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THE USE OF TODD PLANTER FLATS FOR FRESH MARKET TOMATO AND PEPPER TRANSPLANT PRODUCTION

By

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ABSTRACT

THE USE OF TODD PLANTER FLATS FOR FRESH MARKET TOMATO AND PEPPER TRANSPLANT PRODUCTION

By

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Tomato (Lycopersicon esculentum Mill.) and pepper (Capsicum annuum L.) transplants produced in two locations, in several root cell sizes and of various ages, were compared for productivity in Michigan. Plants grown in larger cells were largest and produced highest early and total marketable yields. Larger root cell size was more critical in producing larger transplants than was wider spacing in the flat. Four- to five-week-old tomato transplants fertilized with high nitrogen and low phosphorus produced larger early yields than plants of other ages and fertilizer treatments. Tomato transplants grown in TODD flats in Michigan produced larger early and total marketable yields than transplants produced by Speedling in Florida. Speedling tomato plants shipped by air freight to Michigan produced less ethylene and CO_2 than Michigan plants, indicating little stress during shipment.

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LITERATURE REVIEW

Introduction

Transplanting can be defined as the practice of removing a plant from one place and resetting it in another area (16). The practice of transplanting rests upon methods developed by Old World gardeners. The acreage of vegetables produced from transplants, the high value of these crops, and the considerable cost of transplant production give the ancient practice of transplanting an important place in the economics of vegetable production (32).

The harvested acreage of green peppers in the United States in 1981 was 56,200 acres while the acreage of fresh market tomatoes in 1981 was 128,580 acres (5). The majority of this acreage is planted with transplants. It can be seen that a tremendous number of transplants are set out in the field each year by the fresh market vegetable growers in the United States (54).

Advantages and Disadvantages of Transplanting

Using transplants in crop establishment has both advantages and disadvantages. An important advantage of transplanting in the greenhouse is the reduction in space needed for plant production (32, 51). Without transplanting, it is necessary to use a seed bed of sufficient size to allow for growth to field transplant size without crowding (51). Transplanting reduces the amount of expensive seed needed to establish a good stand in the field. With certain crops, transplanting results in earlier production, allowing growers to take advantage of an early market. The use of transplants also allows for production of warm season crops in areas which normally have too short a season (32).

The main disadvantage of establishing crops by transplanting is the labor involved in growing the plants and planting them in the field. However, this additional expense may be offset by greater early yields and higher prices received for the produce. Another disadvantage of transplanting is the check in growth to the young plants which occurs as a result of disturbing and resetting the root system (51). Depending on many factors, this check in growth may be easily offset by an increase in root branching in crops such as tomatoes, cabbage, lettuce and beets. In other crops such as corn, beans, melons and cucumbers, the check in growth may be severe due to limited root replacement (32).

Problems Encountered During Transplant Production

Several problems are commonly reported by growers setting transplants into the field. The use of poor quality transplants may cause the spread of disease. A large number of tomato transplants are produced in southern Georgia and shipped to the North each year (39). Because these transplants may reach the size suitable for certification in the South when weather conditions are unfavorable in the North, growers are often forced to store transplants. The infection of tomato seedlings by fungal and bacterial diseases increases as the storage period is lengthened (22, 50). Because of this problem, and damage incurred during shipment, some northern growers are reluctant to use southern-grown transplants (39).

Root binding will occur if a plant is stored or grown in a container for an extended period. Root binding is characterized by an inability of the growing root system to expand. This results in a stunted transplant which can exhibit a serious check in growth after transplanting (59).

An important problem affecting the growth of transplanted crops is transplant shock caused by disturbing or resetting a plant's root system. Transplant shock after field-setting is marked by sudden wilting, a decreased rate of new root formation and an overall check in the growth of the plant. In an elaborate set of experiments carried out at Ithaca, New York with several types of vegetables, Loomis found that transplanting always resulted in a check in growth. The check in growth of the transplants was found to be proportional to the size of the plant at the time of transplanting. Large plants were more seriously injured than small transplants in his study because the proportion of retained roots was smaller for the larger transplants. Loomis states:

> those plants having root systems of such a form as to be largely lost in transplanting or whose older roots are heavily suberized so they must depend upon the outer portions of the root system for their moisture supply, will be more seriously injured than plants having a more branched and less heavily suberized root system (32).

Loomis suggests that the root system plays a critical role in transplant recovery. The three most important factors which influence this recovery are: 1) the proportion of the root system retained after transplanting, 2) the capability of the retained roots to absorb water after transplanting, and 3) the rate of new root formation. He found that the immediate effect of transplanting was a reduction in the available water supply to the transplant (32).

The rate of new root formation, which influences water uptake, may be the most significant factor in the reestablishment of transplanted vegetable crops. A correlation was shown to exist between the ease of transplanting and the rate of new root formation. Vegetable species which are easily transplanted exhibit a fast rate of root replacement as well as a fast rate of top growth. Plants which are seriously injured by transplanting usually exhibit a slow rate of root replacement but a rapid rate of top growth. The rate of root replacement decreased with increasing age of the vegetable transplant (32). Thompson and Kelly believed that all factors which affected transplant recovery eventually act by influencing the water supply of the transplant (51).

Cultural Practices Used in Transplant Production

Many different types of transplants are used by fresh market tomato and pepper growers. In the past, growers have used field-grown transplants produced in the Southern United States and shipped north in the spring. Over 700 million tomato transplants are produced in southern Georgia for northern growers each year (39). These southern transplants are grown in the field at close spacing in seedbeds. Often these bare-rooted transplants are not of the quality desired by northern growers. Bare-rooted transplants often lose a considerable portion of their root system upon removal from seedling beds. Observable setbacks in vegetative growth often occur (49). Water and nutritional stress caused by root damage also result in transplant shock (32, 49). Early yields are often reduced due to extensive root damage occurring during removal from seedling beds (12, 34, 49). Diseases caused by production in contaminated seedbeds and prolonged periods of storage before shipment also reduce plant stand and yields (22, 50).

Field-grown transplants are cheaper to produce than other transplant types because less labor and energy are required for field production than for intensive greenhouse production. However, a warm climate is necessary for early production of the field-grown transplants used by northern growers. Soil for field-grown transplants should be fertile, friable, well-drained and free from insect and disease infestation (54).

Growers also use transplants produced in greenhouses for crop establishment. These transplants may be produced in containers or direct-seeded into soil beds in the greenhouse. Greenhouse-grown transplants are often of higher quality than field-grown transplants because the grower maintains control over environmental factors influencing plant growth. However, these transplants are more expensive to produce because of increased energy and labor requirements during their production (54).

The selection of a growth medium for transplant production is an important decision to be made by the transplant producer. An ideal container mix is achieved by combining coarse textured amendments with fine-textured materials. This allows for the formation of many pores for adequate water storage (47). To avoid water stress after transplanting, caused by decreased water retention of certain soil mixes, the grower should irrigate frequently, shade or protect the plants from excessive drying and use a soil mix that contains a sufficient number of small pores (48).

Plants grown in the greenhouse may be started in a seedbed and later transplanted to cells, flats or beds or direct-seeded into containers for growth until field setting. Seeds are sown thickly into a seedbed for transplanting into the greenhouse. When the first true leaves are well developed the seedlings are thinned or transplanted into cells, flats, benches or beds. The taproot is usually broken and many feeder roots are broken off in removing the transplant from a seedbed. This results in increased root branching. Depending on the plant species and size of the transplant, increased root branching may result in an increased absorptive capacity. However, if the roots are seriously disturbed and the soil around the roots does not remain intact, a check in growth may occur (51).

Teubner (49) demonstrated that transplanting bare-root plants or plants with a minimum of soil adhering to the roots resulted in noticeable setbacks in vegetative growth of tomato plants. The adverse effects of transplanting shock on the development of the young flower buds was less apparent but potentially more serious since early yields declined. He attributed the abortion of developing flower buds to the diversion of food reserves to the injured root system along with decreased moisture and nutrient levels as a result of root damage (49).

Wooden flats are commonly used in the greenhouse to propagate fresh market tomato and pepper transplants. Flats are easily used, but are not necessarily the best container to use to produce high quality transplants. Researchers have found that flat-grown transplants produce lower early yields than other container types (34, 49). Transplanting from a flat results in either bare-root transplants or those with a minimum of soil surrounding the root system (49). Transplanting shock created by this root damage often results in water and nutritional stress, flower abortion, setbacks in vegetative growth and decreased early yields (32, 34, 49).

Other types of transplant containers frequently used by vegetable producers include veneer bands, paper bands, clay, peat and plastic pots. Ball (8), Campbell (11) and Nylund (38) have shown that tomato transplants grown in peat, clay or plastic pots produced larger early yields than those grown in flats or paper bands. Nylund also reported that pot-grown tomato transplants produced 117% greater early yields and 16% greater total yields than flat-grown transplants (38). The differences in yield were probably due to decreased root damage during transplanting when pots are used (34). Thompson and Kelly agree that the main advantage in using pots is that the roots are not disturbed when the plant is set in the field (51).

Peat pots are formed from compressed peat material. They remain around plant roots at transplanting thereby minimizing disturbances to the root system. Plastic or clay pots involve additional labor in picking up, washing and storing the containers after transplanting. These pots can be re-used for several years if they are sterilized after each use. Paper and veneer bands are lightweight, inexpensive containers which are not re-usable. They are not particularly sturdy, but are easily stored. Most container types are available in a variety of sizes to meet the needs of vegetable producers (34).

TODD planter flats, produced by Speedling Inc. in Sun City, Florida, are becoming popular as containers for greenhouse-grown vegetable transplants. The flats are made of expandable polystyrene and can be re-used many times. They come in a number of root cell sizes, with a descriptive number indicating the cell size; e.g., a 100 size flat has cells 1 inch across, a 125 size flat has cells 1.25 inches across. The cells are square, inverted pyramids. Speedling claims that the unique inverted pyramid design encourages downward root growth and allows natural air pruning, while minimizing root-binding problems and virtually eliminating transplant shock. Speedling transplants produced in the TODD planter flats are reported to have a 95%-plus survival rate (3).

The most common size of the TODD planter flat measures 68 cm in length by 34 cm wide. The depth of the flat varies from 2.5 to 10 cm. The cell sizes range from 2 cm to 5 cm square. The number of cells varies from 18 for the 200 size flats to 288 for the 080 flats, creating transplants of many sizes to meet the needs of vegetable and bedding plant producers (4).

Speedling recommends using a Cornell Peatlite growing medium in the TODD planter flats. This growing medium consists of peat and vermiculite with a special fertilizer formulation added. The mix provides elasticity, drainage and nutrient exchange capacity to produce transplants that are virtually disease-free (44). Speedlings' ultimate goal is to produce healthy, stocky vegetable seedlings with good green color in approximately 4 to 5 weeks from direct seeding (4).

Speedling tomato and pepper plants are shipped to many parts of the United States, including Michigan. Speedling also markets its TODD planter flats for use by growers in their own greenhouses (2).

Obtaining high quality transplants is one of the most important factors in fresh market tomato and pepper production (13, 24, 25). Transplant quality affects stand establishment, early yield, total yield and fruit size (25, 37). In the case of tomatoes and peppers, a stocky young plant free from insect and disease infestation and possessing neither open flowers nor buds is desired (35, 54).

Early production is usually desired because of the short growing season in the North and the high value of the crop during the first 2 weeks of the marketing season (12, 38). Several cultural practices are known to affect early yields of tomatoes and peppers. These include the method of transplant production, the use of starter solution, fertilization program, the spacing of plants in containers prior to field-setting, the size of the transplant container, and the age of the seedling at transplanting (12, 13, 38). Nicklow and Minges suggest that tailoring cultural practices to a tomato variety may be very important to realize maximum yielding potential (37).

Many researchers have shown that earlier tomato yields in the field are directly correlated with space per plant in the greenhouse (12, 25, 37, 42). Nicklow and Minges found that greater space per plant resulted in more leaves at the first cluster, a stockier plant, and faster overall growth which resulted in earlier flowering and greater early yield (37). Other researchers have shown that tomatoes grown in 3 inch pots produced greater early yields than flat-grown plants (8, 11, 38, 55). Lamm (26) and Knavel (24) reported that tomato plants grown in 4 inch pots produced greater early yields than plants grown in 2 1/4 and 3 inch pots. Romshe (40) demonstrated an increase in both early and total yields of tomatoes grown in plant bands with an increase in the size of the plant bands. He found no differences in yields of tomatoes grown in wood veneer, Manila paper or heavy asphalt paper bands (40). Sayre noted that giving tomato plants 25% more space in the flat by setting out fewer seedlings per flat resulted in earlier yields in the field. However, growing the plants in deeper flats containing 33% more soil did not increase the yields during two growing seasons (42). Kretchman and Short reported that tomato transplants grown in 2-inch TODD planter cells produced slightly larger yields from a single harvest than did transplants grown in 1-inch cells (25).

Several researchers have offered explanations for the increase in early yield of tomatoes with an increase in container space. Casseres believed that young tomato roots from wider spacings were only slightly disturbed at field setting, allowing for resumption of vegetative growth. Plants grown at a closer spacing suffered more damage to their root systems at transplanting and were set-back (12). Nicklow and Minges questioned this explanation. They believed that the wider spacing influenced the physiological condition of the transplant before field setting (37). Knavel reported that tomato plants reach a nutrient starvation stage more quickly when grown in small containers, while larger containers hold enough fertile soil mix to support adequate root development until field setting. Knavel also noted that the spacing of pots on greenhouse benches influenced the early yields of tomato fruit. Greater early yields were obtained from plants grown at an 8 by 8 inch spacing between containers than from plants grown at a 4 by 4 inch spacing. This was true for plants in containers of various volumes and materials (24).

The age of transplant, or stage of physiological maturity, affects plant growth and subsequent yields after transplanting. Nicklow and Minges reported that a relatively small 3-to 5-week-old tomato transplant without flowers or buds produced the largest fruit and the largest total yields. Larger plants with visible flower buds produced earlier yields. Old plants which were overhardened or were in flower were never desirable (37). Casseres and Sayre also found that younger tomato transplants produced larger yields than older transplants (12, 42). Casseres reported that 6-week-old tomato transplants which were tender and capable of quick recovery after transplanting produced greater early and total yield than 10-and 14-week-old plants (12). Sayre found that 7-week-old transplants produced greater early yields than did 9-and 11-week-old transplants (42).

In an experiment repeated over 3 years, Skapski and Lipinski demonstrated that very young and small tomato seedlings 3 to 4 weeks old can be transplanted successfully only in good growing seasons in Poland. These 3-to 4-week-old seedlings produced lower total yields than did transplants 6 to 8 weeks old. Root and shoot growth of 3-to 4-week-old transplants were retarded while older transplants were not seriously affected by adverse weather conditions (45). Babb reported that increased tomato root growth after transplanting was associated with a young state of maturity of the plant, rather than the initial size of the transplant (7).

Transplant Nutrition

It is important to provide tomato transplants with an adequate level of essential nutrients before and after field setting to allow for quick transplant recovery and growth. Otherwise, nutrient deficiency symptoms often appear when seedlings are transplanted into cool spring soils (53, 57). The limited root system of the transplants may also contribute to the development of a nutrient shortage (57).

Phosphorus is a major nutrient that plays an important role in seedling growth and development. It is known to stimulate root production, promote rapid growth in seedlings and is necessary for cellular metabolism (54).

Tomato plants have a high phosphorus requirement early in the season when root systems are small and temperatures are cool (36, 52, 56, 57). Murphy (36) and Jones and Warren (23) have found that early phosphorus uptake is more important in influencing early yield of tomatoes than total phosphorus uptake. Several researchers have shown that greater early phosphorus uptake results in more rapid growth of tomato seedlings and an increase in early tomato fruit yields (7, 36, 41, 56, 57).

Tiessen and Carolus found that tomato root development benefited greatly from high levels of phosphorus and nitrogen in the fertilizer solution (52, 53). Tomato root regeneration was very active the first 3 days after transplanting. Phosphorus was necessary to meet this requirement and unless phosphorus was supplied in the starter fertilizer, soluble phosphorus in the plant tissue remained at low levels, even with adequate nitrogen supplies. A lack of growth resulted in an accumulation of soluble nitrogen (53). Wilcox reported that the phosphorus requirement for optimum root growth of tomato seedlings can be satisfied by placing a small amount of phosphorus fertilizer in close proximity to the root system so that the concentration of phosphorus in the soil solution near the roots increases (56).

Nitrogen is also a major nutrient that strongly affects seedling growth rate. It is known to promote rapid vegetative growth and green color, and is essential in the formation of proteins and other compounds in the tomato (33).

The level of nitrogen in the soil can significantly affect the growth of transplanted tomatoes. Wilcox and Langston reported that nitrogen was the primary limiting element to tomato seedling growth in an experiment using a soluble nutrient solution. They found that direct seeded tomatoes responded more to additional phosphorus than did transplants, but transplanted tomatoes responded more to additional nitrogen (57). Jaworski reported that although phosphorus is the major element limiting high tomato transplant yields in the fields of Georgia, a moderate level of nitrogen was necessary to produce large marketable yields and uniform development of transplanted tomatoes (19). Tiessen and Carolus found that early root growth was depressed when nitrogen was absent from the nutrient solution. This indicated that nitrogen was necessary for root regeneration also (49).

The availability of nitrogen is an important factor in the propagation of tomato plants. High fertilization with nitrogen may cause a build-up of soluble salts in the soil, causing a reduction in plant stand. Over-fertilization may cause seedlings to become too succulent, resulting in susceptibility to disease and physical damage. However, low fertilization with nitrogen may result in small transplants of poor quality. The source of nitrogen in a fertilizer influences its availability (20).

The balance of nitrogen to phosphorus in transplants may be a very important factor influencing plant growth and yielding ability in northern production areas. Jaworski and Webb found that fruit yields were affected by the nitrogen/phosphorus balance. The highest yields were obtained with either low levels of both nitrogen and phosphorus or high levels of both nitrogen and phosphorus. High nitrogen, in the absence of sufficient phosphorus, caused a significant yield reduction (21). Wittwer and Honma recommended applying 30 ppm phosphorus and 200 ppm nitrogen weekly in nutrient solution to seedling tomatoes grown in the greenhouse in artificial media (58).

Potassium is a major element which plays a lesser role in tomato transplant nutrition. High levels of potassium were shown to have little effect on the growth of tomato transplants either in the field or greenhouse (53, 57). Tiessen and Carolus found that initially, tomato root development benefited more from nitrogen and phosphorus in the nutrient solution than from potassium (52). Murphy reported that phosphorus produced a greater response than potassium when working with southern-grown transplants on newly cleared land (36). Jaworski also found that high potassium levels did not affect the marketable yield of transplanted tomatoes (19). Tiessen and Carolus believed that potassium is seldom limiting to the transplant (53).

Vegetable plants often benefit from applications of starter solutions containing soluble fertilizers at transplanting (41, 42, 52, 51). The use of a starter solution enabled transplanted tomatoes to become established more quickly. This resulted in a significant gain in early maturity (41). Transplanting shock was reduced when transplants received high analysis fertilizer in solution. Tiessen and Carolus reported that starter solutions formulated for tomatoes should contain higher phosphorus and perhaps nitrogen and lower potassium levels to promote initial root regeneration and high percentage survival (52). Sayre found that nutrient solutions containing nitrogen, phosphorus and potassium were more effective than solutions which lacked any of these nutrients (41).

Growth of Tomato and Pepper Plants

Tomatoes and peppers both belong to the family Solanaceae. However, the growth pattern of these plants is different. The pepper shoot first forms a single stem which branches into two. One or more flower buds are produced at the point of diversion. After the production of a few more leaves, each branch divides again. Second layer flower buds develop at each point of diversion. Growth than continues in this manner (46).

The pepper root system first forms a primary root which grows downward. By 2 months of age, the root system is well-branched with laterals extending 10 inches on either side of the 10 inch primary root. The tap root is often damaged after transplanting and horizontal and lateral roots constitute an important part of the absorption system. At maturity, most of the root system is located in the top 24 inches of soil (14).

Aung has reported that tomatoes follow a sympodial growth pattern, where the main axis of growth terminates in an inflorescence and successive growth starts from a lateral shoot in the axil of the last initiated leaf.

The axillary shoot below the first inflorescence usually exhibited greater vigor and fruiting ability than any other axillary shoot on the main stem (6). Leonard and Head found that stem length of tomatoes increased uniformly throughout the growth period. Leaf number on the main stem increased steadily until fruit ripening, when a decrease in leaf number occurred (27).

Leonard and Head (27) noted that the tomato plant first develops a primary root. Phase I consisted of a short period of exponential growth of the root. At the same time, exponential growth of the stem occurred and flowers opened. Phase II was marked by a high growth rate of all organs. Phase III showed a drastic decline in the number and amount of roots as the first fruits formed on the plant. An increase in root growth was noted in phase IV as the first fruits were harvested. In phase V root number and length remained constant.

J. P. Hudson (18) reported that the tomato:

> must make continuous and rapid vegetative growth throughout the season if it is to remain in production, although a careful balance must be maintained between vegetative and fruiting activities, if the plant is to produce a heavy yield of the right type of fruit, at the right time.

He believed that the root/shoot ratio played an important role in maintaining this balance. Leonard and Head (27) found that the growth of tomato roots was closely related to the rate of new fruit production (27). Hudson's work suggested that the tomato fruit was able to monopolize the food resources of the plant at the expense of other organs, including the roots (18).

The growth of tomatoes and peppers includes an early exponential phase when growth is potentially unlimited. The embryo of a plant will begin to grow exponentially and photosynthetic efficiency will determine the rate of growth. Growth may be defined as an increase in fresh weight or an accumulation of dry weight (28).

Interactions with the environment and within an individual soon impose limitations on growth and the actual growth curve becomes sigmoidal. The transplant's growth rate is significantly affected by variations in exposure to such environmental factors as light, temperature, carbon dioxide level, water supply and nutrition (28).

Summary

Obtaining high quality transplants is one of the most important factors in fresh market tomato and pepper production (13, 24, 35). The best quality plants are young, stocky, free from insect and disease infestation, and have no open flowers or buds (35, 54). Transplant quality affects stand establishment, early yield, total yield and fruit size (25, 37). The use of certain cultural practices significantly affects tomato and pepper transplant quality. Tailoring cultural practices to tomato and pepper transplants may be very important in realizing maximum yielding potential (37).

Past research has determined that variations in transplant type, container size, transplant spacing, fertilization program and transplant age significantly affect tomato and pepper transplant quality. Transplants produced in large individual containers produce larger early and total yields than bare-root transplants or those produced in smaller individual containers (8, 11, 24, 25, 26, 38, 40, 42, 55). Increased spacing between transplant containers in the greenhouse produced increased yields over closely spaced transplants (12, 25, 37, 42). Tomato transplants required large amounts of phosphorus to promote root growth and large early yields (7, 35, 41, 56, 57). Moderate levels of nitrogen were also necessary to produce large early and total yields (17, 19, 33, 57). Tomato fruit yields were affected by the ratio of nitrogen to phosphorus applied to the transplants (21). In general, tomato transplants of 4 to 7 weeks of age produced larger early and total yields than either older or younger transplants (12, 37, 42, 45).

The purpose of this research was to examine the Speedling system of transplant production using TODD planter flats. This system may prove to be an alternative to the use of bare-rooted Southern transplants for fresh market tomato and pepper production in Michigan. The growth and productivity of these different transplant types were compared. The location of transplant production was studied to determine if high quality TODD transplants could be produced in Michigan or at Speedling of Florida. Cultural practices also play a critical role in determining the quality of tomato and pepper transplants. Various cultural practices were examined in an effort to decrease transplant shock and increase the growth and yield of Pik-Red tomatoes and Lady Bell peppers. The cultural practices studied with respect to their effect on growth, development and yielding ability were: different root cell sizes of TODD planter flats, different transplant spacings within TODD planter flats, various rates of nitrogen and phosphorus fertilization, and different ages of transplants at field-setting. A high quality transplant, exhibiting little if any transplant shock and producing large early and total yields, was desired.

CHAPTER II

A COMPARISON OF THE EARLY GROWTH AND YIELD OF TOMATO AND PEPPER TRANSPLANTS PRODUCED IN THREE DIFFERENT GROWING CONTAINERS

Introduction

Wooden flats are often used to propagate fresh market tomato (*Lycopersicon esculentum* Mill.) and pepper (*Capsicum annuum* L.) transplants in the greenhouse. However, flats are not necessarily the best container to use to produce high quality transplants. Researchers have found that peat, clay or plastic pots produce stockier vegetable transplants and larger early yields than flats or paper bands (34, 49). The differences observed in early yield are usually due to less root damage occurring during transplanting from pots (34). Transplanting shock created by root damage causes water and nutritional stress (32, 49). Abortion of the developing flower buds may result (49).

Several new types of transplant containers are gaining popularity with U.S. growers. The Jiffy-7 pellet is an expandable peat container filled with artificial soil mix and fertilizer. F. G. Teubner recommends placing the entire peat container in the ground at transplanting allowing the root system to remain intact and minimizing transplanting shock (49).

The Speedling system is also reported to produce a high quality transplant with a low mortality rate. The Speedling transplants are grown in polystyrene TODD planter flats containing individual root cells filled with peat-lite soil mix. Each cell is designed as an inverted pyramid to encourage downward root growth and natural air pruning at the open bottom. The tapered root system releases easily from the flat and can be transplanted with minimal root shock according to Speedling. The planter flats are available in several different sizes of root cells (3).

The purpose of this experiment was to compare the early growth and yield of tomato and pepper transplants produced in standard wooden flats, Jiffy-7 pellets and Speedling root cells of size 125. It was of particular interest to determine if it is feasible to use the Speedling system in Michigan as an alternative to bare-rooted or flat-grown transplants.

Materials and Methods

On August 21, 1980, 80 Pik-Red tomato seeds were sown into each of the following: a standard wooden flat measuring 14 by 20 inches, 80 Jiffy-7 pellets and 80 Speedling 125 root cells in one planter flat. The area of each Speedling root cell was 10.1 sq. cm. A peatlite soil mix was used in the flats. In the second experiment, Lady Bell pepper seeds were also planted in a similar manner in a wooden flat, Jiffy-7 pellets and a Speedling 125 planter flat. The plants were grown on benches in the greenhouse.

The seedlings were watered when necessary and fertilized weekly with a soluble 20-20-20 fertilizer at a rate of 3.9 ml fertilizer per liter H_2O after the first two leaves appeared. On September 21, 1980, 20 seedlings were harvested at random from each treatment of the tomato and pepper experiments and measured for height, leaf number, stem diameter and shoot and root fresh weight to give an indication of seedling size at transplanting. Root fresh weight was obtained by washing and weighing the roots of each seedling, while stem diameter was measured with a vernier calliper. Each plant was considered a replication. Results were analyzed by analysis of variance and means separated by Duncan's multiple range test, 5% level.

Of the remaining seedlings, 8 tomato and pepper plants of each treatment were selected at random and transplanted into 25.4 cm pots containing a plastic liner filled with sterile soil. The transplants were fertilized with a soluble 20-20-20 fertilizer at a rate of 3.9 ml fertilizer per liter H_2O at transplanting and each week thereafter. The pots were arranged in a completely randomized design with each plant considered a replication.

One greenhouse bench under fluorescent lighting was used for each experiment. On January 8, 1981, the plants were harvested in a once-over harvest and the number of fruit and fresh weight of the fruit of each plant were recorded.

Results were analyzed by analysis of variance and means separated by Duncan's multiple range test, 5% level.

Results

Stem diameter, shoot fresh weight and leaf number of Jiffy-7 tomato and pepper seedlings before transplanting were significantly greater at 4 weeks of age than those of flat-grown or Speedling 125 plants (Tables 1 and 2). The heights of Jiffy-7 plants and flat-grown plants were not significantly different. Speedling 125 tomato and pepper plants were shorter, had fewer leaves and smaller stem diameter, shoot weight and root weight than plants of the other treatments. In general, after 4 weeks of growth, Jiffy-7s produced the largest, stockiest transplants while the Speedling 125 root cells produced the smallest transplants for both tomatoes and peppers. Root systems of the Jiffy-7 plants were extensive and light yellow in color, while those of the Speedling and flat-grown plants were white at transplanting.

There was no difference in the fresh weight of tomato and pepper fruit for Speedling 125, Jiffy-7 and flat-grown plants (Tables 3 and 4). However, it was noted that Speedling 125 tomato and pepper plants produced more fruit with a greater percentage of red color than did any of the other treatments.

Table 1. Influence of containers on the size of Pik-Red tomato seedlings grown at Michigan State University at 4 weeks of age.

Treatment	Plant[z] height (cm)	Leaf[z] number	Stem[z] diameter (mm)	Shoot fresh[z] weight (g)	Root fresh[z] weight (g)
Flat	25.1b	4.2a	3.8b	3.0b	0.9b
Jiffy-7	24.2b	4.8b	4.1c	3.8c	0.9b
Speedling 125	16.7a	4.0a	2.8a	1.1a	0.5a

[z]Measurements are the means of 20 plants, harvested on September 21, 1980.
Mean separation in columns by Duncan's multiple range test, 5% level.

Table 2. Influence of containers on the size of Lady Bell pepper seedlings grown at Michigan State University at 4 weeks of age.

Treatment	Plant[z] height (cm)	Leaf[z] number	Stem[z] diameter (mm)	Shoot fresh[z] weight (g)	Root fresh[z] weight (g)
Flat	15.3b	5.3a	2.8b	1.3b	0.2a
Jiffy-7	16.6b	6.7b	3.0c	2.3c	0.6b
Speedling 125	11.0a	4.7a	2.0a	0.6a	0.3a

[z]Measurements are the means of 20 plants, harvested on September 21, 1980.
Mean separation in columns by Duncan's multiple range test, 5% level.

Table 3. Influence of containers on the yield of Pik-Red tomato transplants grown at Michigan State University.

Treatment	Fruit[z] number	Fruit[z] weight (g)
Flat	8.6a	706.8a
Jiffy-7	8.8a	769.3a
Speedling 125	9.0a	778.9a

[z]Measurements are the means of 8 plants, harvested on January 8, 1981.
Mean separation in columns by Duncan's multiple range test, 5% level.

Table 4. Influence of containers on the yield of Lady Bell pepper transplants grown at Michigan State University.

Treatment	Fruit[z] number	Fruit[z] weight (g)
Flat	6.3a	215.5a
Jiffy-7	5.8a	284.4a
Speedling 125	5.2a	198.1a

[z]Measurements are the means of 8 plants, harvested on January 8, 1981.
Mean separation in columns by Duncan's multiple range test, 5% level.

Discussion and Conclusions

Speedling 125 tomato and pepper plants were significantly smaller than Jiffy-7 or flat-grown transplants on September 21, 1980. The size of Jiffy-7 and flat-grown plants was similar. The smaller size of the Speedling 125 plants may have been due to their smaller root cell volume than that of the Jiffy-7 or flat-grown plants. Vegetable transplants grown in larger individual containers of flat spacings produced more leaves at the first cluster, a stockier plant and a faster overall growth rate (37). Nicklow and Minges believed that the larger spacings or container sizes influenced the physiological condition of the transplant before field setting (37). The reduced space available to the Speedling transplants relative to the Jiffy-7 and flat-grown transplants apparently resulted in slower growth rates and thus smaller plants at the time of transplanting.

There were no visible differences in the size of the plants of any treatment at fruit harvest. There were no significant differences between treatments in either fruit number or yield. However, it was noted that Speedling 125 tomato and pepper plants produced more fruit with a greater percentage of red color than did either of the other transplant types. This may be an indication that the Speedling 125 plants matured faster than either of the other transplant types.

Speedling 125 plants did not appear to be root-bound and retained all of the root system at the time of transplanting. However, the Jiffy-7 plants appeared to be root-bound, judging from the compacted, yellow appearance of the root system, while the flat-grown plants lost a significant portion of their root systems at transplanting. As a result, the Jiffy-7 and flat-grown plants were more likely to suffer water stress after transplanting. Although the Speedling 125 seedlings were smaller at transplanting, they apparently were able to catch up with the other plants after transplanting due to an actively growing root system. Speedling, Inc. states that transplants produced in TODD planter flats exhibit minimal transplanting shock and a rapid growth rate after transplanting (3, 4). The data from this experiment seem to support this statement.

Several researchers have found that transplants grown in larger individual containers or spacings in a flat were larger at transplanting and produced higher early yields than those grown in smaller containers (12, 24, 25, 26, 32, 37, 40, 42), but the results of this experiment indicated that the total yield from a once-over harvest may be independent of plant size at transplanting. Therefore, we decided to compare the development and yield over the course of the picking season of transplants grown in different TODD root cell sizes and transplanted into the field.

CHAPTER III

STUDIES ON THE EFFECT OF ROOT CELL SIZF, PLANT SPACING AND LOCATION OF PRODUCTION ON DEVELOPMENT AND YIELD OF TOMATO AND PEPPER TRANSPLANTS

Introduction

A preliminary experiment comparing the growth and yielding ability of Speedling 125, Jiffy-7 and flat-grown tomato and pepper transplants showed that Speedling transplants are a possible alternative to bare-rooted plants. The Speedling plants, however, exhibit a lag phase after transplanting before reestablishing a normal growth rate. This is a distinct disadvantage because tomato and pepper plants must make continuous and rapid vegetative growth throughout the season and balance vegetative and fruiting activities. The root/shoot ratio plays an important role in maintaining this balance (18). Speedling plants with larger size root balls appear to establish a rapid growth rate more quickly than plants of the same age with smaller root balls both before and after transplanting.

Numerous researchers have found that transplants grown in larger individual containers were larger at the time of transplanting and produced larger early yields than did plants grown in smaller containers (8, 12, 24, 40, 51). Increased container depth had less effect than increased container area on early yielding ability of tomato transplants (42). Therefore, the area and volume of the root cell container in the TODD planter flat may influence the growth and yielding ability of tomato and pepper transplants.

The spacing between plants while in greenhouse flats may also affect the growth of vegetable seedlings. Transplants grown at wider flat or bench spacings are larger and stockier at the time of transplanting, and maintain a faster growth rate which results in earlier flowering and greater early yield (12, 24, 37). Seedlings grown in larger TODD root cell sizes naturally have wider plant spacings since the sides of each root cell are larger.

The location of transplant production and subsequent shipment of transplants may also play a role in influencing the growth and early yield of tomatoes and peppers. Plants produced in Sun City, Florida may be adversely affected by cultural or shipping practices followed by Speedling, Inc. Increased levels of ethylene and CO_2 gas are produced as a result of any stress experienced in shipment. Ethylene production increases rapidly following trauma cuased by drought, temperature extremes and mechanical wounding (1). Ethylene produced in this manner is known as stress ethylene. Stress ethylene may play a role in senescence of the plant tissues. Increased levels of ethylene produced by Speedling transplants during shipment may detrimentally affect the growth of the transplant seedlings in the field.

These studies were undertaken to compare the growth and yield of tomato and pepper plants produced in different root cell sizes and grown in Florida at Speedling, Inc., and at Michigan State University.

Materials and Methods

A. The Effect of Root Cell Size and Production Location on Yield of Pik-Red Tomato Transplants in 1980.

This experiment was conducted at the Sodus Research Station in Sodus, Michigan in 1980. The Sodus area is the main growing region for fresh market tomatoes in Michigan.

Four-week-old Pik-Red tomato plants of root cell sizes 080, 100A and 125 produced by Speedling Inc. in Florida were shipped to Sodus, Michigan by truck. Pik-Red tomatoes of the same seed lot were also grown in the greenhouse at Sodus, Michigan in TODD flats of 080, 100A, 125, 150 and 175 root cell sizes. Two plantings were made at Sodus, Michigan, resulting in plants of 4 and 6 weeks of age at transplanting.

Speedling plants were sown on May 13, 1980. Michigan plants were sown on April 30 and May 13, 1980. Seeds for Michigan-grown plants were pregerminated for 48 hours and suspended in Viterra-II gel before sowing. All plants were transplanted into the field on June 11, 1980. The roots of the transplants were dipped in soluble 20-20-20 starter fertilizer solution before field setting. The plants were irrigated overhead after transplanting.

Nitrogen was broadcast on the rye cover crop in the field at a rate of 56 kg/ha and plowed down in the spring. 56 kg/ha N and 169 kg/ha K_2O were broadcast and disced in before planting and the plants were sidedressed with N at a rate of 28 kg/ha after fruit set. No P_2O_5 was added since soil test levels were over 337 kg/ha. Overhead irrigation was used when necessary. Fungicides, insecticides and bactericides were applied where necessary to control foliar diseases.

The experiment was designed as a randomized complete block with 3 replications. Six plants were transplanted per plot, with 2 feet between plants and 4 feet between rows. Data collected included the number of live plants and yield per plot. The tomatoes were harvested weekly. Weight of fruit per plot was recorded at each harvest. The first harvest was on August 14, 1980 and harvesting continued until September 17, 1980. Yields of the first 2 weeks were considered as early yield. Yields from the third and fourth weeks were considered as midseason yield, and yields from the fifth and sixth weeks were late yield.

Results were analyzed by analysis of variance and means separated by Duncan's multiple range test, 5% level.

B. The Effect of Root Cell Size and Production Location on Development and Yield of Pik-Red Tomato and Lady Bell Pepper Transplants, 1981.

This experiment was conducted at the Horticulture Research Farm and Plant Science Greenhouses of Michigan State University, East Lansing, Michigan, in 1981.

Pik-Red tomato and Lady Bell pepper seeds were pre-germinated for 48 and 72 hours, respectively, and suspended in Viterra II hydrogel for sowing at Michigan State University. One hundred fifty seeds of each crop were sown into each of 6 cell sizes (080, 080A, 100A, 125, 150, 175) of TODD planter flats on May 4, 1981. The flats were filled with a peatlite soilless mix. As soon as the first true leaves appeared, the plants were fertilized weekly with a soluble 20-20-20 fertilizer at a rate of 3.9 ml fertilizer per liter of H_2O. Transplants were hardened in a lath house at Michigan State University for 3 days before planting in the field.

Pik-Red tomato and Lady Bell pepper seeds of the same lots used at MSU were planted on May 4, 1981 in TODD planter flats of the same 6 cell sizes at Speedling Inc. in Sun City, Florida. Plants were shipped by air freight to Lansing, Michigan on May 27, 1981 in cardboard boxes equipped with air holes for ventilation.

Height, leaf area and shoot dry weight of 4 randomly selected plants from each treatment were measured for Michigan-grown tomato and pepper seedlings at the first true leaf stages. Leaf area was measured using an electronic leaf area meter with digital read-out, while dry weight was measured with a Mettler balance. Height of each plant was measured individually; leaf area and dry weight were pooled for the 4 plants of each treatment. Upon arrival in Michigan, the Speedling plants were measured in the same manner. Results were analyzed by analysis of variance and means separated by Duncan's multiple range test, 5% level.

The tomatoes were planted in the field May 28, 1981. The peppers were planted May 29, 1981. Weather conditions were ideal for good establishment and growth. Roots of all plants were dipped in soluble 20-20-20 starter fertilizer solution. The field was irrigated overhead after transplanting.

Fertilizer was applied to the field at a rate of 56 kg/ha N, 112 kg/ha P_2O_5 and 112 kg/ha K_2O. Fifty-six kg/ha nitrogen was sidedressed after fruit set. The previous cover crop was alfalfa. Irrigation was applied when necessary. Fungicides and insecticides were applied when necessary to control foliar diseases and insects.

The tomato experiment was designed as a randomized complete block with 3 replications in a factorial arrangement of 6 cell sizes and 2 production locations. Each plot contained 28 plants in 2 rows of 14 plants each with 2 feet between plants and 4 feet between rows. Cell size 100A of Speedling peppers was the wrong cultivar; therefore the pepper experiment was divided into two sections and Michigan and Florida yield data were analyzed as two separate randomized complete block designs with 3 replications. Twenty-eight plants were transplanted into each of 33 plots in 2 rows of 14 plants with 2 feet between plants and 4 feet between rows.

Tomato and pepper seedling leaf area and shoot dry weight data were used to determine relative growth rate and net assimilation rate. This growth analysis method was discussed in detail by Leopold and Kriedemann in Plant Growth and Development (27).

Relative growth rate (RGR) was calculated by the formula:

$$RGR = \frac{\ln W_2 - \ln W_1}{t_2 - t_1}$$

where: W_1 = shoot dry weight at time 1

W_2 = shoot dry weight at time 2

t_1 = time 1

t_2 = time 2

RGR is an expression of the increase in weight per unit of original weight over a time interval, t. It is a measure of how quickly a plant is growing.

Unit leaf rate or net assimilation rate (NAR) can be expressed as:

$$NAR = \frac{W_2 - W_1}{t_2 - t_1} \quad \frac{(\ln L_2 - \ln L_1)}{L_2 - L_1}$$

where: W_1 = shoot dry weight at time 1

W_2 = shoot dry weight at time 2

L_1 = leaf area at time 1

L_2 = leaf area at time 2

t_1 = time 1

t_2 = time 2

NAR is the rate of increase in dry weight per unit leaf area. The term is a physiological index representing photosynthetic efficiency of the plant: the plant's capacity to increase in dry weight with respect to the area of its assimilatory surface. Together, RGR and NAR can be used to analyze the response of plant growth to various environmental conditions (27).

Two tomato and pepper plants per plot were harvested 1, 2 and 3 weeks after transplanting for growth analysis. Plant height, leaf number, leaf area and dry weight were collected. Relative growth rate and net assimilation rate were calculated for 3 one-week growth periods following field-setting. Plant height, shoot fresh weight, shoot dry weight, fruit number, and fruit weight were measured for weeks 3 to 8 after transplanting from 2 tomato and pepper plants per plot. All results were analyzed by analysis of variance and means separated by Duncan's multiple range test, 5% level.

Mature tomato and pepper fruit were harvested weekly from the remaining 14 plants per plot. Tomatoes showing red coloration and peppers over 6.4 cm in diameter and length were considered mature. Tomatoes were graded as large fruit (6.7 cm or larger fruit), small fruit (less than 6.7 cm in diameter) and culls. Peppers were graded into large fruit (greater than 6.4 cm in length and diameter) and culls. Fruit number and fresh weight of each grade per plot were recorded.

Tomatoes harvested during the first 2 weeks were considered early yield, fruit harvested from the third and fourth weeks were midseason I yield, and fruit harvested during the fifth and sixth weeks were midseason II yield. Tomato fruit harvested during the seventh and eight weeks were late yield. Results are discussed as early yields and total yields.

Pepper fruit harvested during the first week were early yield. Pepper fruit harvested during the second and third weeks were considered midseason I yield. Pepper fruit harvested from the fourth and fifth weeks were midseason II yield and pepper fruit harvested from the sixth and seventh weeks were late yield.

All yield results were analyzed by analysis of variance. Treatment sums of squares were partitioned into linear, quadratic and cubic effects through trend analysis.

The depth, area and volume of TODD planter flats of root cell sizes 080 through 175 were calculated (Table 5).

Linear regression analysis was used to determine what relationship, if any, existed between these three variables and early season and total yields of tomato and pepper transplants produced at MSU and in Florida. All results were analyzed by use of a regression F test in the analysis of variance.

Table 5. Depth, area and volume of root cell sizes of TODD planter flats produced by Speedling, Inc.

Root cell size[z]	Root cell depth (cm)	Root cell area (cm^2)	Root cell volume (cm^3)
080	3.2	4.1	4.4
080A	4.1	4.1	5.6
100A	7.2	7.8	18.8
125	4.6	10.1	15.4
150	6.4	14.5	30.7
175	6.4	18.7	39.5

[z]Root cell sizes are designations given to TODD planter flats. The numbers represent one side of a square cell, in hundredths of an inch. Thus an 080 cell measures 0.80 inches to a side. Root cells differ in depth, area and volume.

C. A Comparison of Ethylene and CO_2 Production of Tomato and Pepper Transplants Produced at Michigan State University and at Seedling, Inc. in Florida in 1981.

Speedling tomato and pepper transplants were shipped by air freight and arrived at Michigan State University on May 27, 1981. The plants were enclosed in cardboard boxes with air holes for ventilation.

An experiment was performed on the day of their arrival to determine if Speedling plants grown in Florida produced increased amounts of ethylene or CO_2 gas as a result of mechanical stress created by drought, temperature extremes, crushing, or confinement during shipment.

Single tomato or pepper transplants were placed in quart glass Ball jars with screw tops. A rubber septum was inserted snugly into a hole in the top of each Ball jar to allow for extraction of gases produced in the container with a plastic syringe.

Treatments consisted of a control jar of laboratory air and 4 replications of whole Speedling or Michigan-grown 125 tomato and pepper transplants, each in a separate jar. Also included in separate jars were a single tomato shoot, a tomato root, a pepper shoot and a pepper root from each growing location. The severed shoots and roots served as controls producing increased levels of stress ethylene for comparative purposes.

Ethylene levels were monitored at 1, 2 and 12 hours and CO_2 levels were monitored 1 and 12 hours after sealing the jars. Ethylene levels were measured by gas chromatography and CO_2 levels were measured by a CO_2 analyzer. All results were analyzed by analysis of variance and means separated by Duncan's multiple range test, 5% level.

D. A Comparison of the Growth of Tomato Seedlings at Two Spacings in TODD Planter Flats of Various Cell Sizes.

Pik-Red tomato seeds were pregerminated and sown November 24, 1981, as described above, in 6 TODD flats each of root cell sizes 080, 080A, 100A, 125, 150 and 175. The plants were grown in the greenhouse at Michigan State University. In 3 of the flats of each root cell size, 25 seeds were planted in adjacent root cells in a square of 5 root cells to a side. In the other 3 flats of each root cell size, 25 seeds were planted so that the distance between seedlings was approximately 8 cm by 8 cm regardless of root cell size. Since the spacing between adjacent plants increases drastically with increasing root cell size this experiment was performed to judge the effect of root cell size on seedling growth independent of plant spacing.

Leaf area, plant height and shoot dry weight were measured weekly for 5 weeks, beginning December 8, 1981. RGR and NAR were calculated, as described above.

The experiment was designed as a randomized complete block in a factorial arrangement, with each flat as a replication. Data were analyzed by analysis of variance.

Trend analysis was used where appropriate.

Results

A. The Effect of Root Cell Size and Production Location on Yield of Pik-Red Tomato Transplants in 1980.

There was no difference in mortality between Speedling and Michigan tomato plants in 1980. Between 5 and 6 plants survived in each plot.

Age of transplants at field-setting had no significant effect on tomato yield, except for 175-size plants, where 4-week-old transplants produced greater early yields than 6-week-old transplants. Michigan-grown 100 and 175-size plants, 4 weeks old at transplanting, produced the largest early yields (Table 6, Figure 1). All 080-size and all Speedling plants produced low early yields. The other treatments were intermediate. It appears that as the volume of the root cell increased, early yields also increased. Early yields were increased up to 10-fold when plants were grown in size 175 containers. Michigan-grown transplants produced greater early yields than Speedling-grown transplants of comparable root cell sizes.

There were no significant differences among any of the treatments in late and total yields (Table 6, Figures 2 and 3).

Table 6. Influence of different sizes of root cells of TODD planter flats, seeding date and location of transplant production on yield of Pik-Red tomato plants grown at Sodus, MI 1980.

Treatment	Root[w] cell size	Yield (kg/ha)[x]			
		Early[yz] season	Mid-[z] season	Late[z] season	Total[z]
Speedling of Florida	080	0a	8647a	39675a	48322a
	100A	509ab	9970ab	42727a	53205a
	125	1119ab	9257ab	51170a	61547a
MSU sown April 30, 1980	080	305ab	20041cde	49542a	69889a
	100A	3357bcd	19125cde	50763a	73246a
	125	1933abc	16887cd	47915a	66735a
	150	4273cd	25331ef	46389a	76094a
	175	4680cd	31231f	35911a	71821a
MSU sown May 13, 1980	080	1831abc	15972bc	57783a	75484a
	100A	6816de	25433ef	38454a	70601a
	125	2645cd	23398de	40997a	67142a
	150	4069cd	25840ef	38954a	68363a
	175	13123e	24212ef	22177a	65921a

[w]Root cell sizes are designations given to TODD planter flats. The numbers represent one side of a square cell, in hundredths of an inch. Thus an 080 cell measures 0.8 inches to a side. Root cells differ in depth, area and volume of the cell (see Table 5).

[x]Yield measurements are means of 3 replications. Early season yields were harvested August 14 and 22, midseason yields were harvested August 28 and September 4, and late season yields were harvested on September 11 and 17; total yield is a total of all harvests.

[y]A square root data transformation was performed to maintain homogeneity among variances.

[z]Means separation in columns by Duncan's multiple range test, 5% level.

Figure 1. The influence of sowing date, location of production, and root cell size on the early yield of Pik-Red tomatoes in 1980.

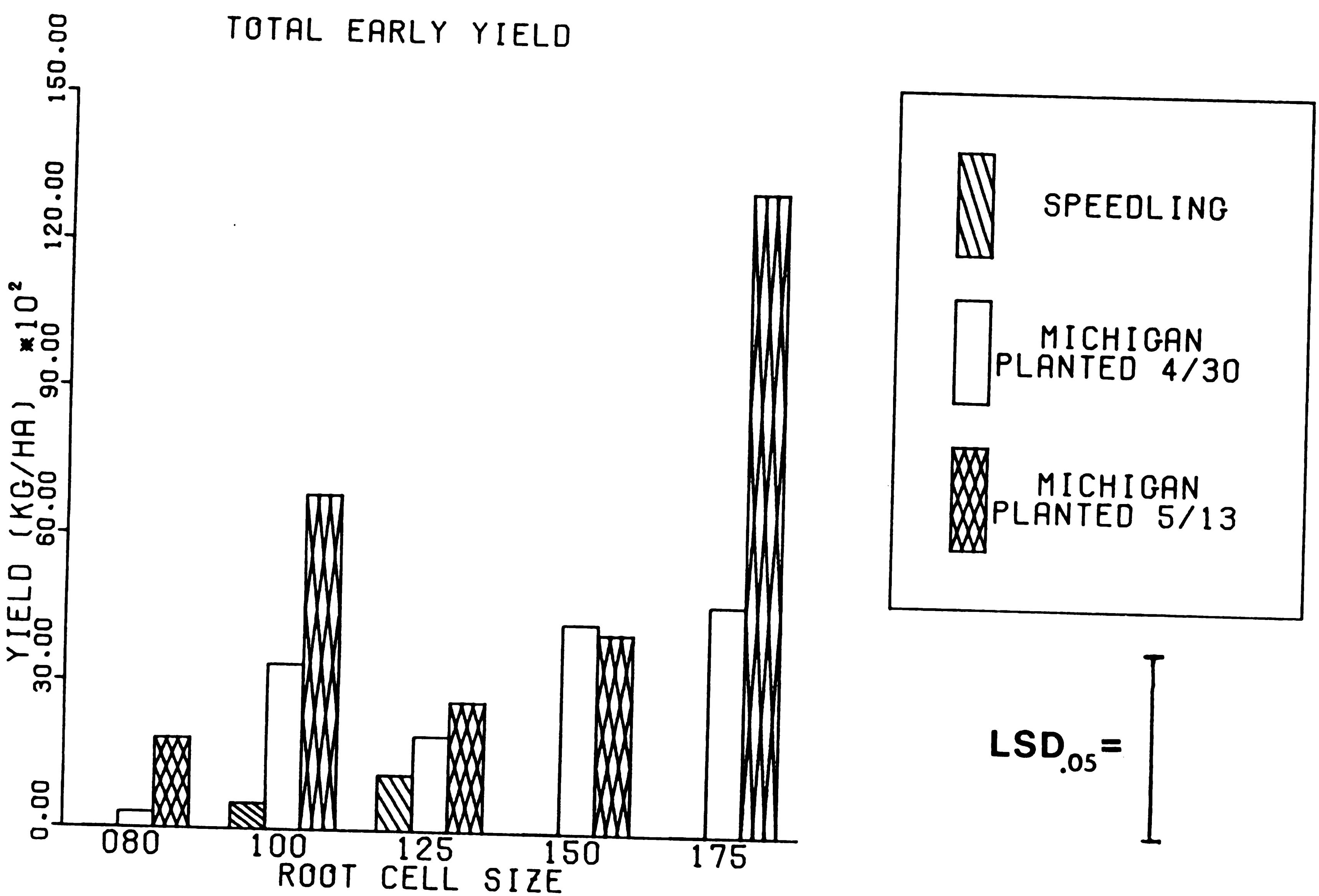

TOTAL EARLY YIELD
YIELD (KG/HA) *10²
0.00
30.00
60.00
90.00
120.00
150.00
080
100
125
150
175
ROOT CELL SIZE
SPEEDLING
MICHIGAN PLANTED 4/30
MICHIGAN PLANTED 5/13
LSD.05=

Figure 2. The influence of sowing date, location of production, and root cell size on the late yield of Pik-Red tomatoes in 1980.

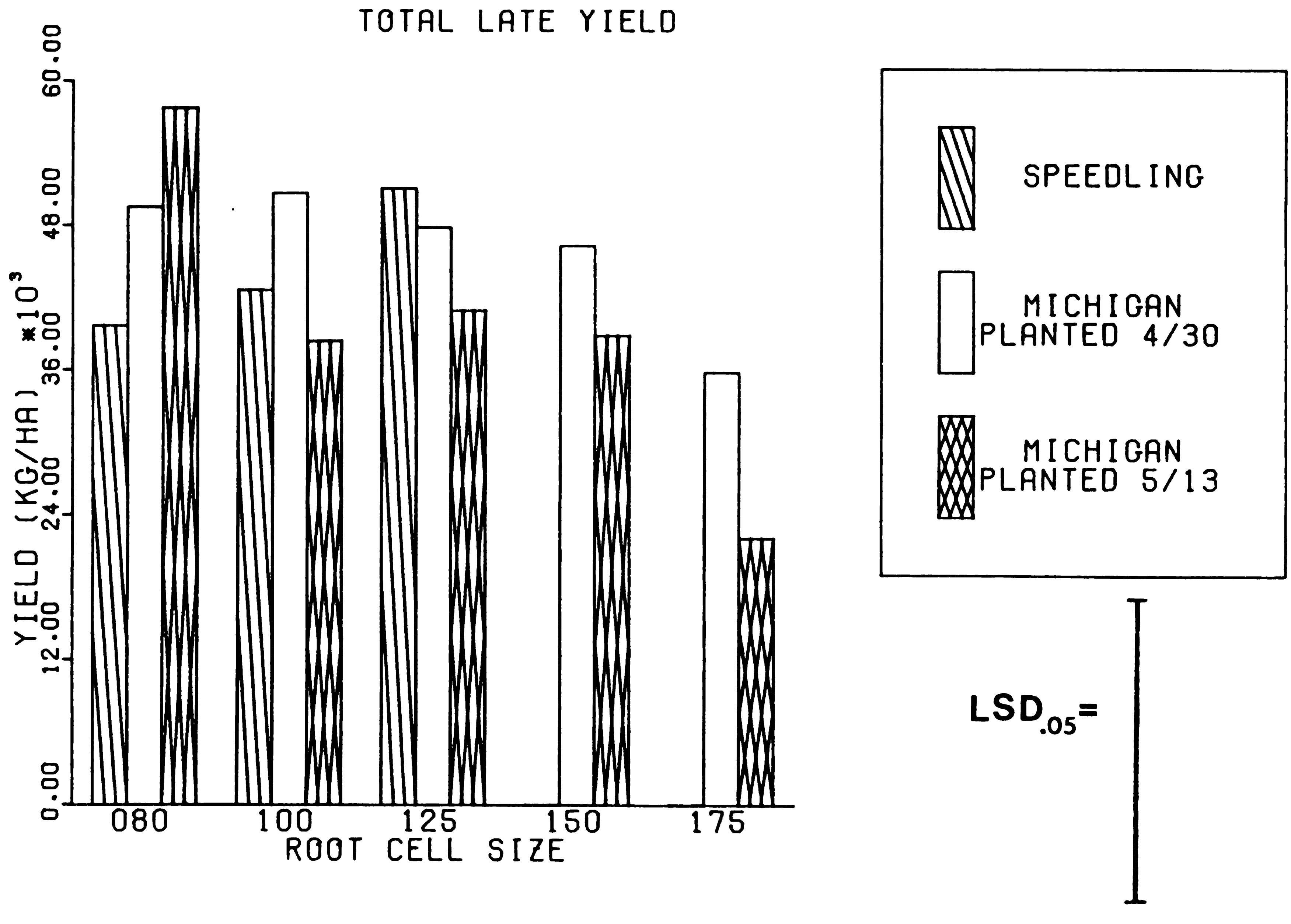
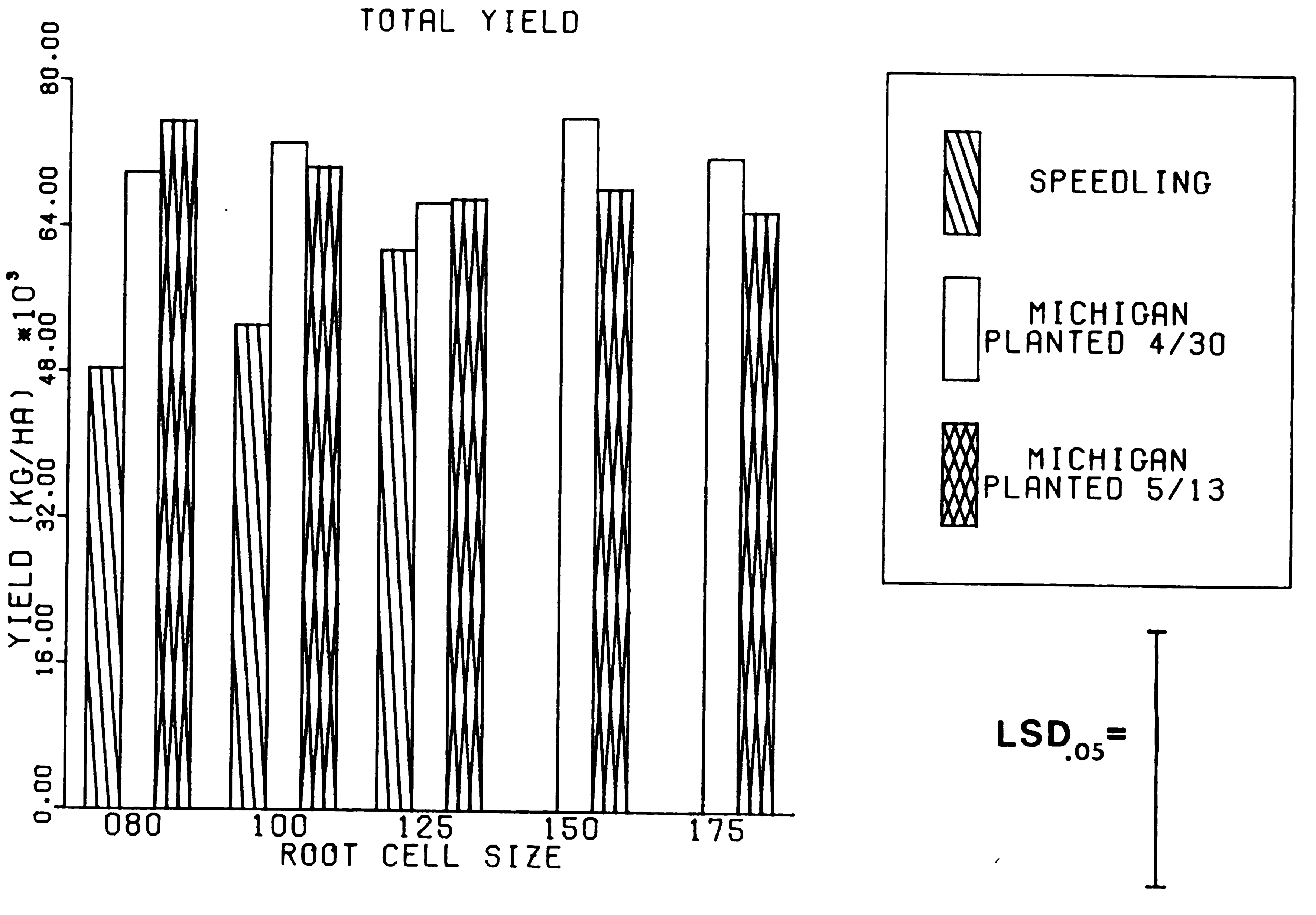

TOTAL LATE YIELD
YIELD (KG/HA) *10³
0.00
12.00
24.00
36.00
48.00
60.00
080
100
125
150
175
ROOT CELL SIZE
SPEEDLING
MICHIGAN PLANTED 4/30
MICHIGAN PLANTED 5/13
LSD.05=

Figure 3. The influence of sowing date, location of production, and root cell size on the total yield of Pik-Red tomatoes in 1980.


TOTAL YIELD
YIELD (KG/HA) *10³
0.00
16.00
32.00
48.00
64.00
80.00
080
100
125
150
175
ROOT CELL SIZE
SPEEDLING
MICHIGAN
PLANTED 4/30
MICHIGAN
PLANTED 5/13
LSD.05=

B. The Effect of Root Cell Size and Production Location on Development and Yield of Pik-Red Tomato and Lady Bell Pepper Transplants, 1981.

Height, leaf area and shoot dry weight of 2-week-old tomato and pepper plants were greatest for seedlings grown in larger root cell sizes (Table 7). The same trend was observed at transplanting for 4-week-old Michigan and Speedling tomato and pepper seedlings (Tables 8 and 9). Plants from larger root cells were taller and had more leaf area and shoot dry weight than plants from smaller root cells.

Speedling pepper plants were significantly taller than Michigan pepper transplants at field-setting. Michigan pepper plants had slightly less leaf area and shoot dry weight than Speedling peppers. Height of Michigan and Speedling tomato plants were not generally different for comparable root cell sizes. Michigan tomato plants had greater leaf area and shoot dry weight than Speedling plants at transplanting (Tables 8 and 9).

Thirteen and nine days after transplanting (respectively) Pik-Red tomato and Lady Bell pepper plants of larger root cell sizes were taller and possessed significantly greater leaf number, leaf area and shoot dry weight than did plants of smaller root cell sizes (Tables 10 and 11). This relationship existed for plant height and shoot dry weight until approximately 6 to 7 weeks after field-setting, when treatment differences were negligible.

Michigan tomato plants were greater in height, leaf area and shoot dry weight than were Speedling tomato plants at every root cell size 20 days after transplanting (Table 12). Michigan pepper plants were significantly shorter than Speedling pepper plants 20 days after transplanting (Table 13). However, Michigan pepper plants possessed greater leaf area than Speedling plants for all root cell sizes at this time. Shoot dry weight increased significantly with greater root cell size, but was generally not different from the two production locations.

Table 7. The influence of root cell size on size of Michigan tomato and pepper plants 14 days after sowing.

	Height[y] (cm)		Leaf Area[z] (cm^2)		Shoot dry weight[z] (g)	
Root cell size	Tomato	Pepper	Tomato	Pepper	Tomato	Pepper
080	5.4a	5.5ab	1.0	1.1	0.01	0.01
080A	6.0ab	5.0a	1.3	0.9	0.03	0.01
100A	8.3c	5.6abc	2.3	1.1	0.03	0.02
125	8.9c	9.0d	2.6	1.4	0.04	0.03
150	7.5bc	6.8c	3.2	2.1	0.04	0.03
175	8.3c	6.3bc	3.1	1.9	0.04	0.02

[y]Height measurements are the means of 4 plants. Mean separation in columns by Duncan's multiple range test, 5% level.

[z]Leaf area and shoot dry weight measurements are the means of 4 seedlings sampled per treatment.

Table 8. The influence of root cell size and location of production on the size of Pik-Red tomatoes 28 days after sowing.

Source	Root cell size	Height[y] (cm)	Leaf area[z] (cm^2)	Shoot dry weight[z] (g)
Michigan	080	10.1a	6.5	0.07
	080A	11.9bc	7.9	0.09
	100A	20.3de	33.5	0.27
	125	22.2fg	45.8	0.30
	150	26.8h	75.7	0.42
	175	20.9def	70.5	0.44
Speedling	080	13.1c	5.5	0.08
	080A	9.3a	6.0	0.06
	100A	10.7ab	7.4	0.12
	125	23.3g	36.2	0.24
	150	19.5d	39.1	0.32
	175	21.6ef	41.8	0.37

[y]Height measurements are the means of 4 plants. Mean separation in columns by Duncan's multiple range test, 5% level.

[z]Leaf area and shoot dry weight measurements are the means of 4 seedlings sampled per treatment.

Table 9. The influence of root cell size and location of production on the size of Lady Bell peppers 28 days after sowing.

Source	Root cell size	Height[y] (cm)	Leaf area[z] (cm^2)	Shoot dry weight[z] (g)
Michigan	080	7.0a	8.9	0.05
	080A	7.3a	9.1	0.06
	100A	10.3b	16.1	0.12
	125	12.1bc	25.4	0.18
	150	13.7cd	28.6	0.23
	175	15.0de	47.6	0.15
Speedling	080	18.4f	15.6	0.15
	080A	16.3ef	11.5	0.11
	125	18.4f	23.4	0.25
	150	23.5g	43.3	0.42
	175	27.0h	46.7	0.49

[y]Height measurements are the means of 4 plants. Mean separation in columns by Duncan's multiple range test, 5% level.

[z]Leaf area and shoot dry weight measurements are the means of 4 seedlings sampled per treatment.

Table 10. The influence of root cell size and location of production on the growth of Pik-Red tomatoes 13 days after transplanting into the field.

Source	Root cell size	Height[z] (cm)	Leaf[z] number	Leaf[z] area (cm^2)	Shoot dry[z] weight (g)
Michigan	080	16.3bc	5.5ab	42.8b	0.42abc
	080A	17.9cd	6.0bc	69.1c	0.71cd
	100A	20.6de	6.0bc	69.3c	0.60cd
	125	23.3ef	6.5bcd	100.6d	0.78de
	150	24.1f	6.7cd	111.4d	1.06e
	175	23.3ef	7.3d	107.1d	1.06e
Speedling	080	13.3a	4.8a	14.5a	0.23a
	080A	12.3a	4.8a	13.4a	0.21ab
	100A	14.6ab	5.8abc	25.4ab	0.34abcd
	125	20.8de	6.0bc	38.1b	0.54abcd
	150	17.9cd	6.3bcd	39.7b	0.50abcd
	175	23.11ef	6.8cd	47.7bc	0.81de

[z]Figures are the means of 2 plants per plot with 3 replications. Mean separation in columns by Duncan's multiple range test, 5% level.

Table 11. The influence of root cell size and location of production on the growth of Lady Bell peppers 9 days after transplanting into the field.

Source	Root cell size	Height[z] (cm)	Leaf[z] number	Leaf[z] area (cm^2)	Shoot dry[z] weight (g)
Michigan	080	7.5a	6.1bcd	16.9ab	0.11a
	080A	8.8ab	5.8abc	18.0ab	0.19ab
	100A	11.8c	6.8def	28.4bed	0.29bc
	125	11.3bc	8.0fg	35.1cd	0.38cd
	150	10.4bc	7.7efg	38.6de	0.38cd
	175	12.8c	8.3g	50.9e	0.52d
Speedling	080	16.8d	4.7a	11.7a	0.15ab
	080A	16.8d	5.3ab	23.6abc	0.15ab
	125	19.0d	6.2bcd	27.2bed	0.27abc
	150	23.2e	6.3cde	34.2cd	0.39cd
	175	19.5d	7.3defg	32.5cd	0.49d

[z]Figures are the means of 2 plants per plot with 3 replications. Mean separation in columns by Duncan's multiple range test, 5% level.

Table 12. The influence of root cell size and location of production on the growth of Pik-Red tomatoes 20 days after transplanting into the field.

Source	Root cell size	Height[z] (cm)	Leaf area[z] (cm^2)	Shoot dry weight[z] (g)
Michigan	080	35.9cd	368.1b	4.06ef
	080A	34.8c	381.5b	3.03cd
	100A	40.0de	553.2c	4.73f
	125	42.6e	632.7cd	5.90g
	150	41.7e	727.9d	5.73g
	175	43.9e	641.2cd	5.90g
Speedling	080	26.4a	152.0a	1.52ab
	080A	25.3a	168.8a	1.26a
	100A	29.3ab	186.2a	2.19bc
	125	36.0cd	276.2ab	3.00cd
	150	31.5bc	275.3ab	2.69cd
	175	36.3cd	378.2b	3.60de

[z]Figures are the means of 2 plants per plot with 3 replications. Mean separation in columns by Duncan's multiple range test, 5% level.

Table 13. The influence of root cell size and location of production on the growth of Lady Bell peppers 20 days after transplanting into the field.

Source	Root cell size	Height[z] (cm)	Leaf area[z] (cm^2)	Shoot dry weight[z] (g)
Michigan	080	12.6a	60.9ab	0.45a
	080A	13.8ab	74.9abc	0.58ab
	100A	18.0cd	126.7cde	1.04cd
	125	15.3abc	137.6de	0.90bc
	150	17.6bcd	151.0de	1.15cd
	175	17.8cd	164.7e	1.31d
Speedling	080	17.2bcd	36.0a	0.50a
	080A	16.9bcd	34.5a	0.44a
	125	20.0d	50.8ab	0.92bc
	150	23.8e	75.2abc	0.96bc
	175	25.3e	100.2bcd	1.28d

[z]Figures are the means of 2 plants per plot with 3 replications. Mean separation in columns by Duncan's multiple range test, 5% level.

Net assimilation rate and relative growth rate calculated for 3 weeks following transplanting were not statistically different for either tomato or pepper plants grown in different root cell size treatments. However, RGR and NAR decreased slightly from field-setting to 10 days after field-setting for transplants of all treatments.

In general, Speedling tomato transplants were shorter and possessed less leaf area and shoot dry weight than Michigan plants of corresponding cell sizes from transplanting until 5 weeks later. Speedling pepper plants were taller and possessed less foliage than did Michigan pepper plants of corresponding cell sizes until 5 weeks after field settings. Tomato and pepper transplants of all root cell sizes and locations did not differ in height or shoot fresh weight six weeks after transplanting. At this point, plant size appeared the same for all treatments (Tables 14 and 15).

Differences in earliness of flowering and fruit-setting appeared 5 to 7 weeks following transplanting (Tables 14 and 15). Michigan and Speedling tomato plants grown in 175-size root cells produced a significantly greater number of flowers and small unripe fruit than plants grown in 080-size cells at this time. Fruit weight also increased with larger root cell size. Michigan tomato plants produced a significantly greater weight of fruit than Speedling tomato plants at most comparable root cell sizes but there were virtually no differences in number of fruit. Michigan pepper plants grown in 175-size root cells produced a greater weight of fruit at 7 weeks after transplanting than did comparable Speedling plants (Table 15).

Table 14. The influence of root cell size and location of production on the growth of Pik-Red tomatoes 47 days after transplanting into the field.

Source	Root cell size	Height[z] (cm)	Fruit[z] number	Fruit[z] weight (g)	Shoot[z] fresh weight (kg)	Shoot[z] dry weight (g)
Michigan	080	80.7a	15.0abc	164.2ab	1.6a	132.5c
	080A	78.3a	16.8abc	231.7bc	1.5a	106.7bc
	100A	82.3a	18.3c	292.5cd	1.5a	121.7bc
	125	79.9a	21.7c	441.7ef	1.5a	124.2bc
	150	84.3a	22.0c	511.7fg	1.8a	140.8c
	175	79.5a	20.5c	605.8g	1.9a	139.2c
Speedling	080	78.8a	9.8ab	80.8a	0.9a	88.3ab
	080A	75.2	9.0a	55.8a	0.7a	65.0a
	100A	78.8a	16.0abc	135.0ab	1.3a	131.7a
	125	77.5a	22.0c	283.3c	1.3a	105.8bc
	150	73.1a	17.5c	222.8bc	1.1a	90.0ab
	175	77.8a	23.2c	393.3de	1.4a	106.7bc

[z]Figures are the means of 2 plants per plot with 3 replications. Mean separation in columns by Duncan's multiple range test, 5% level.

Table 15. The influence of root cell size and location of production on the growth of Lady Bell peppers 44 days after transplanting into the field.

Source	Root cell size	Height[z] (cm)	Number of[z] Flowers Setting Fruit	Fruit[z] number	Fruit[z] weight (g)	Shoot[z] fresh weight (g)	Shoot[z] dry weight (g)
Michigan	080	33.8a	1.7ab	2.0a	3.3a	67.5a	17.8a
	080A	37.7a	1.8abc	2.3ab	4.2a	91.7ab	19.7a
	100A	40.0a	4.7bcde	3.8bcd	20.0abc	116.7ab	21.7ab
	125	43.4a	5.2de	3.8bcd	27.5c	117.5ab	23.0ab
	150	39.7a	2.5abcd	4.8d	26.7c	122.5ab	21.7ab
	175	42.3a	7.5e	4.5cd	45.0d	175.8c	27.5b
Speedling	080	35.3a	2.3abcd	3.0abc	8.3ab	80.8ab	18.0a
	080A	35.3a	1.2a	2.0a	4.2a	75.8a	18.2a
	125	41.1a	5.0cde	3.2abcd	14.2abc	108.3ab	21.8ab
	150	39.7a	6.0e	3.8bcd	21.7bc	115.0bc	21.8ab
	175	43.5a	7.8e	4.8d	24.2bc	134.2bc	24.2ab

[z]Figures are the mean of 2 plants per plot with 3 replications. Mean separation in columns by Duncan's multiple range test, 5% level.

Tomato and pepper fruit were harvested from 14 plants per plot beginning on August 7, 1981, 10 weeks after transplanting. A number of fruit were graded as culls due to blossom end rot in the first harvest. The incidence of blossom end rot decreased the second week of harvest.

Trend analysis was used to analyze the yield data in this factorial experiment. Trend analysis determines if the response of the experimental units to varying levels of a treatment is linear, quadratic or cubic. A linear response indicates that the response of the experimental units to the levels of a treatment fits a straight line or first degree polynomial equation. A quadratic response fits a parabolic curve or second-degree polynomial equation. A cubic response fits to a bi-directional curve or third-degree polynomial equation (29).

Tomato Fruit Harvest

Total early yield of Pik-Red tomatoes increased linearly as root cell size of TODD planter flats increased (Table 16). Early yield of large fruit also increased linearly with increased root cell size (Table 16, Figure 4). Plants grown in 175-size root cells produced more than twice as much early yield as plants grown in 080 root cells.

Location of transplant production also had a significant effect on early yield. Michigan plants across most root cell sizes produced about 40% higher early yields than Speedling transplants (Table 16, Figure 4).

Cull fruit number and weight, small fruit number and weight, large fruit number and total fruit number harvested during the early yield period were not significantly different among root cell sizes or between locations.

Total fruit yield for the 1981 season increased linearly with increasing root cell size (Table 17, Figure 5). Plants grown in 175-size root cells produced up to 25% greater total yield than those grown in 080-size root cells. There were no differences in total yield between Speedling and Michigan transplants. Total large tomato yield increased linearly and quadratically with increased root cell size. Tomato plants grown in size 125, 150 and 175 root cells produced more large fruit during the season than plants grown in size 080, 080A and 100A root cells. Michigan transplants produced 23% more large fruit than Speedling plants across all root cell sizes. Total small and cull fruit yields were not significantly different for either root cell sizes or locations of transplant production.

Total large fruit number of Pik-Red tomatoes harvested over the growing season increased linearly with increased root cell size (Table 18). There was a significant difference in the number of large fruit between locations of production, with Michigan plants producing 18% more large fruit than Speedling plants. There were no differences among treatments and between locations of

Table 16. The influence of root cell size and location of transplant production on early yield of Pik-Red tomato plants in 1981.

Root cell size and source	Total early[z] yield (kg/ha)	Large fruit[z] yield (kg/ha)
Root cell size		
080	8248	4905
080A	7528	3001
100A	9134	3699
125	12789	9171
150	14570	9047
175	17934	12339
linear	**	**
quadratic	NS	*
cubic	NS	NS
Location of transplant production		
Michigan	13625	8534
Speedling	9776	5520
Main effect	**	*

[z]Tomatoes were harvested from 14 plants per plot. Yield figures are the means of 3 replications. Early season yields were harvested during the first 2 weeks of the harvest season on August 6 and August 14, 1981. Large fruit yield refers to the weight of marketable fruit harvested greater than 6.7 cm in diameter. Fruit weight was converted to kilograms/hectare.

*,**Significant at the 5 and 1% levels, respectively.

Figure 4. The influence of root cell size and location of transplant production on early yield of Pik-Red tomatoes in 1981.

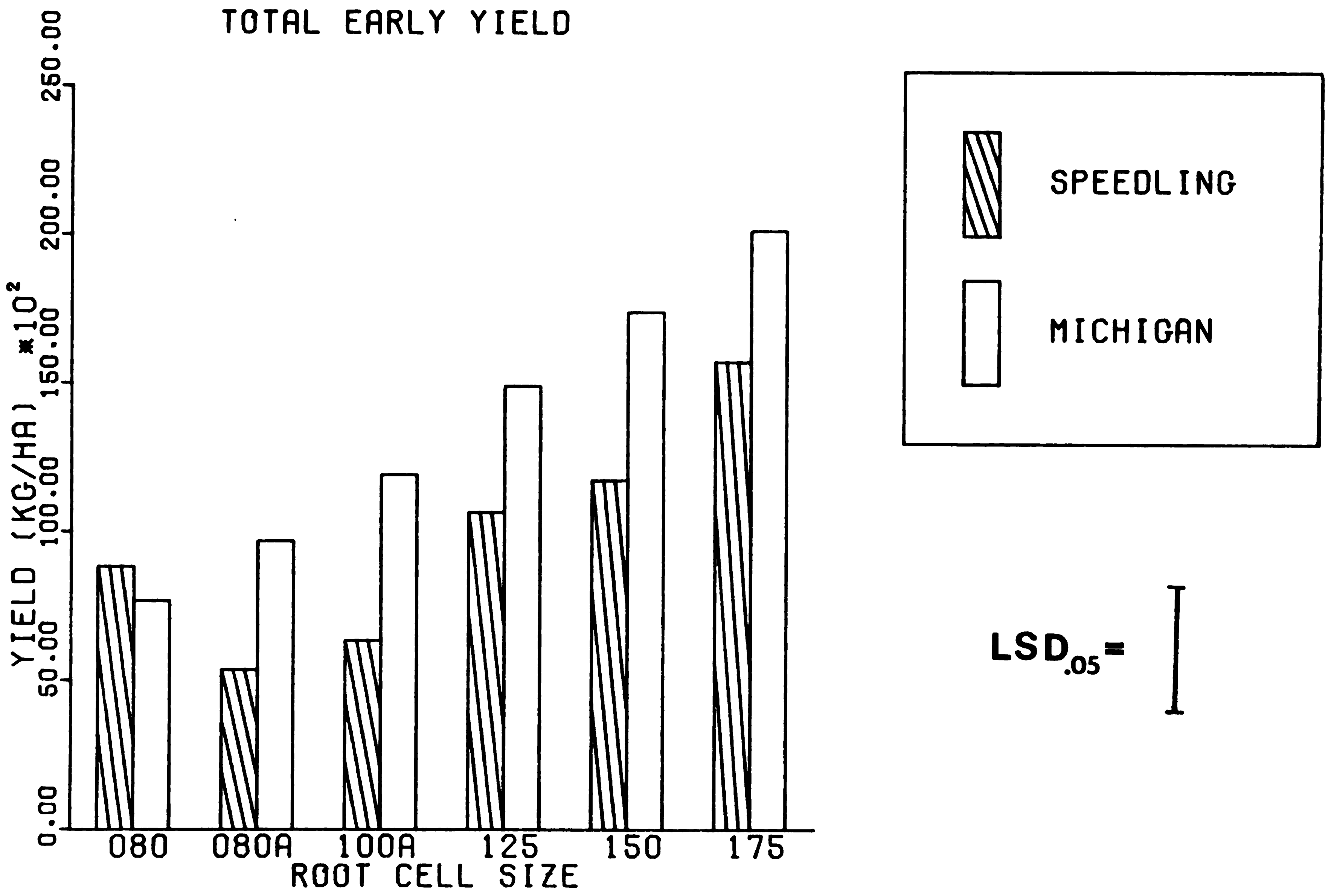

TOTAL EARLY YIELD
YIELD (KG/HA) *10²
0.00
50.00
100.00
150.00
200.00
250.00
080
080A
100A
125
150
175
ROOT CELL SIZE
SPEEDLING
MICHIGAN
LSD.05 =

Table 17. The influence of root cell size and location of transplant production on the total yield of Pik-Red tomato plants in 1981.

Root cell size and Source	Total large[y] fruit yield (kg/ha)	Total small[y] fruit yield (kg/ha)	Total cull[y] fruit yield (kg/ha)	Total fruit[yz] yield (kg/ha)
Root cell size				
080	12012	7303	15464	34778
080A	10726	7761	18339	36886
100A	10871	6402	17099	34371
125	16045	7354	12767	36166
150	15601	5646	15274	36522
175	19933	6896	15420	42248
linear	**	NS	NS	*
quadratic	*	NS	NS	NS
cubic	NS	NS	NS	NS
Location of transplant production				
Michigan	15705	7071	15594	38371
Speedling	12690	6717	15880	35287
Main effect	*	NS	NS	NS

[y]Yield figures are means of 3 replications. Fruit weight was converted to kilograms/hectare.

[z]Total fruit yield is the total yield of all fruit harvested during the season.

*,**Significant at the 5 and 1% levels, respectively.

Figure 5. The influence of root cell size and location of transplant production on the total yield of Pik-Red tomatoes in 1981.

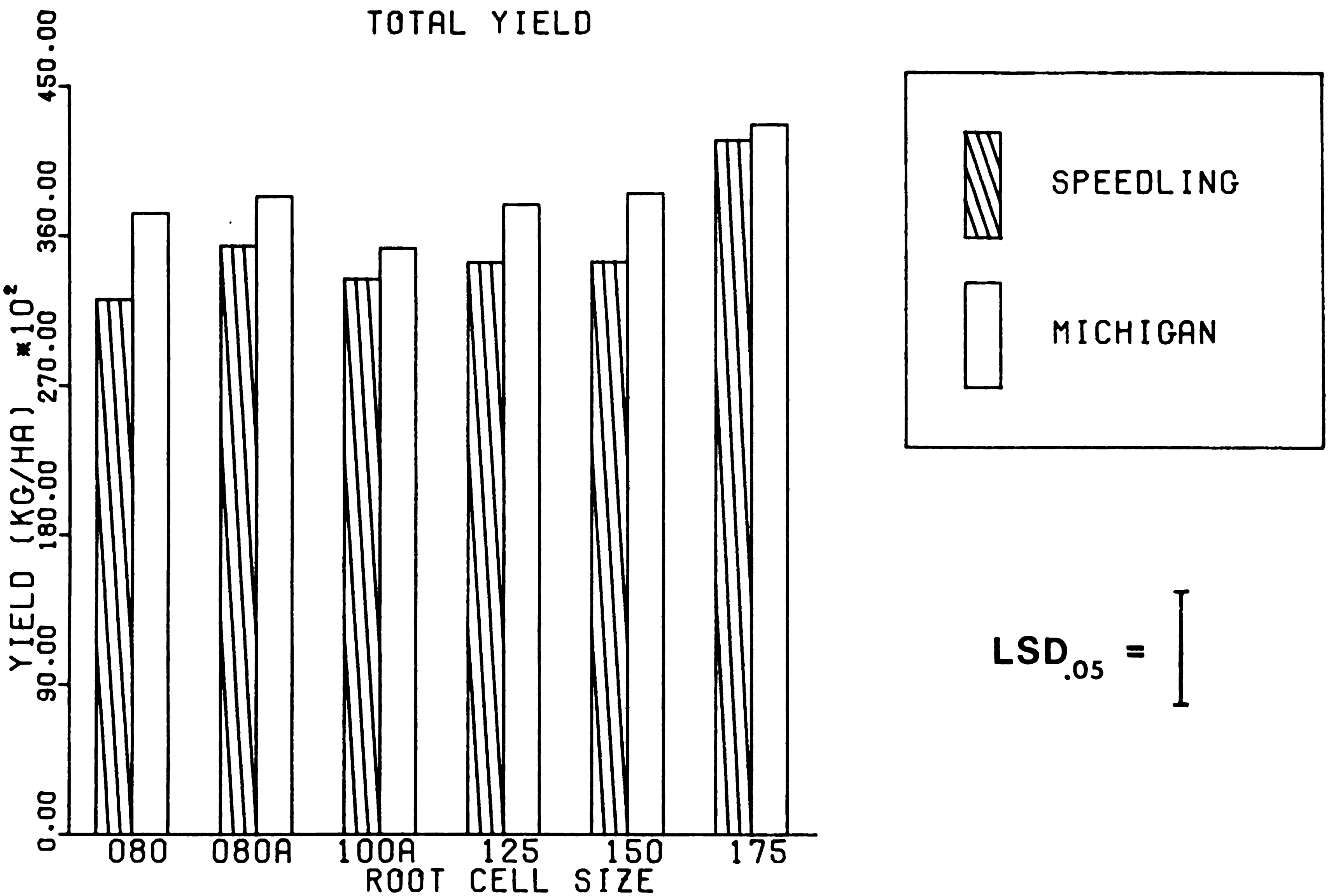

TOTAL YIELD
YIELD (KG/HA) *10²
0.00
90.00
180.00
270.00
360.00
450.00
080
080A
100A
125
150
175
ROOT CELL SIZE
SPEEDLING
MICHIGAN
LSD.05 =

Table 18. Influence of different root cell size of TODD Planter Flats and location of transplant production on the total fruit number of Pik-Red tomato plants in 1981.

Root cell size and source	Total large[y] fruit number per hectare	Total small[y] fruit number per hectare	Total cull[y] fruit number per hectare	Total[yz] fruit number per hectare
Root cell size				
080	56831	60629	95833	213293
080A	50207	65670	114022	229899
100A	49825	45567	112292	207684
125	74002	56569	76532	207103
150	70767	46004	84429	201200
175	86324	53420	83557	223301
linear	*	NS	NS	NS
quadratic	NS	NS	NS	NS
cubic	NS	NS	NS	NS
Location of transplant production				
Michigan	71386	58925	95829	226140
Speedling	58406	51310	91937	201653
Main effect	*	NS	NS	NS

[y]Fruit numbers are means of 3 replications. Fruit number was converted to number per hectare.

[z]Total fruit number is the total number of all fruit harvested during the season.

*,**Significant at the 5 and 1% levels, respectively.

production for total small fruit number, total cull fruit number and total fruit number produced during the 1981 growing season.

There were no significant interactions at any time between root cell size and location of production in any category of fruit number or weight.

Most of the tomato fruit was harvested during the early and midseason II harvesting periods. In general, over the course of the picking season, a similar number of large and small fruit were harvested for plants of all root cell sizes (Table 18). Almost twice as much large fruit weight as small fruit weight was harvested throughout the season for plants of all root cell sizes (Table 17). Cull fruit weight amounted to 30 to 50% of the total tomato fruit yield. Most of the cull fruit was harvested during the early season.

Total early yield of Michigan and Speedling Pik-Red tomatoes was highly correlated at the 1% level with both the area and volume of the root cell in the TODD planter flat in which they were produced (Figures 6 and 7). As the area and the volume of the root cell increased, total early tomato yields increased. Depth of the root cells was not highly correlated with tomato early yield.

Midseason and late tomato yield production was not significantly correlated with either depth, area or volume of the root cell. However, the total large fruit yield of

Figure 6. The effect of root cell surface area on early yield of Pik-Red tomatoes, 1981.

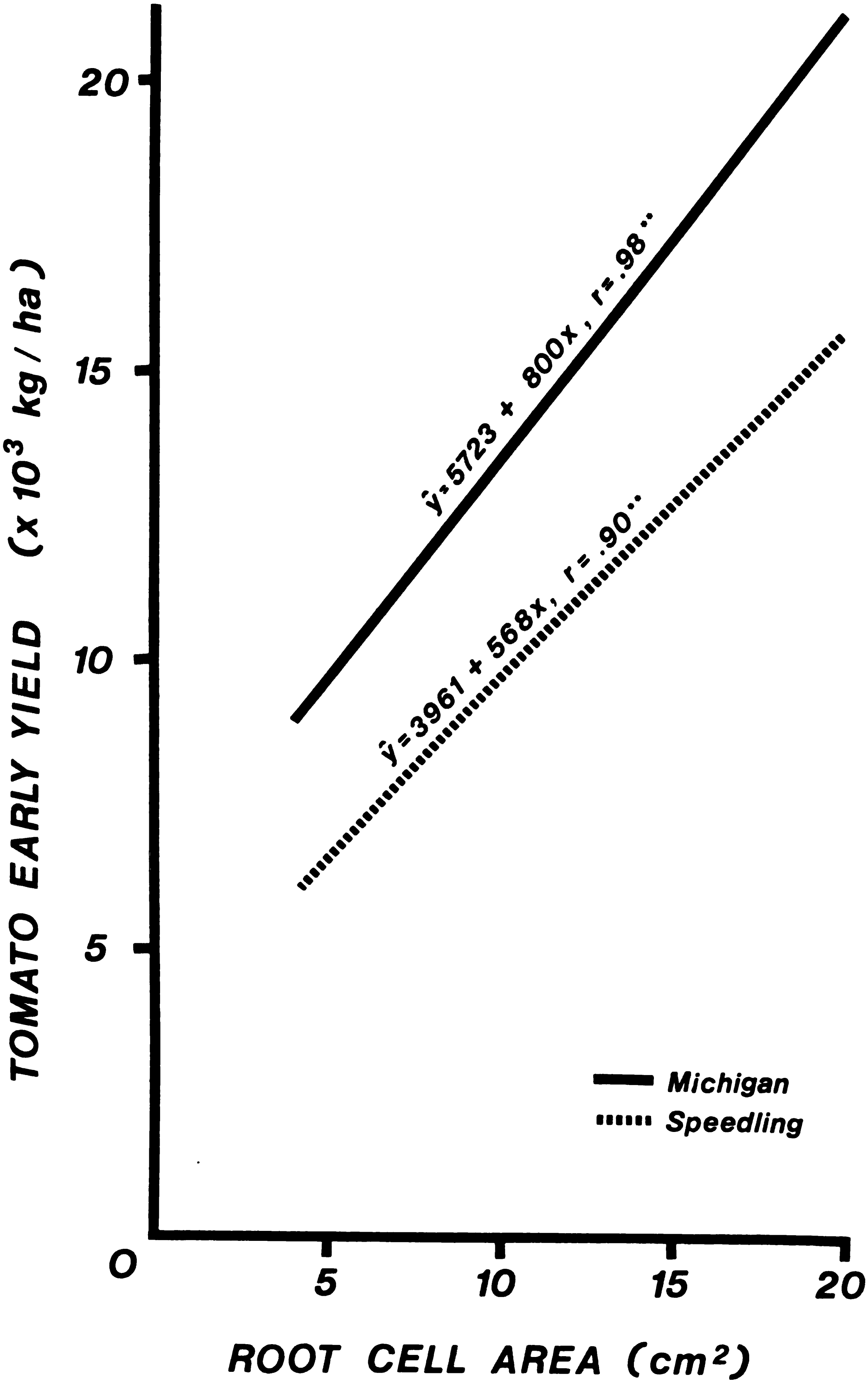
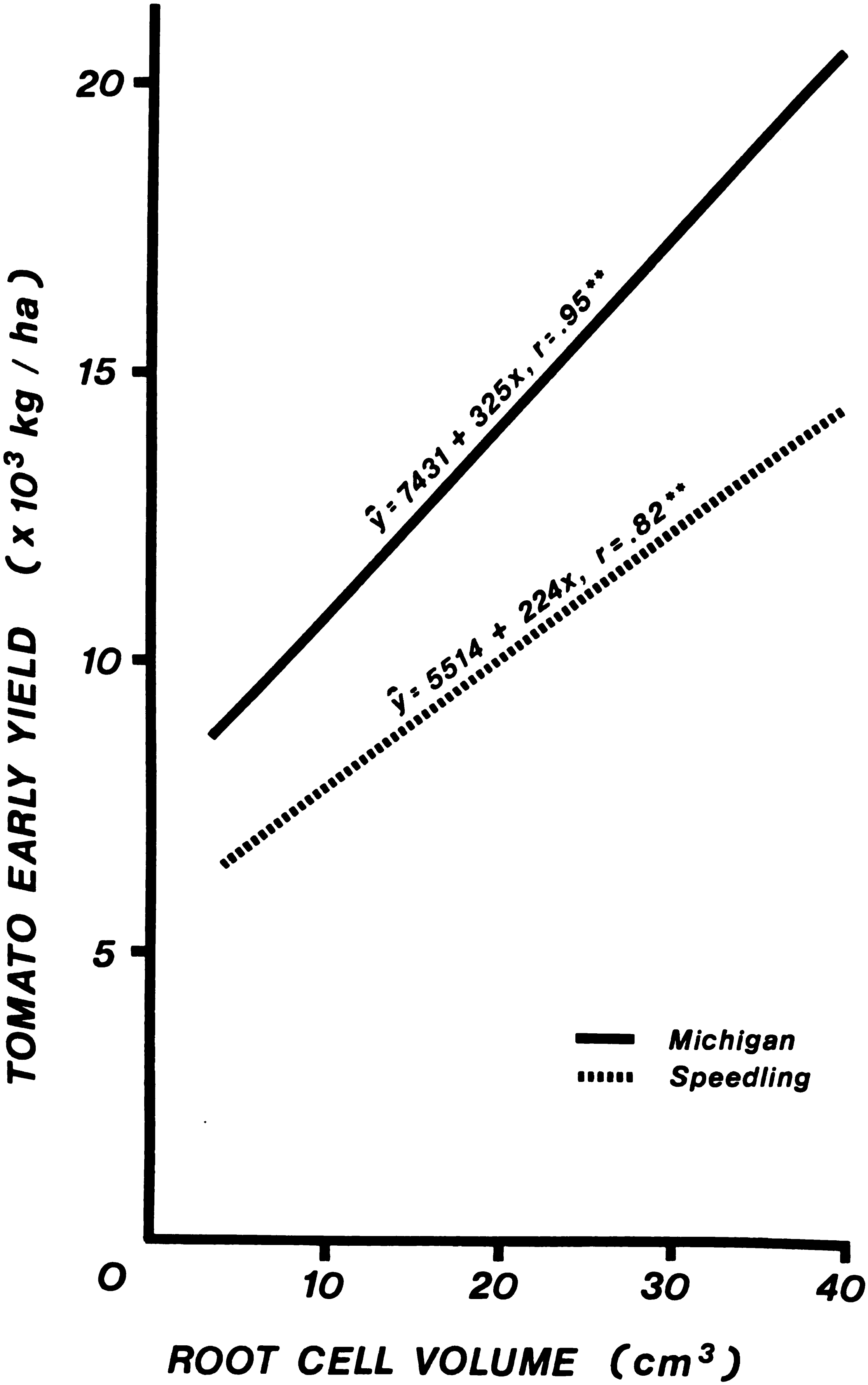

TOMATO EARLY YIELD (x 10³ kg / ha)
20
15
10
5
0
5
10
15
20
ROOT CELL AREA (cm²)
ŷ=5723 + 800x, r=.98**
ŷ=3961 + 568x, r=.90**
Michigan
Speedling

Figure 7. The effect of root cell volume on early yield of Pik-Red tomatoes, 1981.


TOMATO EARLY YIELD (x 10³ kg / ha)
20
15
10
5
0
10
20
30
40
ROOT CELL VOLUME (cm³)
ŷ = 7431 + 325x, r = .95**
ŷ = 5514 + 224x, r = .82**
Michigan
Speedling

marketable tomatoes was highly correlated at the 1% level with area and volume of the root cells (Figures 8 and 9). Increased root cell area and volume resulted in more large fruit over the harvest season for tomato transplants from both seedling locations. The depth of root cells was not significantly correlated with tomato yields at any time during the growing season.

Pepper Fruit Harvest

Total early yields of Michigan Lady Bell peppers increased linearly with increased root cell size (Table 19, Figure 10). Total early yields of Speedling peppers increased linearly and quadratically with increased root cell size. Total early yields of Speedling 080-, 125- and 150-size plants were similar, while that of 175-size Speedling plants was greater, creating a significant linear and quadratic response. Use of 175-size root cells resulted in up to a 50% increase in early yield of Lady Bell pepper transplants over both production locations. Early yields of large fruit increased linearly with increased root cell size for Michigan transplants. There were no differences in early yields of large fruit between cell sizes for Speedling transplants. Early yields produced by Michigan and Speedling transplants of comparable root cell sizes appeared to be similar.

There were no differences in total yield and total

Figure 8. The effect of root cell area on total large fruit yield of Pik-Red tomatoes, 1981.

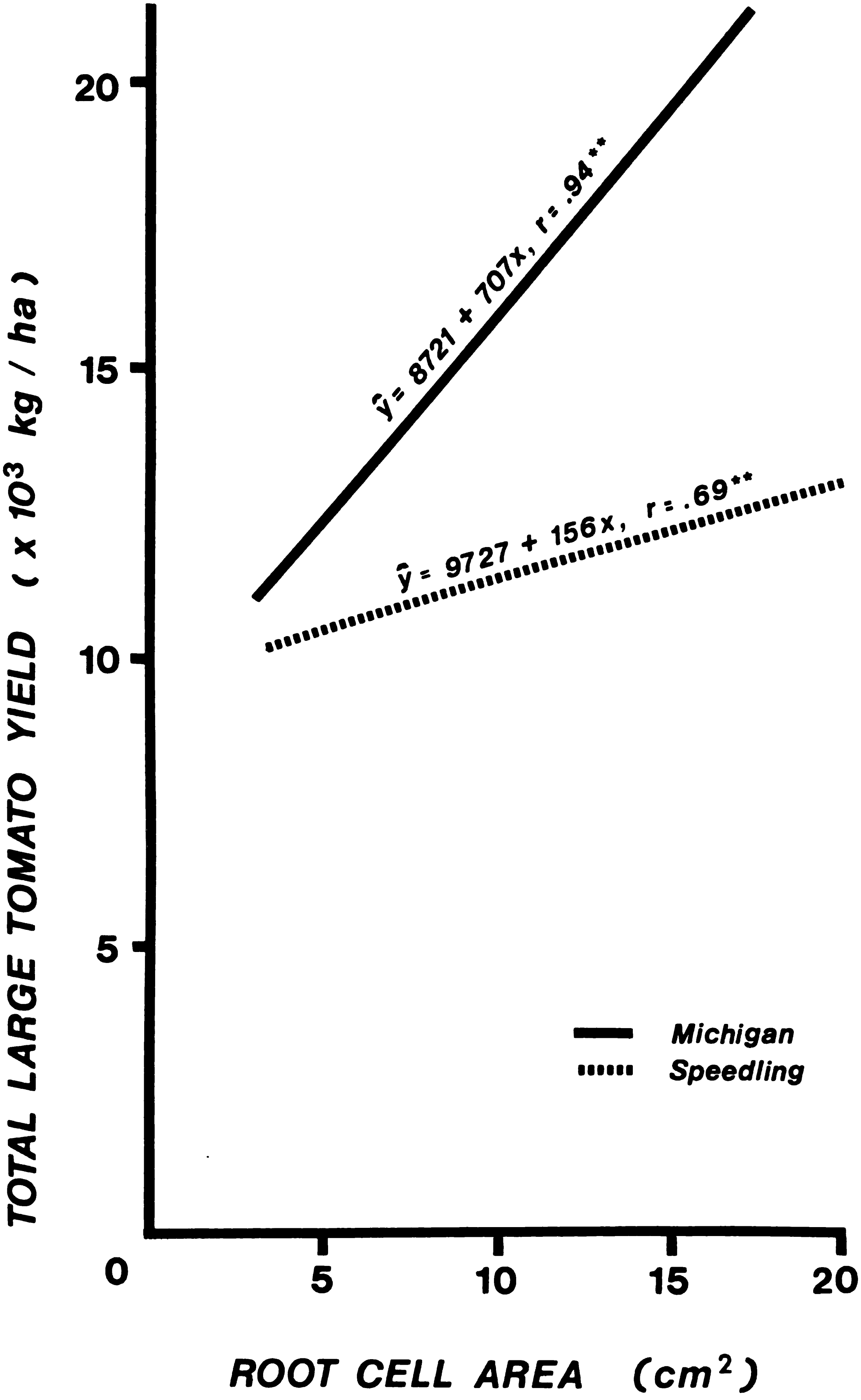

TOTAL LARGE TOMATO YIELD (x 10³ kg / ha)
20
15
10
5
0
5
10
15
20
ROOT CELL AREA (cm²)
ŷ = 8721 + 707x, r = .94**
ŷ = 9727 + 156x, r = .69**
Michigan
Speedling

Figure 9. The effect of root cell volume on total large fruit yield of Pik-Red tomatoes, 1981.

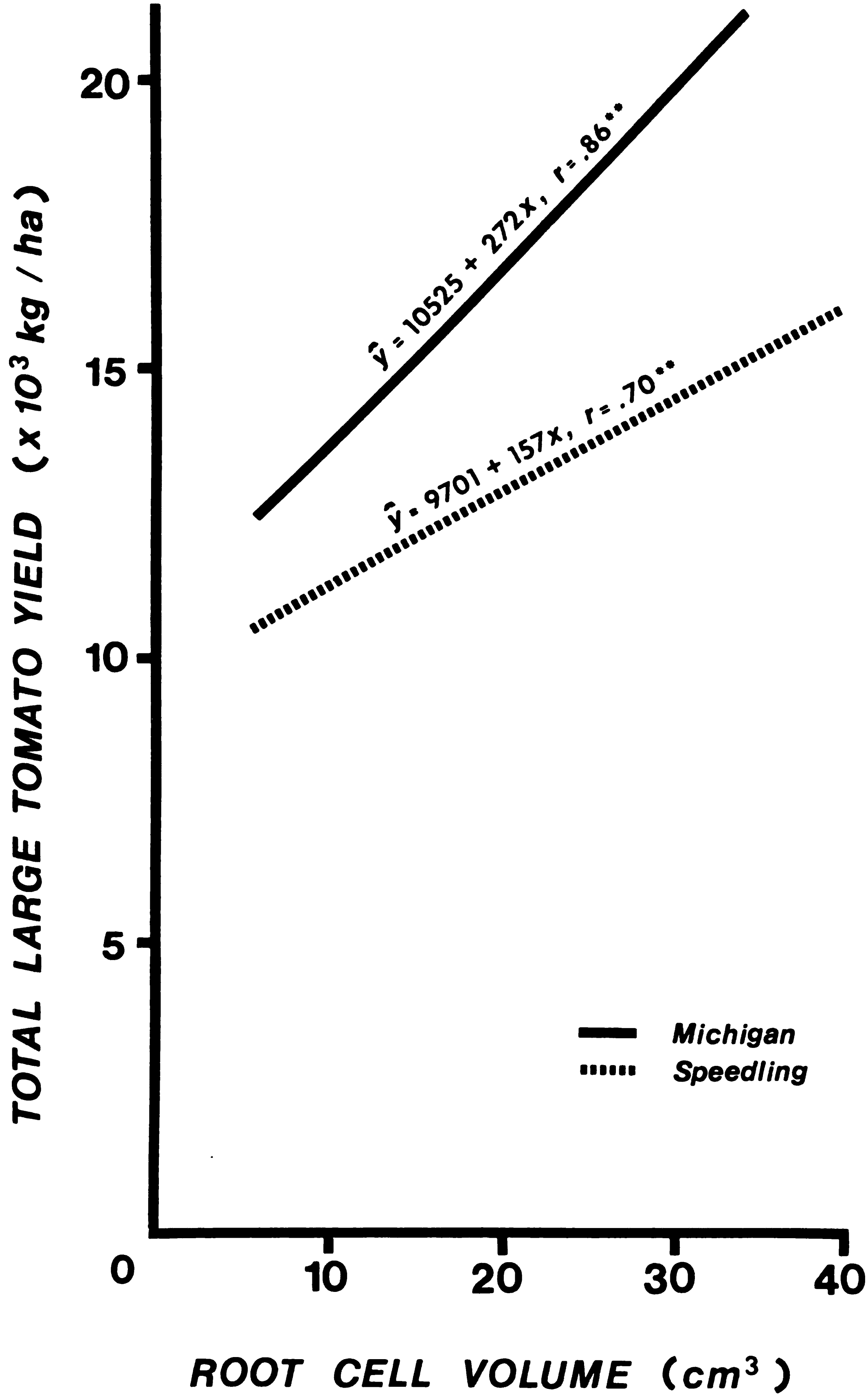

TOTAL LARGE TOMATO YIELD (x 10³ kg / ha)
20
15
10
5
0
10
20
30
40
ROOT CELL VOLUME (cm³)
ŷ = 10525 + 272x, r = .86**
ŷ = 9701 + 157x, r = .70**
Michigan
Speedling

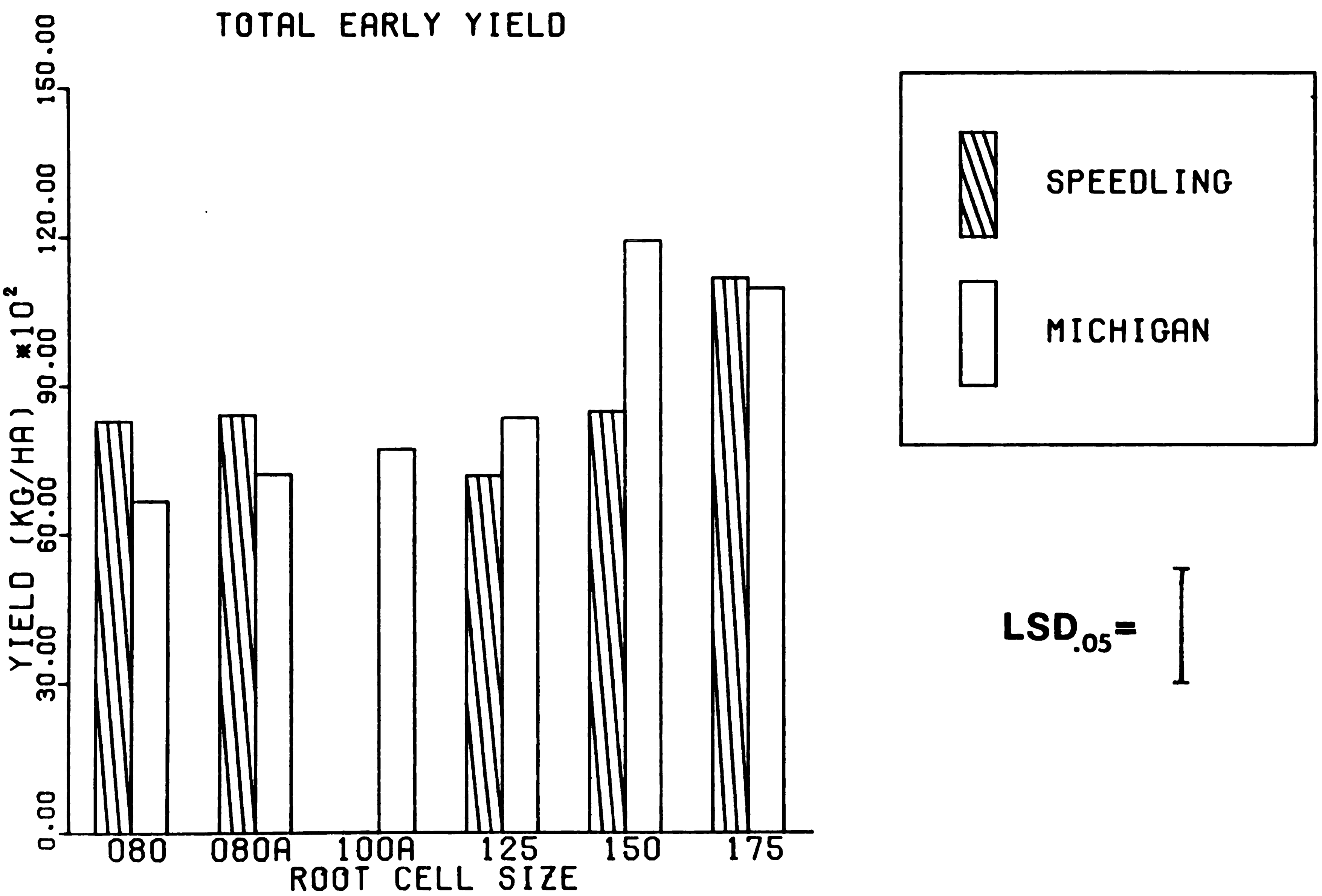
Table 19. The influence or root cell size and location of transplant production on the early yield of Lady Bell pepper plants in 1981.

Root cell size and source	Total early[z] yield (kg/ha)	Large fruit[z] early yield (kg/ha)
Root cell size		
Michigan		
080	6671	6511
080A	7223	6802
100A	7732	6816
125	8357	7790
150	11932	11540
175	10973	10261
linear	**	*
quadratic	NS	NS
Speedling		
080	8284	8124
080A	8415	8255
125	7194	7121
150	8458	8357
175	11176	10726
linear	*	NS
quadratic	*	NS

[z]Peppers were harvested from 14 plants per plot. Yield figures are the means of 3 replications. Early season yield was harvested during the first week of the harvest season on August 12, 1981. Large fruit yield refers to the weight of marketable fruit greater than 6.4 cm in diameter and length. Michigan and Speedling treatments were analyzed as separate experiments to avoid an unbalanced analysis created by the absence of treatment Speedling 100A.

*,**Significantly at the 5 and 1% levels, respectively.

Figure 10. The influence of root cell size and location of production on the total early yield of Lady Bell peppers in 1981.


TOTAL EARLY YIELD
YIELD (KG/HA) *10²
0.00
30.00
60.00
90.00
120.00
150.00
080
080A
100A
125
150
175
ROOT CELL SIZE
SPEEDLING
MICHIGAN
LSD.05=

large pepper yield for plants of any root cell treatment (Table 20, Figure 11). Total cull yield increased linearly and quadratically with increased root cell size of Speedling transplants, with 175-size plants producing the most culls.

There were no differences among root cell sizes or between locations for cull numbers and weights, and small fruit numbers and weights during early, midseason and late harvest periods. There were no significant differences between plants of different root cell sizes and locations in total small fruit numbers or yield, total large fruit numbers or yield and total fruit numbers or yield (Tables 20 and 21). There were no significant interactions between root cell size and location of production for any parameter measured.

The majority of the large peppers were harvested during the early and midseason II harvest periods from root cell sizes 100A, 125, 150 and 175. Cell sizes 080 and 080A produced the greatest percentage yield during the midseason I harvest period. Cull peppers constituted less than 5% of the total pepper fruit weight throughout the season.

Total early yield of Michigan Lady Bell peppers was highly correlated at the 1% level with both the area and the volume of the root cells of TODD flats (Figures 12 and 13). Total early yields of Speedling peppers was not highly correlated with either the area or the volume of the

Table 20. The influence of root cell size and location of transplant production on the total yield of Lady Bell pepper plants in 1981.

Root cell size and source	Total large[y] fruit yield (kg/ha)	Total cull[y] yield (kg/ha)	Total fruit[yz] yield (kg/ha)
Root cell size			
Michigan			
080	25624	641	26260
080A	26147	1557	27699
100A	24329	1352	25680
125	25214	1714	26932
150	31563	903	32438
175	27237	1687	28920
linear	NS	NS	NS
quadratic	NS	NS	NS
Speedling			
080	27586	872	28458
080A	30346	772	31117
125	29343	567	29910
150	29551	929	30476
175	31056	1600	32656
linear	NS	*	NS
quadratic	NS	*	NS

[y]Yield figures are means of 3 replications. Fruit weight was converted to kilograms/hectare.

[z]Total fruit yield is the total yield of all fruit harvested during the season. Michigan and Speedling treatments were analyzed as separate experiments to avoid an unbalanced analysis created by the absence of treatment Speedling 100A.

*,**Significant at the 5 and 1% levels, respectively.

Figure 11. The influence of root cell size and location of production on the total yield of Lady Bell peppers in 1981.

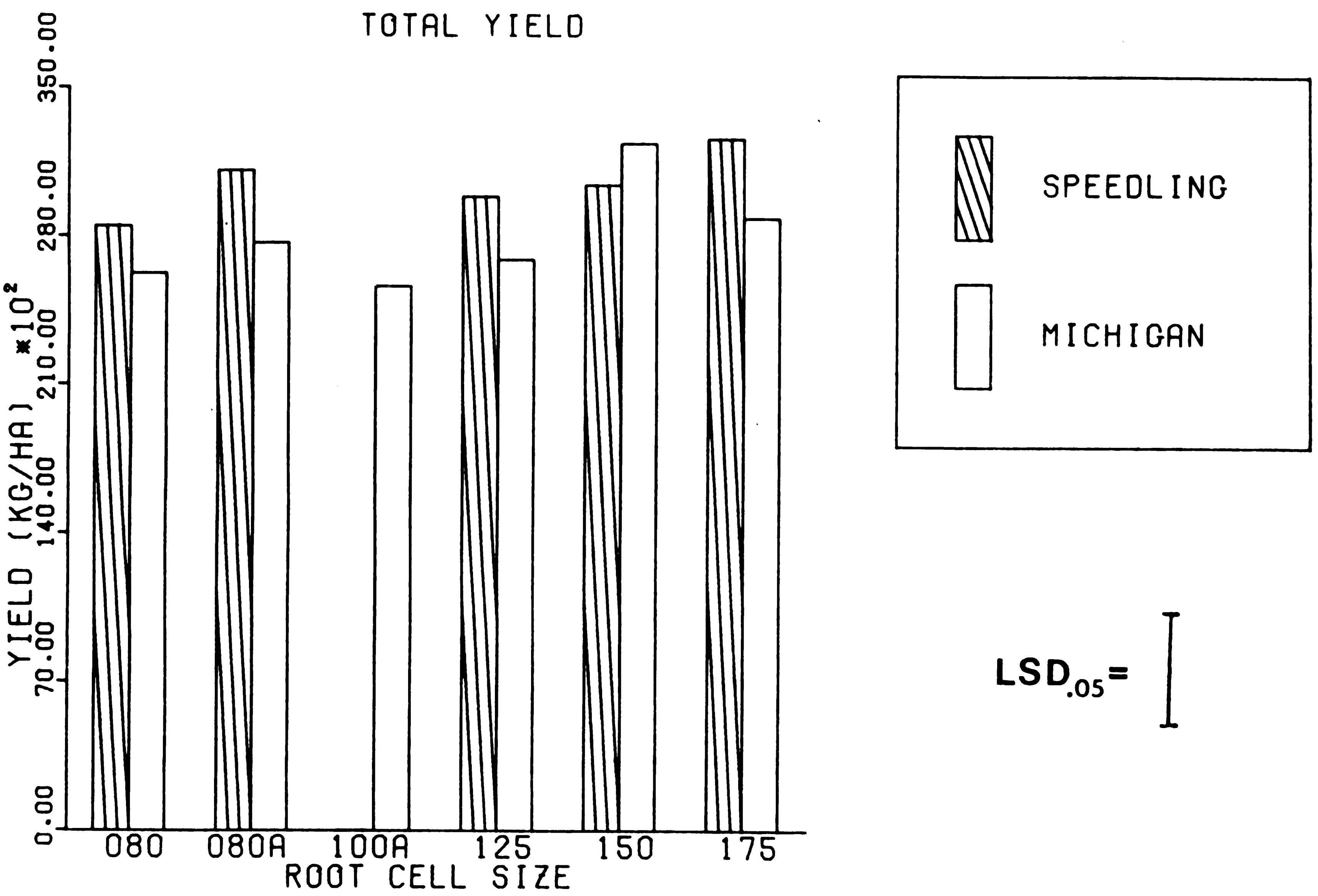

TOTAL YIELD
SPEEDLING
MICHIGAN
LSD.05 =
YIELD (KG/HA) *10²
0.00
70.00
140.00
210.00
280.00
350.00
080
080A
100A
125
150
175
ROOT CELL SIZE

Table 21. Influence of different root cell size of TODD Planter Flats and location of transplant production on the total fruit number of Lady Bell pepper plants in 1981.

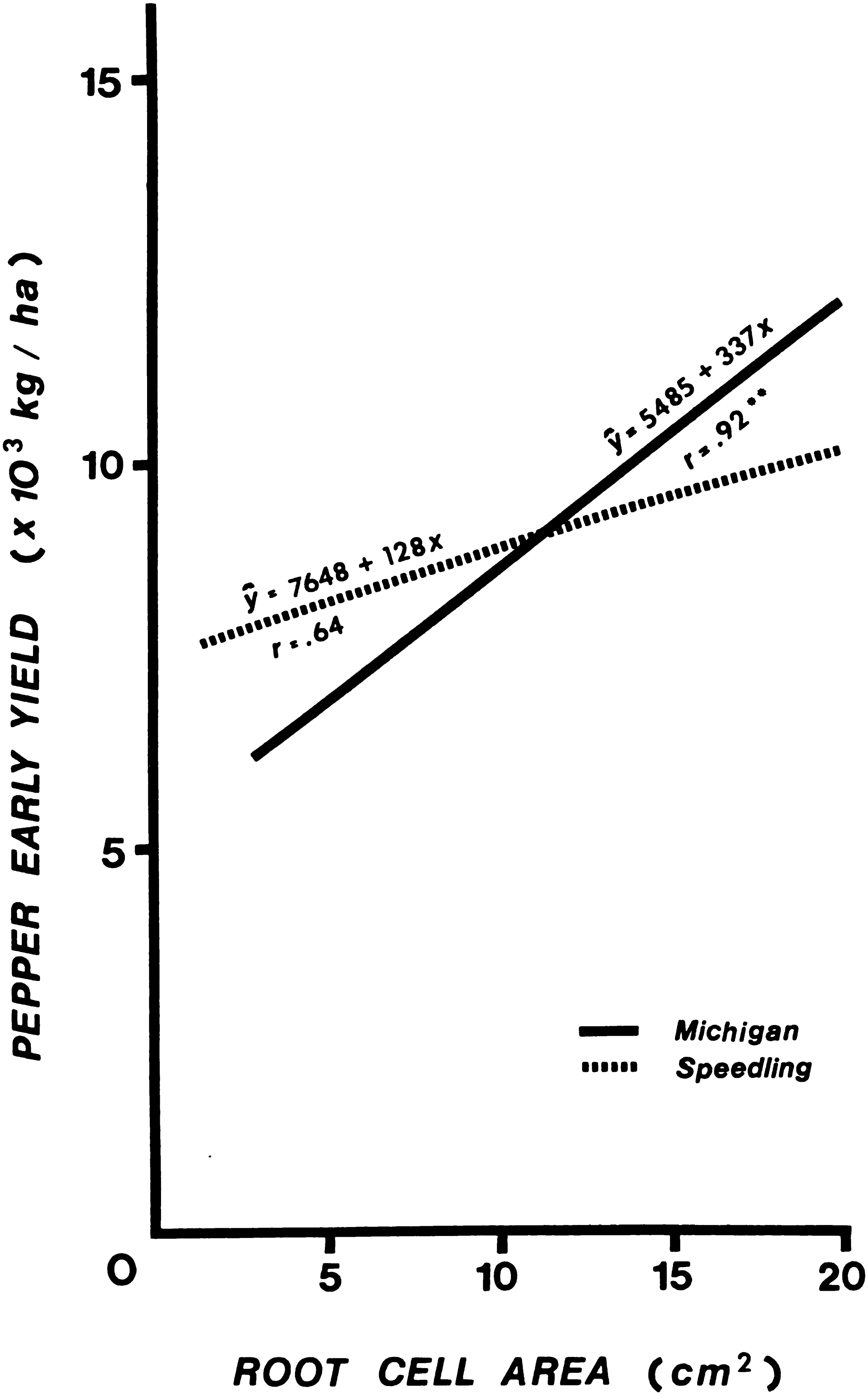
Treatment	Total large[y] fruit number per hectare	Total red[y] fruit number per hectare	Total cull[y] fruit number per hectare	Total[yz] fruit number per hectare
Root cell size				
Michigan				
080	168569	3861	5949	178379
080A	181652	5949	12191	199792
100A	161728	6840	11597	180165
125	162923	7135	10107	180165
150	190269	4460	6539	201268
175	172733	8321	13379	194433
linear	NS	NS	NS	NS
quadratic	NS	NS	NS	NS
Speedling				
080	178673	3569	5648	187890
080A	199188	3569	5351	208108
125	191160	891	3272	193541
150	199188	4460	5949	209597
175	200970	4460	10701	216131
linear	NS	NS	*	NS
quadratic	NS	NS	*	NS

[y] Fruit numbers are means of 3 replications. Fruit number was converted to number per hectare.

[z] Total fruit number is the total number of all fruit harvested during the season.

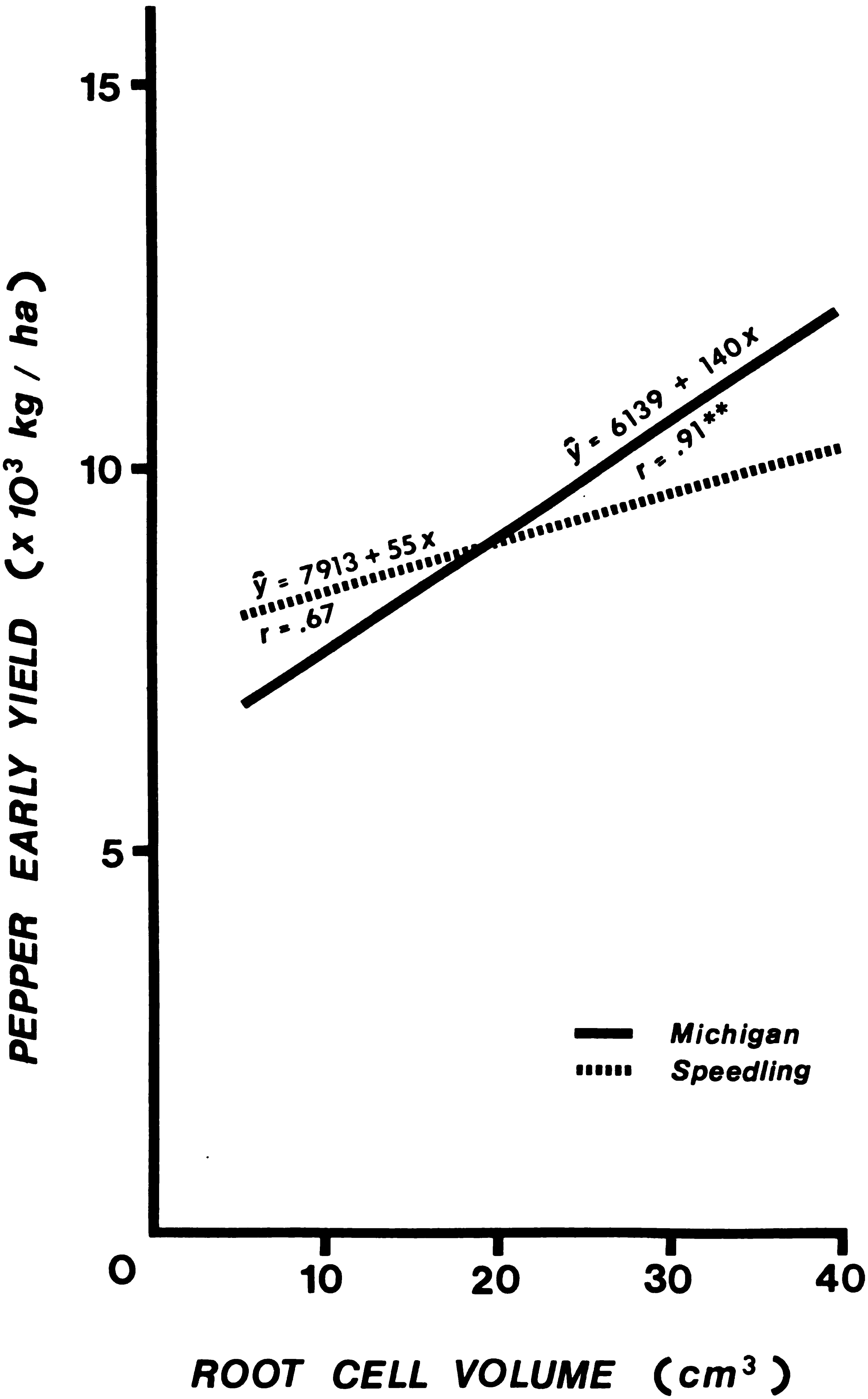
*,** Significant at the 5 and 1% levels, respectively.

Figure 12. The effect of root cell area on early yield of Lady Bell peppers, 1981.



15
10
5
0
5
10
15
20
PEPPER EARLY YIELD (x 10³ kg / ha)
ROOT CELL AREA (cm²)
ŷ = 7648 + 128x
r = .64
ŷ = 5485 + 337x
r = .92**
Michigan
Speedling

Figure 13. The effect of root cell volume on early yield of Lady Bell peppers, 1981.


PEPPER EARLY YIELD (x 10³ kg / ha)
15
10
5
0
10
20
30
40
ROOT CELL VOLUME (cm³)
ŷ = 6139 + 140x
r = .91**
ŷ = 7913 + 55x
r = .67
Michigan
Speedling

root cells. The depth of the container did not appear to influence early yield of peppers as it was never highly correlated with early yield.

In general, midseason, late and total pepper yields were not significantly correlated with either depth, area or volume of the root cell.

C. A Comparison of Ethylene and CO2 Production of Tomato and Pepper Transplants Produced at Michigan State University and at Speedling, Inc. in Florida in 1981.

All tomato and pepper seedlings and excised plant parts produced increased levels of ethylene and CO_2 compared to the laboratory air control at 2 and 12 hours after placement in glass Ball jars (Tables 22 and 23). Intact Michigan tomato seedlings produced significantly greater amounts of ethylene and CO_2 at 1 hour after placement in glass jars than the Speedling tomato seedlings. The Michigan pepper seedlings produced a similar amount of ethylene and CO_2 as compared to the Speedling pepper seedlings.

Two hours after placement in the jars, the ethylene production of whole seedlings had increased slightly over production at 1 hour (Table 22). However, the Michigan tomato seedlings still produced a greater amount of ethylene than the Speedling tomato seedlings. There was no difference in the levels of ethylene produced by Michigan and Speedling pepper seedlings.

Twelve hours after placement in the jars, Michigan tomato seedlings had produced significantly greater levels of ethylene and CO_2 than Speedling tomato seedlings (Tables 22 and 23). The levels of ethylene and CO_2 produced by Michigan and Florida pepper seedlings were not significantly different. The levels of ethylene and CO_2 produced by tomato and pepper plants of both locations increased after enclosure in glass jars for 12 hours as compared to the

Table 22. Production of ethylene (C_2H_4) by Pik-Red tomato and Lady Bell pepper seedlings grown in Michigan and at Speedling in Florida at 1, 2 and 12 hours.

Treatment	C_2H_4 (ppm)					
	1 hr		2 hr		12 hr	
	Michigan	Speedling	Michigan	Speedling	Michigan	Speedling
1. Air control[x]	.013	.013	.007	.007	.013	.013
2. Excised tomato shoot[y]	.016	.010	.036	.014	.140	.060
3. Excised pepper shoot[y]	.016	.012	.011	.015	.024	.055
4. Tomato seedling[z]	.030a	.013b	.049a	.019b	.071a	.027b
5. Pepper seedling[z]	.014a	.012a	.020a	.012a	.031a	.030a

[x]Air control = laboratory air in which the experiment was conducted.

[y]Tomato and pepper shoots without roots; figures represent a reading from one plant.

[z]Tomato and pepper seedlings refer to the entire plant. Seedling figures represent the mean of 4 plant readings. Mean separation within treatments by Duncan's multiple range test, 5% level.

Table 23. The level of CO_2 gas produced by Pik-Red tomato seedlings and Lady Bell pepper seedlings grown in Michigan and at Speedling in Florida at 1 and 12 hours.

Treatment	CO_2 (ppm)			
	1 hr		12 hr	
	Michigan	Speedling	Michigan	Speedling
1. Air control[x]	.046	.046	.049	.049
2. Excised tomato shoot[y]	.350	.070	.620	.220
3. Excised pepper shoot[y]	.080	.060	.270	.170
4. Tomato seedling[z]	.290a	.110b	1.063a	.373b
5. Pepper seedling[z]	.143a	.110a	.503a	.343a

[x]Air control = laboratory air in which the experiment was conducted.

[y]Tomato and pepper shoots without roots; figures represent a reading from one plant.

[z]Tomato and pepper seedlings refer to the entire plant. Seedling figures represent the mean of 4 plant readings. Mean separation within treatments by Duncan's multiple range test, 5% level.

levels of these gases detected after 1 and 2 hours of enclosure.

D. A Comparison of the Growth of Tomato Seedlings at Two Spacings in TODD Planter Flats of Various Root Cell Sizes.

Tomato, leaf area, shoot fresh weight, and shoot dry weight increased in a linear manner with increased root cell size at 15 days (Table 24). Height also increased with increased root cell size, but in a linear and quadratic manner. At 14 days of age, increased plant spacing resulted in significantly increased height, shoot fresh weight and shoot dry weight of tomato seedlings grown in all root cell sizes. No interactions between root cell size and spacing were significant at this time.

When the tomato seedlings were 30 days old, leaf area, fresh weight and dry weight increased in a linear manner with increased root cell size (Table 25). There were no significant trends in plant height among root cell size treatments. Increased spacing in the flat resulted in significantly decreased plant height and increased shoot dry weight for seedlings of all root cell sizes. A significant interaction between plant spacing and root cell size was noted for fresh weight.

At 45 days of age, plant height, leaf area and shoot fresh weight increased in a quadratic manner with increased root cell size (Table 26). This quadratic response was significant because the plants grown in root cell size

Table 24. The influence of cell size and spacing on the growth of 15-day-old Pik-Red tomato seedlings on December 8, 1981.

Treatment	Height^z (cm)	Leaf Area^z (sq cm)	Shoot Fresh Weight^z (g)	Shoot Dry Weight^z (g)
Root cell size				
080	4.7	1.9	.24	.02
080A	5.7	2.0	.28	.03
100A	8.2	4.3	.36	.05
125	8.8	4.7	.44	.06
150	7.9	5.4	.40	.06
175	8.5	6.2	.47	.07
linear	*	**	**	**
quadratic	**	NS	NS	NS
Spacing in flat				
Normal	7.1	4.0	.34	.05
Wide	7.5	4.1	.39	.06
Main effect	*	NS	*	**
Spacing x cell size	NS	NS	NS	NS

^z Two plants were harvested per plot. Measurements are the means of 3 replications.

*,** Significant at the 5 and 1% levels, respectively.

Table 25. The influence of cell size and spacing on the growth of 30-day-old Pik-Red tomato seedlings on December 23, 1981.

Treatment	Height[z] (cm)	Leaf Area[z] (sq cm)	Shoot Fresh Weight[z] (g)	Shoot Dry Weight[z] (g)
Root cell size				
080	15.0	30.4	0.95	.10
080A	16.2	34.4	1.03	.09
100A	19.2	55.7	1.54	.13
125	18.6	52.9	1.53	.16
150	20.1	59.0	1.84	.17
175	17.0	67.2	1.91	.17
linear	NS	**	**	**
quadratic	NS	NS	NS	NS
Spacing in flat				
Normal	19.2	52.2	1.43	.15
Wide	16.2	47.6	1.50	.13
Main effect	*	NS	NS	*
Spacing x cell size	NS	NS	*	NS

[z]Two plants were harvested per plot. Measurements are the means of 3 replications.

*,**Significant at the 5 and 1% levels, respectively.

Table 26. Influence of cell size and spacing on the growth of 45-day-old Pik-Red tomato seedlings on January 7, 1981.

Treatment	Height[z] (cm)	Leaf Area[z] (sq cm)	Shoot Fresh Weight[z] (g)	Shoot Dry Weight[z] (g)
Root cell size				
080	21.2	80.2	3.13	.26
080A	22.3	78.1	3.00	.23
100A	28.5	157.3	6.37	.47
125	24.0	98.1	3.73	.28
150	31.7	206.2	8.45	.65
175	28.3	166.7	6.45	.45
linear	NS	NS	NS	*
quadratic	**	**	*	*
Spacing in flat				
Normal	27.4	123.3	4.94	.36
Wide	24.7	138.9	5.44	.43
Main effect	**	NS	NS	NS
Spacing x cell size	*	**	*	NS

[z]Two plants were harvested per plot. Measurements are the means of 3 replications.

*,**Significant at the 5 and 1% levels, respectively.

150 were of a larger size than plants grown in size 175 root cells. Shoot dry weight increased in a linear and quadratic manner with increased root cell size. Increased flat spacing resulted in decreased plant height. Significant interactions between root cell size and spacing were noted for plant height, leaf area and shoot fresh weight.

Interactions between spacing and root cell sizes were significant only when tomato plants were between 4 and 7 weeks of age (Tables 25 and 26). At smaller root cell sizes, the differences between plant size at different spacings were negligible throughout the experiment. However, when simple effects were examined, plants of root cell sizes 125 and 150 grown at the wider spacing were taller and possessed greater leaf area and fresh weight at 45 days of age than plants of comparable root cell sizes at normal spacings. In all cases, when simple effects and interactions were graphed, plants grown in root cell size 150 at the wide spacing were largest. Plants grown in root cell size 175 at wider spacings were smaller than plants of the same cell size at normal spacing and root cell size 150 at both spacings.

The results of the growth analysis of seedling tomatoes at 6 different root cell sizes and 2 different flat spacings were variable. Relative growth rate (RGR) and net assimilation rate (NAR) varied slightly with different root cell sizes and spacings, but were generally not significantly different for separate growth periods. There were no significant differences in the average RGR and NAR of all root cell sizes from the 4 growth periods. Root cell size treatments 080 and 150 maintained the greatest RGR and NAR throughout the experiment.

Discussion and Conclusions

Tomato and pepper seedlings grown in larger size root cells were taller and possessed greater leaf area and shoot dry weight at 4 weeks of age, just before field-setting. Nicklow and Minges (37) also found that transplants produced in larger containers were stockier and possessed more leaves at the first cluster. They believed that increased container space influenced the physiological condition of the transplant before field-setting. However, Knavel (24) proposed that larger containers hold enough fertile soil mix to support adequate root development until field-setting, while transplants grown in small containers encounter nutrient starvation more quickly.

After field-setting, the tomato and pepper seedlings from both production locations grown in larger size root cells exhibited greater height, leaf number and shoot dry weight for 6 weeks. From 5 to 7 weeks after field-setting, these tomato and pepper seedlings also produced a greater number of flowers and small unripe fruit than plants grown in smaller size root cell. These observations were not unexpected since Nicklow and Minges found that larger container size resulted in a faster overall growth rate which in turn resulted in earlier tomato flowering (37).

The depth and volume of the rooting medium are known to influence the rate of growth of the plant root system. Plant roots tend to grow more rapidly if fewer structural limitations are imposed (18). Leonard and Head (27) noted that until fruit formation, the tomato root system undergoes rapid horizontal and vertical growth. They found that the rate of growth of tomato roots was closely related to the rate of new fruit production. With a more expansive root system, a plant has greater capacity for water and nutrient uptake which in turn promotes greater vegetative growth and fruit development. It may be that transplants grown in larger root cell sizes were able to produce a larger, more efficient root system both before and after field setting. It is important to note that the entire root ball was retained by the plant at transplanting. New root initiation from the center section of the root ball had occurred within 1 week after transplanting for all treatments. However, the 175-size root ball had a much greater surface area for new root initiation and appeared to undergo more root initiation than did the 080-size root ball. A larger initial root system which promotes increased uptake of water and nutrients and undergoes greater new root initiation may account for the earlier maturity of plants grown in larger size TODD planter flats.

The results of the tomato and pepper root cell size experiments of 1980 and 1981 were very similar. Seedlings grown in larger size root cells produced significantly greater early yields in 1980 and 1981 than those grown in smaller size root cells. Many researchers have found that larger containers and greater space per plant resulted in earlier flowering and greater early yield (24, 25, 26, 37, 40, 42). Transplants grown in larger size root cells also produced a significantly greater amount of large early fruit than transplants grown in smaller size root cells. As mentioned previously, Knavel believes that larger containers provide increased nutrient availability which can positively influence plant size and eventual plant maturity (24). Plants grown in smaller root cells reached harvest maturity approximately 1 week later than plants of larger size root cells. Increased container size may have allowed for the production of a larger, more efficient transplant root system which resulted in decreased transplant shock because of initially increased water uptake and new root formation.

In 1981, 175-size tomato plants produced significantly greater total yields than 080-size plants. However, in the 1980 tomato experiment and the 1981 pepper experiment, there were no differences in total yields between root cell sizes. Increased early yields resulted in reduced yields later in the season, with no net increase in yield.

Several researchers have also found that larger sizes of transplant containers resulted in only increased early yields (24, 26). Apparently, the advantage of larger cell size on transplant growth and early yield does not last throughout the picking season.

The findings that early and total large yields were highly correlated with area and volume of the root cell and weakly correlated with cell depth agreed with the findings of Sayre (42). He reported that providing increased area and volume in a flat by setting out fewer seedlings resulted in earlier yields in the field. However, growing the plants in deeper flats containing 33% more soil did not increase yields during 2 growing seasons. Increased area and volume, which allow for less plant competition, increased nutrient availability, and greater lateral root growth, play an important role in influencing transplant size, maturity and yielding ability.

The large size root cells also had wider spacings between plants owing to the physical arrangement of the root cells in the TODD planter flats. Results of spacing indicated that larger root cells were more critical in forming larger plants than was wider plant spacing. General trends showed that although increased spacing sometimes resulted in transplants of significantly greater weight and leaf area, increased root cell size produced greater increases in transplant size and maturity.

Plants grown in 175-size root cells at wide spacings were actually smaller than 150- or 175-size plants at normal spacings. These findings may be due to increased water stress imposed upon plants grown in 175-size root cells at wide spacings. Increased sunlight penetrated the canopy of 175 plants at wide spacing and may have lead to drying of the peatlite mix. It has been demonstrated that plants with a larger leaf surface area lose larger amounts of water. If a plant loses considerable water, even though not wilted, cell division and enlargement decrease, the products of photosynthesis accumulate, and rate of growth is reduced, leading to decreased plant height, leaf area and weight (54).

Generally, the relative growth rate (RGR) and net assimilation rate (NAR) of plants of various root cell sizes were not significantly different after transplanting. This indicates that any differences in RGR and NAR which normally accompany differences in plant size may have occurred early in the first 4 weeks of development of the transplant before field setting since all transplants grew at a similar rate after field setting.

Judging from the outward appearance of the Florida Speedling plants upon their arrival in Michigan in 1980 and 1981, it appeared that Speedling had hardened-off their transplants by withholding nitrogen and phosphorus prior to shipping. If so, this may account in part for their relatively small size, smaller leaf area and smaller shoot dry weight than Michigan plants of the same age of comparable root cell sizes. Nitrogen and phosphorus are essential major nutrients known to stimulate root and shoot production and affect seedling growth rate and transplant quality (33, 54).

These apparent nutrient deficiencies may also help to explain why Speedling plants produced smaller early tomato yields after field setting in 1980 and 1981. Although sufficient nutrients were present in the field soil, the nutrient deficient condition of the Speedling seedling may have resulted in increased transplant shock after field setting. This in turn may have resulted in a slower rate of initial root growth, a slower rate of shoot growth, and overall slower maturity of Speedling plants as compared to Michigan plants.

Transplant quality may also be affected by conditions encountered during shipment or storage. Stressful conditions may induce increased seedling respiration and ethylene production (1). The increased levels of ethylene gas sampled at 1 hour from the excised tomato and pepper shoots may have been due to stress ethylene produced as a result of severe mechanical injury to the seedlings. However, since the non-injured whole tomato and pepper seedlings of both locations produced greater levels of ethylene throughout the experiment, it is more likely that any differences observed in ethylene and CO_2 production between excised Michigan and Speedling treatments were due to size differences among the seedlings. It would be expected that larger plants and plant organs would produce more ethylene and exhibit increased respiration over a 12 hour period than smaller plant parts.

Intact Michigan tomato seedlings produced greater levels of ethylene and CO_2 than did Speedling tomato plants while Michigan and Speedling pepper seedlings produced similar levels of ethylene and CO_2 throughout the experiment. Therefore, Florida-produced Speedling transplants did not suffer sufficient mechanical injury or stressful conditions to result in increased production of ethylene and CO_2. Florida plants were shipped in cardboard cartons containing air holes for ventilation, preventing the build-up of ethylene gas and auto-catalytic ethylene production which could result in eventual plant senescence (1). The differences observed in ethylene and CO_2 production between Michigan and Florida seedlings may be due to seeding size differences. Michigan tomato seedlings and shoots were larger than Florida tomato seedlings, while Michigan and Florida peppers possessed similar amounts of leaf area and shoot dry weight.

It appears that any apparent reduction in quality of Florida Speedling plants was not due to mechanical injury or increased production of stress ethylene during shipment. Instead, it appears that hardening the seedlings by withholding major nutrients may have resulted in apparent nutrient deficiency symptoms such as chlorosis and anthocyanin build-up.

In 1980, transplants were sown at 2 sowing dates in the greenhouse. Four-week-old 175-size tomato transplants produced greater early yields than did 6 1/2 week-old tomato transplants of the same size. Plant age therefore plays an important role in influencing early yielding ability of tomato transplants. Older transplants may have been more root bound at the time of field-setting, resulting in greater initial transplant shock and slower recovery. Further investigation of the effect of plant age on transplant yielding ability should be undertaken.

In summary, the size and dimensions of the transplant container and the cultural practices followed at a particular location of transplant production play important roles in influencing transplant quality and determing the early yielding ability of vegetable transplants. An individual transplant container that possesses greater area and volume but is not particularly deep is optimal for production of greater early yield of fresh market tomatoes and peppers. When grown at normal spacing in the TODD planter flat, root cell size 175 produced the largest tomato and pepper transplants, the largest early yields and the greatest weight of marketable fruit. Early yields were highly correlated with root cell depth and area; the largest root cell sizes producing the largest early yields and the greatest weight of marketable fruit.

The spacing of plants within the TODD planter flat was not critical in affecting plant size or growth.

Michigan tomato transplants produced significantly larger early yields than Speedling tomato transplants. Speedling tomato transplants were smaller in size than Michigan transplants of the same age before field-setting. Speedling pepper transplants were taller but of a similar weight and produced similar early yields when compared to Michigan transplants of the same age. Cultural practices involving fertilization and lighting may have played an important role in determining transplant growth and yielding ability.

CHAPTER IV

THE EFFECT OF NITROGEN AND PHOSPHORUS FERTILIZATION OF PIK-RED TOMATO TRANSPLANTS ON THEIR DEVELOPMENT AND YIELD IN THE FIELD

Introduction

Transplant nutrition has an effect on development and yield of tomatoes in the field. Dark green, rapidly growing plants recovered more quickly from transplanting and produced a larger early yield of marketable fruit (previous experiments). However, it is sometimes commercially necessary to withold nutrients from vegetable transplants to maintain acceptable transplant size and maturity. On the other hand, judicious use of nutrients may be able to speed up plant growth in the greenhouse to reduce transplant production time.

It is important to provide tomato transplants with an adequate level of essential nutrients before and after field-setting to allow for quick transplant recovery and growth. Phosphorus (P) plays an important role in seeding growth and development. It is known to stimulate root production, promote rapid growth in seedlings and is necessary for cellular metabolism (54). Early P uptake is more important in influencing early yield of tomatoes than total P uptake (23, 36). Greater early P uptake results in more rapid growth of tomato seedlings and an increase in early tomato fruit yields (7, 36, 41, 56, 57).

Nitrogen (N) also strongly affects seedling growth rate. It promotes rapid growth and chlorophyll development, and is essential in the formation of proteins and other compounds (33). N has been reported to be the primary limiting element to tomato seedling growth (57). Tiessen and Carolus (52) stated that N is necessary for root regeneration in the tomato transplant. Moderate N levels in the field produce larger marketable yields and uniform development of transplanted tomatoes (19).

The availability of applied N and P is an important factor to consider in the propagation of tomato plants, so that seedlings are neither under-fertilized nor over-fertilized. The balance of N to P in transplants may be an important factor influencing tomato plant growth and yielding ability in northern production areas. Fruit yields are affected by the N/P balance. Greatest yields were obtained with either low levels of both N and P or high levels of both N and P (21). The N/P balance may also affect the root/shoot ratio of tomato seedlings. The root/shoot ratio plays an important role in maintaining a balance between vegetative growth and fruiting of the plant so large fruit yields are produced early in the picking season (18).

These studies were conducted to determine the effects of N and P fertilization of transplants on tomato development and yield in the field.

Materials and Methods

A. An Evaluation of Different Levels of Nitrogen and Phosphorus on the Early Growth of Pik-Red Tomatoes

This experiment was conducted at the Plant Science Greenhouses of Michigan State University, East Lansing, Michigan. On March 29, 1981 potting medium containing one part sphagnum moss to one part vermiculite was prepared. Esmigran (Mallinckrodt Chemical Co.), a long term source of micronutrients such as Fe, Mn, Zn, Cu, B and Mo, was added to the soil mix at a rate of 55.5 g/cu meter. Fe chelate sequestrene (Ciba Geigy) was also added to the mix at a rate of 27.8 g/cu meter, along with dolomitic limestone at a rate of 3 kg/cu meter. Superphosphate (0-46-0) was added to the medium in 3 rates: 15, 30, and 60 ppm available phosphorus. A colorimetric soil test was performed for verification. Twenty-seven TODD 100A planter flats were filled with the media, 9 each containing low, medium and high P levels.

Pik-Red tomato seed was pregerminated for 72 hours and suspended in Viterra II hydrogel before sowing. One seed was placed in each root cell on March 30, 1981. When the first true leaves emerged, 3 levels of soluble N (100, 200 and 400 ppm) were applied weekly. K_2SO_4 and KNO_3 were used to provide the desired levels of N and maintain a concentration of 1100 ppm potassium in each N treatment. These levels of N and P were recommended by Wittwer and Honma as being low, moderate and high levels of available N and P for weekly application to greenhouse tomatoes (58).

Each treatment consisted of 3 TODD 100A planter flats treated with various levels of N and P. Each flat served as a replication. The experiment was completely randomized in a 3 by 3 factorial arrangement, with 3 levels of available P (15, 30 and 60 ppm) and 3 levels of N (100, 200 and 400 ppm). The flats were placed on adjacent benches in the greenhouse under fluorescent lighting of 14 hours/day.

Growth analysis started 2 weeks after sowing on April 13, 1981, when first true leaves developed and samples were taken every 7 days thereafter for 1 month. Eight plants were sampled at random from each of the 27 flats at each harvest. Height and leaf number were measured individually for the 8 plants, while leaf area, shoot dry weight, and root dry weight for each flat were taken as the mean of the pooled results of the 8 seedlings sampled for each flat. Relative growth rate (RGR) and net assimilation rate (NAR) were calculated using the growth analysis method discussed by Leopold and Kriedemann in Plant Growth and Development (28). Dry weight root to shoot ratios were calculated to determine if the N/P balance affects the root/shoot ratio of Pik-Red tomato seedlings. Data was analyzed by analysis of variance.

B. The Effect of Nitrogen and Phosphorus Nutrition and Transplant Age on Development and Yield of Pik-Red Tomatoes in the Field

Twelve TODD 100A planter flats were prepared as described above, with 4 each containing each of the 3 available P levels (15, 30, and 60 ppm). Pik-Red tomatoes were sown as described above into 1 flat of each P level on April 22, April 29, May 6, and May 13. The 3 N levels (100, 200, 400 ppm) were applied weekly to different P levels to create the following 3 nutrient treatments: high N - low P, moderate N - moderate P, low N - high P. Flats were also seeded on 4 different dates to create a factorial experiment consisting of 3 nutrient treatments at 4 sowing dates. The plants were grown in the Plant Science Greenhouse, as described above. The flats were arranged at random on greenhouse benches.

Data on seedling growth was collected periodically as soon as the first true leaves developed. Four plants were sampled at random from each flat. Height and leaf number were measured individually for the 4 plants, while leaf area, shoot dry weight, and root dry weight for each treatment were taken as the mean of the pooled leaf area and dry weight of the 4 seedlings sampled for each flat. Data were analyzed by analysis of variance.

On May 30, 1981, the remaining tomato seedlings were transplanted into the field. Roots of transplants were dipped into soluble 20-20-20 starter fertilizer solution at a rate of 3.9 ml fertilizer per liter of H_2O. The field was irrigated overhead after transplanting. Fertilizer was applied to the planting field at a rate of 56 kg/ha N, 112 kg/ha P_2O_5 and 112 kg/ha K_2O. The plants were sidedressed with 56 kg/ha N after the first fruit set. Irrigation was applied as necessary. Fungicides and insecticides were applied when necessary to control foliar diseases and insects.

The experiment was designed as a randomized complete block with 3 replications. The treatments were arranged factorially with 4 ages of tomato seedlings at transplanting (3, 4, 5 and 6 weekly) and 3 levels of fertility. Each plot consisted of 28 plants in 2 rows of 14 plants each. Rows were 4 feet apart, with 2 feet between plants in rows.

Two plants per plot were harvested every week for 3 weeks after planting for growth analysis. Plant height, leaf number, leaf area and dry weight were measured. Relative growth rate (RGR) and net assimilation rate (NAR) were calculated using the growth analysis method described previously. Information on plant height, fresh weight, fruit number and fruit weight was collected for weeks 3 to 9 after transplanting. All results were analyzed by analysis of variance.

As the fruit matured, yield was taken once each week from 14 plants per plot. Tomatoes showing any red coloration were harvested. Harvested tomatoes were graded as large fruit (greater than 6.7 cm in diameter), small fruit (less than 6.7 cm in diameter) and culls. Fruit number and fresh weight were recorded. Tomato fruit harvested during the first two weeks were considered early yield.

All results were analyzed by analysis of variance. Treatment sums of squares were partitioned into linear, quadratic and cubic effects through trend analysis.

Results

A. An Evaluation of Different Levels of Nitrogen and Phosphorus on the Early Growth of Pik-Red Tomatoes

Three weeks after seeding tomato, seedlings fertilized with high levels of N had statistically greater height, leaf area and shoot dry weight than seedlings treated with low levels of N (Table 27). At this time there were no significant differences in plant size or weight associated with differences in P levels.

Significant differences were obtained among N treatments for height, leaf area, shoot dry weight and root dry weight of tomatoes 4 weeks after seeding (Table 28). A high level of N resulted in up to 75% increases in these parameters. Root dry weights were statistically

Table 27. The influence of different levels of nitrogen and phosphorus on the growth of Pik-Red tomato seedlings 3 weeks after sowing.

Treatment	Height[x] (cm)	Leaf area[x] (sq cm)	Shoot dry weight[x] (g)	Root dry weight[x] (g)	Root/shoot ratio[x]
Nitrogen level[y]					
High	11.0	110.5	0.40	0.23	0.58
Moderate	9.0	69.9	0.30	0.24	0.80
Low	7.7	45.3	0.26	0.21	0.81
Main effect	**	**	**	NS	
Phosphorus level[z]					
High	9.3	76.9	0.32	0.21	0.66
Moderate	9.4	76.1	0.31	0.23	0.74
Low	9.0	72.6	0.33	0.23	0.70
Main effect	NS	NS	NS	NS	
N level x P level	NS	NS	NS	NS	

[x]Measurements are the means of 8 plants per plot with 3 replications.

[y]Nitrogen levels from high to low refer to the weekly application of 400, 200 and 100 ppm nitrogen, respectively.

[z]Phosphorus levels from high to low refer to the media incorporation of 60, 30 and 15 ppm phosphorus, respectively.

*,**Significant at the 5 and 1% levels, respectively.

Table 28. The influence of different levels of nitrogen and phosphorus on the growth of Pik-Red tomato seedlings 4 weeks after sowing.

Treatment	Height[x] (cm)	Leaf area[x] (sq cm)	Shoot dry weight[x] (g)	Root dry weight[x] (g)	Root/ shoot ratio
Nitrogen Level[y]					
High	20.1	280.5	1.72	0.57	0.33
Moderate	13.3	154.0	1.06	0.42	0.40
Low	10.3	85.1	0.73	0.43	0.59
Main effect	**	**	**	**	
Phosphorus Level[z]					
High	14.8	181.4	1.22	0.53	0.43
Moderate	14.8	176.4	1.21	0.45	0.37
Low	14.1	161.8	1.09	0.44	0.40
Main effect	NS	NS	NS	*	
N level x p level	NS	NS	**	NS	

[x]Measurements are the means of 8 plants per plot with 3 replications.

[y]Nitrogen levels from high to low refer to the weekly application of 400, 200 and 100 ppm nitrogen, respectively.

[z]Phosphorus levels from high to low refer to the media incorporation of 60, 30 and 15 ppm phosphorus, respectively.

*,**Significant at the 5 and 1% levels, respectively.

different when different levels of P were applied. Use of 60 ppm P resulted in increased root dry weights as compared to 30 or 15 ppm P. A significant N x P interaction was obtained for shoot dry weight. Use of a high level of N and a moderate level of P resulted in the greatest tomato shoot dry weight.

Five and 6 weeks after seeding, significant differences were observed in plant height, leaf area, shoot dry weight and root dry weight of seedling tomatoes fertilized with different levels of N (Tables 29 and 30). Application of 400 ppm N resulted in increased height, leaf area, shoot dry weight and root dry weight. Five weeks after seeding 60 ppm P resulted in significantly increased plant height. Six weeks after seeding, a significant interaction between N and P levels was noted for leaf area. In this case, a high or low level of P and a high level of N resulted in greater leaf area than a moderate level of P and high level of N. Significant differences in plant height, leaf area and shoot dry weight occurred with increasing levels of P fertilization. However, the increases in height, leaf area and shoot dry weight with the use of increased rates of P were slight when compared with the increased measurements obtained with the application of high levels of N.

The greatest root to shoot ratios of tomato seedlings were obtained throughout the experiment when a low to moderate level of N was applied with a moderate to high

Table 29. The influence of different levels of nitrogen and phosphorus on the growth of Pik-Red tomato seedlings 5 weeks after sowing.

Treatment	Height[x] (cm)	Leaf area[x] (sq cm)	Shoot dry weight (g)	Root dry weight (g)	Root/ shoot ratio[x]
Nitrogen Level[y]					
High	24.8	604.3	3.43	0.87	0.25
Moderate	15.7	249.8	1.91	0.76	0.40
Low	12.1	266.8	1.16	0.50	0.43
Main effect	**	**	**	**	
Phosphorus Level[z]					
High	18.2	478.8	2.29	0.71	0.31
Moderate	18.0	328.2	2.22	0.75	0.34
Low	16.5	313.9	2.00	0.68	0.34
Main effect	*	NS	NS	NS	
N level x P level	NS	NS	NS	NS	

[x]Measurements are the means of 8 plants sampled per plot with 3 replications.

[y]Nitrogen levels from high to low refer to the weekly application of 400, 200 and 100 ppm nitrogen, respectively.

[z]Phosphorus levels from high to low refer to the media incorporation of 60, 30 and 15 ppm phosphorus, respectively.

*,**Significant at the 5 and 1% levels, respectively.

Table 30. The influence of different levels of nitrogen and phosphorus on the growth of Pik-Red tomato seedlings 6 weeks after sowing.

Treatment	Height[z] (cm)	Leaf area[x] (sq cm)	Shoot dry weight[x] (g)	Root dry weight[x] (g)	Root/shoot ratio[x]
Nitrogen Level[y]					
High	25.8	637.6	3.31	1.10	0.33
Moderate	16.6	263.5	1.67	1.02	0.61
Low	12.5	172.9	1.21	0.83	0.69
Main effect	**	**	**	*	
Phosphorus Level[z]					
High	18.7	384.4	2.15	1.07	0.50
Moderate	19.0	337.7	2.25	0.97	0.43
Low	17.3	351.8	1.80	0.91	0.51
Main effect	*	**	**	NS	
N x level x P level	NS	**	NS	NS	

[x]Measurements are the means of 8 plants sampled per plot with 3 replications.

[y]Nitrogen levels from high to low refer to the weekly application of 400, 200 and 100 ppm nitrogen, respectively.

[z]Phosphorus levels from high to low refer to the media incorporation of 60, 30 and 15 ppm phosphorus, respectively.

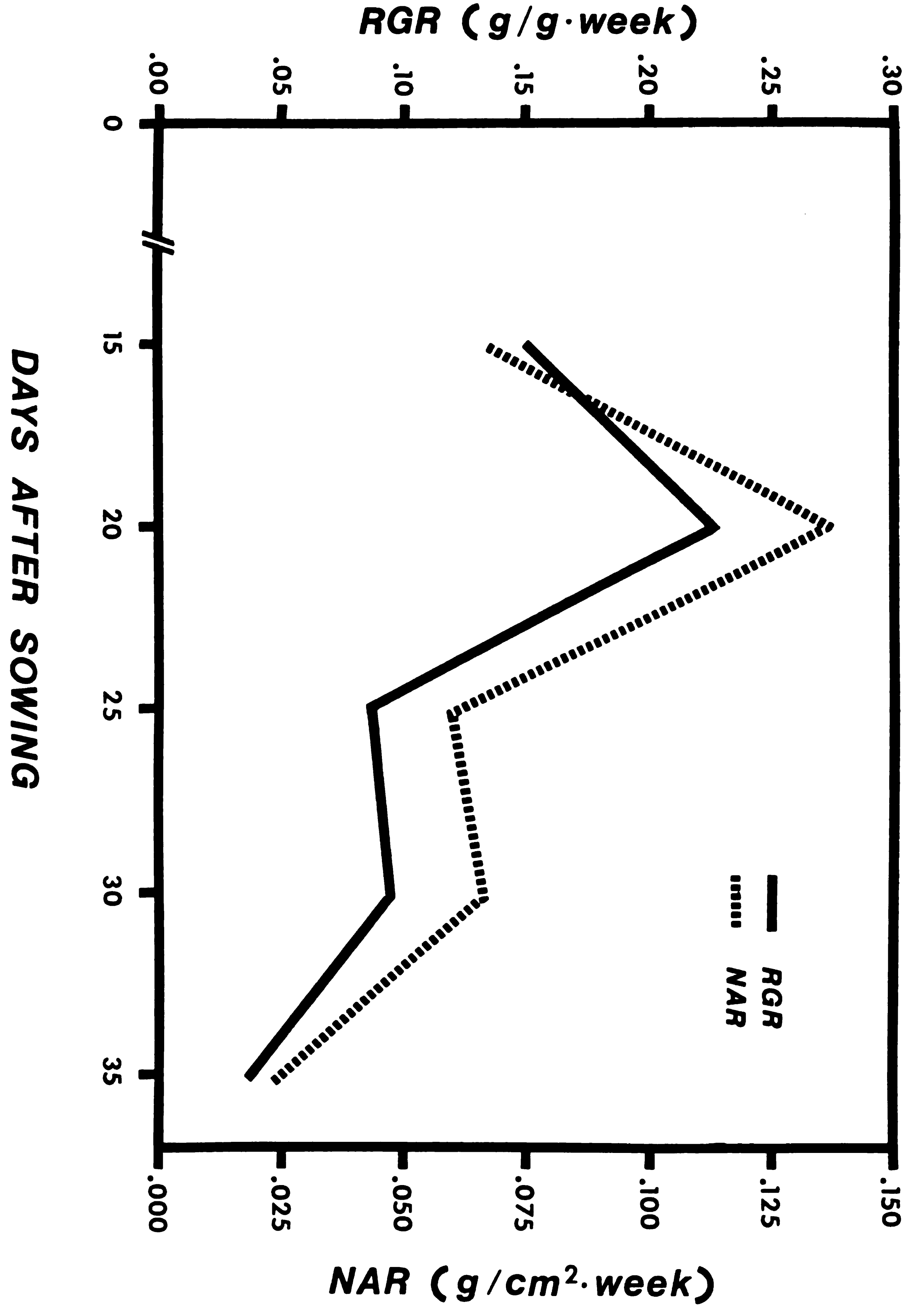
*,**Significant at the 5 and 1% levels, respectively.

level of P. The N/P balance affects the root/shoot ratio of the Pik-Red tomato seedlings. Hudson believes that this ratio is critical in affecting the yield and maturation of the tomato fruit (18).

Net assimilation rate (NAR) was never significantly different between treatments at any of the different growth periods throughout the experiment. However, relative growth rate (RGR) of those seedlings grown at high levels of N was significantly greater than that of seedlings grown at low levels of N from 3 to 5 weeks after seeding. Tomato seedlings that received 400 ppm N grew more rapidly for the first 5 weeks than those seedlings that received either 200 or 100 ppm N.

NAR increased for seedlings of all treatments from 15 to 20 days after seeding, decreased and then remained fairly constant from 25 to 30 days after sowing and reached a minimum level from 30 to 35 days after sowing (Figure 14). The phososynthetic efficiency of the tomato seedlings from all nutrient treatments was greatest when seedlings were 3 weeks old and then decreased to a minimum level of efficiency at 5 to 6 weeks of age. The RGR of all treatments also reached a maximum level at 3 weeks, and then decreased to a constant level at 3 1/2 to 4 1/2 weeks and decreased still further at 5 to 6 weeks after seeding. The tomato seedlings of all treatments were growing most rapidly at 3 weeks of age, when

Figure 14. The influence of days after sowing on the mean relative growth rate (RGR) and net assimilation rate (NAR) of Pik-Red tomato plants of all nutrient treatments.


RGR (g/g·week)
.00
.05
.10
.15
.20
.25
.30
0
15
20
25
30
35
DAYS AFTER SOWING
RGR
NAR
.000
.025
.050
.075
.100
.125
.150
NAR (g/cm²·week)

photosynthetic efficiency was also greatest. Seedlings of all treatments grew less rapidly from 4 to 6 weeks of age, when photosynthetic efficiency decreased.

B. The Effect of Nitrogen and Phosphorus Nutrition and Transplant Age on Development and Yield of Tomatoes in the Field

Growth of Pik-Red tomato seedlings, planted at different dates and fertilized with different levels of N and P, was monitored in the greenhouse and in the field.

Older tomato seedlings were taller than younger tomato seedlings for the duration of the greenhouse experiment (Table 31). Older seedlings also possessed greater leaf area and shoot dry weight than did the younger tomatoes. At field-setting, 6-week-old transplants were at least twice as tall and possessed 7 times as much leaf area and shoot dry weight as 3-week-old tomato seedlings.

Fertilizer treatments also influenced seedling growth before transplanting (Table 31). Those seedlings fertilized with high N and low P were taller and had greater leaf area and shoot dry weight than those seedlings fertilized with low N and high P. At transplanting, 3-week-old seedlings fertilized with low N levels were smallest. An interaction between plant age and nutrient level was significant for transplant height. Plant height was greatest in tomatoes of 6 weeks of age fertilized with high N. The interaction was significant because 3-week-old plants treated with moderate levels of N were taller than 3-week-old plants treated with high levels of N.

Table 31. The influence of different levels of nitrogen and phosphorus and plant age on the growth of Pik-Red tomatoes at transplanting.

Treatment	Height[w] (cm)	Leaf area[x] (sq cm)	Shoot dry weight[x] (g)
Age at Transplanting[y]			
6 weeks	20.9	50.1	0.40
5 weeks	20.5	48.7	0.31
4 weeks	15.7	20.7	0.15
3 weeks	8.0	7.0	0.05
Main effect	**	**	**
Nutrient Level[z]			
High N-Low P	18.3	40.0	0.25
Moderate N-Moderate P	17.0	35.1	0.25
Low N-High P	13.5	20.7	0.20
Main effect	**	**	*
Planting Date x Nutrient Level	**	NS	NS

[w]Height measurements are the means of 4 replications.

[x]Leaf area and shoot dry weight measurements represent the mean of the pooled leaf area and shoot dry weight of 4 seedlings sampled per treatment.

[y]Age at transplanting from 6 weeks to 3 weeks corresponds to the date of seeding of TODD planter flats on April 22, April 29, May 6 and May 13, 1981, respectively.

[z]Nitrogen levels from high to low refer to the weekly application of 400, 200 and 100 ppm nitrogen, respectively; while phosphorus levels from high to low refer to the media incorporation of 60, 30 and 15 ppm phosphorus, respectively.

*,**Significant at the 5 and 1% levels, respectively.

Three weeks after transplanting, significant differences in height, leaf number, leaf area and shoot dry weight were observed with transplants of different ages (Table 32). Plants that were 4, 5 and 6 weeks old at field-setting were larger than 3-week-old transplants. Those treatments fertilized with moderate levels of N and P were significantly greater in height and leaf area than were plants of other nutrient treatments. There was a significant interaction between planting date and nutrient level for leaf area. The 5-week-old tomato plants treated with a moderate level of N generally produced greater leaf area, while 6-week-old transplants treated with a high level of N produced a smaller amount of foliage.

There were no significant differences in RGR or NAR between any treatments 3 weeks after transplanting.

Five weeks after field-setting, plants that were 3 weeks old at transplanting were shorter, possessed fewer flowers setting fruit and less dry weight than the older plants, which were similar in size (Table 33). There were no differences in these measurements as a result of different nutrient treatments. There were significant interactions between planting date and nutrient level for shoot dry weight and number of flowers setting fruit. Plants 4 weeks old at field setting and treated with a high level of N produced the greatest number of

Table 32. The influence of different levels of nitrogen and phosphorus and plant age on the growth of Pik-Red tomatoes 3 weeks after transplanting.

Treatment	Height[x] (cm)	Leaf area[x] (sq cm)	Shoot dry weight[x] (g)
Age at Transplanting[y]			
6 weeks	34.4	234.6	2.67
5 weeks	37.5	234.6	2.57
4 weeks	33.5	236.7	2.26
3 weeks	26.5	152.6	1.55
Main effect	**	**	**
Nutrient Level[z]			
High N-Low P	31.6	195.1	2.03
Moderate N-Moderate P	35.8	243.6	2.50
Low N-High P	31.4	203.2	2.26
Main effect	**	**	NS
Planting Date x Nutrient Level	NS	**	NS

[x]Figures are the means of 2 plants harvested per 3 replications on June 17, 1981.

[y]Age at transplanting from 6 weeks to 3 weeks corresponds to the date of seeding of TODD planter flats on April 22, April 29, May 6 and May 13, 1981, respectively.

[z]Nitrogen levels from high to low refer to the weekly application of 400, 200 and 100 ppm nitrogen, respectively, while phosphorus levels from high to low refer to the media incorporation of 60, 30 and 15 ppm phosphorus, respectively.

*,**Significant at the 5 and 1% levels, respectively.

Table 33. The influence of different levels of nitrogen and phosphorus and plant age on the growth of Pik-Red tomatoes 5 weeks after transplanting.

Treatment	Height[x] (cm)	Number of flowers setting fruit	Shoot dry weight[x] (g)
Age at Transplanting[y]			
6 weeks	65.7	4	46.9
5 weeks	63.4	6	48.4
4 weeks	64.3	7	47.2
3 weeks	60.1	2	41.1
Main effect	*	**	*
Nutrient Level[z]			
High N-Low P	64.6	5	46.1
Moderate N-Moderate P	62.3	4	45.8
Low N-High P	63.2	5	45.8
Main effect	NS	NS	NS
Planting Date x Nutrient Level	NS	*	*

[x]Figures are the means of 2 plants harvested per 3 replications on July 2, 1981.

[y]Age at transplanting from 6 weeks to 3 weeks corresponds to the date of seeding of TODD planter flats on April 22, April 29, May 6 and May 13, 1981, respectively.

[z]Nitrogen levels from high to low refer to the weekly application of 400, 200 and 100 ppm nitrogen, respectively; while phosphorus levels from high to low refer to the media incorporation of 60, 30 and 15 ppm phosphorus, respectively.

*,**Significant at the 5 and 1% levels, respectively.

flowers setting fruit. Plants 6 weeks old at transplanting and fertilized with a moderate level of N produced the greatest shoot dry weight.

At 7 weeks after transplanting, plant height and fruit weight were significantly greater for transplants 4 and 5 weeks of age compared to transplants of 3 and 6 weeks of age (Table 34). Increased height was also observed with the high N-low P treatment.

There were no significant differences between any nutrient or plant age treatments for fruit weight 9 weeks after field setting. Plants of all treatments were of a similar size 9 weeks after transplanting.

Although tomato plants of all treatments were of a similar size 9 weeks after transplanting, there were large differences in early yields (Table 35, Figure 15). With increasing plant age, total early yields increased in a linear and quadratic manner, while large fruit early yield increased in a quadratic manner. This is reflected in the finding that plants of 4 and 5 weeks of age out-yielded plants of 3 and 6 weeks of age at transplanting. Plants set in the field at 4 and 5 weeks of age produced double the large fruit early yield and up to 60% increases in total early yield over plants set in the field at 3 or 6 weeks of age.

The level of N and P applied before field-setting also

Table 34. The influence of different levels of nitrogen and phosphorus and plant age on the growth of Pik-Red tomatoes 7 weeks after transplanting.

Treatment	Height[x] (cm)	Number of flowers setting fruit[x]	Total fruit weight[x] (g)	Shoot dry weight[x] (g)
Age at Transplanting				
6 weeks	81.5	7	145.0	95.8
5 weeks	83.6	9	196.9	98.1
4 weeks	79.9	8	217.8	88.3
3 weeks	76.3	6	72.8	79.2
Main effect	**	NS	**	NS
Nutrient Level[z]				
High N-Low P	82.8	8	189.4	94.6
Moderate N-Moderate P	80.9	7	159.4	86.5
Low H-High P	77.3	7	125.6	90.0
Main effect	**	NS	NS	NS
Planting Date x Nutrient Level	NS	NS	NS	NS

[x]Figures are the means of 2 plants harvested per 3 replications on July 15, 1981.

[y]Age at transplanting from 6 weeks to 3 weeks corresponds to the date of seeding of TODD planter flats on April 22, April 29, May 6, and May 13, 1981, respectively.

[z]Nitrogen levels from high to low refer to the weekly application of 400, 200 and 100 ppm nitrogen, respectively; while phosphorus levels from high to low refer to the media incorporation of 60, 30 and 15 ppm phosphorus, respectively.

*,**Significant at the 5 and 1% levels, respectively.

Table 35. The influence of different levels of nitrogen and phosphorus and plant age on the early yield of Pik-Red tomatoes in 1981.

Treatment	Total early yield[x] (kg/ha)	Large fruit early yield[x] (kg/ha)
Age at Transplanting[y]		
6 weeks	11593	8599
5 weeks	15439	11273
4 weeks	15507	11452
3 weeks	9287	6588
linear	*	NS
quadratic	**	**
Nutrient Levels[z]		
High N Low P	14788	11024
Moderate N-Moderate P	13164	10093
Low N-High P	10918	7318
linear	**	**
quadratic	NS	NS

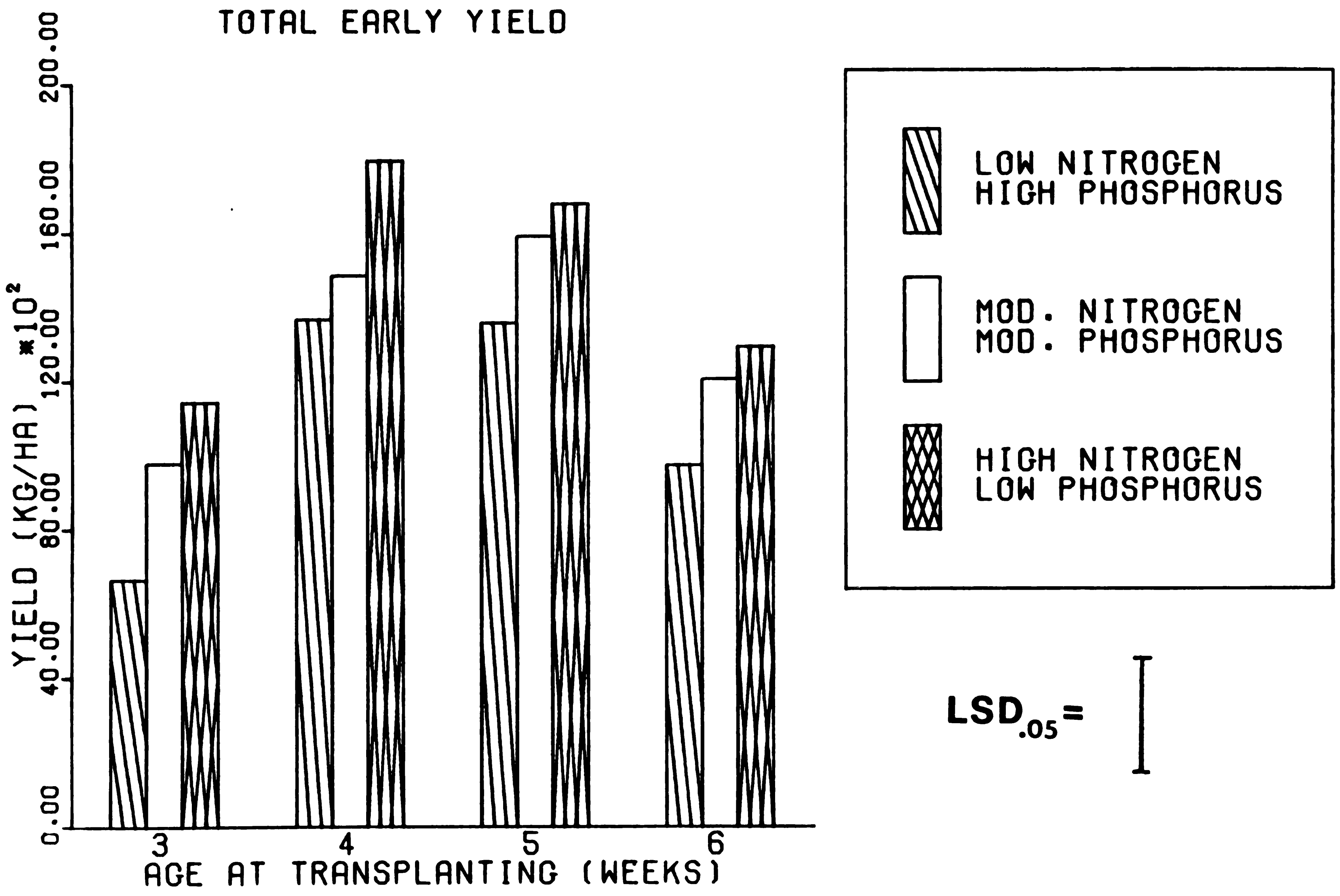
[x]Tomatoes were harvested from 14 plants per plot. Yield measurements are means of 3 replications. Early season yields were harvested during the first 2 weeks of the harvest season on August 13 and August 20. Large fruit yield refers to the weight of marketable fruit harvested greater than 6.7 cm in diameter. Fruit weight was converted to kilograms/hectare.

[y]The tomato seeds were sown at 4 different dates; April 22, April 29, May 6 and May 13, 1981, so that seedlings were 6, 5, 4 and 3 weeks of age at transplanting.

[z]Three different levels of nitrogen and phosphorus were applied to the seedlings as fertilizer treatments before field setting.

*,**Significant at the 5 and 1% levels, respectively.

Figure 15. The influence of different levels of nitrogen and phosphorus before field-setting and transplant age at field-setting on the early yield of Pik-Red tomatoes.


TOTAL EARLY YIELD
YIELD (KG/HA) *10²
0.00
40.00
80.00
120.00
160.00
200.00
3
4
5
6
AGE AT TRANSPLANTING (WEEKS)
LOW NITROGEN
HIGH PHOSPHORUS
MOD. NITROGEN
MOD. PHOSPHORUS
HIGH NITROGEN
LOW PHOSPHORUS
LSD.05 =

had an effect on early yields (Table 35, Figure 15). As levels of N increased and levels of P decreased in the fertilizer before field-setting, total and large fruit early yields also increased in a linear manner. The high N and low P treatment produced the greatest early yields, indicating that 400 ppm N and 14 ppm P applied together before transplanting were important in increasing tomato fruit productions 11 weeks after field setting.

Although 4- and 5-week-old transplants produced greater early yields, 3- and 6-week-old transplants produced larger yields later in the season. Four-and 5-week-old tomato transplants dropped in production at midseason, so that significant differences in late season yields were detected. Four and 5-week-old tomato transplants matured approximately 1 to 2 weeks earlier than 3- or 5-week-old transplants.

No significant differences in small fruit number or weight or cull fruit number or weight were found among treatments at any of the 4 harvest periods. However, total small fruit yield and total fruit yield increased in a linear fashion with increasing plant age. Six-week-old transplants produced the greatest total small yields and total yields (Table 36, Figure 16). The level of N and P applied to transplants before field-setting had little effect on total yield of Pik-Red tomatoes. No significant differences were observed in total fruit number or total fruit weight among the nutrient treatments.

Table 36. The influence of different levels of nitrogen and phosphorus and plant age on the total yield of Pik-Red tomatoes in 1981.

Treatment	Total large yield[tx] (kg/ha)	Total small yield[tw] (kg/ha)	Total cull yield[tv] (kg/ha)	Total yield[tu] (kg/ha)
Age at Transplanting[y]				
6 weeks	86459	11423	14083	111965
5 weeks	85892	9418	15042	110352
4 weeks	80137	9374	13647	103114
3 weeks	80355	7674	14432	102460
linear	NS	**	NS	*
quadratic	NS	NS	NS	NS
Nutrient Levels[z]				
High N-Low P	83897	9854	15325	109055
Moderate N-Moderate P	86339	9472	13036	108858
Low N-High P	79385	9112	14552	102983
linear	NS	NS	NS	NS
quadratic	NS	NS	NS	NS

[t]Yield measurements are means of 3 replications. Fruit weight was converted to kilograms/hectare.

[u]Total fruit yield is the total yield of all fruit harvested during the season.

[v]Cull yield refers to the weight of non-marketable fruit harvested.

[w]Small fruit yield refers to the weight of marketable fruit harvested less than 6.7 cm in diameter.

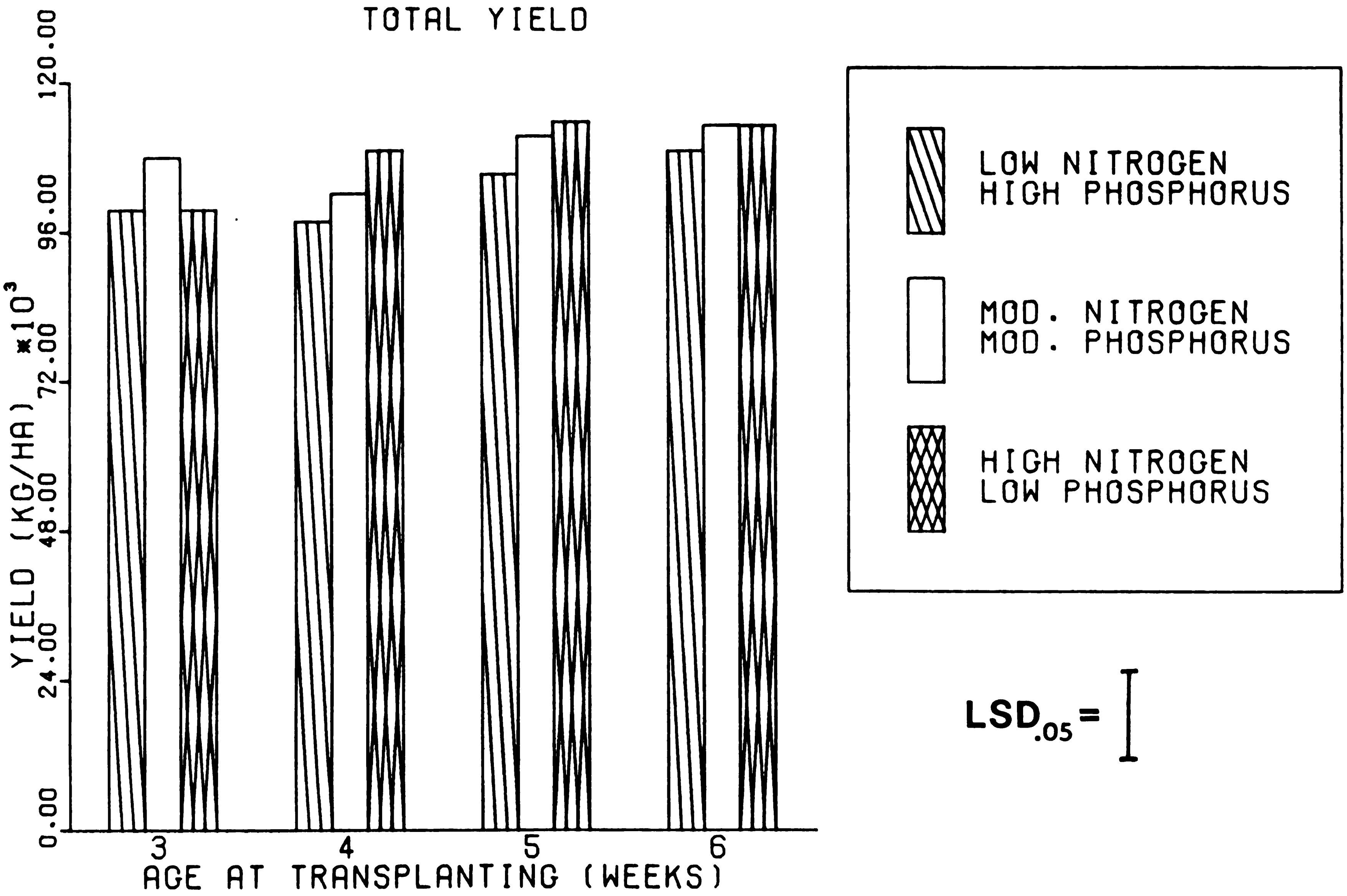
[x]Large fruit yield refers to the weight of marketable fruit harvested greater than 6.7 cm in diameter.

[y]The tomato seeds were sown at 4 different dates; April 22, April 29, May 6 and May 13, 1981; so that seedlings were 6, 5, 4 and 3 weeks of age at transplanting.

[z]Three different levels of nitrogen and phosphorus were applied to the seedlings as fertilizer treatments before field setting.

*,**Significant at the 5 and 1% levels, respectively.

Figure 16. The influence of different levels of nitrogen and phosphorus before field-setting and transplant age at field-setting on the total yield of Pik-Red tomatoes.


TOTAL YIELD
YIELD (KG/HA) *10^3
0.00
24.00
48.00
72.00
96.00
120.00
3
4
5
6
AGE AT TRANSPLANTING (WEEKS)
LOW NITROGEN HIGH PHOSPHORUS
MOD. NITROGEN MOD. PHOSPHORUS
HIGH NITROGEN LOW PHOSPHORUS
LSD.05 =

Discussion and Conclusions

The levels of N and P fertilizer applied to tomato transplants before field-setting significantly affected seedling growth and development both before and after transplanting into the field. High levels of N produced increases in tomato seedling height, leaf area and shoot dry weight. Moderate to high levels of P produced slight increases in seedling height, leaf area, shoot dry weight and root dry weight. Wilcox and Langston reported that N was the most limiting element to tomato seedling growth in an experiment using a soluble nutrient solution. A small increase in seedling growth was also observed with increased P levels (57). Although the availability of P has been reported to be most critical in increasing the tomatoes' growth rate and yielding ability (7, 23, 36, 41, 56, 57), Wilcox and Langston believe that the optimum soil temperature in the greenhouse resulting in increased availability of phosphorus and the age and condition of the tomato seedlings accounts for the lack of great response of tomato seedlings produced in the greenhouse to high levels of P fertilizer (57).

High levels of N also promoted significant increases in the relative growth rate of seedling tomatoes. This was not unexpected since researchers have shown that N strongly affects seedling growth rate by promoting rapid growth (33, 57).

Several significant interactions occurred between N levels and P levels for plant height, leaf area and shoot dry weight in the first nutrient experiment. In most cases, the interaction was significant because a high level of N and a moderate level of P promoted the largest increases in plant height, leaf area and shoot dry weight. Jaworski and Webb found that the balance of N to P is a very important factor influencing tomato growth and yielding ability (21). In this case, the optimal level of fertilization for the production of the largest tomato transplants was 400 ppm N and 30 ppm P.

Tomato seedlings from all nutrient treatments exhibited the greatest net assimilation rate and relative growth rate at 3 weeks of age and the lowest RGR and NAR at 6 weeks of age. The embryo of a plant begins to grow in an exponential manner and photosynthetic efficiency will determine the rate of growth (28). Until 3 weeks of age, seedling growth was still increasing and NAR and RGR were greatest at this point. After 3 weeks of age, it appears that interactions with the environment began to impose limitations and seedling growth slowed as RGR and NAR decreased.

The root to shoot ratio of tomato seedlings was only slightly altered by nutrient treatments. The greatest root to shoot ratio was observed with a low to moderate level of N and a moderate to high level of P. Low levels of N decrease shoot development and high levels of P are known to stimulate root production (33, 52, 53, 54). Hudson (18) and Leonard and Head (27) have emphasized the importance of root-shoot balance in tomato fruit production.

In the field experiment, tomato seedlings were produced at 3 levels of N and 3 levels of P. Treatments were designed to alter the root to shoot ratios of the seedlings in an effort to produce a transplant with a large, quickly growing initial root system. As before, those seedlings fertilized with a high level of N and a low level of P were larger than those seedlings fertilized with a low level of N and a high level of P at transplanting. A high level of N and a low level P before transplanting resulted in increased plant height and number of flowers setting fruit after transplanting, while a moderate level of N and P resulted in increased leaf area after transplanting. Nutrient treatments affected plant growth less in the field than did plant age at transplanting. Apparently, the tomato seedlings of all nutrient treatments were able to utilize the available nutrients in the field to overcome any initial differences in plant size created by preplant nutrient treatments by the time of the first fruit ripening.

Although plant size was similar, at first fruit ripening early yielding abilities of the plants fertilized with different starter nutrient treatments were varied. Tomato transplants fertilized with high levels of N and low levels of P produced greater early yields than transplants fertilized with low levels of N and high levels of P, even though plant size was similar. Early yields increased in a linear manner with increasing N and decreasing P. Transplants fertilized with high N and low P were significantly larger in size at transplanting. Wilcox and Langston found that transplanted tomatoes responded more to N starter fertilizer than to P starter fertilizer when transplanted into the field. Increased N before transplanting resulted in larger tomato plants exhibiting earlier maturity (57). Jaworski also found that moderate levels of N were necessary to produce large marketable yields and uniform development of transplanted tomatoes (19).

The tomato transplant carries a potential nutrient reserve to be drawn upon during the re-establishment of its root system (57). Apparently, increased N applied before field-setting produced a larger seedling with a greater N reserve, resulting in earlier maturity and larger early yields. By midseason, plant maturity and yielding abilities of plants from all nutrient treatments were similar.

The role of applied P in the development of transplanted tomatoes may have been minor because field soil temperatures were warm and transplants from all treatments possessed an intact root system at the time of planting, which was able to forage for sufficient levels of P. Apparently, P was not a limiting factor in transplant growth and development. Under these conditions, plants with a lower root/shoot ratio produced greater early yields.

Transplant age significantly affected seedling size at transplanting. Six-week-old tomato seedlings were larger in size than either 3, 4 or 5 week-old tomato seedlings, most likely because of a longer growth period. However, 3 to 5 weeks after transplanting into the field, plants of 4 and 5 weeks of age caught up in size and produced a greater number of flowers setting fruit and shoot dry weight than other treatments. Significant interactions between planting date and nutrient level for shoot dry weight and number of flowers setting fruit occurred as plants of 4 and 5 weeks of age from all nutrient treatments produced greater measurements than plants of 3 and 6 weeks of age.

The age of the transplant at field-setting was very important in determining early yielding ability of tomato transplants. Four- and 5-week-old plants produced the greatest early yields while 3- and 6-week-old plants produced larger late and slightly larger total yields. Skapski and Lipinski found that very young and small transplants of 3 to 4 weeks of age produced lower yields than older transplants, particularly during adverse weather conditions (45). Three-week-old plants were very small and immature at transplanting, which may account for their delayed maturity and lower early yields. Transplants of 4 and 5 weeks of age were able to recover more quickly after transplanting than other age treatments probably because they were of adequate size and were not yet root bound. Casseres found that transplants which were tender and capable of quick recovery after transplanting produced larger early yields (12). Nicklow and Minges reported that a relatively small 3- to 5-week-old tomato transplant without flowers or buds produced the largest fruit and larger overall yields. Older plants which were over-hardened or were in flower were not desirable (37). Six-week-old plants may have been overhardened or slightly root-bound at transplanting which resulted in greater transplant shock and slightly delayed plant maturity, causing lower early yields.

Midseason yields were similar for all transplant treatments. However, 3- and 6-week-old transplants produced the largest late season yields. These transplants exhibited delayed maturity and produced a greater percentage of ripe fruit later in the season. Total yields were fairly similar for all plant ages and nutrient treatments. Cultural practices applied before field-setting such as fertilizers and date of sowing were short-lived in their effects on the yielding ability of tomato transplants.

SUMMARY

SUMMARY

In conclusion, the use of larger sizes of TODD root cells resulted in larger early yields and total marketable yields in fresh market tomatoes and peppers. A high level of N and a low level of P applied to tomato transplants in TODD flats before field-setting resulted in larger transplant size and greater early yields. The use of tomato transplants 4- to 5-weeks-old at field-setting resulted in larger early yields. Tomato transplants grown in Michigan produced larger early yields and slightly larger total marketable yields than transplants produced by Speedling of Florida and shipped north. Hardening transplants by withholding major nutrients may have been responsible for decreased early yields of Speedling transplants. Packaging and shipping of plants from Florida to Michigan by air freight appeared to have no stressful effects on Speedling plants, as measured by ethylene and CO_2 production.

On the basis of this work, the best method of obtaining large early yields for fresh market tomato and pepper production involves the following: the use of size 175 TODD planter flats, the weekly application of high level of N fertilizer (400 ppm) and a low level of P fertilizer

(15 ppm) to tomatoes, and the transplanting of tomato seedlings at 4 to 5 weeks of age.

The most cost-effective method of obtaining large total yields for fresh market tomato and pepper production involves the following: the use of smaller sizes of TODD planter flats, the weekly application of a high level of N (400 ppm) and a low level of P (15 ppm) to tomatoes, and the transplanting of tomatoes when seedlings are 4 weeks of age.

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