YIELD COMPARISON OF TRANSPLANTED TOMATO AND PEPPER PLANTS GROWN IN DIFFERENT SIZED CELL PACKS

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Yield Comparison of Transplanted Tomato and Pepper Plants

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF SCIENCE

ABSTRACT

Weinmann, Todd Joseph; M.S.; Department of Plant Sciences; College of Agriculture, Food Systems, and Natural Resources; North Dakota State University; July 2010. Yield Comparison of Transplanted Tomato and Pepper Plants Grown in Different Sized Cell Packs. Major Professor: Dr. Harlene Hatterman-Valenti.

Field experiments were conducted at Fargo, North Dakota, in 2006 and repeated at Fargo, Oakes, North Dakota, and Absaraka, North Dakota, in 2007 to compare time to harvest and yields from tomatoes (*Lycopersicon esculentum* var. esculentum) and peppers (*Capsicum annuum)* that had been initially grown in different sized cell packs. A second objective was to determine if root manipulations to tomatoes at the time of transplanting could overcome root-bound effects of delayed establishment and reduced yields. Three tomato cultivars with differing growth or fruiting characteristics were used: 'Big Beef' an indeterminant cultivar, 'Sungem', a determinant cultivar, and 'Roma', a determinant paste cultivar, and two pepper cultivars with differing fruiting characteristics: 'Big Bertha' a green bell pepper cultivar and 'Cherry Bomb', a hot pepper cultivar were used. Two weeks after seeding, pepper and tomato seedlings were transplanted into one of three cell packs with cell volumes of 84, 137, and 287 cm^3. Seedlings were grown in cell packs in the green house before acclimating for 7 days and transplanting into a black or white plastic covered row system in the field. The second study evaluated three root manipulation treatments: dipped in auxin after one-fourth of the bottom part of the roots were removed, dipped in auxin without one-fourth of the bottom part of the roots removed, four vertical cuts to the root ball

for root-bound seedlings, and untreated roots grown in 84 cm^3 cells and immediately planted.

Tomato seedlings grown in the 287 cm^3 cell packs were visually larger than seedlings in 84 or 137 cm^3 cell packs when transplanted to the field. However, all plants flowered at similar times and fruit growth did not differ. Results suggest that the three cell volumes did not influence the period between field transplanting and the first harvest or the total yield. Pepper seedlings grown in the 287 cm^3 cell packs were visually larger than seedlings in 84 or 137 cm^3 cell packs when transplanted to the field. With the peppers (bell and hot) the three cell volumes did not influence the period between field transplanting and the first harvest, but an increase in yield was seen with the 287 cm^3 cell packs followed by the 137 and 84 cm^3 cell packs respectively.

None of the root manipulations altered the time from field transplant to first harvest or the total yields compared to the untreated roots. Results suggest that root manipulation to root-bound tomato seedlings when transplanting in the field will not hasten field establishment or shorten the period between transplanting and the first harvest, and will not increase yield.

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INTRODUCTION

Seedling tomatoes and peppers are purchased every year to grow in the home garden or for commercial production. The cold climate and short growing season of North Dakota requires home owners and commercial growers alike to improve production practices for warm-seasoned vegetables such as tomatoes and peppers that require a long growing season, generally between 70 to 85 days in North Dakota, and warm temperatures of 20 to 25 °C to ripen fruit.

Over the past five years, garden centers have changed bedding plant practices due to increases in production costs. The main change in the bedding plant industry has been the decrease in the number of plants per unit area sold to the public. To accomplish this, the number of cells per cell pack was decreased, while the cell volume was increased. However, questions arise as to seedling container size requirements and how cell volume influences plant growth and development. In addition, secondary questions arise about the effects of root-bound seedlings when plants are not sold in a timely manner and if there are methods to overcome delayed establishment with root-bound seedlings. Information regarding the right container for purchasing transplants is limited in the Northern Great Plains region. This information would provide home-owners and commercial growers of these crops insight on increased yield and economics, and lengthening the harvest season.

Root development influences plant establishment and is dependent on the root environment container size and any stresses prior to being transplanted to the field. Cell pack size directly influences the root environment due to cell volume and the amount of rooting media in each cell and indirectly influences the effects of wet-dry cycles and moisture stresses.

LITERATURE REVIEW

Tomato and pepper production in the Northern Great Plains is limited by a short growing season and a limited number of adapted cultivars. Increasing yield by planting seedling transplants from cell packs has been used to shorten the time to fruit production and increasing the harvest period. However, it is not known whether altering the root environment prior to transplanting to the field will have any measurable impact on yield or earlier harvest with herbaceous plants such as tomatoes and peppers. Similarly, it is unknown whether physical alterations of the roots that are root-bound or the addition of a rooting hormone will aid or hinder field establishment and final field production.

Tomato Requirements

Tomatoes are one of the most popular vegetable crops in the United States. Fresh market tomatoes are grown year-round with Florida and California accounting for 79% of the total U.S. production (Swaider et al., 1992). The plant is actually a herbaceous perennial in its native habitat, but is grown as an annual in the U.S. because it is easily killed by frost.

Tomatoes can have one of three different growth habits; indeterminate, semi-determinate, and determinate. The indeterminate type plants usually produce three or four leaves between flower clusters (Swaider et al., 1992). The primary shoot suppresses side shoot development, so there is considerably less branching compared to determinate plants. The shoot does not end in a flower cluster, thus continues to grow until a frost or some other factor kills it.

Determinate type plants produce only one or two leaves between flower clusters (Swaider et al., 1992). The shoot terminates in a flower cluster after several clusters have been established. Shoot termination forces side shoots to develop from axillary growing points, which repeat the pattern. Flowering is concentrated in a shorter period of time than in indeterminate types. Determinate type plants are often referred to as bush types because growth tends to be compact and symmetrically circular compared to the sprawling growth pattern of indeterminate type plants.

Semi-determinate type plants have characteristics between the other two types. Plants tend to have several lateral flower clusters, but stems will also terminate in flower clusters (Swaider et al., 1992).

Since tomatoes are classified as a warm season plant they are planted after frost concerns have passed. A well drained loam soil with a pH of 6.2 to 6.8 is recommended; however, they will grow in most soils. There should be at least 61 cm between staked plants, and at least 76 cm between caged plants. Tomatoes grown without staking or caging will also benefit from having at least 61 cm between them. This will benefit air flow, will decrease the disease potential, and increase photosynthesis (Utzinger and Brooks, 2010).

Cultural Practices in Growing Tomatoes

Tomato transplants are started in cell packs to provide an extension to the growing season. The transplants are chosen for planting by their freedom of disease and insect pests, four to six true leaves, lack of blossoms and a sturdy stem. When grown staked or with cages, the support systems are placed when the transplants are small to avoid root damage. Unstaked or uncaged transplants are usually mulched with black plastic or an organic type of weed barrier such as weed free straw (Utzinger and Brooks, 2010). Concerns with slugs are warranted with the organic types of weed barriers.

Determinate cultivars require a shorter frost-free period (≈ 80 days) until fruit harvest compared to indeterminate cultivars (≈ 120 days) (Swaider et al., 1992). Optimum growth occurs at day air temperatures between the range of 18 to 24 °C and stops at a maximum temperature of 35 °C or a minimum temperature of 12 °C. Temperature markedly affects flowering and fruit set with high day temperatures (≥ 32 °C) in conjunction with low humidity being capable of destroying the viability of pollen. Low temperatures may also reduce the viability of pollen and thus decrease fruit set. Conditions such as hot, drying winds, insufficient light, excessive nitrogen, moistures stress, and insect/disease injury can cause flowers to drop and in return decrease fruit set. Thus, if internal or external conditions are not favorable at flowering, the plant will shed its flowers before setting fruit.

Pepper Requirements

Peppers are classified into six different horticultural types (bell, Anaheim chile, jalapeno, cherry, wax, and Tabasco) based on their wide variation in fruit size, shape, and color (Swaider et al., 1992). Bell peppers make up two-thirds of the total pepper production in the United States with Florida and California as the largest producing states. Chile peppers are the most widely grown pungent pepper, with New Mexico as the largest producing state.

Peppers are determinate with a single stem that terminates in a flower bud (Swaider et al., 1992). They are considered a warm-seasoned plant, thus are planted after frost concerns have passed. A well-drained soil with good tilth and a pH of 6.0 to 6.8 is recommended; however, they will grow in most soils. At least 46 cm between the plants will benefit air flow and will decrease disease potential and increase photosynthesis (Utzinger, 2010).

Flowers are self-pollinated and flowering is day-neutral, but hastened under long days and warm temperatures (Swaider et al., 1992). Sweet peppers grow best at air temperatures between 18 to 29 °C, while most pungent peppers grow best at air temperatures above 24 °C. Consistent warm night temperatures (above 21 °C) are important for successful production of some pungent pepper types such as tabasco. High temperatures (above 32 °C) will cause flower abortion in sweet peppers, while these temperatures will increase the fruit set of many pungent pepper types. Fruit set of all pepper types will not occur at temperatures less than 16 °C.

Cultural Practices in Growing Peppers

Transplants are started in cell packs to provide an extension to the growing season. The transplants are chosen for planting by their freedom of disease and insect pests, three to five true leaves, lack of blossoms and a sturdy stem. It is recommended to water peppers immediately after planting. They are grown without staking or caging. Transplants can be grown with mulched black plastic or an organic type of weed barrier such as weed free straw (Utzinger and Brooks, 2010). Concerns with slugs are warranted with the organic types of weed barriers.

Cell Pack Volume Impact on Yield

The efficiency of transplant production incorporated into commercial or garden production is important for yield and reducing the time of the harvest. More plants can be grown in smaller cell packs, but an increase in root-bound plants is noticed with smaller cell packs when compared to seedlings grown in larger cell packs. Differences between species and cultivars have been reported and have shown conflicting results (NeSmith and Duval, 1998).

Transplant age was compared in Florida for tomato and pepper crops (Leskovar et al., 1991). The transplant age ranged from two weeks to six weeks with one week intervals between them. No differences in yield were discovered between the transplants. Thus production costs could be saved by using younger transplants rather than growing them longer.

Similarly, muskmelon transplants utilizing cell pack volumes of seven to 100 cm^3 did not show consistent results when comparing total yield (Maynard et al., 1996). A switch to different transplant cell volumes and a more efficient utilization of greenhouse space needs to be compared as being more or less beneficial for the grower.

A comparison of container size was done on tomato seedlings grown in Michigan and Florida (Weston and Zandstra, 1986). Less transplant shock was suffered by transplants from cells of larger volume. Earliest yield, largest transplant size, and greatest marketable weight were found in plants grown in the largest cells that were 39.5 cm^3. However, total yields were similar between the different cell sizes. In addition, a larger and earlier yield was reported from the seedlings grown in Michigan than those grown in Florida.

Vavrina and Arenas (1997) compared two cell-volumes for tomatoes grown in the spring or fall and reported that seedlings grown in 4.4 cm X 4.4 cm cells had a greater yield and produced fruit earlier than those grown in the industry standard of 2.5 cm X 2.5 cm cells. In the fall treatments, there was not a significant difference in marketable fruit of extra large size. However, in spring treatment, the 4.4 cm X 4.4 cm cells had a significant increase in marketable extra-large fruit. Extra-large fruit of good quality brings a premium price on the market. Similarly, the marketable fruit totaled greater for those grown in the spring compared to the fall-grown tomatoes, but may have been hampered by a frost that ended the trial before it was complete in the fall.

Plant yield responses to cell increasing volume may not be similar for all vegetables. Weston (1988) found that the shorter and less vigorous pepper transplants from small cells had similar yields to more vigorous transplants from larger cells. In addition, seedlings that were older when transplanted had significantly higher yields than younger seedlings. The 40 cm^3 volume cells showed an earlier yield increase of 37% above the smaller 5.6 cm^3 volume cells, but the difference in total yield was not significant. Larger yields were produced by transplants that were 60 days old compared to transplants that were 50, 40, and 30 days old.

A study incorporating compact-growth-habit tomatoes was done in North Carolina in 1991 and 1992 (Kemble et al., 1994b). The study used planter flats that had volumes of 9 cm^3, 14 cm^3, 27 cm^3, 37 cm^3, and 80 cm^3. The cells in the planter flats with volumes of 37.1 cm^3 had net returns that were higher than the other flat cell volume sizes.

The effect of cell volume with pre-transplant development and post transplant yield was studied on the muskmelon cultivars 'Mission' and 'Superstar'. Cell volumes of 7 cm^3, 22 cm^3, 25 cm^3, 26 cm^3, 36 cm^3, 50 cm^3, 70 cm^3, and 100 cm^3 were evaluated (Maynard et al., 1996). With the 'Mission' muskmelon, an increase in cell volume resulted in an increase in total yield during one growing year in Indiana and two growing years in Florida. With the 'Superstar' muskmelon, an increase in cell volume resulted in an increase in total yield for one growing year at both locations. In Indiana with 'Mission' the increase in earlier yields as the cell volume increased was linear even though the total yield was not affected by the cell volume.

Earlier yields from transplants with an increased root volume were observed in Michigan, in tomato plants grown in two different locations. Research done by Weston and Zandstra (1986), showed that as the cell volume increased, the plants were earlier yielding. In comparison of the different treatments, the total fruit yield was not significant. Treatments of "root cell size and location of transplant production" and "root cell size and spacing on growth of 15 and 30 day old seedlings" did not differ significantly with the total yield. Total yield comparison between the large vigorous plants and the small less-vigorous plants was similar.

According to Vavrina and Arenas (1997), tomatoes grown in larger container cells of 4 cm^3 had earlier harvestable tomatoes than the 3 cm^3 container cells. The initial cost of production would need to be compared to other costs that are incurred with early harvest price and shortened season situations.

The bell pepper 'Yolo Wonder L' was tested in differing cell sizes of 6 cm^3, 15 cm^3, 19 cm^3, 31 cm^3, and 40 cm^3, to evaluate cell-volume influence on yield (Weston, 1988). The experiment was conducted in Kentucky and Florida and it was discovered that the large cells produced larger earlier yields in both environments, but the total yields were not greater. Cell size did not show a significant effect on the total yield. The larger cell transplants had fruit that was harvestable two weeks earlier than the transplants that had come from cells that were smaller. The smaller celled transplants produced less vigorous and smaller plants than the larger cell volume, but did not affect total yield comparison.

Marr and Jirak (1990) found similar yields for transplanted tomato plants of the same age, but grown in the different sized trays containing 200, 406, and 648 plugs per tray. They reported that seedling tomato transplants held up to four weeks in the different sized plug trays and then transplanted to larger containers allowed for a decrease in space required that otherwise would be needed for 6 weeks if the transplants were held in larger containers of 48 cells in a flat. A decrease in yield was observed for plants held from five to seven weeks. They noted that reduction in regrowth was seen in plants of the higher density smaller plug trays of 648 and 406 units than the plug trays that contained 200 units.

Cell Pack Volume Impact on Physiological and Morphological Changes

Physiological and morphological changes as well as transplant quality changes have been observed with decreasing root volume. Root restriction and container size will affect anthesis, the uptake of nutrients, respiration, water uptake, chlorophyll levels, photosynthesis, accumulation of biomass, and shoot and root growth. Conflicting data has been published with regard to decreasing the soil volume. Differences have been noted between species and cultivars and the time span that a plant is kept in a container is also a factor to consider. The largest concern with root restriction and container size is the post performance of the transplants (NeSmith and Duval, 1998)

A comparison of leaf area and dry weight of 'Marmande' tomato plants grown in cell volumes of 7 cm^3, 35 cm^3, and 230 cm^3 found that plant growth was lowered when associated with root restriction (Mugnai et al., 2000). An increase in the root to shoot ratio was also observed as the cell volumes decreased. There is more root to shoot and the smaller cells have more roots and less shoots.

Flowering is essential for fruit production in tomatoes and peppers. To increase efficiency in the greenhouse during transplant production, one wants to use the smallest amount of area for the largest number of transplants without delaying anthesis. Cell volumes of 27 cm^3 through 37 cm^3 were found to be the smallest cell pack sizes that could be used without delaying anthesis in tomatoes and peppers (Kemble et al., 1994a).

Dwarf tomato plants can result when the cell volume restricts root growth. Root restricted plants had lower leaf areas, smaller fruit size, and fewer mature harvestable fruit (Ruff et al., 1987). However, root restriction did not decrease the harvest index. This may aid growers in production, as a similar harvest index was seen between plants grown in larger or smaller containers. A smaller plant size and a harvest index that was constant would allow for higher tomato planting densities. Increased root restriction has been shown to cause earlier fruit maturation while flower production declined proportionately as the density of roots that were bound or restricted increased. However, root restriction in peppers corresponded with an earlier fruit set that was earlier than when roots were less restricted (NeSmith et al., 1992).

Cell volumes of (3, 27, 37 and 80 cm^3) were used by Kemble et al. (1994a) for tomato transplants. They observed that there was a decrease in the time to anthesis when the cell volume was increased.

A study done in Pisa, Italy utilizing cell volumes of 7 cm^3, 35 cm^3 and 230 cm^3 with the 'Marmanade' tomato showed that restricted root volumes caused an increase in root to shoot ratio and a decrease in growth of the leaf area of the plants (Mugnai et al., 2000).

'Better Bush' tomatoes were grown in container volumes of 450 cm^3 and 13,500 cm^3. Roots of plants grown in the smaller volume container formed a mat that was highly branched, while roots of plants grown in the larger volume container formed a long tap root with branching. They suggested that in space limited conditions, 'Better Bush' or smaller container volume tomatoes would be more efficient in fruit production than tomato plants requiring larger container volumes (Ruff et al., 1987).

In comparison, kiwifruit was grown in containers of different volume (Tonutti and Giulivo, 1990). It was discovered that the plants grown in reduced volume containers and in closer planting densities had decreased shoot growth. Root dry weight was reduced and root system spread was inhibited. Shoot growth rate was decreased in smaller containers and in plants grown in a more densely spaced environment. Increased competition of roots grown more densely together caused a reduction of the aerial part of the kiwi plants.

The 'Sunny' tomato variety was studied using a flotation system and direct seeding transplant production methods (Leskovar et al., 1994). It was discovered that the fruit yields were similar, even though direct seeded transplants had more prominent basal roots, while the floating system had more prominent lateral roots. Earlier yields occurred with the floating system compared to the direct seeding system.

Researchers found that cell shape did not affect root growth, but did affect plant growth (Liptay and Edwards, 1994). They found that narrow cells caused a decrease in tomato height and that height increased when the cell-shape was a rectangle instead of a square. Plants grown in a rough-textured, inner-surfaced cell had roots that were smaller and stubby in appearance when compared to roots in the smooth-textured, inner-surfaced cell. The shoot growth was not different between the smooth textured inner surface and the rough textured inner surface cells.

According to Birchell and Whitcomb (1997), even though the roots on tomatoes were found to be bound in a cell, no difference in the plant growth was detected. It has been shown that restricted roots in 'Jupiter' bell peppers has resulted in anthesis and fruiting to began earlier than less restricted roots (NeSmith et al., 1992). According to Nishizawa and Saito (1998) the tomato varieties of 'Korokoro' and 'Ougata-fukujo' did not show a significant difference in dry matter regardless of container size.

Transplant Shock and Stress

Slowing the rate at which plants grow allows them to adjust or acclimate to the stress of planting in the field and helps them adjust to the shock of being transplanted (Marr, 1994). By withholding water and or decreasing the temperature from the greenhouse environment, acclimation or hardening-off can be accomplished. Vegetative growth can be reduced by decreasing available nitrogen, and root development can be encouraged by increasing the soil phosphorous level for three to five days before transplanting. The acclimated plants will have changed in that their leaves will thicken and their waxy leaf covering will increase. The acclimatization process also allows plants to change physiologically so that they can be grown with less initial stress. Seedlings grown in the low stress environment of a greenhouse will need to be hardened off or acclimated to avoid transplant shock when transplanting into the field. When a plant is placed into a field setting directly from the greenhouse, transplant shock can occur because of environmental changes and cultural practices. Symptoms of transplant shock can include increase wilting, stunted growth, and delayed flowering.

To avoid transplant shock, plants from cell packs or individual containers should be healthy, free of pests and diseases, have four to six true leaves and not have blossoms or fruit on them. These seedlings are usually set outside of the greenhouse on a cloudy day and brought in at night. Moving the seedlings out of the greenhouse during the day and back into it at night will help the plants adjust to the climate outside. Most seedlings will be ready to plant in the field after acclimatization of 1-2 weeks (Burrows and Graper, 2003).

Production Practices

Growing healthy and damage free transplants has the advantage of an earlier starting period. Transplants are often exposed to cold temperatures when they are planted into the field or garden. This stress of cold temperatures can delay growth, anthesis, fruit development, and possibly delay overall yields and harvest. Another stress is the change of fertilization practices between the greenhouse application and the field setting. To promote higher and earlier yields, N and P need to be used to condition seedlings during their initial phase of transplant production (Melton and Dufault, 1991).

Mulches are used to decrease water loss and to save time spent on weeding (Smith, 1999). Getting to the market early is important for most vegetables including peppers and tomatoes. Black or clear plastic used for tomatoes grown in the field or garden will keep them more healthy, cleaner, and in most instances, the total yield will be increased. The time span that a plant is kept in a container also is a factor to consider (NeSmith and Duval, 1998).

OBJECTIVES

This study was conducted to determine and evaluate early harvest and potential yield differences of transplanted tomato and pepper plants by planting transplants from various sized containers and also by root alterations of tomatoes. It was believed that the yield following treatment will be increased by utilizing a larger container instead of a smaller container. The research was conducted to address following questions: Will the size of the container affect the yield of the tomato and pepper transplants? Will manipulation of restricted root growth (root-bound plants) for herbaceous plants such as tomato affect yield potential? The specific objectives of this study were to evaluate the effect of: 1. seedling container size for transplanted tomato and pepper on total yield, 2. seedling container size for transplanted tomato and pepper on the early harvest period, and 3. manipulating root-bound tomato seedlings for field transplant on yield and harvest time.

MATERIALS AND METHODS

Experiments were conducted at one location in 2006 at the NDSU Agriculture Experiment Station test plots immediately west of the North Dakota State University main campus in Fargo, ND. The experiments were repeated at three locations in 2007: the NDSU Agriculture Experiment Station test plots immediately west of the North Dakota State University main campus in Fargo, ND; the Oakes Research Extension Center, near Oakes, ND; and the North Dakota State Research Arboretum, near Absaraka, ND. Tomatoes and peppers were transplanted at the Fargo location on May 9, 2006, and May 29, 2007; and on June 6, 2007 and June 13, 2007 at Absaraka, and Oakes respectively. The fields were initially planted in rye in late summer and killed with glyphosate and tilled into the ground in the fall prior to freezing temperatures.

One field study was done to investigate the yield potential of tomatoes and peppers when utilizing various container sizes for transplanting. A second field study was done to examine the methods to alleviate root-bound tomato plants and the impact on yield potential.

This study examined the indeterminate variety ‘Big Beef’ and the determinate variety of “Sungem” and the determinate paste tomato cultivar of ‘Roma’. The study also examined the bell pepper cultivar of ‘Big Bertha’ and the hot pepper cultivar of ‘Cherry Bomb’.

Cultivars were chosen that had different growth habits, but similar days to maturity. The tomato and pepper plants were started in the greenhouse on March 24, 2006 and March 22, 2007 and maintained in the greenhouse until one week before they were transplanted at the plot sites. Heat and humidity was controlled to avoid fungus and disease outbreaks. All plants received water from the same source and the same amount of sunlight. Watering was done by overhead sprinklers and inspection of cells that have been missed were done and watered by hand. The sites were tilled and dragged with a harrow in the spring and 49 kg N/ha, 98 kg P_2O_5/ha, and 49 kg K_2O/ha as a 5-10-5 fertilizer was incorporated into the soil with spring tillage. Black plastic was placed as a weed barrier and the edges were dug into the soil with an x cut into the plastic at appropriate spaces for plant placement. The environments were overhead irrigated at all sites, except the Absaraka environment that received drip irrigation, at a rate of 5 cm of water per week including rainfall. Weeds between the rows were controlled by roto-tilling and those coming through the plastic along side of the plant were pulled by hand. Rodenticide boxes having "Warfarin Ready-to-Use" baits were placed in the plots to kill rodents that entered from neighboring grassy fields. Harvesting and yield weighing was done by hand. One repetition in the Fargo 2007 environment area was compromised by human theft of fruit and the data from this area was not included in this study.

Seeds were planted into germination flats in Sunshine Mix #1 and placed under glass greenhouse conditions of natural sunlight with supplemental watering of approximately 3 cm per week. They reached 3 cm in height from the base to the uppermost stretched up leaf tip on May 9, 2006, and were transplanted into cell packs of 84, 137, and 287 cm^3.

The plants were transplanted four and eight weeks later into a field plot that had a silty-clay soil type and a winter rye cover crop that was mowed and tilled into the soil on May 7, 2006. Winter rye was grown to encourage alleopathic weed control and mowed as a natural weed barrier and soil erosion stabilizer to protect the soil from the overhead irrigation system that was employed. Steps were taken to ensure that the transplants were treated the same and that they were handled in a manner that gave them all equal survivability. Planting the transplants into an environment such as a rotation of spring wheat followed by winter rye should reduce the incidence of disease transmittability. Plastic was used for the tomato and pepper studies as an additional weed control measure and to assist with soil warming.

The second study examined methods to alleviate root-bound plants and the impact on yield and early harvest potential. The transplants were grown in a glass greenhouse as previously described. Plants were grown in 84 cm^3 plugs for 8 weeks. The transplants had the following treatments applied to them: (i) dipped in auxin and one-fourth of the bottom part of the roots cut off, (ii) dipped in auxin, (iii) one-fourth of the bottom part of the roots cut off, and (iv) unaltered roots. Data collection and analysis was identical to the first field study. The total yield were recorded and statistically compared.

The experimental design was a randomized complete block with four replications for the tomatoes and four replications for the peppers. Treatment and variety were considered fixed effects. Environments and blocks within each site were considered random effects. Mean squares were equated to expected mean squares to determine the proper denominator for F-tests. The variety source of variation was tested, using the environment X variety mean square as the denominator for the F-test. Data collected includes comparison of environments and treatments for yield. All data was analyzed using ANOVA in Statistical Analysis Systems (SAS)[1]. Fisher's Protected LSD test at a significant level of 0.05 was used for means separation where appropriate.

Tomato Container Volume Study

Three tomato cultivars with differing growth or fruiting characteristics were used: 'Big Beef', an indeterminant cultivar with73 days to maturity; "Sungem", a determinant cultivar with 58 days to maturity, and 'Roma' a determinate tomato paste cultivar with 75 days to maturity.

All of the tomatoes were grown in a glass greenhouse at North Dakota State University. Supplemental light was not utilized. Plants were watered by hand and a 200 ppm N fertilization rate was applied two times per day as a soluble 20-20-20 fertilizer until it drained out from the bottom of the flats. The tomato seedlings were transplanted into the different container volumes of 84, 137, 287 cm^3 two weeks after hand seeding into a seed tray using Sunshine 21 mix as the rooting media.

Seedlings were grown in the various container volumes for two weeks prior to acclimating outside in a wind protected area for one week. Following field transplanting into the plastic row system, all plants were watered and plant height measured (Table 1).

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[1] SAS version 9.1, Statistical Analysis Systems Institute, SAS Circle, P.O. Box 8000, Cary, NC 25712-8000.

Table 1. Average tomato height at transplanting for the container volume study for the 2006-2007 growing season.

Tomato cultivar	Fargo 2006	Fargo2007	Absaraka 2007	Oakes 2007
	-------------------	------------------- cm	-------------------	-------------------
'Big Beef'	36	38	42	43
'Sungem'	31	31	34	37
'Roma'	31	31	36	38

The tomatoes fruits were harvested every 10 days beginning on August 5, 2006 at the 2006 Fargo site, on August 30, 2007 at the Fargo 2007 site, on August 14, 2007 at the Oakes site, and on August 7, 2007 at the Absaraka site.

Fruit harvest stopped at first frost. This harvest continued from August 5 to October 9, 2006 and from August 10 to October 9, 2007 at the Fargo sites. The harvest at Abasaraka continued from August 7 to October 9, 2007, and at Oakes the harvest continued from August 10 to October 9, 2007. Tomato fruits were graded according to USDA standards by "red" color and acceptable quality or cull defects. The red color refers to the USDA standards of more than 90 percent of the fruit shows the red coloring on the fruits surface. The acceptable quality or cull defects refer to cuts and broken skins, catface channels implying slight touching would cause the skin to break and the fruit to leak, and scars that are not from catfacing (USDA, 1997). The fresh weight of the fruit was recorded per plot for each harvest. Diseased and split fruit were graded as culls and discarded regardless of size. Data was not used from the culls.

The trial at each of the four environments consisted of 36 experimental units or plots (four replications, a factorial combination of three varieties x three container sizes per replication). However, theft of fruit occurred in one replication (Fargo 2007) therefore this replication was excluded from the study because of the loss of yield. Each experimental unit consisted of three plants, spaced on 91 cm centers with 240 cm between rows. Rogue weeds were hand pulled around plants and disked under between rows once a week.

Pepper Volume Study

Two pepper cultivars with differing fruiting characteristics: 'Big Bertha', a green bell pepper cultivar with 72 days to maturity, and 'Cherry Bomb', a hot pepper cultivar with 62 days to maturity were used in this study.

The pepper plants were grown in a glass greenhouse at North Dakota State University. Supplemental light was not utilized. Plants were watered by hand and a 200 ppm N fertilization rate was applied two times per day as a soluble 20-20-20 fertilizer until it drained out of the flats. The pepper seedlings were transplanted into the different container volumes of 84, 137, 287 cm^3 two weeks after hand seeding into a seed tray using Sunshine 21 mix as the rooting media.

Peppers were transplanted upon arrival at the Fargo location on May 9, 2006 and May 29, 2007 for the Fargo environment, and on June 13 and June 6, 2007 for the Oakes and Absaraka, ND environments, respectively. Seedlings were grown in the various container volumes for two weeks prior to acclimating outside in a wind protected area for one week. Pepper transplants were transported by truck and planted immediately upon arrival at each study site. The average pepper height at transplanting is shown in Table 2.

Table 2. The average transplant height of peppers for each of the study sites for the 2006-2007 growing season.

Tomato Type	Fargo 2006	Fargo 2007	Absaraka 2007	Oakes 2007
	----------------------	----------------------	cm----------------------	----------------------
'Big Bertha'	23	23	27	32
'Cherry Bomb'	26	26	31	33

Peppers were harvested approximately every 10 days with harvest stopping at first frost. The harvest went from August 5 to October 9, 2006 and from August 10, to October 9, 2007 for the Fargo site. Pepper harvest at Abasaraka went from August 7, to October 9, 2007, and at Oakes the harvest went from August 10, to October 9, 2007.

The design of the pepper field experiments was a randomized complete block with four replications. Experimental units contained two plants spaced on 91 cm centers. Row spacing was 240 cm. Pepper fruit were graded according to USDA standards for sweet (bell) peppers of "mature" green, and acceptable quality or cull defects. Mature green implies that the peppers stage of development can handle normal shipping and handling. The red peppers were harvested when the color of the pepper fruit had more than 90 percent red surface color on the fruits surface. The unacceptable quality or cull defects refer to sunscald, openings or punctures in the walls of the pepper, scars greater than 3 cm in diameter, sunburn discoloration greater than 25 percent of the pepper walls, and bacterial spot greater than a 3 cm circle diameter (USDA 1997). The fresh weight of the fruit was recorded per plot for each harvest. Diseased and split fruit were graded as culls and discarded regardless of size.

The trial at each of the four environments consisted of 24 experimental units or plots (four replications, a factorial combination of two varieties x three container sizes per replication). Each experimental unit consisted of two plants, spaced on 91 cm centers with a 240 cm between rows.

Tomato Rootbound Container Study

Seeds of the cultivar 'Sungem' were initially grown in a glass greenhouse at North Dakota State University. Supplemental light was not utilized. Plants were watered by hand and a 200 ppm N fertilization rate was applied two times per day as a soluble 20-20-20 fertilizer until it drained out of the flats. Tomato seeds were planted into a seed tray using Sunshine 21 mix as the rooting media and then transplanted into cell packs with a volume of 84 cm^3 using Sunshine 21 mix as the rooting media two weeks after seeding. Seedlings were grown for two weeks prior to acclimating outside in a wind protected area for one week. Tomatoes were transported by truck and transplanted immediately upon arrival at the Fargo location on May 9, 2006 and May 29, 2007 and on June 6 and June 13 for the Absaraka and Oakes environments, respectively. Table 3 shows the average transplant height of the plants transplanted at each site. Tomatoes were harvested initially on August 5, 2006 and August 30, 2007 for the Fargo environments, and on August 10, 2007, and August 22, 2007 for the Oakes and Absaraka environments, respectively.

The design of the field experiment was a randomized complete block with three replications. Experimental units consisted of four plants placed on 91 cm centers with a 240 cm row spacing. Tomato fruit were harvested approximately

Table 3. Average 'Sungem' tomato height at transplanting for the rootbound container study for the 2006-2007 growing seasons.

Tomato Cultivar	Fargo2006	Fargo 2007	Absaraka 2007	Oakes 2007
	--cm--			
'Sungem'	31	31	34	33

every 10 days with harvest stopping at first frost. Fruit was harvested from August 5 to October 9, 2006 and August 10 to October 9, 2007 for the Fargo environment and from August 10 to October 9, 2007 for both the Oakes and Absaraka environments.

Tomato fruit were graded according to USDA standards by "red" color and acceptable quality or cull defects. The red color refers to the USDA standards of more than 90 percent shows the red coloring on the fruits surface. The acceptable quality or cull defects refer to cuts and broken skins, catface channels implying slight touching would cause the skin to break and the fruit to leak, and scars that are not from catfacing (USDA 1997). The fresh weight of the fruit was recorded per plot for each harvest. Diseased and split fruit were graded as culls and discarded regardless of size.

The trial at each of the four environments consisted of 16 experimental units or plots. A randomized complete block design for three root modifications and a control were all evaluated using the same variety. Each experimental unit consisted of four plants, spaced on 91 cm centers with a 240 cm between rows.

Soil

The soil at the Fargo environment was a Fargo silty clay with a pH of 7.5 and 2% organic matter. At Oakes, the soil was a Hecla loamy fine sand with a 6.7 pH and 2.4% organic matter, while at Absaraka, the soil was a Spottswood loam with a 7.2 pH and 2.0 % organic matter. Average values of soil tests for elemental soil nitrogen (N), phosphorous (P), and potassium (K) average from soil samples tested by the NDSU Soil Testing lab for the Fargo 2006, Fargo 2007, Absaraka 2007, and Oakes 2007 environments are found in Table 4.

Field preparation at all environments consisted of fall disc-tilling followed by spring disc-tilling and a single pass with a field cultivator to smooth the planting bed. Winter rye was the previous fall cover crop at all environments. No fungicide and no insecticide were applied at any of the environments.

Soil types

Fargo soil. The Fargo silty clay is a soil that has poor drainage found on the glacial lake plains (USDA, 1985). The silty clay surface layer is black and is about 25 cm deep. The silty clay subsurface is dark gray and about 25 cm deep. The next silty clay layer is dark grayish brown and about 76 cm deep. The olive gray substratum is about 152 cm deep. The soil has a high water holding capacity, slow permeability, and is poorly drained. The soil needs drainage to be suitable for cultivated crops and horticultural crops. Artificial means are often incorporated to aid in removal of excess surface water. Tilth is considered to be poor.

Table 4. Soil test values of soil nitrogen (N), phosphorous (P), and potassium (K) averaged for Fargo 2006, Fargo 2007, Absaraka 2007, and Oakes 2007 environments.

Environments	N	P	K
	----------ppm----------		
Fargo2006	6	10	412
Fargo 2007	9	30	420
Absaraka 2007	6	27	213
Oakes 2007	5	26	170

Hecla soil. The Hecla loamy fine sand is a soil that is moderately well drained and found on lake plains and on swales of outwash plans (USDA, 1993). The loamy fine sand surface is about 50.8 cm deep. It goes from black near the surface to very dark gray deeper in the profile. The next layer is 30.48 cm thick and very dark grayish brown. The layer below this is about 15.24 cm deep and dark gray. The grayish brown substratum is about 152.4 cm deep. The soil is rapidly permeable with slow runoff. The soil has a low available water capacity. The soil is used for cultivated crops and hay or pasture. Tilth is considered to be fair.

Spottswood soil. The Spottswood loam is a soil that is moderately well drained and on flats of outwash plains (USDA, 1993). The black loam surface area is about 23 cm deep. The next layer is about 64 cm deep. It goes from surface coloring of a loam that is very dark gray clay, to a loam of black clay to grayish brown followed by olive brown and then a loam that is mottled and gravelly. The light olive brown substratum is about 152 cm deep and is considered to be a gravelly coarse sand. The soils permeability is considered moderate to rapid . The runoff is slow and moderate available water capacity is observed. The soil is used for cultivated crops and range or pasture. Tilth is considered to be good.

RESULTS AND DISCUSSION

Tomato Container Volume Study

No treatment differences were detected for total yield regardless of cell volume when combined across all environments (Appendix, Table 1A). No significant interaction occurred except for environment by variety. Environment was significant for total yield. However, environment is considered random and the best estimate of future performance is the mean averaged across environments. There was no difference between the three different cell volumes with regards to hastening the first harvest (Appendix, Table 2A).

Total yield for the interaction of tomato varieties and environment is presented in figure 1. Data suggests that varieties responded differently at each environment primarily due to the high yield of 'Roma' at the Fargo 2007 environment.

Total yield for the varieties of 'Big Beef', 'Sungem', and 'Roma' tomatoes in the container volume study are in Appendix Table 3A. A disadvantage of the larger cells (287 cm^3) is that they require more space in the greenhouse for planting and establishment of the transplants than the 84 cm^3 or 137 cm^3 volumes, and therefore, increase the cost for establishing transplants for garden centers that grew their own transplants. An advantage of utilizing the 84 cm^3 volumes over the 137 cm^3 and 287 cm^3 volumes is requiring less greenhouse space and less soil mix. Increased root binding was observed with the smaller volume of 84 cm^3 followed by 137 cm^3 and then the 287 cm^3 volumes, respectively. This may

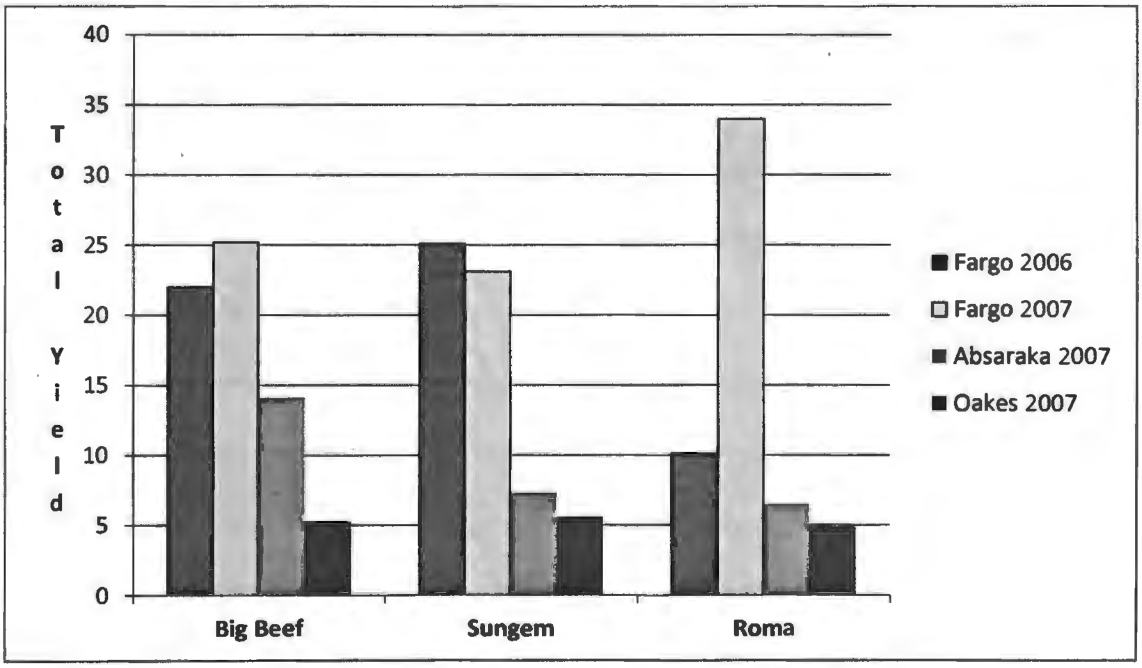

Figure 1. Effect of environment and tomato variety on total yield when averaged over three container sizes.

become an important issue for garden centers that grow their own transplants as containers with root bound seedlings will dry out faster.

The lack of significant difference in total yield for the three tomato cultivars and the three different container volumes was unexpected since Kemble et al., (1994a) and Vavrina and Arenas (1997) reported earlier fruit and greater total yield when tomato seedlings were grown in larger containers. Similarly, Weston and Zandstra (1986) reported earlier tomato yields and greatest marketable weight in plants grown in the largest cells. However, their largest cell volume was 40 cm^3 which was half the size of the small cell volume in this study. Vavrina and Arenas (1997) also reported that their fall planted trial did not have total yield differences compared to their spring planted trial, which they attributed to the environment and a frost event that terminated the trial earlier than expected. Thus, the short growing season in North Dakota compared to Florida, Michigan, and North Carolina, where the previously mentioned research was conducted, may have contributed to the lack of difference in total yield for the varying container sizes.

Pepper Container Volume Study

For the pepper container volume study, the difference between environments was significant, but to provide general information across all environments data was pooled over environments (Appendix, Table 4A). There was also a significant interaction between pepper variety and environment (Figure 2). Data suggests that varieties responded differently at each environment primarily due to the high yield of 'Cherry Bomb' at the Oakes environment.

Treatment was significant for total yield (Appendix, Table 4A). Results showed that the larger the container volume, the higher the pepper yield, regardless of variety. Total yield for pepper variety by container volume for each environment is provided in Appendix, Table 5A. Total yield means for volume treatments 84, 137, and 287 cm^3 of peppers for the field study for 2006-2007 are in Table 5.

When analysis was done including hastening harvest time as a factor there was not a significant interaction of time by variety nor was there a difference between container volumes (Appendix, Table 6A). Thus, even though larger container volumes increased total yield, they did not hasten fruit set or ripening.

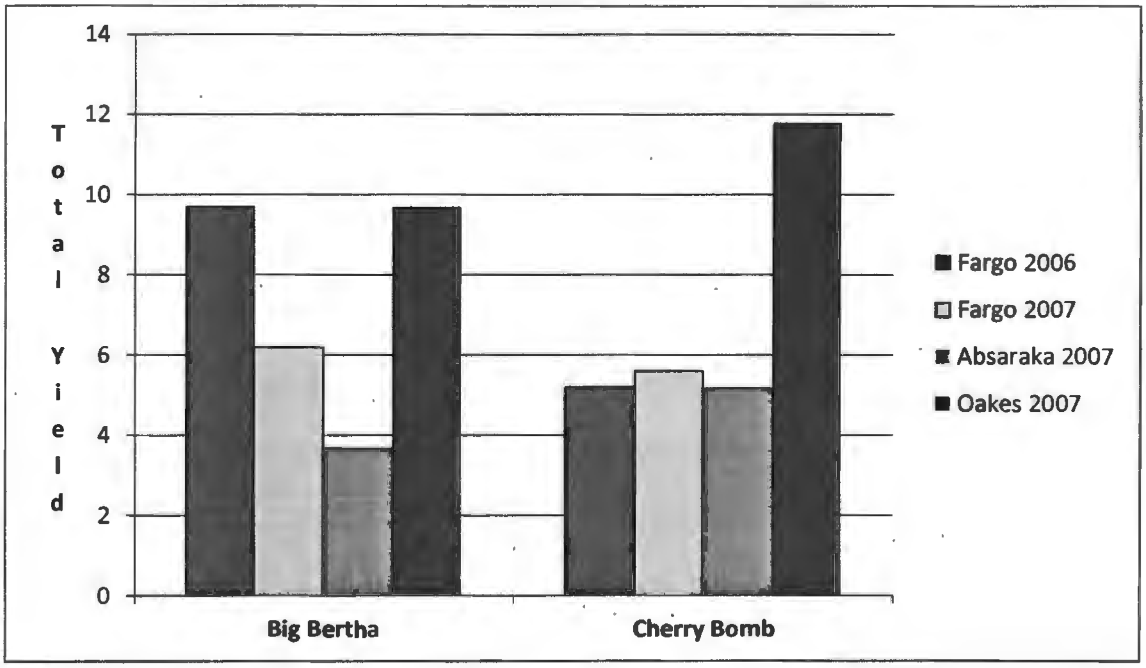

Figure 2. Effect of environment and pepper variety on total yield when averaged over three container sizes.

Table 5. Total yield means for volume treatments 84, 137, and 287 cm^3 of Peppers for the Field Study for 2006-2007.

Volume Treatment cm^3	Fargo 2006	Fargo 2007	Absararaka 2007	Oakes 2007	Mean
84	2.9	4.3	1.9	8.5	4.4a
137	2.7	4.5	2.4	8.7	4.6ab
287	2.6	7.1	3.2	9.0	5.5b

Means within a column not followed by same letter are significantly different ($p<= 0.05$).

A disadvantage of the larger cells (287 cm^3) is that they require more space in the greenhouse for planting and establishment of the transplants than the 84 cm^3 or 137 cm^3 volumes, and therefore, increase the cost for establishing transplants. An advantage of utilizing the 84 cm^3 volumes over the 137 cm^3 and 287 cm^3 volumes is requiring less greenhouse space and less soil mix. Increased root binding was observed with the smaller volume of 84 cm^3 followed by 137 cm^3 followed by the 287 cm^3 volumes, respectively. Pepper plants are warm-season plants and the cool growing temperatures of 2006 and 2007 reduce growth and pollination.

Flowers are self-pollinated and flowering is day-neutral, but hastened under long days and warm temperatures (Swaider et al., 1992). Sweet peppers grow best at air temperatures between 65 to 85 °F, while most pungent peppers grow best at air temperatures above 75 °F. Consistent warm night temperatures (above 70 °F) are important for successful production of some pungent pepper types such as tabasco. High temperatures (above 90 °F) will cause flower abortion in sweet peppers, while these temperatures will increase the fruit set of many pungent pepper types. Fruit set of all pepper types will not occur at temperatures less than 60 °F. Inconsistent rainfall can cause blossom end rot and smaller yields. Average weekly air temperature, soil temperature and rainfall for Absaraka, Oakes, Fargo 2007 and Fargo 2006 are in Appendix Tables 7A, 8A, 9A, and 10A, respectively. The cool growing conditions during 2006 and 2007 may have also contributed to the lack of yield difference between root treatments, since pepper plants are warm-season plants and cool temperatures reduce growth and pollination.

Tomato Rootbound Study

The study of the 'Sungem' tomato plants that had been root-bound and grown in 84 cm^3cells had one of the following treatments.

Total yields of fruit from root-bound tomato plants grown in 84 cm^3 cells : (i) dipped in auxin and one-fourth of the bottom part of the roots cut off, (ii) dipped in auxin, (iii) one-fourth of the bottom part of the roots cut off, and (iv) unaltered roots were not significantly different. Even though the treatments utilized it did not have a significant effect on the season's totally yields, there was a significant yield difference due to environment (Appendix Table 7A). Total yield for the 'Sungem' tomato variety rootbound analysis for the 2007 growing season is found in Appendix Table 8A.

When analysis was done including hastening harvest time as a factor there was no significant interaction of time by variety and there was no interaction of time by transplant container size treatment (Appendix, Table 9A).

Determinate cultivars require a shorter frost-free period (≈ 80 days) until fruit harvest compared to indeterminate cultivars (≈ 120 days) (Swaider et al., 1992). Optimum growth occurs at day air temperatures between the range of 18 to 24 °C and stops at a maximum temperature of 35 °C or a minimum temperature of 12 °C. Temperature markedly affects flowering and fruit set with high day temperatures (≥ 32 °C) in conjunction with low humidity being capable of destroying the viability of pollen. Low temperatures may also reduce the viability of pollen and thus decrease fruit set. Conditions such as hot, drying winds, insufficient light, excessive nitrogen, moistures stress, and insect/disease injury can cause flowers to drop and in return decrease fruit set. Thus, if internal or external conditions are not favorable at flowering, the plant will shed its flowers before setting fruit. Inconsistent rainfall can cause blossom end rot and smaller yields. Average weekly air temperature, soil temperature and rainfall for Absaraka, Oakes, Fargo 2007 and Fargo 2006 are in Appendix Tables 10A, 11A, 12A, and 13A, respectively. The cool growing conditions during 2006 and 2007 may have also contributed to the lack of yield difference between root treatments, since tomato plants are warm-season plants and cool temperatures reduce growth and pollination.

SUMMARY

Field experiments were conducted to evaluate the differences in yield and hastening of harvest for tomatoes and peppers that had been grown in different sized cell packs and also to compare yields and hastening of harvest for the determinate tomatoes 'Sungem' that had different treatments applied to their root systems at the time of transplanting.

This study examined the indeterminate variety 'Big Beef' and the determinate variety of 'Sungem' and the paste tomato variety of 'Roma'. The study also examined the bell pepper cultivar of 'Big Bertha' and the hot pepper cultivar 'Cherry Bomb'. In the first study the peppers and tomato plants were grown in cell volumes of 84, 137, and 287 cm^3. In the second study the roots of tomato plants grown in 84 cm^3 cells had one of the following treatments: dipped in auxin and one-fourth of the bottom part of the roots cut off, dipped in auxin, one-fourth of the bottom part of the roots cut off, and unaltered roots.

This research showed that growing tomatoes in the different sized cell packs showed no significant difference in total fruit yield or hastening of harvest. This research also showed that growing peppers in larger cell packs increased total fruit yield, but it did not hasten fruit harvest.

The difference between environments was significant, but to provide general information across all environments data was pooled over environments. Tomato and pepper varieties responded differently over environments. Data suggests that varieties responded differently at each environment primarily due to the high yield of 'Roma' at the Fargo 2007 environment. Data also suggests that

varieties responded differently at each environment primarily due to the high yield of 'Cherry Bomb' at the Oakes environment.

This research also showed that manipulating the roots of root-bound plants by dipping in auxin and one-fourth of the bottom part of the roots cut off, dipped in auxin, one-fourth of the bottom part of the roots not cut off, did not affect tomato yield compared to untreated. When analysis was done including the harvest time as a factor there was no difference in fruit yield, suggesting that root treatments did not hasten fruit set or ripening.

Growers of transplants will need to compare their own costs of greenhouse space and the cost of growing plants in different sized cells to evaluate the economic feasibility for them to alter their current methodology of planting.

Further research based on these results may be warranted in the areas of utilizing different soil mediums in initial planting of seeds for the above experiments and comparison of their results on yield differences across different environments. Similarly, further research on shorter season cultivars would be beneficial to see if there are any advantages to a larger rooting volume for potentially faster growing plants. Lastly, the comparison if a species that does not produce adventitious roots prolifically along its stem would be beneficial for the root-bound study to identify if the tested treatments from this study could help alleviate root-bound plants during field establishment.

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APPENDIX

Table 1A. Partial ANOVA for total yield including sources of variation, degrees of freedom, mean squares, and F values for tomato container volume results of the tomato cultivars for the field study 2006 and 2007.

Sources of variation	Degrees of freedom	Mean Square	F Value	Pr>f
Model	54	1870	10.58	0.0001**
Environment (Env)	4	20600	116.58	0.0001**
Replication (Rep)	10	739	4.18	0.0001**
Treatment	2	278	1.13	0.3705
Env X T	8	246	1.4	0.2109
Variety (V)	2	186	1.06	0.3522
Env X V	8	677	3.83	0.0007**
T X V	4	82	0.46	0.7618
Env X T X V	16	157	0.89	0.5833
Error	80	177		

*Significant at the 0.05 probability level
**Significant at the 0.01 probability level

Table 2A. Partial ANOVA for the first harvest yield including sources of variation, degrees of freedom, mean squares, and F values for tomato container volume results for the field study of 2006 and 2007.

Sources of variation	Degrees of freedom	Mean Square	F Value	Pr>f
Model	44	25	2.77	0.0001**
Environment (Env)	4	43874	64.5	0.0001**
Replication (Rep)	10	1776	2.61	0.0085
Treatment (T)	2	61.7	0.16	0.8541
Variety	2	436	0.77	0.4946
Env X V	8	567	0.83	0.5756
T X V	4	1198	1.13	0.3780
Env X T X V	16	1062	1.56	0.0994

*Significant at the 0.05 probability level
**Significant at the 0.01 probability level

Table 3A. Total yield for the varieties of ‘Big Beef’, ‘Sungem’, and ‘Roma’ tomatoes in the container volume study for the 2006 and 2007 growing season.

	Total Yield			
Container Size	Fargo2006	Fargo 2007	Absaraka 2007	Oakes 2007
---cm^3---	---------------------kg/plot---------------------			
		‘Big Beef’		
84	20	23	13	4
137	24	28	16	6
287	22	24	14	6
Total	66	75	43	16
		‘Sungem’		
84	30	24	7	6
137	19	30	4	6
287	26	16	11	5
Total	75	70	22	17
		‘Roma’		
84	10	33	5	5
137	8	36	5	5
287	12	33	10	4
Total	30	102	20	14

Table 4A. Partial ANOVA for total yield including sources of variation, degrees of freedom, mean squares, and F values for *Capsicum annuum* (pepper) container volume results for the field study of 2006 and 2007.

Sources of variation	Degrees of freedom	Mean Square	F Value	Pr>f
Model	44	25	2.77	0.0001**
Environment (Env)	4	162	18.04	0.0001**
Replication (Rep)	15	10	1.17	0.3157
Treatment (T)	2	11	4.47	0.0496*
Env X T	8	2.5	0.28	0.971
Variety (V)	1	3.5	0.39	0.5323
Env X V	4	40	4.46	0.0028**
T X V	2	10	1.15	0.3209
Env X T X V	8	8	0.89	0.5269
Error	75	9		

*Significant at the 0.05 probability level
**Significant at the 0.01 probability level

Table 5A. Total yield for the varieties of 'Big Bertha' and 'Cherry Bomb' peppers in the container volume study for the2006 and 2007 growing season.

	Total Yield			
Container Size	Fargo2006	Fargo 2007	Absaraka 2007	Oakes 2007
---cm^3---	--------------------	kg/plot	--------------------	
		'Big Bertha'		
84	11	7	3	9
137	10	5	3	11
287	8	7	5	9
Total	29	19	11	29
		'Cherry Bomb'		
84	5	5	5	13
137	6	4	5	10
287	5	8	6	13
Total:	16	17	16	36

Table 6A. Partial ANOVA for the first harvest yield including sources of variation, degrees of freedom, mean squares, and F values for *Capsicum annuum* (pepper) container volume results for the field study of 2006 and 2007.

Sources of variation	Degrees of freedom	Mean Square	F Value	Pr>f
Model	44	453	2.02	0.0001**
Environment (Env)	4	3091	19.5	0.0001**
Replication (Rep)	15	158	0.71	0.7689
Treatment (T)	2	129	2.02	0.0035
Env X T	8	120	0.54	0.8251
Variety (V)	1	779	1.65	0.2678
Env X V	4	471	2.10	0.0887
T X V	2	66	0.45	0.6550
Env X T X V	8	148	0.67	0.7204

**Significant at the 0.01 probability level

Table 7A. Partial ANOVA for total yield including sources of variation, degrees of freedom, mean squares, and F values for total yield "Sungem" Tomato Rootbound Analysis for the field study in 2006 and 2007.

Sources of variation	Degrees of freedom	Mean Square	F Value	Pr>f
Model	28	3640	22.83	0.0001**
Environment (Env)	4	24500	154.04	0.0001**
Replication (Rep)	9	170	1.07	0.4112
Treatment	3	101	1.25	0.3366
Env X T	12	82	0.51	0.8096
Error	31	160		

*Significant at the 0.05 probability level
**Significant at the 0.01 probability level

Table 8A. Total yield for the 'Sungem' tomato variety in the rootbound analysis for the2006 and 2007 growing season.

Root Treatment	Total Yield Fargo 2006	Fargo 2007	Absaraka 2007	Oakes 2007
	--------kg/plot--------			
		'Sungem'		
One	50	17	4	9
Two	38	21	2	7
Three	18	17	9	9
Four	25	14	8	8
Total:	131	69	23	33

Untreated = 1, Cut X roots = 2, Cut X roots + Hormone = 3, Root Base Cut = 4.

Table 9A. Partial ANOVA for the first harvest yield including sources of variation, degrees of freedom, mean squares, and F values for Tomato root-bound study results for the field study of 2006 and 2007.

Sources of variation	Degrees of freedom	Mean Square	F Value	Pr>f
Model	28	3916	2.88	0.0001**
Environment (Env)	4	21556	15.84	0.0001**
Replication (Rep)	9	1166	0.86	0.6919
Treatment (T)	3	1333	01.77	0.2054
Env X T	12	751	0.55	0.7969

*Significant at the 0.05 probability level
**Significant at the 0.01 probability level

Table 10A. Average weekly air temperature, soil temperature and rainfall for Absaraka field study for 2007. Weather data collected at the NDSU NDAWN station at Prosper, North Dakota.

Week starting date	Average air temperature	Average bare soil temperature	Total rain fall
	----------------------(°C)----------------------		---(mm)----
06-06	14	21	38
06-13	16	20	64
06-20	17	24	0
06-27	15	21	4
07-04	16	22	11
07-11	12	19	27
07-18	16	23	8
07-25	16	23	1
08-01	13	20	9
08-08	13	20	7
08-15	11	16	6
08-22	10	17	27
08-29	12	20	0.0
09-05	7	14	36
09-12	4	12	3
09-19	9	16	49
09-26	5	13	9
10-03	8	13	17
10-10	4	8	6
Averages:	12	18	
Totals:			320
Max:	17	24	64
Min:	4	8	0
Std. Dev.:	4	4	

Table 11A. Average weekly air temperature, soil temperature and rainfall for Oakes field study for 2007. Weather data collected at the NDSU NDAWN station at Oakes, North Dakota.

Week starting date	Average air temperature	Average bare soil temperature	Total rain fall
	------------------------(°C)------------------------		-------mm-----
06-13	16	20	61
06-20	18	24	5
06-27	15	21	15
07-04	17	23	0
07-11	13	20	2
07-18	18	24	19
07-25	18	24	26
08-01	15	21	11
08-08	15	21	30
08-15	13	17	24
08-22	11	18	27
08-29	14	21	0
09-05	9	15	18
09-12	5	12	5
09-19	9	16	20
09-26	6	14	19
10-03	7	13	6
10-10	4	7	6
Averages:	12	18	
Totals:			268
Max:	18	24	61
Min:	4	7	0
Std. Dev.:	5	5	

Table 12A. Average weekly air temperature, soil temperature and rainfall for Fargo field study for 2007. Weather data collected at the NDSU NDAWN station at Fargo, North Dakota.

Week starting date	Average air temperature	Average bare soil temperature	Total rain fall
	-----------------------(°C)-----------------------		-------mm-----
05-29	14	19	34
06-05	12	19	23
06-12	18	22	90
06-19	17	24	0
06-26	16	22	0
07-03	18	24	10
07-10	13	19	18
07-17	18	24	0
07-24	18	25	2
07-31	16	22	12
08-07	16	22	16
08-14	13	17	6
08-21	13	19	32
08-28	14	21	0
09-04	11	17	27
09-11	6	12	2
09-18	11	17	36
09-25	8	14	10
10-02	9	14	12
10-09	5	9	7
Averages:	13	19	
Totals:			336
Max:	18	25	90
Min:	5	9	0
Std. Dev.:	4	4	

Table 13A. Average weekly air temperature, soil temperature and rainfall for Fargo field study for 2006. Weather data collected at the NDSU NDAWN station at Fargo, North Dakota.

Week starting date	Average air temperature	Average bare soil temperature	Total rain fall
	------------------------(°C)------------------------		--------mm-----
05-09	6	11	24
05-16	6	14	0
05-23	15	21	19
05-30	14	21	7
06-06	12	17	3
06-13	16	22	1
06-20	14	20	16
06-27	15	22	0
07-04	14	21	0
07-11	19	26	0
07-18	16	23	3
07-25	19	26	49
08-01	15	21	5
08-08	17	23	22
08-15	14	21	9
08-22	14	21	26
08-29	13	19	49
09-05	10	17	0
09-12	12	18	23
09-19	5	11	26
09-26	6	13	0
10-03	6	12	2
10-10	-2	4	6
Averages:	12	18	
Totals:			290
Max:	19	26	49
Min:	-2	4	0
Std. Dev.:	5	5	