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A comparison of hydroponic and conventional methods of vegetable transplant production

Stephen J. Komar

To the Graduate Council:

I am submitting herewith a thesis written by Stephen J. Komar entitled "A comparison of hydroponic and conventional methods of vegetable transplant production." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Plant, Soil and Environmental Sciences.

David L. Coffey, Major Professor

We have read this thesis and recommend its acceptance:

Joanne Logan, Vernon Reich

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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Associate Vice Chancellor and
Dean of the Graduate School

A Comparison of Hydroponic and Conventional Methods of Vegetable Transplant Production

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Stephen J. Komar
May 1999

Dedication

This thesis is dedicated to my mother Maureen H. Komar who did without for her children.

Acknowledgments

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Abstract

Traditional float bed culture, common in the production of tobacco transplants, was used to investigate the potential for hydroponic transplant production of peppers and cabbage. Experiments were conducted in the summer and fall, 1998 at The University of Tennessee Agricultural Experiment Station, Knoxville, Tennessee. Two varieties of peppers, 'King Arthur' bell and 'Grande' Jalapeno, and the cabbage variety 'Charmant' were seeded independently in 128 cell Styrofoam trays in conventional growing media. Pepper trials consisted of a conventional hydroponic treatment, a heated hydroponic treatment and a conventional treatment. Cabbage trials consisted of four treatments; aerated-hydroponic, aerated- shaded (30%), and non-aerated hydroponic under both shaded and non-shaded conditions. Transplant growth, vigor, and development were monitored in both experiments and total yield and quality of yield were determined after transplant.

Temperature enhanced the germination rate of pepper with the heated treatment resulting in the fastest germination for the 'Grande' jalapeno variety. Pepper plants in both the heated and conventional hydroponic treatments grew faster and larger than those in the conventional treatment. Total mean fresh and dry weights of both root and shoot material were consistently greater for the hydroponic treatments, with the heated treatment showing the greatest positive trends in plant growth and development.

Pepper transplants from all treatments survived equally well in the field.

No differences were observed in days until flowering, first fruit set, early yield, total yield or in fruit quality. A significant difference in yield was observed between varieties with 'Grande' Jalapeno producing the greatest early and total yields.

Cabbage transplants grew faster and were larger when grown in the aerated nutrient solution producing transplants that were taller, heavier and that had wider and longer leaves than in non-aerated treatments. Shading of aerated plants reduced shoot weight, leaf length and leaf width. Total plant stand in the field was less for both aerated treatments with the shade + aeration treatment producing the lowest percentage of surviving plants. There was no difference observed in total percentage of plants producing marketable heads or in marketable head weight . Yields were greatest in the non-aerated treatments with the full sun-aeration plants producing the greatest yield.

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1. Introduction

Agricultural production in East Tennessee has been dominated by the production of tobacco. A large percentage of the region's most desirable agricultural land is devoted to tobacco production, resulting in greater than 223 million dollars of net income in 1998. The future of tobacco consumption in the United States is unclear with the threat for severe taxation on tobacco products as well as rising health concerns associated with tobacco use. These factors necessitate that farmers develop strategies to maintain their income while producing crops suitable to the region. A cost effective production system utilizes equipment that tobacco farmers have already invested in for tobacco production.

The consumption of peppers *Capsicum annum* has increased steadily in the United States over the past several years. The predicted increase in demand for fresh market peppers makes the production of peppers a viable alternative and/or supplement to tobacco production provided that an economically profitable yield of marketable fruit can be obtained. Cabbage *Brassica oleracea var capita* is also an important vegetable crop in Tennessee with 263 hectares grown annually with an estimated value of 1.7 million dollars per year. Climate is a major limiting factor for successful production of both peppers and cabbage in the state. Below optimal early spring and above optimal late summer temperatures create problems for stand establishment, fruit set and maturation of peppers. Cabbage production is often hindered by low temperatures in the spring and high temperatures in the fall. The effects of the cool spring temperatures are easily managed by producing transplants in temperature-controlled greenhouses. However, the high summer and early fall temperatures are immensely more difficult to overcome. Experiments were conducted in the spring and fall, 1998 at The University of Tennessee Experiment Station, Knoxville, Tennessee. Traditional float bed culture, common in the production of tobacco transplants, was used to investigate the potential for hydroponic transplant production of peppers and cabbage.

2. Review of Literature

Hydroponics: A Historical Perspective

Although research in hydroponic vegetable production has increased dramatically in recent years, it is by no means a new science. Hydroponics dates back to the hanging gardens of Babylon, the floating gardens of the Aztecs, as well as, the Egyptian hieroglyphic record (Resh, 1978). In the 1600's the first scientific study of plant growth was conducted by Van Helmont, a Belgian scientist who planted a 2.27 kg willow shoot in a 90.8 kg mass of soil. After five years, the willow weighed nearly 73 kg while the soil had lost only 57 g. This simple test proved that for most plants, nutrients are obtained from the soil solution and air (Sutherland, 1987). The modern era of hydroponics began in 1936 with the experiments of Dr. W.E. Gericke at the University of California. Gericke performed several experiments in hydroponics including his most famous in which he grew a tomato plant to a height of 7.5 meters in twelve months (Sutherland, 1987). The term hydroponics stems from the Greek word *hudor* meaning water and *ponos* meaning labor and literally means working with water (Resh, 1978). Although hydroponic research began simply, it has quickly grown into an extensive science with amazing advances in just 50 years.

Hydroponic Methods

One of the fundamental distinctions among hydroponic methods is the concept of open versus closed systems. In an open system, the nutrient solution flows over the plant roots once and is not reused. In a closed system, the excess solution is recovered, replenished, and put directly back into the system (Resh, 1978). Hydroponics is further categorized into three distinct subgroups: liquid hydroponic systems, aeroponic systems and floating systems (Jensen and Collins, 1985). While all of these systems have their merits, floating systems have recently been used in tobacco transplant production in the state of Tennessee and in commercial transplant production systems in other states.

Floating Hydroponic System

The floating hydroponic system is a system in which plants are grown in Styrofoam trays filled with a soil-less potting mix floated over a nutrient solution with the roots being allowed to grow into the solution (Sutherland, 1987). This system was developed by Jensen and Collins (1985). In Tennessee this system has been predominantly used in the production of tobacco transplants. This system has several advantages over conventional methods of producing transplants. These include: better plant survival; faster early season growth as compared to conventional transplants; easy management of plant growth; optimal nutrient and water management; ability to save unused plants and the potential to manipulate the solution temperature to maximize plant development (Miller et al.,1998). These characteristics make hydroponic production of other crops a potentially viable alternative to conventional production of both transplants and as an alternative method of production for fresh market vegetables. The feasibility of using this method for vegetable production has been researched for leafy vegetables such as lettuce. In a cooperative experiment between Kraft, Inc. and the University of Arizona (1980), a hydroponic greenhouse method was tested (Jensen and Collins, 1985). In this experiment a 0.5 hectare "raceway" production system was tested in which head lettuce was seeded in 2.5 cm thick Styrofoam floats and staggered with 300 cm^2 spacing between each plant. The plants were floated over a nutrient solution and allowed to grow until harvest . The results of this test showed that lettuce could be produced both effectively (5.4 million heads/year) and economically (19.0 cents/head). This system has proven to be simple, inexpensive and can potentially be used as a model to develop production strategies for other high value crops.

Float Bed Construction

By convention, float beds are constructed with treated lumber. The float bed frame is then covered with a thick plastic liner which can be secured with staples. It is very important to level the area in which the beds are to be placed. According to Miller et al. (1998), a bed that is not level can cause uneven depths of the water in the beds, while causing nutrients to concentrate in the liner. The float system is such that it allows for the heating of the nutrient solution. This can easily be accomplished with a standard water bed heater. When heating the solution the heater should be placed between the ground and the plastic liner. The size of the bed should be calculated based on the number of plants needed. Miller et al. (1998) determined that a bed 6.08 x 2.10 m can hold a total of 51 trays. This system can produce more than 6500 transplants per bed if 128 cell trays are used. The float beds can be filled with a variety of nutrient solutions at different concentrations determined by factors such as: plant type, region, ambient temperature, and field requirements.

Determination of Transplant Quality

Peppers. Commercial peppers are conventionally established using transplants or by direct seeding. Due to the relatively short growing season in Tennessee, the use of greenhouse grown transplants is a commonly used practice. Several studies have shown that peppers grown from transplants had significantly greater yields than those of the same variety grown from direct seeding in the field (Weston and Zandstra 1989; Leskovar et al.,1989). The production of healthy transplants is an important step in successful pepper production. According to Markovic et al. (1995) the production of pepper seedlings is the most important and most sensitive phase of pepper production. The production of healthy transplants is believed to play an important role in the total productivity of peppers including early yields and total yields (Markovic et al.,1995). Leskovar et al. (1989) found that sweet pepper plants grown in pots in a nursery developed faster initial root growth and increased fruit growth and development when compared to direct seeded plants. Seedling development is believed to influence the total yields of other crops such as tomatoes. Canham (1966) determined that the future yield of some tomato plants depended on the first week of seedling growth. The early growth and development of transplants is believed to decrease susceptibility to post-transplant shock which can significantly reduce yields while increasing the number of days until first harvest. Markovic et al. (1995) stated that conventionally grown pepper transplants are susceptible to stress at transplanting and after transplanting can require one month in the field before normal growth and root development continues. Dufault (1994) concluded that slow recovery from transplant shock can delay early yields and reduce marketability of peppers. Transplant growers may harden seedlings by decreasing nutrients before transplanting (Dufault, 1994). Hardening prepares transplants for the stresses associated with transplanting, however, nutrient hardened transplants may be slow to recover from transplant shock even if sufficient nutrients are applied after transplanting (Aloni et al.,1991). The health and vigor of transplants is an important characteristic when determining the yield potential of many transplants. According to Dufault (1986) pretransplant conditioning plays a crucial role in the young plants recovery from shock and in their potential productivity. Plant performance after transplanting has been found to be influenced by the plant's physiological age. Weston (1988) found that sixty day old pepper seedlings had greater height, leaf area, and shoot dry weight then younger seedlings. This difference in transplant size was found to be related to early yielding ability with sixty day old seedlings producing 70% more early yields then did younger seedlings (Weston, 1988). Markovic et al. (1995) stated that seedling height is a basic indicator of plant health and should range from 16-20 cm at time of transplanting for peppers. The increase in dry matter associated with larger plants is also believed to lessen the effects of transplant shock in peppers. According to Markovic et al. (1995) 11-12% dry matter is needed to adequately protect transplants from stresses associated with transplanting. The development of larger, healthier transplants can greatly increase the productivity of peppers while lessening the instances of losses due to transplant shock.

Cabbage. Due to the relatively narrow production window, cabbage has traditionally been grown from transplants in Tennessee. The development of healthy cabbage transplants is crucial in order to obtain marketable heads during the short periods in which conditions are favorable for production. The size of cabbage transplants has been reported to be an indicator of transplant health. Miller et al. (1969) reported that yields were greater in cabbage plants that were designated as large at transplanting. Cabbage transplants are susceptible to bacterial diseases (Rutledge, 1998). The production of locally grown transplants can decrease the risk of bacterial transmission. Cabbage is a biennial which can form seed stalks if the transplants are exposed to temperatures below 4.4^{0} C. followed by warmer temperatures (Rutledge, 1998). The formation of seed stalks can greatly reduce the percentage of marketable heads being produced. This can be prevented by growing transplants locally if drastic changes in temperature are not common.

Factors Affecting Plant Growth and Development

Temperature

<u>Peppers.</u> Temperature is an important environmental factor affecting successful development of peppers. During germination, and while the plant is young, the optimal temperature has been determined to be at least 30^0C (Andrews, 1984). Temperature has been found to affect the germination of pepper seeds. Coons et al. (1989) found maximum rates and percentages of both hot and sweet pepper seeds at temperatures of 25 to 30^0C. Temperature has been shown to affect the growth of pepper seedlings. Ho and Adams (1995) stated that the temperature at the root zone affects water and nutrient uptake. This is supported by Moorby and Graves (1980) who determined that increased root temperature increases plant growth, transpiration, and ion uptake. According to Ho and Adams (1995) the daily uptake of water increased by 30%,with proportional increases in Ca, Mg, K, and N when the temperature of pepper plants was increased from 14-26^0C. White (1937) concluded that the optimal rooting temperature for good root and plant growth for tomato is 20-33^0C. Although the response to the temperature of the root zone is usually smaller then for ambient temperatures, changes in root zone temperature has been found to increase the nutrient content in plants such as tomato (Adams, 1989). Knavel (1977) found that growing pepper transplants to first anthesis required 10 weeks for plants grown at 24^0 C, 8 weeks at 27^0 C and 6 weeks for plants grown in a greenhouse during summer months. Knavel also determined

that low temperatures retard growth and increase the number of days until first flowering in pepper.

Cabbage. Cabbage plants are very susceptible to temperature variation. Cabbage is a cool season biennial which is well suited for cool temperatures, but is much less tolerant to temperatures in the mid to upper 20's (^{0}C) (Rutledge, 1998). The optimum temperature for cabbage production is between 15.5-24 ^{0}C (Lorenz and Maynard, 1988). Temperature is the main limiting factor in the successful production of cabbage in Tennessee with high temperatures during the early fall season and a relatively short period with adequate temperatures for marketable head formation. Temperature variation can result in the formation of seed stalks if transplants are grown in cool temperatures and transplanted into warmer temperatures. Seed stalk formation has been reported in Tennessee on several occasions when transplants were purchased from other regions (Rutledge, 1998).

Nutrition

Peppers. Plant nutrition is very important to successful growth and development of peppers and cabbage. Several studies have been conducted relating nutrient availability to yield. Studies involving plant available nitrogen have found large disparities in the optimum rates of N depending on regional and seasonal differences in environment and cultural practices (Hartz et al.,1993). Thomas and Heilman (1964) reported that leaf tissue N accounted for as much as 81% of the variability in pepper yields. Nitrogen concentration has been found to affect transplant growth and development. Leskovar (1989) concluded that pepper root and shoot growth responded positively to increased nitrogen applications. Melton and Dufault (1991) indicated that N rate affected plant height, stem diameter, leaf count, leaf area ,and fresh shoot weight in tomato seedlings. Hochmoth (1991) reported that tomato plants grown at N rates of 60-90-120 mg/l were significantly shorter then plants grown at higher N rates 30 days after transplanting. The effects of nitrogen application rate on yields of solanaceous crops has been studied extensively with mixed results. Thomas and Heilman (1964) determined that pepper fruit yields increased with additional application of N fertilizer. This is in agreement with Knavel (1977) who determined that N deficiency in bell pepper can delay harvest. The stage of development of peppers can affect the amount of N needed. According to Thomas and Heilman (1964) an increase in required N may be due to N moving from leaf tissue into developing fruit during heavy fruit set. A similar response was reported in tomato plants with Increased N requirements being observed in tomatoes during fruit set. Hochmoth (1991) developed a five step nitrogen solution for growing hydroponic tomatoes, starting with 70 mg/l during the vegetative state and increasing to 150 mg/l during fruit set. While high N rates have been found to increase yields, excessive rates have been found to decrease yields. Rates of N above 200 kg/ha have been found to depress tomato yield (Clark et al.,1991). According to Hochmoth (1991) high fertilization of N has been found to decrease pepper fruit quality. Other studies relate P availability to plant growth and development. The concentration of P in nutrient solution had a direct effect on plant development with low concentrations of P resulting in weak growth with narrow glossy leaves (Miller, 1961). The concentration of P also has been found to have an effect on fruit development. Miller (1961) found that low concentrations of P in nutrient solution resulted in decreased fruit diameter and length. Thomas and Heilman (1964) ,however, determined that P content did not significantly affect yields of peppers. High concentrations of P (243 mg/L) have been found to reduce yield of cucumber particularly during later harvesting (Massey et al.,1986). Potassium concentration has also been related to the growth and development of solanaceous crops. Potassium deficiencies have been found to lead to a stunting of growth, accompanied by a bronzing of leaves and ultimately defoliation (Miller, 1961). High concentrations of K have also been found to affect fruit production. According to Miller (1961), high levels of K appeared to favor fruit production in tomatoes although some blossom end rot was noted. Potassium deficiencies have been linked to blotchy ripening in tomatoes (Adams ETaL, 1993). Adams (1989) reported that increasing the concentration of K in hydroponic solution caused a marked reduction in the number of tomato fruits with ripening disorders. Hochmoth (1991), however, reported that little effect of K concentration was found on fruit quality. Other nutrients such as Ca and Mg have been found to affect fruit quality. Miller (1961) determined that Ca deficiency can lead to blossom- end rot in tomato with at least half of fruit grown under low Ca concentrations showing this condition. Miller (1961) has also concluded that peppers grown under low Mg concentrations demonstrated a reduction in fruit number and size when compared to higher concentrations. Micronutrients have been found to affect the growth and development of plants. For example, growth, earliness of flowering, and early yields of tomatoes were improved by high levels of Fe, however, total yields were not significantly affected (Adams, 1993). The concentration and timing of application of plant nutrients is crucial for successful production of solanaceous crops. These nutrients are generally plentiful in a soil environment but must be added in the correct amounts in a hydroponic system.

Cabbage. The major fertilizer requirements for cabbage, and leafy cool season crops in general, in Tennessee are nitrogen, phosphate and potash (Rutledge, 1998). Nitrogen is the main limiting nutrient in cabbage production with several studies reporting increased yields in response to increased N applications (Thomas et al.,1970, Masson et al.,1991). Kratky and Mishima (1981) reported reductions in yields, earliness and quality of lettuce heads were related to very low rates of N with higher rates producing a higher quality product. Similar results were reported in broccoli plants with higher quality plants and higher yields being reported at increased N rates (Masson et al.,1991). Phosphate has been reported to increase root growth and development (Rutledge, 1998). Depending on soil conditions P application requirements for cabbage can range from 56 to 224 kg/ha (Lorenz and Maynard, 1988). Csizinszky and Schuster (1985) reported that increased cabbage yields were observed in treatments that included increased P rates. Potassium has been reported to increase head firmness (Rutledge, 1998). Increasing K rates has been shown to increase yields, but an increase in the total percentage of burst heads was increased nearly 40 % (Peck et al.,1987). Little research has been conducted relating transplant production methods to yields. Kratky and Mishima (1981) reported that the appropriate fertilization of transplants increased yields of lettuce.

Aeration

Dissolved oxygen concentration at the root zone is an important factor in the physiological processes occurring during plant growth and development. This is of particular importance in hydroponic culture. The concentration of dissolved oxygen in solution is not correlated with air temperature but is strongly correlated with solution temperature (Giselrod and Kempton, 1983). The depletion of oxygen is enhanced by high root temperature due to increased root respiration and an increase in the activity of microorganisms competing for available oxygen (Ho and Adams, 1995). Insufficient gas exchange caused by poor root aeration can result in the accumulation of organic acids, ethylene gas, and dissolved carbon dioxide and may restrict root metabolic activity (Jackson, 1980). The uptake of water and nutrients is reduced by poor aeration at the root zone. Arnon and Hoagland (1940) reported that tomato plants grown without aeration at the root zone absorbed 30% less K, 26-28 % less nitrate, Mg, P, and

Ca than those in properly aerated solutions. This was supported by Xu and Adams (1994) who reported that in deep hydroponic culture the uptake of K and Ca was reduced by 50% in non-aerated nutrient solution. This reduction in uptake resulted in a 42% reduction in dry matter accumulation. According to Giselrod and Kempton (1983) tomato plants were adversely affected when the dissolved oxygen content of solution fell below 3 Mg/l. Hydroponic culture is well suited for improving the aeration at the root zone thus allowing for higher temperatures to be tolerated .

3. A Hydroponic System for Cabbage Transplant Production in Tennessee[1]

Introduction

Cabbage *Brassica oleracea* gp. Capitata is an important vegetable crop in the state of Tennessee. In 1988, 263 ha were grown for fresh market sales contributing an estimated $1.2 million in agricultural income (Rutledge, 1998). Cabbage is a cool season biennial which is quite well suited for cool temperatures, but is much less tolerant to temperatures greater than 25^0 C (Rutledge, 1998). Traditionally, cabbage is grown as either a spring or early fall crop. Temperature is the limiting factor in the successful production of cabbage in Tennessee with the possibility for relatively high temperatures during early fall periods and a relatively short period with adequate temperatures for spring production. The development of early maturing varieties has decreased considerably the severity of early season stresses with early varieties maturing in approximately 70-90 days as compared to 90-100 days for late maturing varieties (Rutledge, 1998). Early season stress remains a great concern incabbage production in the state. Traditionally, cabbage has been produced from greenhouse grown transplants. High costs associated with heating and cooling of a greenhouse greatly decrease the profitability of cabbage production. There has been much research conducted in several aspects of cabbage

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production including: nitrogen fertilization (Hara and Sonoda, 1982, Knavel and Herron, 1981 and White and Forbes, 1976), container size (Dufault and Waters, 1985), and plant spacing (Halsy et aL., 1966). Larger transplants have been positively correlated with increased yields (Miller, Splinter and Wright, 1969). However, little research has been presented relating production methods to plant growth.

In Tennessee, tobacco transplants are being successfully grown with a hydroponic "float system" with plants grown in styrofoam trays filled with a potting mix (Rutledge, 1997). The trays are floated over a nutrient solution with the roots being allowed to grow into the solution (Sutherland, 1987). This system has several advantages over conventional methods of production. These include: better plant survival, faster early season growth, easy management of plant growth, optimal nutrient and water management, ability to save unused plants, and the ability to alter the nutrient solution temperature to maximize plant development (Miller et al.,1998). Dissolved oxygen concentration at the root zone is an important factor in the physiological processes occurring during plant growth and development. This is of particular importance in hydroponic culture. The concentration of dissolved oxygen in solution is not significantly correlated with air temperature but is highly correlated with solution temperature (Giselrod and Adams, 1983). The depletion of oxygen is enhanced by high root temperature due to increased root respiration and an increase in the activity of microorganisms competing for available oxygen (Ho and Adams, 1995). Insufficient gas exchange caused by poor root aeration can result in the accumulation of organic acids, ethylene gas, and dissolved carbon dioxide and may restrict root metabolic activity (Jackson, 1980). The uptake of water and nutrients is reduced by poor aeration at the root zone (Arnon and Hoagland, 1940). Arnon and Hoagland (1940), reported that tomato plants grown without aeration at the root zone absorbed 30% less K, 26-28 % less nitrate, Mg, P, and Ca then those in properly aerated solutions. This was supported by Xu and Adams (1994) who reported that in deep hydroponic culture the uptake of K and Ca was reduced by 50% in a non-aerated nutrient solution. This reduction in uptake resulted in a 42% reduction in dry matter accumulation. According to Giselrod and Kempton (1983) tomato plants were adversely affected when the dissolved oxygen content of solution fell below 3 mg/l. Hydroponic culture is well suited for improving the aeration at the root zone thus allowing for higher temperatures to be tolerated . The success of float systems in tobacco transplant production in the state suggests that a float system may also be beneficial for the production of cabbage transplants.

The objectives of this study were to determine the feasibility of using a floating hydroponic system to produce cabbage transplants for fall production, to determine the effects of aeration of the nutrient solution, and to determine the effects of shading of on transplant growth and subsequent field performance.

Materials and Methods

Experiments were conducted at the Knoxville Experiment Station (KES), Knoxville TN. Seeds of the cabbage *Brassica oleracea* gp. Capitata cultivar 'Charmant' (Holmes Seed, Canton, Ohio) were sown, 1 seed per cell, in 128 cell styrofoam trays (Speedling Corp. Sun City, FL) in conventional growing media (Pro-Mix) on 15 July, 1998. Trays were placed into a 70% shade house for 7 days and allowed to germinate. Seven days after seeding (DAP) the plants were removed from the shade house and were placed into one of four treatments: hydroponic full sun, aerated hydroponic full sun, hydroponic 30% shade, aerated hydroponic 30% shade. Float-beds consisted of four 8 tray structures, constructed of treated lumber lined with 1.5 ml black polyethylene plastic film and filled with approximately 378 l of water. Peters Professional (5-11-26) fertilizer (Marysville, Ohio) was added to the beds at the recommended rate and was amended with additional nutrients to bring the total concentration of nutrients to; 200 ppm N, 210 ppm K, 193 ppm Ca, 40 ppm Mg, 5 ppm Fe. Trays were floated on the nutrient solution and allowed to grow. Recommended pest control practices were followed as needed. Aeration was provided by forcing compressed air into .64 cm commercial soaker hose at a pressure of 103.5 kpa. To disperse the air, a 1.52 m length of soaker hose was run through the center of each of the beds. The solution was aerated continuously throughout the entire experiment. Shading was provided by placing float-beds in a 6.10 x 6.10 m shade house covered with black nylon mesh providing 30% shade. A ten plant sample was taken on 14 August, 1998 (28 DAP) from each of the four treatments. Plants were measured for: height, fresh shoot weight, and fresh root weight. Plant height was established by measuring from the root node to the apex to the nearest 0.5 cm. Fresh weights were measured individually on a digital scale (Acculab-200 Bradford, MA). The first true leaf was measured for length and width to compare relative leaf growth. Plant were mechanically transplanted into the field on 21 August, 1998 (35 DAP). Plant spacing was 30.5 cm between plants and 91.4 cm spacing between rows. The field was fertilized with 181.6 kg of a 6-12-12 analysis fertilizer prior to transplanting. Transplants were irrigated by overhead sprayers as needed throughout the season. The experimental design was a randomized complete block with four replications. Recommended cultural practices were followed. Plants were harvested on 26 October, 1998 (103 DAP). Total number of marketable heads was determined and weight per head, percent of stand producing marketable heads and yields projected on a per hectare basis.

Data Analysis

Individual plants were subject to one way analysis of varience using the General Linear Models procedure (SAS 1989). Treatment means were separated using Duncans Multiple Range procedure (SAS 1989).

Results and Discussion

Plant Growth

Transplants grew fast and vigorously when subjected to aeration under both light intensities. Aeration produced plants which were greater than 50% taller than non-aerated plants ($P<0.05$). Plants in the full sun plus aeration treatment produced the tallest transplants with a mean height to the apex of the first leaf of 5.7 cm. This is much taller than both the shade minus aeration and the full sun minus aeration treatments (3.51 cm and 3.28 cm respectively) (Table 1). Aeration of the nutrient solution increased fresh shoot weight when compared to the non-aerated treatments. Aerated treatments produced plants which were on average 6 grams heavier than the non-aerated treatments at 28 DAP. Aeration also increased leaf width and leaf length of transplants. Plants in the full sun plus aeration produced the longest and widest leaves with a mean length of 8.6 cm and a width of just under 6 cm. This was both larger and wider than the non-aerated treatments grown under both light intensities. Shading of the aerated plants reduced shoot weight, leaf length, and leaf width ($P<0.05$). Overall, the plants grown under full sun and aerated conditions produced plants which were ready for transplant in the shortest time(approximately 21 days). This is probably due to increased nutrient uptake in the aerated treatments relative to the non-aerated treatments. Similar results were reported by Arnon

Added: 100 mL soln. to ea. 3/22

DW 1 Fine 3/23

DW 2 "

KT 1 "

PS 2 "

All others: wilting

Poss Exp: Too much liquid, over feeding/watering

Taken outside @ 11 A.M. a stem tied 3/2
to handle of jug w/ kite string

Table 1. Influence of transplant production method on cabbage transplants 28 days after planting at The University of Tennessee Knoxville Experiment Station, Fall 1998.

transplant production method	shoot fresh weight (g)	root fresh weight (g)	plant height (cm)	first true leaf length (cm)	first true leaf width (cm)
Full Sun + Aeration	7.72 a	0.087 b	5.70 a	8.61 a	5.99 a
Full Sun - Aeration	2.82 c	0.141 a	3.85 b	5.02 c	3.85 c
30% Shade + Aeration	4.60 b	0.084 b	5.54 a	6.87 b	4.89 b
30% Shade - Aeration	1.70 c	0.094 b	3.28 c	3.96 d	3.06 c

Means within the same column followed by the same letter are not different according to Duncans Multiple Range Test ($P<0.05$)

and Hoagland (1940) and Xu and Adams (1983) who reported that nutrient uptake decreased in hydroponic plants grown in non-aerated nutrient solutions.

Field Performance

Heavy rain delayed transplanting until August 21, 1998 (35 DAP). During this time transplants in the aerated treatments became too large for ideal transplanting, while plants under non-aerated treatments were the ideal size. The increased size of the aerated plants resulted in breakage of the stems in the mechanical transplanter when placed into the field. This resulted in a large reduction in the percentage of aerated plants that survived transplanting, which contributed significantly to yield reductions when projected on a per area basis (Table 2). This problem may be prevented by removing plants from the float beds prior to transplanting to harden them off. This is a common practice in tobacco production in Tennessee. The percentage of surviving plants that produced marketable heads ranged from 44 to 59%. Most heads that were unmarketable were of insignificant size. This was not a treatment effect and would have been considerably higher if harvesting had been delayed. The aerated treatments produced slightly, although not significantly more, marketable heads then the non-aerated treatments, with the aerated shade house plants yielding the greatest total percentage. Total marketable head weight was not different among the transplant production methods. Because of the higher plant survival, total marketable yield was higher in non-aerated

Table 2. Influence of transplant production method on cabbage stand and yield at The University of Tennessee Knoxville Experiment Station, Fall 1998.

transplant production method	total plant stand (%)	stand producing marketable heads (%)	Average marketable head weight (kg)	total yield marketable heads (mg ha^{-1})
Full Sun + Aeration	71.1 b	53.3 a	1.19 a	15.64 bc
Full Sun - Aeration	88.9 a	50.3 a	1.22 a	20.18 a
30% Shade + Aeration	46.9 c	58.8 a	1.31 a	11.87 c
30% Shade - Aeration	97.2 a	43.6 a	1.25 a	18.68 ab

Any means in the same column followed by the same letter are not different according to Duncans Multiple Range Test (P<0.05) production plots with both non-aerated treatments yielding significantly higher for transplants grown under both light intensities. The floating hydroponic system lends its self well to the production of cabbage transplants, especially transplants for fall production. The rapid growth observed in the aerated beds allows for a later seeding date, thus avoiding and minimizing the risk of heat stress related injury incurred in late July and early August temperatures. The system also prevents damage due to water stress by providing the plants with a constant supply of both water and nutrients. This system may also allow for earlier harvest which would maximize profitability.

4. A Comparison of Hydroponic to Conventional Methods of Production of Pepper Transplants[2]

Introduction

The consumption of peppers *Capsicum annum* has increased steadily over the past several years. The production of peppers in East Tennessee has been hampered by a relatively cool spring season for seedling development, and above optimal summer temperatures for fruit set and maturation. These climatic conditions necessitate that in the commercial production of peppers, crops be established using transplants to maximize yield potential during months of optimum growing conditions. The use of transplants for pepper production has been found to increase yields as compared to direct seeding (Weston and Zandstra, 1989, Leskovar and Cantcliffe, 1991). Leskovar and Cantcliffe (1991) found that sweet pepper plants grown in a nursery developed faster initial root growth and increased fruit growth and development when compared to direct seeded plants. Tomato transplants were reported to have higher plant survival, faster establishment, greater uniformity, and earlier maturity than direct seeded plants (Weston and Zandstra, 1989). The production of healthy, vigorous transplants has an important role in the total productivity of peppers including, early and total yields (Markovic et al.,1995). Transplant quality at the time of transplanting has been found to affect stand establishment and yields (Chipman, 1961). The seedling stage of pepper development is believed to be the most

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important and sensitive period for successful production (Markovic et al.,1995). Physiological age of pepper transplants has been determined to significantly affect yielding potential of plants in the field. Weston (1988) found that sixty day old seedlings produced 70% more yields than did younger seedlings (30,40,50 days old, respectively). McGraw and Creig (1986) also observed a similar trend of increased fruit set from older pepper seedlings (77 days vs 55 days) of different cultivars.

Temperature is an important environmental factor affecting successful development of peppers. During germination, and while the plant is young, the optimal temperature is at least 30^{0}C (Andrews, 1984). Temperature has been shown to affect the growth of seedlings. Ho and Adams (1995) reported that the temperature at the root zone affects water and nutrient uptake. This is supported by Moorby and Graves (1980) who determined that increased root temperature increases plant growth, transpiration, and ion uptake. According to Ho and Adams (1995) the daily uptake of water increased by 30%,with proportional increases in Ca, Mg, K, and N when the temperature of pepper plants was increased from 14 to 26^{0}C. White (1937) concluded that the optimal rooting temperature for good root and plant growth in tomato is $20\text{-}33^{0}$C. Although the response to the temperature of the root zone is usually smaller than for ambient temperatures, changes in root zone temperature have been found to increase the nutrient content in plants such as tomato (Adams, 1989). Temperature has been found to affect the germination of pepper seeds. Coons

et al. (1989) found maximum germination rates and percentages of both hot and sweet pepper seeds occurred at temperatures of 25-30^{0}C. Knavel (1977) found that growing pepper transplants to first anthesis required 10 weeks for plants grown at 24^{0} C, 8 weeks at 27^{0} C and 6 weeks for plants grown in a greenhouse during summer months. Knavel (1977) also determined that low temperatures retard growth and increase the number of days until first flowering. Many studies have been conducted relating fertilization of pepper transplants to yields (Knavel, 1977, Masson et al.,1991, Dufault, 1994), flat size (Weston, 1988), pH (Stoffella et al.,1991), and ambient and root zone temperature (Deli and Tiessen, 1969, Cochran, 1932).

Very little research has been conducted relating the production method of transplants to pepper yields. In the state of Tennessee tobacco transplants have been successfully grown utilizing a hydroponic "float system" (Rutledge, 1997). The floating hydroponic system produces plants grown in styrofoam trays filled with a potting mix. The trays are floated over a nutrient solution with the roots being allowed to grow into the solution (Sutherland, 1987). This system has several advantages over conventional methods of production. These include: better plant survival, faster early season growth, easy management of plant growth, optimal nutrient and water management, ability to save unused plants, and the ability to alter the nutrient solution temperature to maximize plant development (Miller et al.,1998). The success of float systems in tobacco transplant production suggests that a float system may be beneficial for the production of pepper transplants.

The objectives of this study were to evaluate the effects of a hydroponic system as compared to a conventional production system for pepper transplants, to determine how altering the temperature in a hydroponic system affects growth and development of pepper transplants, to determine if the transplant production system has an affect on subsequent plant development and yields, and to compare the performance of specific types of peppers grown under hydroponic production methods.

Materials and Methods

Greenhouse

Greenhouse experiments were conducted in 1998, at the University of Tennessee , Knoxville, Tennessee. The glass greenhouse utilized was maintained at 24^0 C under natural light conditions. Seeds of two cultivars of two types of peppers: 'Grande' jalapeno and 'King Arthur' bell (Peto Seed, Saticoy, CA) were hand seeded in 128 cell styrofoam trays (Speedling Corp., Sun City FL.) in conventional growing media on 31 March, 1998. Trays were placed into one of three treatments: conventional, non-heated hydroponic, or heated hydroponic growing conditions.

The conventional treatment consisted of trays being placed on a greenhouse bench under traditional culture. Plants were allowed to germinate and were watered as needed. Plants were fertilized with 20:20:20 Peters water soluble fertilizer at the recommended rate weekly beginning 28 days after seeding (DAP) and continuing until time of transplant. The non-heated hydroponic treatment consisted of conventional hydroponic culture similar to that used in tobacco production. Selected trays were placed into traditional float bed culture immediately after seeding. Float-beds consisted of two 8 tray structures, constructed of treated stock lumber lined with a 5 mil. plastic and filled with water to a total volume of approximately 380 l. Peters Professional (5-11-26) fertilizer was added to the water with additional nutrients being added to bring solution to the recommended nutrient rates (200 ppm N, 210 ppm K, 193 ppm Ca, 40 ppm Mg, 5 ppm Fe). The heated hydroponic treatment consisted of a floating hydroponic system similar to that in treatment two. The nutrient solution was heated to 32^{0} C, by placing a conventional water bed heater between the floor of the greenhouse and the plastic liner of the float bed. The nutrient solution was thermostatically regulated and monitored daily to ensure proper temperature.

Data Collection

Plants were monitored daily for germination. A plant was considered germinated at the first emergence of the seedling through the soil. To compare germination rates, plants were counted daily until 50% of all seeds planted had germinated. Ten randomly selected plants were removed from each of the three treatments weekly beginning 28 DAP and continuing until 49 DAP. Plants were measured for the following: height, stem and leaf fresh weight , fresh root weight, and number of leaves. Plant height was measured from soil level to the first true leaf to the nearest 0.5 centimeter. Plants were combined by treatment and their weight recorded to the nearest 0.1 g on a digital scale (Acculab model 1200 Bradford MA). Roots were removed from plants, washed and towel dried, combined, then weighed as above. Plant shoots and roots were dried for 24 hours at 75^0 C to determine percent dry matter. The number of leaves was counted for each plant. Plants were removed from float beds on 4 May, 1998 and hardened off in the greenhouse by decreasing watering until 18 May, 1998 (49 DAP). Plants were transplanted in the field on 18 May, 1998.

Field Evaluation of Transplants

Transplants were hand planted on raised beds covered with 1.5 ml black polyethylene plastic mulch. The experimental design was a completely randomized design with a factorial treatment arrangement and four replications for each of the two cultivars and three treatments. For yield there were repeated measurements taken over four separate harvest periods. Beds were spaced 2.1 m. apart. The plants were planted on double rows 0.61 m apart with staggered 45.7 cm plant spacings. Sixteen plants were set per each replication with 10 plants being randomly selected from each replication for measurement. Dead plants were replaced until fourteen days after transplanting. Plants were drip irrigated as needed and fertigated at the rate of 1.12 kg/ha of N per day. Recommended procedures were followed for weed and insect control.

Data Collection

Days until first flower were determinated by monitoring the plots daily until the first flower was visible on one of the ten measured plants in each of the four replications beginning at transplant into the field. The total days until first fruit set were similarly determined. Yields were established by harvesting each ten plant replication separately. Fruit was harvested at the mature green stage according to USDA standards and total yields determined and projected on a per hectare basis. Missing plants were corrected for by dividing the total number of plants harvested by the total possible plants and total yield projected on a per hectare basis. Fruits were harvested four times during the season. An estimation of the fruit quality was done by sampling five individual fruit from each of the replications during the second and third harvests. Circumference and length were measured for each fruit (cm).

Data Analysis

Plant height, days until first flower, first fruit set and total number of leaves were analyzed using the General Linear Models Procedure and least square means separated with LSD (SAS, 1989). The model measured the effects of treatment, cultivars and treatment by cultivar interaction. Total yield per hectare was analyzed in the Mixed procedure (SAS 1997) and least square means separated using the LS means procedure. This model measured treatment and cultivar effects with repeated measures over four harvests and all possible interactions.

Results and Discussion

Plant Growth

Temperature influenced the germination rate of Grande Jalapeno with 50% of seeds in the heated hydroponic treatment germinating in 10 days as compared to 13 and 17 days for the hydroponic and conventional treatments respectively (Table 3). Temperature did not appear to influence the gemination rate of the bell type that was evaluated, but these results are based on non-replicated data. The possible effect of temperature on pepper germination is supported by Coons (1989) who reported that the germination of pepper seeds occurred at the fastest rate at 25^0 C in several cultivars he evaluated. The relative growth rate was faster for the hydroponic treatments with the heated treatment having the fastest growth for both types of pepper evaluated (Fig.1). Plants grown in both hydroponic treatments grew faster than those in the conventional treatment with the heated treatment producing the largest transplants consecutively over the entire growing period. Both hydroponic treatments grew significantly larger when compared to the previous week at both 35 and 42 DAP. The conventional treatment showed significant growth when compared to the previous week on 35 and 49 DAP . The slowed growth associated with the hydroponic trials at 49 DAP may be associated with the shock encountered after removal of the transplants from the hydroponic treatments. The increased growth found in the hydroponic trials may be attributed to increased uptake of nutrients and optimum water availability. Ho

Table 3. Effect of production method on total number of days until 50% germination, first flower and first fruit for pepper cultivars evaluated at the University of Tennessee Experiment station, Knoxville, 1998.

Transplant production Method	Grande Jalapeno			King Arthur Bell		
	50% germ	first flower	first fruit	50% germ	first flower	first fruit
Conventional	17.0	29.0	29.0	15.0	30.0	33.0
Hydroponic	13.0	29.0	29.5	15.0	31.5	31.0
Heated Hydro	10.0	29.0	30.0	13.0	31.5	31.5

Mean number of days after transplanting until first flower and first fruit set. Values within a given column followed by a different letter differ (P<0.05). Number of DAP until 50% germination was not tested.

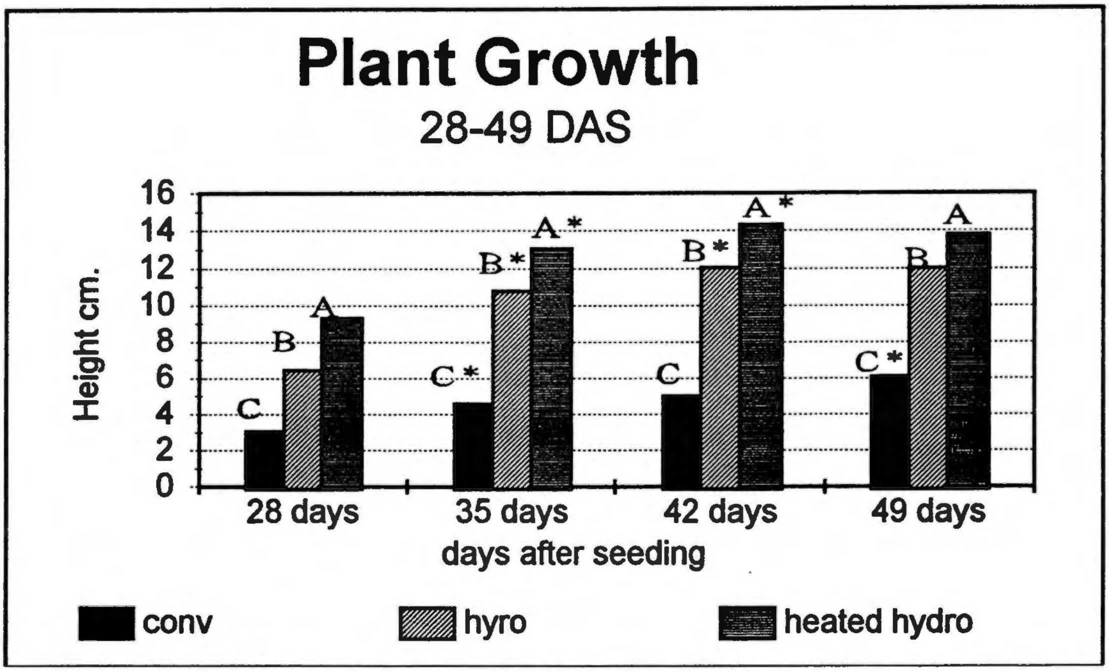

Figure 1. Weekly differences in plant height of Grande Jalapeno (cm) per each treatment. * indicates significant growth from previous time. Any bars followed by a different letter within the same day are significantly different (P <0.05).

and Adams (1995) reported that nutrient uptake increased 30% in peppers when the temperature was increased from 14 to 26 ^{0} C. Plants in the heated hydroponic and hydroponic treatments consistently produced larger transplants with a greater number of leaves. The greatest difference in plant height occurred between the conventional and heated hydroponic treatments with a mean final plant heights of 13.80 and 11.45 cm, for the heated treatments of 'Grande' and 'King Arthur', respectively, as compared to 6.10 and 5.75 cm in the conventional treatments. These heights were slightly lower then those recommended by Markovic (1988) who reported that pepper plants should be 16-20 cm at time of transplanting. Ninety-one percent of the variation in plant height could be explained by the difference in treatments (data not shown). Mean number of leaves was also greater for plants in the hydroponic treatments than for those in the conventional treatment with the means of final leaf counts being 12.0 for both cultivars for the heated trials and 11.4 and 10.9, respectively, for those in the conventional treatment. The mean total fresh and dry weights of both shoot and root material were consistently greater from plants in the hydroponic treatments. The heated hydroponic treatments showed the greatest trends in fresh shoot weight, however these data were not replicated. The percentage of dry matter for the roots and shoots was less for the heated hydroponic treatments for the periods that the plants were on the float beds (data not shown). The final total percent dry matter increased upon removal from the float beds for both cultivars with the heated hydroponic treatments having the greatest total percent dry matter for the 'King Arthur' bell (Table 4) variety and the hydroponic treatments having a greater dry matter percentage for the 'Grande' jalapeno variety (Table 5). A higher percentage of dry matter is believed to lessen the effects of post transplant shock. All treatments produced final percent dry matter contents greater than 11-12% which is recommended by Markovic (1986) for optimal field performance. Overall, plants grown under the hydroponic treatments appeared to be further developed then plants grown in the conventional treatments.

Field Performance

Plants from all treatments survived equally well in the field. The total number of plants that survived was similar for all treatments for both cultivars (data not shown). Most plants that died did so due to "collaring" caused by the plastic mulch touching and girdling the stems of the plants. There were no differences in the total number of days until the first flower and subsequent first fruit set. No difference in treatment effect was observed in early yields (Table 6), or fruit quality for each cultivar (data not shown). This finding was in direct conflict with Weston (1988) who reported that taller pepper plants produced 70% greater early yields. This lack of differences in field performance may be due to the insufficient maturity of the transplants in this study. The importance of transplant maturity is supported by Markovic (1988) who reported that the optimum height of pepper transplants is 16-20 cm with reduced yields occur ing with less mature plants. There was no difference in total yields among treatments. A significant

Table 4. Effect of production method on 'King Arthur' Bell plant root and shoot weights 49 DAP evaluated at The University of Tennessee Experiment Station, Knoxville , 1998

transplant production method	Fresh Shoot (g) *	Fresh root (g) *	shoot % Dry matter *	Root % dry matter *
Conventional	18.9	8.9	14.97	9.55
Hydroponic	22.1	9.5	13.89	9.89
Heated hydroponic	36.2	13.9	15.61	10.14

* Total weight (g) for roots and shoots from a ten plant sample.

Table 5. Effect of production method on 'Grande' jalapeno plant root and shoot weights 49 DAP evaluated at The University of Tennessee Experiment Station, Knoxville , 1998.

Transplant Production Treatment	Fresh Shoot (g) *	Fresh root (g) *	shoot % Dry matter *	Root % dry matter *
Conventional	28.2	11.6	16.49	10.86
Hydroponic	28.9	10.2	19.03	13.04
Heated hydroponic	37.7	11.4	18.83	12.89

* Total weight (g) roots and shoots from a ten plant sample.

Table 6. Effect of hydroponic treatments on early yields and total yields of peppers evaluated at the Knoxville Experiment Station, Knoxville, TN, 1998.

Treatment	First Harvest (kg/ha)		Total Harvest (kg/ha)	
	Grande Jalapeno	King Arthur Bell	Grande Jalapeno	King Arthur Bell
Conventional	4439	3199	22801	19952
Hydroponic	3629	1251	20553	14369
Heated Hydro	4698	2246	22547	16745
Average Yield	4256*	2232	21978*	17019

Any number followed by a * had a significantly greater yield for that harvest. Any value in a given column followed by a different letter differ (P<0.05).

difference in total yields was observed between cultivars with 'Grande' jalapeno producing significantly greater yields than the 'King Arthur' bell.

In conclusion, transplant production systems have a significant influence on the growth and development of pepper seedlings with hydroponic systems producing the largest transplants. Increased temperature of the nutrient solution appears to improve germination rates, plant growth and development, and overall transplant quality. The significant shock associated with removing transplants from the float beds probably affects the transplants' survival and performance after being placed in the field. This may necessitate hardening the transplants by removing them from the float beds for a period of time before transplanting them into the field. Environmental adaptation and physiological differences among cultivars may result in different responses to transplant growing conditions. The effect of transplant shock may be lessened by allowing the plants to stay on float beds longer to establish a larger transplant. The float system allows several advantages to producers. The significant growth which occurs in the hydroponic treatments may allow for a later seeding date reducing greenhouse costs. The constant supply of nutrients and water will require less labor then traditional methods of production. These advantages can increase the profitability of pepper production and may assist producers reach the market at the most profitable time.

5. General Summary

The purpose of this study was to evaluate the potential of using a hydroponic system, as is currently being used in tobacco production, for the production of vegetable transplants.

The results obtained in these experiments suggest that faster growth and better quality vegetable transplants can be produced by a hydroponic system than by conventional methods of production.

Temperature influences the growth and development of pepper transplants with plants grown in heated nutrient solution germinating faster, growing larger and being ready for transplant earlier than those grown in non-heated nutrient solution.

Aeration of the nutrient solution influences the development of cabbage transplants with aerated trials resulting in faster growing and larger transplants. Cabbage transplant quality was also better in aerated trials resulting in taller, plants with more shoot mass than those grown in non-aerated treatments.

Future research is required in order to determine optimum parameters of the hydroponic system needed for vegetable transplant production. Future areas of needed research include; aeration of heated nutrient solution in pepper transplant production, determining the optimum nutrient solution concentration, dissolved oxygen concentration and temperature for transplant development and determining the optimum time to harden transplants in order to maximize the benefits obtained from the system.

The production of healthy transplants in a timely manner will benefit the vegetable industry in Tennessee by allowing for local production of quality transplants. The development of such an industry would allow tobacco producers to establish a suitable substitute and/or augmentation to tobacco production if needed. By using existing facilities, tobacco producers can make this transition in the most cost effective manner.

Literature Cited

Adams, P. 1989. Some effects of root temperature on the growth and nutrient uptake of tomatoes in NFT. Proceedings of the 7th international congress of soilless culture, Flevhof, 1988. 73-82.

Adams, P. and L.C. Ho. 1993. The susceptibility of modern tomato cultivars to blossom end rot in relation to salinity. J. Hort. Sci. 67:827-839.

Aloni, B. T., Pushkar, and L. Karni.1991. Nitrogen supply influence carbohydrate partitioning of pepper seedlings and transplant development. J. Amer. Soc. Hort. 116:995-999.

Andrews, Jean.1984. Peppers the domesticated capsicums. University of Texas Press, Austin, TX.

Arnon, D.I. and D.R. Hoagland. 1940. Crop production in artificial culture solutions and in soils with special reference to factors influencing yields and absorption of inorganic nutrients. Soil Sci. 50:463-484.

Canham, A.E. 1966. Raising young tomato plants with soil warming and supplementary light. Proc. Symp. Tech. Intl. Soc. Hort. Sci. 4:81-88.

Chipman, E.W. 1961. The effect of seeding and plant topping on the production of early and total yields of ripe tomatoes. Proc. Amer. Soc. Hort. Sci. 77:483-486.

Clark, C.A., C.D. Stanley D.M. Mynard, G.J. Hochmuth, E.A. Hanlon, and D.Z. Haman.1991. Water and fertilizer management of microirragated fresh market tomatoes. Trans, ASAE. 34:429-435

Coffey, D.L., C.E. Sams, C.A. Mullins, J.E. Wyatt, and R.D. LaLone. 1990. Performance of Cabbage Cultivars in Tennessee. Tennessee Farm and Home Science. 153:10-13.

Cochran, H.L. 1932. Factors affecting flowering and fruit set in the pepper. Proc. Amer. Soc. Hort. Sci. 29:434-437.

Coons, J.M., R.O. Kuehl, N.F. Oebker, and N.R. Simons. 1989. Seed germination of seven pepper cultivars at constant or alternating temperatures. J. Hort. Sci. 64(6):705-710.

Deli, J. and H. Tiessen. 1969. Interaction of temperature and light intensity on flowering of Capsicum frutescens var grossum cv. 'California Wonder'. J. Amer. Soc. Hort. Sci. 94:349-351

Dufault, R.J. 1986. Influence of nutritional conditioning on muskmelon transplant quality and early yield. J. Amer. Soc. Hort. Sci. 115:698-703.

Dufault, R.J. 1994. Long term consequences and significance of short-term pretransplant nutritional conditioning. Hort Technology. 4:41-42.

Dufault, R.J. and L. Waters, Jr. 1985. Container size influences broccoli and cauliflower transplant growth but not yield. HortScience. 20:682-684.

Giselrod, H.R. and R.J. Kempton.1983. The oxygen content of flowing nutrient solutions used for cucumber and tomato culture. Sci. Hort. 20:12-33.

Halsey,L.H., J.F. Beeman, D.R. Hensel, W.W Dean, and V,L. Guzman. 1966. Influence of variety and spacing on yields of cabbage from a single harvest. Proc. Fla. State Hort. Soc. 79:194-201.

Hara, T. And Y. Sonada. 1982. Cabbage-Head development as affected by nitrogen and temperature. Soil Sci. Plant Nutr. 28:109-117.

Hartz, T.K. M. Lestrange, and D.M. May.1993. Nitrogen requirements of drip irrigated peppers. Hort Science. 28(11): 1097-1099.

Hochmoth, G. 1991. Fertilizer programs for tomatoes in Florida. Proc. 1990 Annu. Amer. Greenhouse Veg. Growers Ass. Conf. And trade show, Jacksonville, Fla. 1-3 Nov.1990.

Ho, L.C. and P. Adams.1995. Nutrient uptake and distribution in relation to crop quality. Acta Hort.396:33-44.

Jackson, M.B. 1980. Aeration in the nutrient film technique of glasshouse crop production and the importance of oxygen, ethylene and carbon dioxide. Acta Hort. 98:61-78.

Jensen, M.H, and W.L. Collins.1985. Hydroponic Vegetable Production. Hort Reviews. 7:483-558.

Knavel, D.E. 1977. The influences of nitrogen on pepper transplant growth and yielding potential of plants grown with different levels of soil nitrogen. J. Amer. Soc. Hort. Sci. 102: 533-535.

Knavel, D.E. and J.W. Heron. 1981. Influence of tillage system, plant spacing, and nitrogen on head weight, yield, and nutrient concentration of spring cabbage. J. Amer. Soc. Hort. Sci. 106:540-545.

Leskovar, D.I. D.J. Cantliffe, and P.J. Stoffella.1989. Pepper (*Capsicum annum L.*) Root growth and its relation to shoot growth in response to nitrogen. J. Hort. Sci. 64:711-716.

Lorenz, O.A., and D.N. Maynard. 1988. Knott's Hanbook for Vegetable Growers. John Wiley and Sons, New York, New York.

Markovic, C.V. A. Takac, Z. Illin.1995. Enriched Zeolite as a substrate component in the production of pepper and tomato seedlings. Acta Hort. 396:321-324.

Massey, D.M., P. Adams, and G.W. Winsor.1986. Five years work on NFT. Grower los, BGIA supplement, 23 January: 90, 93, 94, 97, and 99.

Masson, J., N.Tremblay, and A. Gosselin. 1991. Effects of nitrogen fertilization on hps supplementary lighting on vegetable transplant production. II. Yield. J. Amer. Soc. Hort. Sci. 116(4):599-602.

Melton, R.R and R.J. Dufault.1991. Nitrogen phosphorous and potassium fertility regimes affect tomato transplant growth. Hort Science. 26:141-142.

McGraw, B.D. and J.K. Creig. 1986. Effect of transplant age and pruning procedure on yield and fruit set of bell pepper. Hortscience. 21(3):430-431.

Miller, C.H. 1961 Some effects of different levels of five nutrient elements on bell peppers. Proc. Amer. Soc. Hort. Sci. 77:440-448.

Miller, G.H., W.E. Splinter, and F.S. Wright. 1969. The effect of cultural practices on the suitability of cabbage for once-over harvest. Amer. Soc. Hort. Sci. 94:67-69.

Miller, R.D. D.J. Fowlkes, and M.J. Buschermole. 1998. Producing tobacco float plants by direct seeding in outdoor water beds. Tennessee Ext. Bul. Unpublished.

Moorby, J. and C. Graves.1980. Root and air temperature effects on growth and yields of tomatoes and lettuce. Acta Hort. 98: 29-43.

Resh, Howard.1978. Hydroponic Food Production. Woodbridge Press, Santa Barbara, CA.

Rutledge, A.D. 1998. Commercial Cabbage Production Guide. University of Tennessee Extension Bull. 44. 24 pp.

Rutledge, A.D. 1997. Float plant system for vegetable plant production. University of Tennessee Ext. Bull. 268. 14 pp.

SAS Institute. 1989. SAS/Stat Users Guide, Version 6. Gary, N.C.
Sutherland, S. 1987. Hydroponics for Everyone. Hyland House Publishing, Melbourne, Austria.

Stoffella, P.J. M.L. Dipaola, A. Pardossi, and F.Tognoni. 1991. Rhizosphere ph influences early root morphology and development in bell peppers. Hort Sci 26(2):112-114.

Thomas, J.R. and M.D. Heilman.1964. Nitrogen and phosphorous content of leaf tissue in relation to sweet pepper yields. Amer. Soc. Hort. Sci. 85:419-425.

Weston, A.L. 1988. Effect of flat size transplant age, and production site on growth and yield of pepper transplants. HortScience.23(4):709-710.

Weston, L.A. and B.H. Zandstra.1989. Transplant age and n and p nutrition effects on growth and yield of tomatoes. Hort Science. 24:88-90.

White, P.R. 1937. Survival of isolated tomato roots at suboptimal and supraoptimal temperatures. Plant Physiology. 12:771-776.

White, J.M. and R.B. Forbes. 1976. Effect of spacing and fertilizer rates on cabbage yield and head weight. Proc. Fla. State Hort. Soc. 89:118-120.

Xu, Z. and P. Adams.1994. Effect of interplanted rice on the growth of tomato in deep solution culture and the response to salinity. J. Hort. Sci. 69:319-328.

Vita

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