining amount of nitrogen needed to satisfy soil recommendations was applied at lay-by.

Pest Management. Pest control for each location and for each year were similar among the locations and recommended practices were followed (Kemble et al, 2014). Weed and pest management were practiced at each test location for all years (Table 4). Fields at Jones Farm and the Horticulture Crops Research Station were fumigated before planting using 1,3-Dichloropropene (Telone II; Dow Agrosciences LLC, 9330 Zionsville Rd., Indianapolis, IN, 46268), at a rate of 84.2 L ha^{-1} (Jones Farm) and 102.9 L ha^{-1} (Horticulture Crops Research station). The Cunningham Research station did not apply fumigation to the fields prior to planting.

Different pest management products were used among the various test locations and years (Table 4). To control weeds, clomazone (Command®3ME, HELENA Chemical Company, 225 Schilling Blvd., Suite 300, Collierville, TN 38017) at 2.5 L ha^{-1} (Cunningham) and 2.7 L ha^{-1} (Horticulture Crops) was applied each year. Flumioxazin, (Valor™, Valent USA Corp., 1600 Riviera Avenue, Suite 200, Walnut Creek, CA 94596-8025) was applied to the bedded rows prior to planting at 174 mL ha^{-1} (Cunningham) and 207 mL ha^{-1} (Jones Farm and Horticulture Crops). The use of flumioxazin and clomazone are primarily used for palmer amaranth control (Meyers et al., 2010). Jones Farm also applied 828 mL ha^{-1} Clethodim (Select™, Valent USA Corp., 1600 Riviera Avenue, Suite 200, Walnut Creek, CA 94596-8025) herbicide for grass control within the study fields for each year.

Insect management was similar among all locations and years for each test. Bifenthrin (Sniper®, Loveland Products, Inc., PO Box 1286, Greeley, CO 80632-1286) was applied at 657.1 mL ha^{-1} (Jones Farm and Cunningham) and 731.1 mL ha^{-1} (Horticulture Crops) and Chlorpyrifos (Lorsban®, DOW AgroSciences LLC, 9330 Zionsville Rd., Indianapolis, IN, 46268) was applied at 5.6 L ha^{-1} (Cunningham and Horticulture Crops) and 4.9 Lha^{-1} (Jones Farm). Bifenthrin and chlorpyrifos are typically applied for grub and wireworm control at pre-plant (Willis et al, 2010).

Data Collected. Em50 ECH2O weather monitoring data loggers; (Decagon Devices; 2365 NE Hopkins Court; Pullman, WA 99163) were set up within each test location either prior to or at planting to record ambient air temperatures, relative humidity, precipitation, and soil moisture and temperature at two different depths (5.1 cm and 15.2 cm) beneath the soil surface. These loggers were placed within each field at all locations for all years. However, some data loggers malfunctioned and data for only certain years and locations data were recorded. Precipitation data were also collected from on site weather stations or with regional weather stations provided by the State Climate Office in North Carolina with the later being used to fill data missing from malfunctioning data loggers. Plant stands were recorded for each test 14 to 20 days after transplanting to determine plant establishment response to the holding treatments. Harvesting was achieved by using a tractor mounted chain digger. The center two rows of each plot were harvested and totaled 18.3 m linear row for each treatment and depending on plant stand; a maximum of 60 plants per plot. Roots were graded and counted and weighed into the four grades; U.S. Number 1, canner, jumbo, and culls or misshapen roots (USDA, 2005). Yield data were analyzed on an area basis (MT ha^{-1}), a per 18.3 m linear plot row basis, and on a per plant basis.

Statistical analysis. To determine the statistical significance of independent variables within a plot row area as well as an overall hectare basis, the PROC GLM procedure of SAS 9.3 (SAS Institute Inc.100 SAS Campus Drive; Cary, NC 27513-2414, USA) was used. The data were analyzed collectively across the seven studies in 2010 through 2013 which did not impose an irrigation treatment. The significance of main effects (holding treatment and environment), and the interaction for each independent variable were determined. When the probability of committing a Type I Error was less than P=0.05 for any variable, this result was highlighted. If no interaction for a variable was detected, the main effects that were significant were reported. Irrigation results are also presented among holding treatments to determine the effect of irrigation on plant survival and overall stands among the holding treatments.

Results

Yield and plant stand data were analyzed for each test location and year. Environment (location and year) had a significant effect (Table 5). This result was expected since there are variations that commonly occur within the environment within a given year as well as within a test location. Holding treatments influenced yields for total yields at the 0.015 level of significance (Table 5). However, U.S. number 1 and cull root yields were significant at the 0.07 level of significance (Table 5). Total yield, canner and jumbo yields were not influenced by holding treatments. Percent plant stand was also influenced by holding treatments (Table 5). Irrigation was another treatment that was added to the 2012 and 2013 tests conducted at the Horticulture Crops Research Station in Clinton with the goal to compare more optimal soil moisture conditions with dry soil conditions, and to impose these conditions simultaneously in the same test planting. The data from these two tests were combined and analyzed for main effects (irrigation, holding, and environment) and for interactions. Data for the 2012 and 2013 tests are presented in a similar manner as the 2010 through 2013 non-irrigated holding tests.

Yields. Total yields represent the yields of U.S. number 1, canner, jumbo, and cull roots. When evaluating the main effects of the various holding treatments across all tests, transplants held for 1 DBP had greater total yields than all other holding treatments with a mean yield of 46.8 MT ha^{-1} (Table 6).

The interaction of environment and holding treatment significantly ($P \leq 0.05$) impacted the yields of U.S. number 1 and total marketable roots (Table 5). Table 7 presents U.S. number 1 and total marketable yields among the holding treatments within each test location and year to show interaction response. Considerable variation in U.S. number 1 yields existed among locations and years with average yields ranging from 19.3 to 45.2 MT ha^{-1} (Table 7). Among locations, Jones farm produced the lowest U.S. number 1 yields while in 2010 and 2011 CRS and HCRS produced high yields. Despite the variation across environments, within years where significance occurred, the 7 DBP holding treatment resulted in the lowest yields of U.S. number 1 roots while the 1 DBP holding treatment was one of the highest yielding treatments (Table 7). The highest yield of U.S. number 1 roots was not always attained with the 1 DBP treatment within each environment; however it was numerically the highest producing treatment in 5 out of the 7 tests (Table 7). Holding treatment for U.S. number 1 yields was significant at the $P \leq 0.067$ level which does indicate a consistent response to holding treatment (Table 5). Across all the tests for U.S. number 1 yields, the 1 DBP holding treatment resulted in a yield of 32.3 MT ha^{-1}. Total marketable yields represent all size grades except for culls. When evaluating main effect for holding treatment only, the 1 and 3 DBP holding treatments produced the greatest yields across all environments. However, the 1 DBP holding treatment produced significantly greater yields (45.7 MT $ha^{-1)}$ than the DOP (42.4 MT ha^{-1}), 5 DBP (41.5 MT ha^{-1}), and 7 DBP (40.4 MT ha^{-1}) treatments (Table 7). The 3 DBP holding treatment resulted in intermediate marketable yields (42.6 MT ha^{-1}) that were comparable to all holding treatments but was numerically higher than the DOP, 5, and 7 DBP holding treatments (Table 7). In regards to an interaction response among environments and holding treatments, total marketable yields were again similar to the results seen for U.S. number 1 yields with considerable variation in total marketable yields between locations with average yields ranging from 25.7 to 28.3 MT ha^{-1} at the Jones Farm location up to 59.9 to 62.7 MT ha^{-1} at the CRS location (Table 7). Despite the variations, the 1 DBP holding treatment tended to produce the greatest yields of total marketable roots for most locations (Table 7). The exception was the 2011 CRS test in which yields were similar regardless of holding treatment. The harvest of plants the DOP resulted in a total yield decrease compared to the 1 DBP holding treatment (Table 6).

Yields of U.S. number 1 and total marketable roots seem to correspond to percent plant stand as presented above. Percent plant stand was greater than 90% in the 1 and 3 DBP holding treatments when evaluating main effects of holding treatments (Table 8). Although plant stands for the 1 and 3 DBP holding treatment were not different from the DOP and 5 DBP treatments, they were the only two treatments that averaged 90% plant stand across test locations. The 7 DBP holding treatment had lower ($P \leq 0.05$) plant stands of 79.4% (Table 8). Similar to the yields, percent plant stand was considerably variable among environment and holding treatment (Table 5). Percent plant stands were lower when transplants were held 7 DBP for both the Jones Farm tests compared with all other holding times with stands of 55.4% (2010) and 53.8% (2011) (Table 8). Plant stands were similar across holding treatments for the CRS and HCRS environments; however in 2010 at CRS and in 2012 at the HCRS, the 7 DBP treatment had plant stands (85% and 82%, respectively) than the other holding treatments. Plant stands averaged 90% or more at the CRS and HCRS locations for the other holding treatments.

Irrigated vs. Non-irrigated. The use of irrigation to examine moisture effects at planting and to determine yield and root set differences among holding treatments was conducted in 2012 and 2013 at the HCRS, Clinton, NC. No differences among years for root numbers per 18.3 m plot row was observed due to variations in environment and irrigation, therefore data were analyzed as a combined data set for 2012 and 2013 tests (Table 9). The combined analysis of the data over the two seasons resulted in no irrigation effects on root number per 18.3m linear plot row, root per hill, and percent stand (Table 9). There were also no main effects for year or holding treatment, as well as irrigation effects (irrigation * holding treatment) (Table 9). When analyzing root production on a per hill basis, there again were no irrigation, treatment, or interaction effects on root grades (Appendix B, Table 1). There were also no statistical differences among treatments for percent stand when comparing irrigation treatments. Yields, when analyzed for root weight (MT ha^{-1}), did show significant treatment effects among the holding treatments for U.S. number 1, total, and total marketable weights (Table 10). Yields were greatest for the 1 DBP treatment which had significantly higher total yields than the other holding treatments. The high yields for U.S. number 1 and jumbo roots contributed to the high total yields for the 1 DBP treatment. Jumbo, canner, and cull yields were all statistically the same among the holding treatments regardless if irrigation was applied or not.

Discussion

Differences in yield and plant stand occurred across environments (years and locations); however responses due to holding treatment were more apparent under certain environments. The single largest factor that influenced yields and plant survival can be attributed to environment. Each location and year was different in terms of soil type, cultural management, and in particular, precipitation. Precipitation amounts influenced soil moisture levels at each test location for each year. The amount of precipitation is important since soil moisture markedly influences storage root initiation (Gajanayake et al., 2013). Rainfall data collected among the various locations and years show that Jones Farm had consistently lower amounts of rainfall within the first 15 days after planting (DAP) compared to the research station locations in 2010 and 2011 (Figure 1). Villordon et al. (2010) has shown that adventitious root development begins approximately13 days after transplant in the field and any moisture deficit before and during this stage will detrimentally impact final storage root numbers and yields. The Jones Farm test locations had limited rainfall (Figure 1) which likely created moisture stress and subsequently produced the lowest yields of the three test locations (Table 7). Rainfall amounts at the HCRS in 2012 were higher than the rainfall amounts at Jones Farm in 2011 (Figure 1), however the yield results were similar (Table 7). The similar yields for these tests were likely due to the greater soil moisture which was measured as volumetric water content using the Decagon data loggers that were present within each test location within the field. Volumetric water content (VWC) was recorded within the soil at two different depths of 5.1 cm and 15.2 cm among each of the test locations for each year. Although the loggers that recorded these data did not always function properly, the data that was recorded provided insight into the soil moisture levels at the time the transplants were being planted and how it possibly affected root development, stands, and overall yields. The lack of precipitation at the Jones Farm location (2010 and 2011) as well as at HCRS in 2012 influenced the soil moisture levels within the first 15 days after transplant such that they were lower than the other test locations. VWC at Jones Farm, over both years, ranged from 8% at the 5.1 cm soil depth to 11.4% at the 15.2 cm soil depth (Figure 2). Similarly, VWC ranged from 9.3 to 12.1% between the two depths at HCRS (Figure 4). The soils at each location were similar in soil structure which influences the water holding capacity of the soil. Jones Farm soil was a Norfolk while HCRS soil was an Orangeburg; both are classified as sandy loam soils. According to Saxton (2005), sandy loam soils are at field capacity when soil ranges anywhere between 11-22% water by volume depending on texture and the permanent wilting point is reached when soil moisture reaches 3-12% water by volume. The data from these two locations show that soil moisture was not optimal and neared the permanent wilting point for sandy loam type soils at the 5.1 cm and the 15.2 cm depth below the soil surface. Consequently, the low soil moisture at planting likely reduced yields at both locations. On the other hand, VWC levels at CRS (2011) ranged from 13.2-13.5% at each soil depth (Figure 3). The soil type at CRS is a Goldsboro which is a loamy sand or finer textured soil than the soils found at Jones Farm and the HCRS locations. The VWC levels were more optimal for the tests conducted at the CRS and the 2011 and 2013 HCRS locations within the first 15 days after transplanting which likely allowed the transplants to become better established and form more adventitious roots as was indicated by the higher percentage plant stand values and yields (Table 8). These results emphasize the importance of soil type and moisture conditions at planting. Gajanayake et al. (2013) found that among 'Beauregard' and 'Evangeline' varieties, soil moisture contents of 0.167 and 0.199 $m^3 \cdot m^{-3}$ were optimal for maximum storage root formation. The soil moisture content measured at the CRS was similar to the optimal values found by

Gajanayake et al. and also resulted in the greatest yields among all locations and years in our study. Rainfall in 2013 was excessive (20 cm) through the early stages of the growing season as VWC levels at HCRS averaged 37.2% (Figure 3). VWC was well above field capacity for the soil type where the test was located, (~16%), thus, neither the irrigation at planting nor the holding treatments were an important or the critical factor affecting plant stands or yields. Rather, the wet soil conditions were the overriding factor. Again, at the CRS, soil moisture conditions were close to optimal as the percent stands and yields were not influenced by holding treatment in tests conducted in 2010 and 2011.

The irrigation treatment that was implemented in 2012 and 2013 at HCRS was to demonstrate the importance of having readily available moisture at planting and that holding treatments mainly played an important role when moisture was limiting in terms of plant stand and yield. The irrigation component was included as a treatment to follow up on the results that had been seen in previous years results at Jones Farm (dry) and CRS (more optimal soil conditions). Unfortunately, the 2012 and 2013 growing seasons were wet, especially at planting. Because of this, soil moisture was similar at both soil depths for the irrigated and non-irrigated portions of the field in 2012 and the excessive rainfall in 2013 kept soil moisture levels elevated in both portions of the test field (Figure 4). The elevated soil moisture levels available to the plants during the growing season resulted in no differences among holding treatments for yield and plant stand between irrigated and non-irrigated settings.

In summary, the results of this study show that holding transplants for 1 DBP can be beneficial, resulting in better yields and improved plant stands. Results also show that yields decrease as transplants are held for more than 3 DBP. This study also shows that environment and soil moisture play a more important role in how well transplants produce roots and survive than holding treatments. Thus, if soil moisture is adequate, then holding of transplants may not influence yields or stands; however, it can be used as insurance if there is limited or no rainfall forecasted within the near future either before or soon after transplanting to improve plant stands and yields.

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Table 1. Study planting dates, harvest dates, and days after planting (DAP).

	2010			2011			2012			2013		
Location[z]	**Plant**	**Harvest**	**DAP**	**Plant**	**Harvest**	**DAP**	**Plant**	**Harvest**	**DAP**	**Plant**	**Harvest**	**DAP**
Jones Farm	6-24	10-26	124	6-30	11-8	131	X	X	X	X	X	X
CRS z	6-25	11-3	132	6-21	10-10	111	X	X	X	X	X	X
HCRS y	X [y]	X	X	6-23	10-25	124	6-19	10-9	113	6-20	10-9	111

[z] CRS represents Cunningham Research Station and HCRS represents Horticulture Crops Research Station.
[y]. "X" represents when no test was planted during given year or location.

Table 2. Soil classification[z] at each test location[y] for each year.

Location	2010	2011	2012	2013
Jones Farm	Norfolk	Norfolk	X	X
CRS	Norfolk	Goldsboro	X	X
HCRS	X [xz]	Norfolk/Blanton	Faceville/Orangeburg	Norfolk

[z] **Norfolk**: Fine-loamy, kaolinitic, thermic Typic Kandiudults; **Goldsboro**: Fine-loamy, siliceous, subactive, thermic Aquic Paleudults; **Faceville**: Fine, kaolinitic, thermic Typic Kandiudults; **Orangeburg**: Fine-loamy, kaolinitic, thermic Typic Kandiudults; and **Blanton**: Loamy, siliceous, semiactive, thermic Grossarenic Paleudults
[y] CRS represents Cunningham Research Station and HCRS represents Horticulture Crops Research Station.
[x] "X" represents when no test planted during given year or location.

Table 3. Total fertilization rates (kg ha^{-1}) at each test location[z] for each year.

	2010			2011			2012			2013		
Location	N	P	K	N	P	K	N	P	K	N	P	K
Jones Farm	89.7	44.8	224.0	89.7	44.8	224.0	X	X	X	X	X	X
CRS	56.3	67.2	170.2	57.3	67.2	170.2	X	X	X	X	X	X
HCRS	X [y]	X	X	76.2	44.8	273.4	76.2	44.8	273.4	76.2	40.3	271.1

[z] CRS represents Cunningham Research Station and HCRS represents Horticulture Crops Research Station.
[y] "X" represents when no test planted during given year or location.

Table 4. Weed and pest management products used at each test location[z] for each year.

	2010		2011		2012		2013	
Location	Insect	Weed	Insect	Weed	Insect	Weed	Insect	Weed
Jones Farm	Bifenthrin Chlorpyrifos	Flumioxazin Clethodim	Bifenthrin Chlorpyrifos	Flumioxazin Clethodim	X	X	X	X
CRS	Bifenthrin	Clomazone Flumioxazin	Bifenthrin	Clomazone Flumioxazin	X	X	X	X
HCRS	X[y]	X	Bifenthrin Chlorpyrifos	Clomazone Flumioxazin	Bifenthrin Chlorpyrifos	Clomazone Flumioxazin	Bifenthrin Chlorpyrifos	Clomazone Flumioxazin

[z] CRS represents Cunningham Research Station and HCRS represents Horticulture Crops Research Station.

[y] "X" represents when no test planted during given year or location.

Table 5. Anova for main effects of environment and transplant holding treatment; and interaction effects.

	No.1	Canner	Jumbo	Cull	Total	Total Mkt.	% Stand
Env. [z]	<0.0001	<0.0001	<0.0001	0.0034	<0.0001	<0.0001	<0.0001
Trt. [y]	0.0668	0.3130	0.4980	0.0725	0.0152	0.0297	0.0411
Env.*Trt.	0.0075	0.3456	0.5169	0.2151	0.2361	0.0546	<0.0001

[z] Env. refers to environment (location and year).
[y] Trt. refers to transplant holding treatments.

Table 6. Total yields (MT ha^{-1}) [z] by holding treatment.

	Holding Treatments				
	DOP	1 DBP	3 DBP	5 DBP	7 DBP
Total Yields	43.3 b	46.8 a	43.6 b	42.4 b	42.3 b

[z] Treatments followed by different letter are significant within row at the 0.05 level.

Table 7. Yields (MT ha^{-1})[z] in response to environment and holding treatments.

Trt.	Jones'10	Jones'11	CRS'10	CRS'11	HCRS'11	HCRS'12	HCRS'13	Main Effects (Trt.)[y]
				U.S. Number 1				
DOP	20.5	19.6 bc	38.3 a	46.9	37.7	22.9	30.9 ab	29.9
1 DBP	22.2	24.0 a	39.9 a	43.8	42.1	24.7	36.3 a	32.3
3 DBP	22.1	24.5 a	38.4 a	47.4	38.4	20.0	25.6 b	29.8
5 DBP	17.6	21.2 ab	42.2 a	42.8	39.0	20.4	25.2 b	28.8
7 DBP	13.9	16.6 c	32.5 b	45.2	38.2	23.7	31.4 ab	27.7
Avg.	19.3	21.2	38.3	45.2	39.1	22.3	29.9	29.7
Pr>F[w]	0.1017	0.0014	0.0022	0.5598	0.3147	0.6302	0.0459	
				Total Marketable				Main Effects (Trt.)[x]
DOP	28.5	26.6 cd	60.0 a	63.8	53.2	30.2	45.4	42.4 b
1 DBP	29.1	30.7 ab	62.3 a	64.3	57.8	35.5	50.1	45.7 a
3 DBP	27.8	31.8 a	61.8 a	62.9	55.1	27.8	41.3	42.6 ab
5 DBP	24.1	28.1 bc	63.0 a	61.1	55.0	29.9	39.8	41.5 b
7 DBP	19.2	24.3 d	52.4 b	61.5	57.2	31.1	47.4	40.4 b
Avg.	25.7	28.3	59.9	62.7	55.7	30.9	44.8	42.5
Pr>F[w]	0.1641	0.0036	0.0197	0.7922	0.5681	0.3243	0.1146	

[z] Treatments followed by different letter are significant within column at the 0.05 level.
[y] Yields of U.S. number 1 roots among main effect holding treatment.
[x] Yields of total marketable roots among main effect holding treatment.
[w] Significance among environments for each year between holding treatments. ($Pr \leq 0.05$)

Table 8. Interaction among environments and holding treatments on percentage plant stands.

Trt.	Jones'10	Jones'11	CRS'10	CRS'11	HCRS '11	HCRS '12	HCRS '13	Main Effects (Trt.) [z]
	Percent Plant Stand							
DOP	82.1 a	71.3 b	88	99.6	97.5	93.8	94.6	87.4 a
1 DBP	86.3 a	82.5 a	92	97.1	99.6	92.5	99.6	90.5 a
3 DBP	93.3 a	86.7 a	92	98.3	97.5	87.9	98.3	91.3 a
5 DBP	95.4 a	67.1 b	92	97.9	96.7	91.7	91.7	88.2 a
7 DBP	55.4 b	53.8 c	85	95.8	99.2	82.1	99.2	79.4 b
Average	82.5	72.3	89.9	97.7	98.1	89.6	96.7	87.4
Pr>F [y]	0.0015	<0.0001	0.2971	0.1108	0.1969	0.1091	0.2823	

[z] Percent plant stand among main effect holding treatment.
[y] Significance among environments for each year between holding treatments. (Pr≤0.05); Means followed by the same within letter column are not significantly different.

Table 9. The main effect of irrigation and holding time and their interaction on roots classified by plot, plant, and percent stand. (2012 and 2013 data combined).

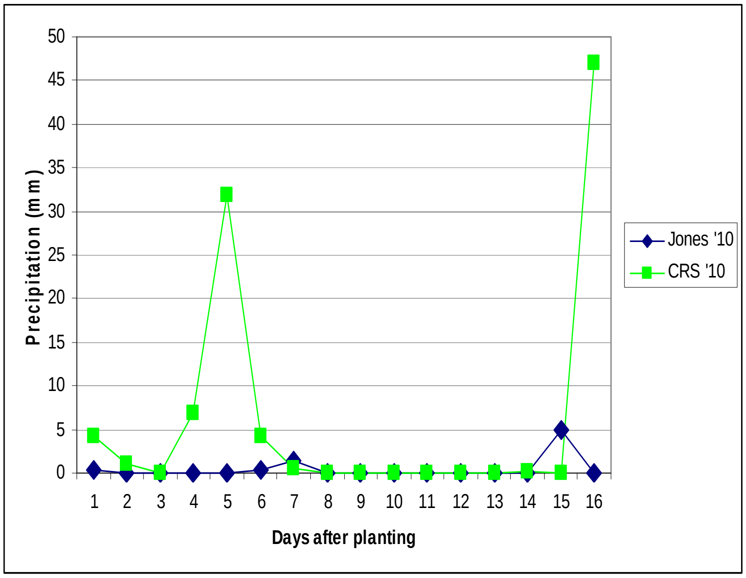
Dependent Variable	Year	Irr	Treat	Irr. x Treat
		Per 18.3 m Plot		
No. 1	0.3148	0.9325	0.1915	0.1704
Canner	0.1553	0.4691	0.4252	0.3784
Jumbo	0.1361	0.9833	0.5044	0.1509
Cull	0.2591	0.6940	0.6074	0.9604
Tot. Mkt.	0.1894	0.6815	0.9510	0.1208
Total	0.1868	0.6558	0.9464	0.1103
% Stand	0.5374	0.5219	0.6242	0.3890
		Per Plant		
No.1	0.2376	0.7069	0.1778	0.4552
Canner	0.1020	0.4300	0.3380	0.5219
Jumbo	0.1754	0.8820	0.6439	0.1315
Cull	0.2860	0.8605	0.4301	0.8817
Total	0.1107	0.8306	0.7918	0.3112

Table 10. Effects of irrigation when combining tests on yields, (MT ha^{-1}), among various holding durations, 2012 and 2013.

	Yield (MT ha^{-1})[z]					
Trt	US no. 1	Canner	Jumbo	Cull	Total	Total Mkt.
DOP	26.9 ab	5.7	5.3	0.4	38.3 b	37.9 a
1 DBP	28.3 a	5.7	6.1	0.6	40.7 a	40.1 a
3 DBP	24.1 bc	5.8	5.9	0.5	36.3 b	35.8 a
5 DBP	23.7 c	6.4	4.7	0.4	35.2 b	34.8 a
7 DBP	26.4 a-c	5.8	5.3	0.6	38.1 b	37.5 b
Pr>F (Yr.)	0.0548	0.0921	0.1277	0.3588	0.0018	0.0116
Pr>F(Irr.)	0.5611	0.8903	0.5623	0.8457	0.0209	0.1299
Pr>F(Trt.)	0.0141	0.6162	0.5404	0.5457	0.0035	0.0057
Pr>F(I*T)	0.1195	0.7436	0.4467	0.9389	0.0587	0.0738

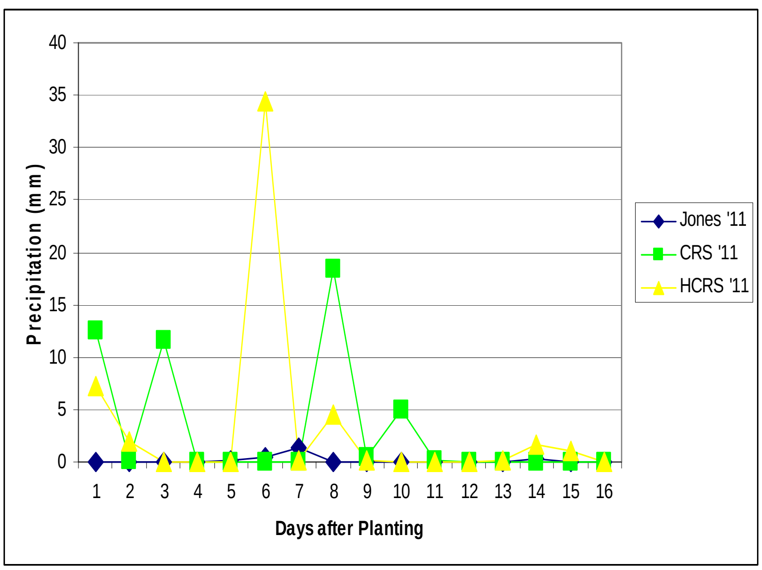
[z] Means followed by the same letter within column are not significantly different according to PROC ANOVA (Pr≤ 0.05).

Figure 1. Precipitation (mm) from 0 to 15 DAP accumulation at each test location and for each test year: A) Cunningham Research Station and Jones Farm, 2010; B) Cunningham Research Station, Horticultural Crops Research Station, 2011; and C) Horticultural Crops Research Station, 2012 and 2013.



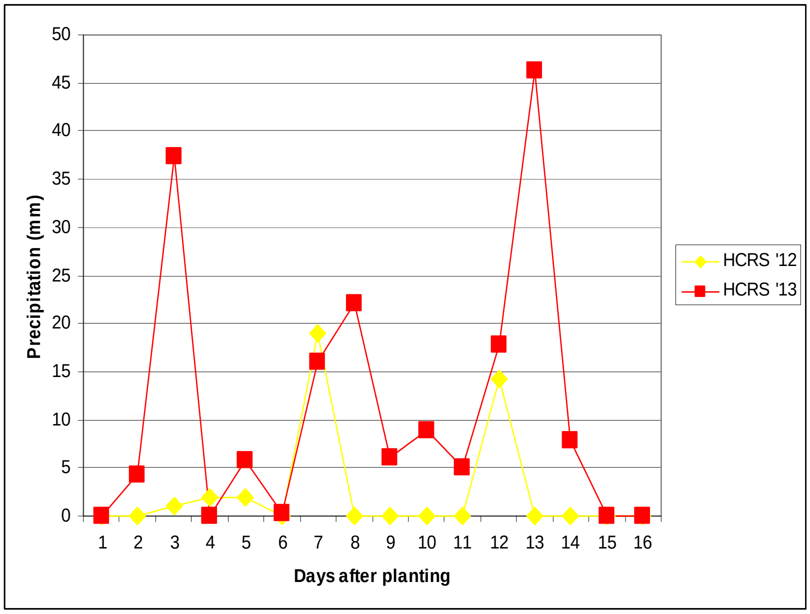
50
45
40
35
30
25
20
15
10
5
0
Precipitation (mm)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Days after planting
Jones '10
CRS '10

(A)



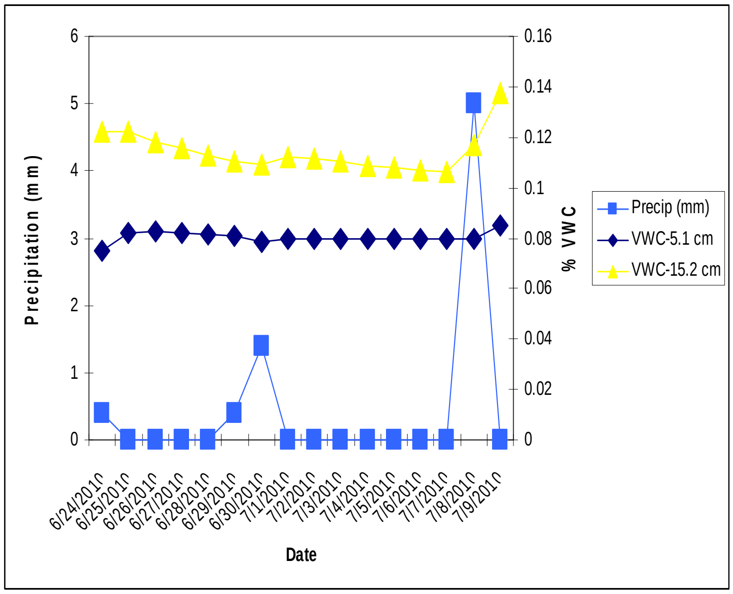
40
35
30
25
20
15
10
5
0
Precipitation (mm)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Days after Planting
Jones '11
CRS '11
HCRS '11

(B)

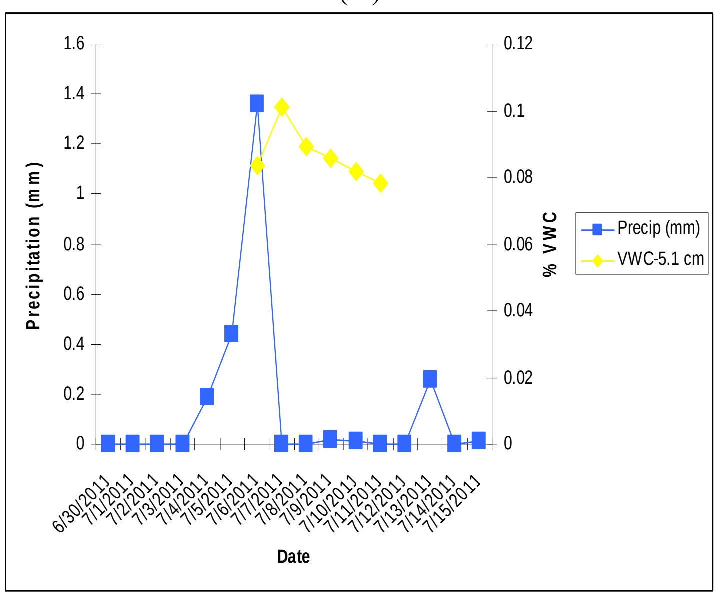


50
45
40
35
30
25
20
15
10
5
0
Precipitation (mm)
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Days after planting
HCRS '12
HCRS '13

(C)



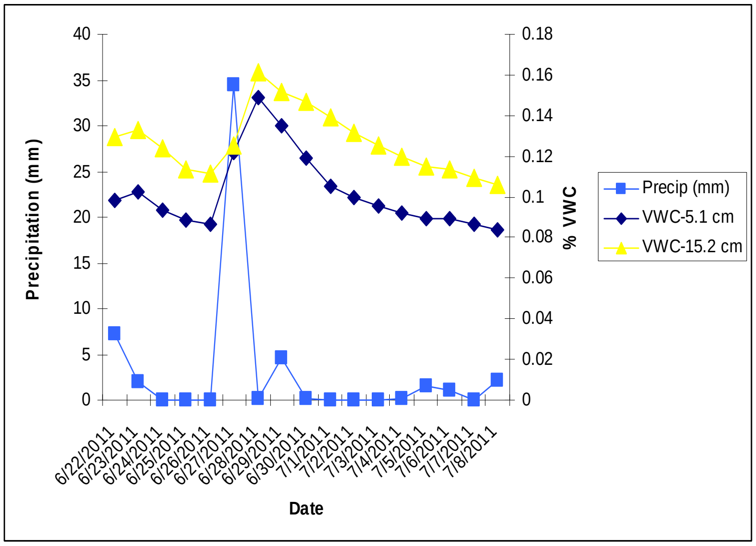
(A)



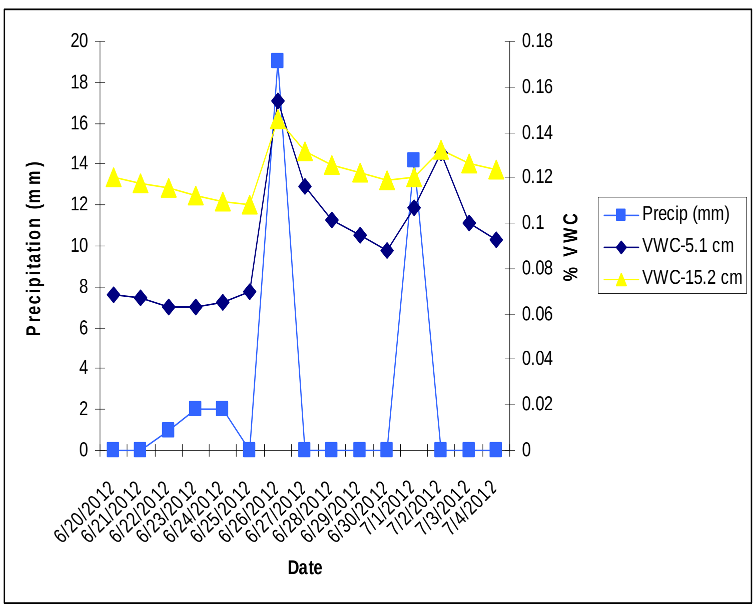
(B)

Figure 2. Precipitation and VWC at Jones Farm test locations for A) 2010 and B) 2011.

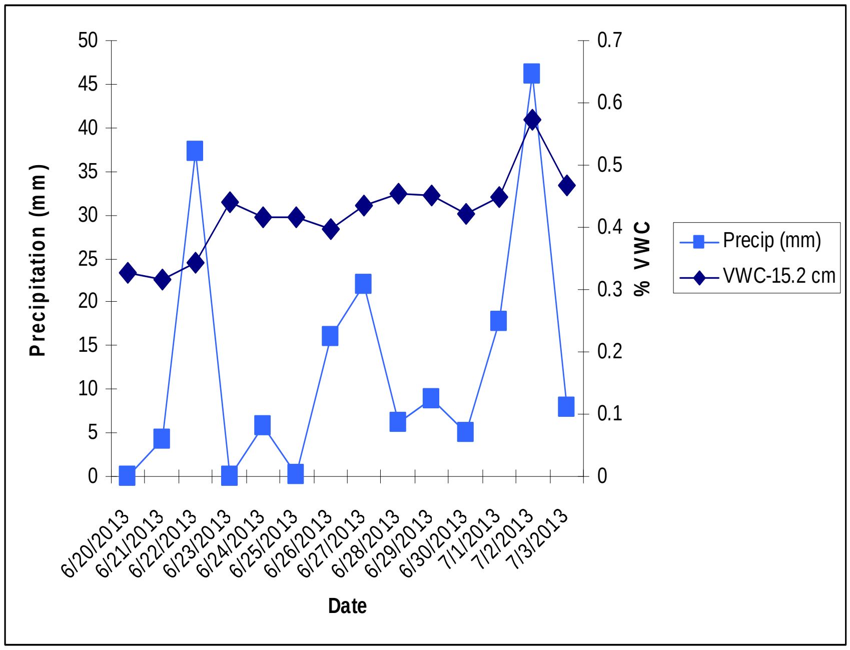
Figure 3. Precipitation and VWC at HCRS test locations for A) 2011, B) 2012, and C) 2013.


Precipitation (mm)
% VWC
Date
Precip (mm)
VWC-5.1 cm
VWC-15.2 cm
6/22/2011
6/23/2011
6/24/2011
6/25/2011
6/26/2011
6/27/2011
6/28/2011
6/29/2011
6/30/2011
7/1/2011
7/2/2011
7/3/2011
7/4/2011
7/5/2011
7/6/2011
7/7/2011
7/8/2011

(A)

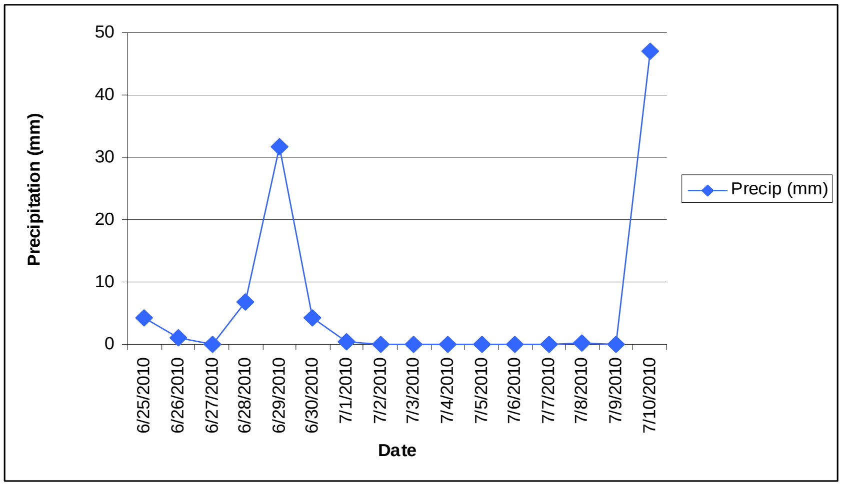

Precipitation (mm)
% VWC
Date
Precip (mm)
VWC-5.1 cm
VWC-15.2 cm
6/20/2012
6/21/2012
6/22/2012
6/23/2012
6/24/2012
6/25/2012
6/26/2012
6/27/2012
6/28/2012
6/29/2012
6/30/2012
7/1/2012
7/2/2012
7/3/2012
7/4/2012

(B)

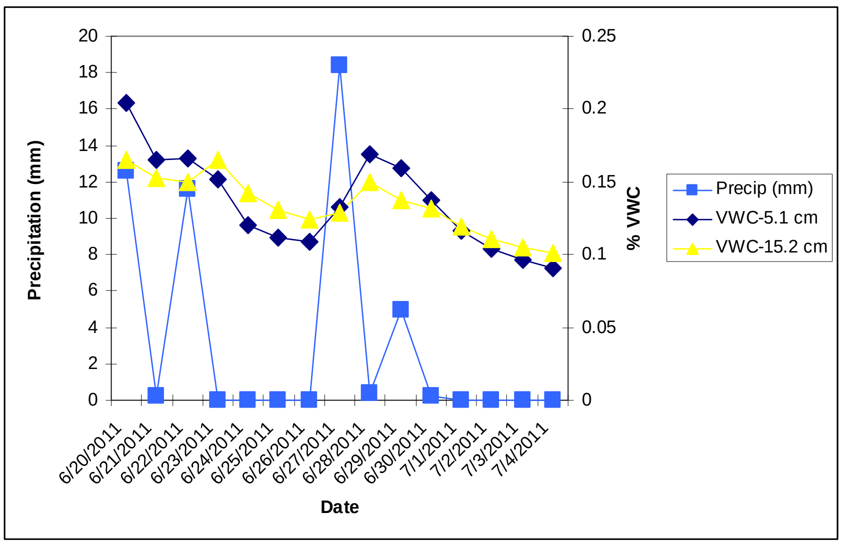


Precipitation (mm)
% VWC
Date
Precip (mm)
VWC-15.2 cm
50
45
40
35
30
25
20
15
10
5
0
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
6/20/2013
6/21/2013
6/22/2013
6/23/2013
6/24/2013
6/25/2013
6/26/2013
6/27/2013
6/28/2013
6/29/2013
6/30/2013
7/1/2013
7/2/2013
7/3/2013

(C)



(A)



(B)

Figure 4. Precipitation 0 to 15 DAP at CRS test: A) 2010 and precipitation and VWC at CRS test 0 to 15 DAP: B) 2011.

APPENDICES

Appendix A: Chapter 1

Table 1. Effects on plant stand by the interaction of irrigation and planting depth; 2013.

	Planting Depth [z]	
Irrigation Treatment	5.1 cm	15.2 cm
Irrigated	93.3 a	79.2 b
Non-Irrigated	92.1 a	92.5 a

[z] Means followed by the same letter within column are not significantly different according to PROC ANOVA (Pr≤ 0.05).

Appendix B: Chapter II

Table 1. Average storage room temperature and relative humidity recorded when stored in equipment shelter during holding duration of transplants for each test location [z] and year.

	2010		2011		2012[x]		2013	
Location	ºC	% RH	ºC	% RH	ºC	% RH	ºC	% RH
Jones Farm	28.8	67.7	27.4	66.3	X	X	X	X
CRS	28.9	69.6	26.8	59.6	X	X	X	X
HCRS	X [y]	X	27.6	62.3	NA	NA	24.1	70.3

[z] CRS represents Cunningham Research Station and HCRS represents Horticulture Crops Research Station.
[y] "X" represents when no test planted during given year or location.
[x] Data recorded with HOBO unit was not in correct parameters, therefore data could not be presented.

Table 2. Total precipitation (mm.) amounts recorded 0 to 15 days after planting per test location[z] and year.

	Precipitation (mm) – 0 to 15 DAP			
Location	2010	2011	2012	2013
Jones Farm	7.2	11.1	X	X
CRS	96.1	69.2	X	X
HCRS	X [y]	53.6	38.2	351.3

[z] CRS represents Cunningham Research Station and HCRS represents Horticulture Crops Research Station.
[y] "X" represents when no test planted during given year or location.

Table 3. Mean volumetric water content (VWC) of soils at two soil depths 0 to 15 DAP at each location[z] and year[y].

	VWC (m^3/ m^3)							
	2010		2011		2012		2013	
Location	5.1 cm	15.2 cm	5.1 cm	15.2 cm	5.1 cm	15.2 cm	5.1 cm	15.2 cm
Jones Farm	0.080	0.114	0.087	NA	X	X	X	X
CRS	NA	NA	0.135	0.132	X	X	X	X
HCRS	X[x]	X	0.102	0.126	0.093	0.121	0.372	

[z] CRS represents Cunningham Research Station and HCRS represents Horticulture Crops Research Station.
[y] Decagon loggers did not always record therefore missing data occurred in 2010 and 2013. 2013 VWC was recorded on the station at a depth of 20 cm.
[x] "X" represents when no test planted during given year or location.

Table 4. Mean volumetric water content (VWC) of soils at two soil depths 0 to 15 DAP at Horticulture Crops Research Station within each irrigated setting for each year[z].

	2012 - Irrigated		2012 – Non-Irrigated		2013 – Irrigated/NI
Location	5.1 cm	15.2 cm	5.1 cm	15.2 cm	20cm
HCRS	0.071	0.143	0.093	0.121	0.372

[z] Decagon loggers did not record in 2013; therefore VWC was recorded by the State Climate Office weather station located on the research station at a depth of 20 cm.