EFFECTS OF PLASTIC MULCH, ROW COVER, AND CULTIVAR SELECTION ON GROWTH OF TOMATOES (*Lycopersicon esculentum* Mill.) IN HIGH TUNNELS

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By

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The undersigned, appointed by the Dean of the Graduate School, have examined the thesis entitled

EFFECTS OF PLASTIC MULCH, ROW COVER, AND CULTIVAR SELECTION ON GROWTH OF TOMATOES (*Lycopersicon esculentum* Mill.) IN HIGH TUNNELS

Presented by Robert Andrew Read

A candidate for the degree of Master of Science

Andy hereby certify that in their opinion it is worthy of acceptance.

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ABSTRACT

Tomato plants (*Lycopersicon esculentum* Mill.) were grown to: 1) evaluate their early season yield characteristics when grown using different mulch types with and without row cover; and 2) evaluate yield potential among different cultivars when grown in high tunnels. Row covers did not significantly increase total, or US number 1 yield of high tunnel tomatoes. Clear plastic mulch significantly increases early yield of grade 1 fruit over all other treatments. Total early yields from BHN 543, and Merced were significantly greater than all other cultivars. Due to early fruit ripening characteristics, BHN 543 could fit into a double cropping system for growers wanting to replant their high tunnels with a fall crop. Full season yield of grade 1 and 2 fruit combined was significantly greater for Merced than any other cultivar. The heirloom tomato cultivar Brandywine produced significantly less early total and grade 1 fruit per plant than Merced or BHN 543.

Chapter 1

Introduction

Enhanced early season production and improved quality are important factors for warm season vegetable crop growers. The intent is to grow crops where otherwise they could not survive by modifying the growing environment to prolong the harvest period, often with earlier maturity, greater yields and improved quality, making commodities available when there is no outdoor production (Wittwer and Castilla, 1995). Climate is the predominant factor that determines food and fiber production (Dalrymple, 1973). Therefore, growers who have the ability to modify their climate have a competitive advantage over growers in the same region that do not have the ability to manipulate their climate. Manipulation of the growing season can be achieved through a variety of cultural practices. Structures such as greenhouses are an effective means in lengthening the growing season but require initial investments of $5.86/ft^2, compared to $1.50 - $2.00/ft^2 for high tunnels (MSU Greenhouse Extension Guide). Operational costs required to run greenhouses have also proven to be greater than potential returns for many warm season vegetables (Atherton and Rudich, 1986). Other, less expensive season extension strategies that have been proven effective include: row covers (Motsenbocker, 1989), plastic mulch (Lamont, 1993), and high tunnels (Coleman, 1989).

Little is known however about the effects of row cover and different colored plastic mulches on high tunnel grown tomatoes in the Central Midwest. The objective of the first study was to compare the effects on tomatoes of black plastic mulch, clear plastic mulch, and no mulch, each with and without row cover when used in high tunnels. The effect of environmental factors within high tunnels on yield of popular field grown tomato cultivars is also a topic about which little is known. The objective of the second study was to determine yield characteristics throughout the growing season for several popular tomato cultivars commonly grown in Missouri.

Chapter 2

Review of Literature

The development of the polyethylene polymer in the 1930's, and its release onto the market in the early 1950's in the form of plastic films, allowed for profitable production of certain vegetables within plastic covered structures (Lamont, 1996). During this time period, unheated plastic covered structures became popular for vegetable production in Asian and Mediterranean countries. Glasshouses in Northern Europe that were used for vegetable production prior to the 1950's underwent a shift to production of high value ornamental crops such as flowers and potted plants (Wittwer and Castilla, 1995). During this time period E.M. Emmert began research growing crops in plastic covered structures with the use of mulch and row covers at the University of Kentucky (Emmert, 1954, 1955, 1956, 1957). These developments during the early 1950's gave rise to a new system of vegetable production known worldwide as plasticulture.

Important inputs of a plasticulture system include plastic and non-plastic components such as: plastic mulch, plastic film, row cover, drip irrigation, fertigation and windbreaks (Lamont, 1996). Sound crop rotations, crop scouting, and aggressive marketing of crops should be practiced to maximize productivity of a plasticulture system.

To understand a plasticulture system it is important to understand its individual components.

Plastic Mulch

E.M. Emmert (1956) found black polyethylene mulch to be the cheapest and most efficient method used to mulch vegetables. Benefits of plastic mulch include: increased and earlier harvests, higher quality produce, better weed control and insect management, and more efficient use of irrigation water and fertigation nutrients (Lamont, 1993). Major advances in plastics have taken place since E.M. Emmerts' work in the early 50's. Today growers can choose from a variety of mulches, each of which has its own specific application.

To extend the growing season of a certain crop, it is necessary to grow the crop in sub-optimal conditions such as cold weather. Cool soil temperatures can have a number of adverse effects on plant root growth such as: slower cell division and cell maturation rates, reduced water uptake, and reduced nutrient uptake (Nielsen, 1974). Black and clear mulches have shown the greatest soil warming potential among the various mulch colors (Ham et al., 1993). However, black and clear mulches heat the soil in different ways, and how the mulch is applied to the soil is directly related to its effectiveness.

Black mulch reflects less short-wave radiation (10%) and absorbs more radiation (90%) than any other colored mulch (Teasdale, 1995). Dark colored mulches (black or red) typically have higher surface temperatures than clear or white mulch (Decoteau et al., 1989). The heat absorbed by dark -colored mulches is conducted to the soil surface, which raises the soil temperature (Tarara, 2000). Therefore, it is very important to apply dark plastics tightly over the bed to maintain good soil- to -mulch contact. An air gap between the mulch and the soil creates a greater distance for the heat to travel before entering the soil and, consequently, much of the heat created at the mulch surface is lost to the atmosphere (Tarara, 2000).

Clear mulch absorbs only 5% of short-wave radiation, reflects 11%, but transmits 84% of it (Tarara, 2000). Clear mulch surface temperatures do not reach the levels found on black plastic due to their low absorption rates of short-wave radiation. Clear plastics actually heat the soil by transmitting light to the soil surface, rather than conducting heat like dark plastics (Ham and Kluitenberg, 1994). Consequently, laying clear mulch loosely across the soil creates an insulating air gap between the mulch and soil that results in higher daytime temperatures under clear plastic than black plastic mulch (Liakatas et al., 1986). If clear plastic is laid tightly across the bed its effects will be minimized, and in this situation black plastic laid tightly across the bed would be more effective at heating the soil (Liakatas et al., 1986). Research with clear plastic surface mulch in combination with supported row covers, has shown that clear plastic mulch is more effective than black plastic in increasing early yield and total yield of spring transplanted tomatoes (Ricketson and Thorpe, 1983). In controlled environments plant root growth increases with increased temperature from a minimum to an optimum temperature (Diaz-Perez and Batal, 2002) and increases past optimum temperatures are accompanied by decreased root and shoot growth (Miller, 1986). Although no data are available for optimum root zone temperature for field tomatoes (Diaz-Perez and Batal, 2002), research has shown that nutrient uptake from nutrient solutions are optimal at 25°C (Tindall et al., 1990). Research using black mulch for production of field tomatoes has shown temperatures that steadily hovered 10-25 degrees above optimum temperature throughout the season, and in these conditions straw mulch actually outperforms black plastic (Tindall et al., 1991). In an effort to avoid the soil warming effects associated with dark or clear plastics some growers will use white plastic as an alternative.

White mulch absorbs 51% of short-wave radiation, reflects 48% into the atmosphere, and transmits only 1% of it to the soil (Tarara, 2000). This low rate of radiation absorption (clay loam soils have an absorption rate of 70-86% depending on moisture levels (Tarara, 2000)), and high rate of reflection leads to soil temperatures that are at or below temperatures found on bare ground (Ham et al., 1993, Decoteau et al., 1989). Although, increased foliage found over white plastic does not necessarily lead to higher photosynthate produced (Decoteau et al., 1989).

Weed control is another important benefit of using mulch. In open- field tomato production, a “critical weed free period” of 28-55 days exists, during which time a single thorough hand hoeing will prevent yield loss (Weaver and Tan, 1983). Weeds growing before this timeframe will not compete significantly with the crop, whereas weeds growing beyond this point will reduce yields primarily by shading the crop (Jensen et al., 1989). Black mulch effectively stops weed growth by intercepting nearly all-incoming radiation and, in combination with its soil warming effects, promotes early season weed growth. Early season weed growth is confined and suppressed by clear plastic mulch as the season progresses, making removal of the plastic and cultivation unnecessary (Ricketson and Thorpe, 1983). Because weeds growing beneath clear plastic will push up and against the mulch, care must be taken to firmly secure down the mulches edges to prevent weeds from growing out from under the plastic and interfering with crop growth.

Floating Row Covers

Spun bonded fabric row covers, also known as floating row covers were first used in the southern United States as tobacco seedbed covers (Wells and Loy, 1985). Small diameter continuous filaments of polyester or polypropylene are spun in a web form onto a collection belt. Next, the fibers are bonded with heat and pressure into a thin sheet of flexible and porous fabric (Vaughn, 1992). Fabric row covers are lightweight (10-50g/m^2), and can be placed directly over crops without the use of hoops for support (Wells and Loy, 1985). Row covers modify a plant’s growing environment in regard to light, soil and air temperatures, humidity, and air movement (Wells and Loy, 1985). Floating row covers are applied loosely over plants and secured at the edges. As the plants grow they push against and lift the row cover, which necessitates their removal on tall- growing crops such as tomatoes.

Time between flowering and fruit development is much shorter at high rather than moderate temperatures (Adballa and Verkerk, 1968). Wells and Loy (1985) showed that temperatures under row cover can be several degrees warmer than ambient ones, and research has also shown that temperatures under row covers can reach levels that may cause abortion of flowers and unripe fruit (Wolfe et al., 1989; Wells and Loy, 1985). Early yields on spring plantings will be reduced if row covers are not removed while tomatoes are flowering (Rubeiz, I.G. and Freiwat, M.M. 1995; Peterson, R.H. and Taber, J.G., 1991). In addition to regulating temperatures around the plant, row covers also moderate low temperature extremes in the soil (Wells and Loy, 1993). Wells and Loy (1993) report that seedlings of fall seeded lettuce in uncovered plots were pushed from the soil with alternating freezing and thawing, while covered seedlings were not affected by the weather fluctuations. The heat trapping effect of row covers is more pronounced on fall crops rather than spring crops due to the large amount of heat stored in the soil following the summer (Wells and Loy, 1993).

Drip Irrigation

Various reports have shown that vegetable yields can be increased by the use of drip irrigation (Doss et al., 1977; Gornat et al., 1973; Renquist et al., 1982; Shmueli, M. and D. Goldberg, 1971; Williams, J.W. and Sistrunk, W.A. 1979). The increased yield when using drip irrigation has been attributed to better water utilization (Manfrinato, 1974), higher oxygen concentration in the root zone (Gornat et al., 1973; Inden, 1956), and increased vegetative growth (Doss, 1977; Renquist, 19825), which resulted in more flower clusters and increased fruit number (Renquist, 1982). Seventy-four to seventy five percent of the roots of shallow rooted vegetables have been found in the upper 10 to 15cm of the soil during experiments conducted on sandy soils using drip irrigation and mulch (Bruce et al., 1980; Bruce et al., 1985; Singh et al., 1989). Although, in heavier soils a higher percentage of roots will grow more deeply because of a greater water holding capacity of the subsoil (Tindall, 1991). Therefore, in sandy soils, plants are at greater risk of drought stress due to their lack of deep roots, and care should be taken to apply water before the upper 10 to 15cm of soil is allowed to become dry.

Shrivastave et al. (1994) showed that using drip irrigation with plastic or organic mulch increased tomato yields with less water applied, when compared to drip irrigation with no mulch. Bhell (1988) found that early yields of tomatoes could be increased by 80% with the use of trickle irrigation and plastic mulch, over no irrigation and no mulch treatments. These results were most likely due to a greater amount of weed pressure in the non-mulched treatments, which highlights the importance of utilizing all of the various components of a plasticulture system.

High Tunnels

High tunnels are unheated plant forcing structures covered with clear plastic and made of metal bows connected to pipes that are driven into the ground and come in various shapes. The end-walls are enclosed, and can be equipped with doors wide enough to allow for entry of small equipment. High tunnels have no electric or gas hookups and therefore have no supplementary heat or ventilation. A water line for drip irrigation is the only connection needed for crop production in high tunnels. Although high tunnels have not been used extensively in the United States, they have, and are, being used extensively in Southern Europe, the Middle-East, and Asia (Wells, 1991).

High tunnels must be manually ventilated during cool and sunny weather to remove excess heat and humidity (Wells and Loy, 1993). Ventilation is facilitated by the use of a three to five foot high role-up side-wall that extends the length of the structure on both sides, allowing for cross ventilation (Wells and Loy 1993). The width of a high tunnel cannot exceed twenty feet without suffering from inadequate ventilation (Wells and Loy, 1993). Excessive humidity caused by less -than -optimal ventilation within high tunnels is a factor that can negatively impact plant growth (Castilla, 1992). When humidity is too high, water will condense in droplets on the inner surface of the tunnels plastic covering. Condensation on the plastic covering has a negative effect on the transmission of solar radiation if the droplets persist during daylight hours (Jaffrin et al., 1990). Relative humidity levels above 90% can also cause developmental disorders related to localized calcium deficiency, promote outbreak of fungal diseases, and decrease flower pollination (Cockshull, 1988).

In Connecticut, tomatoes transplanted into tunnels on May 1 ripened three weeks earlier than tomatoes planted into the field on the same date (Gent, 1991). Gent (1991) reported that tomatoes transplanted into high tunnels on April 3, ripened 13 days earlier than plants transplanted into tunnels on April 17. April 13 transplants yielded less than six pounds of fruit per plant after seven weeks of harvest, compared to nine pounds of fruit per plant for April 17 plantings. In this study, Gent also found that ventilation at 30°C within the tunnels was optimum during spring production. As a general rule for spring tomato production, tunnels should be vented on sunny days when the outside temperature reaches 10°C (Gent, 1991). Conversely, for fall production Gent found that reducing ventilation to achieve warm days reduced marketable percentage and size of fruit, and increased disease levels. Ventilation for fall production should take place when the inside temperature reaches 14°C to achieve the highest yield, fruit size, and fruit quality (Gent, 1991). Each two week delay in planting after July 15 delayed ripening by one month and reduced yields (Gent, 1991). However, the July 15 planting ripened throughout September, which was in direct competition with field production. Therefore, a late July planting in high tunnels may be the best compromise between yields, and timing, to come into the market when field production has ceased (Gent, 1991).

Economics of High Tunnel Production

Overall yields for a single tomato crop grown within high tunnels are reported to be just over two pounds per square foot (Wells, 1999; Upson, 2002). Both of these researchers allocated about 110 hours of labor annually per high tunnel. When all costs of building and operating a high tunnel are calculated, with depreciation of the structure figured over a ten year period and tomato sales calculated at $1.50 a pound, Wells (1999), and Upson (2002) both found that a profit could be realized from the first tomato crop produced within a high tunnel.

The main benefit of the high tunnel is the premium price received from the early yields between the middle of June and mid-July (Gent, 1991). In Connecticut, Gent (1991) reported harvests slightly less than one pound of fruit per square foot from mid-June through mid-July. While these yields may sound low, it is important to remember that these tomatoes are available when prices are three times that of tomatoes sold after field tomatoes come onto the market. A fall crop of tomatoes planted on July 17 can yield just over one pound of fruit per square foot, with the harvest beginning in late September, and extending into November (Gent, 1991). Therefore, it may be profitable for growers to consider pulling plants in mid-July when field tomatoes are plentiful, and planting a fall crop that will be marketed after field crops are killed by frost.

Cultivar Selection

Tomatoes are bred to grow in a variety of climates and growing conditions (Kopsell, 2000). Some tomato cultivars will produce a crop in less than two months while others take more than three months of hot weather to produce ripe fruit. Tomatoes differ among cultivars in their response to different light and fertilizer levels (Conover, 1997). Significant differences among cultivars in number of flowers have been observed when tomato plants were grown using fabric row covers (Peterson, 1991). Tomato cultivars bred for outdoor production will typically have more leaf area than is desirable for plants grown in high tunnels (Saglam, 2000). In a protected growing area such as a high tunnel greater leaf area can promote an environment that is conducive to fungal diseases within the plants foliage due to moisture retention and lack of air movement (Saglam, 2000).

Chapter 3

Effect of Mulch and Row Covers on Yield of Tomatoes in High Tunnels

<u>Abstract</u>

Row covers and plastic mulch are effective at enhancing early yield of warm season vegetables (Wells and Loy, 1985; Bhella, 1988). Little is known however about the effects of row cover and different colored plastic mulches on high tunnel grown tomatoes in the Central Midwest. The objective of this research was to compare the effects on tomatoes of black plastic mulch, clear plastic mulch, and no mulch, each with and without row cover when used in high tunnels. Total marketable yield and yield of US number1 fruit from clear plastic mulch without row cover was significantly greater than yield from bare ground without row cover. Early marketable yield from clear plastic mulch without row cover was significantly greater than yield from black plastic mulch with row cover, and bare ground with and without row cover. In this study, clear plastic mulch was the most effective mulch treatment at increasing plant growth. Row cover provided frost protection early in the season, although it minimized the soil warming ability of clear and black plastic mulch by filtering incoming solar radiation.

<u>Introduction</u>

E.M. Emmert (1956) found black polyethylene mulch to be the cheapest and most efficient method used to mulch vegetables. Benefits of plastic mulch include: increased and earlier harvests, greater marketable yields, better weed control and insect management, and more efficient use of irrigation water and fertigation nutrients (Lamont, 1993). Major advances in plastics have taken place since E.M. Emmert's work in the early 50's. Today growers can choose from a variety of mulches, each of which has specific applications.

To extend the growing season of a certain crop, it is necessary to grow the crop in sub-optimal conditions such as low temperature. Cool soil temperatures can have a number of adverse effects on plant root growth such as slower cell division and cell maturation rates, reduced water uptake, and reduced nutrient uptake (Nielsen, 1974). Black and clear mulches have shown the greatest soil warming potential among the various mulch colors (Ham et al., 1993). However, black and clear mulches heat the soil in different ways, and the manner in which the mulch is applied to the soil is directly related to its effectiveness.

Black mulch reflects less short-wave radiation (10%), and absorbs more radiation (90%) than any other colored mulch (Teasdale, 1995). Dark colored mulches (black or red) typically have higher surface temperatures than clear or white mulch (Decoteau et al., 1989). The heat absorbed by dark colored mulches is conducted to the soil surface, which raises the soil temperature (Tarara, 2000). Therefore, it is very important to apply dark plastics tightly over the bed to maintain good soil -to- mulch contact. An air gap between the mulch and the soil creates a greater distance for the heat to travel before entering the soil and, consequently, much of the heat created at the mulch surface is lost to the atmosphere (Tarara, 2000).

Clear mulch absorbs only 5% of short-wave radiation, reflects only 11%, but transmits 84% of short-wave radiation (Tarara, 2000). Clear mulch surface temperatures do not reach the levels found on black plastic due to their low absorption rates of short-wave radiation. Clear plastics actually heat the soil by transmitting light to the soil surface, rather than conducting heat like dark plastics (Ham and Kluitenberg, 1994). Consequently, laying clear mulch loosely across the soil creates an insulating air gap between the mulch and soil that results in higher daytime temperatures under clear plastic than black plastic mulch (Liakatas et al., 1986; Ham et al., 1993). If clear plastic is laid tightly across the bed, its effects will be minimized and, in this situation, black plastic laid tightly across the bed would be more effective at heating the soil (Liakatas et al, 1986). Research with clear plastic surface mulch in combination with supported row covers, has shown that clear plastic mulch is more effective than black plastic in increasing early yield and total yield of spring transplanted tomatoes (Ricketson and Thorpe, 1983).

Weed control is another important benefit of using mulch. In open field tomato production, a "critical weed free period" of 28-55 days exists, during which time a single thorough hand hoeing will prevent yield loss (Weaver and Tan, 1983). Weeds growing before this timeframe will not compete significantly with the crop, whereas weeds growing beyond this point will reduce yields primarily by shading the crop (Jensen et al., 1989). Black mulch effectively stops weed growth by intercepting nearly all-incoming solar radiation. Clear mulch on the other hand transmits a large portion of incoming radiation, and in combination with its soil-warming effects promotes early season weed growth. Early season weed growth is confined and suppressed by clear plastic mulch as the season progresses, making removal of the plastic and cultivation unnecessary (Ricketson and Thorpe, 1983). Because weeds growing beneath clear plastic will push up and against the mulch, care must be taken to firmly secure the mulches edges to prevent weeds from growing out from under the plastic and interfering with crop growth. Spunbonded fabric row covers, also known as floating row covers, were first used in the southern United States as tobacco seedbed covers (Wells and Loy, 1985). Small-diameter continuous filaments of polyester or polypropylene are spun in a web form onto a collection belt. Next, the fibers are bonded with heat and pressure into a thin sheet of flexible and porous fabric (Vaughn, 1992). Fabric row covers are lightweight (10-50g/m^2), and can be placed directly over crops without the use of hoops for support (Wells and Loy,1985). Row covers modify a plant's growing environment with regard to light, soil and air temperatures, humidity, and air movement (Wells and Loy, 1985). Floating row covers are applied loosely over plants and secured at the edges. As the plants grow they push against and lift the row cover, which necessitates their removal on tall growing crops such as tomatoes.

Time between flowering and fruit development is much shorter at warmer rather than moderate temperatures (Abdalla and Verkerk, 1968). Wells and Loy (1985) showed that temperatures under row cover can be several degrees warmer than ambient, and research has also shown that temperatures under row covers can reach levels that may cause flower and unripe fruit abortion (Wolfe et al., 1989; Wells and Loy, 1985). Early yields on spring plantings will be reduced if row covers are not removed while tomatoes are flowering (Rubeiz, I.G. and Freiwat, M.M.1995; Peterson, R.H. and Taber, H.G., 1991). In addition to regulating temperatures around the plant, row covers also moderate low temperature extremes in the soil (Wells and Loy,1993). Wells and Loy (1993) report that seedlings of fall - seeded lettuce in uncovered plots were pushed from the soil with alternating freezing and thawing, while covered seedlings were not affected by the weather fluctuations. The heat trapping effect of row covers is more pronounced on fall crops rather than spring crops due to the large amount of heat stored in the soil following the summer (Wells and Loy, 1993). The objective of this research was to compare the effects on tomatoes of black plastic mulch, clear plastic mulch, and no mulch, each with and without row cover when used in high tunnels.

Materials and Methods

Four high tunnels (HT) were constructed in June, 2001 at the University of Missouri Bradford Research and Education Center located near Columbia, Missouri (Lat. 38N, Long. 92W). The experiments were carried out during fall of 2001, and the spring and fall of 2002. The soil, a fine Mexico silt loam, montmorillonitic, mesic Mollic Endoaqualf, was tilled, graded, and leveled prior to construction. Soil samples were taken prior to planting and analyzed by the University of Missouri soil-testing laboratory. Soil pH was 6.0, with 1.9% organic matter (see Appendix I). Each HT was 6mx11mx3m, giving 66 m^2 of total planting space (Stuppy Greenhouse Mfg., Inc., Kansas City, MO). Bows were spaced 1.2 meters apart, and one purlin was used for each tunnel. For ventilation, a 1m high roll-up sidewall was used. The roll-up sidewall extended the length of both sides of the high tunnels and was rolled up manually. Tunnels were built with the long axis oriented east-west to intercept the areas prevailing south by southwest wind. Each tunnel was covered with a single layer of clear 6 mil plastic (K-50, Klerk's Plastic Products Manufacturing Inc., Richburg, SC). Plots were irrigated with 2.54 cm of water weekly through 8mm t- tape with 12" emitter spacing and a flow rate of 0.450 gpm (TSX-508, T-Systems International, San Diego, CA). Row cover treatments consisted of covering with a double layer of Agribon AG-19 row cover, which weighs 19g/m^2 (Agribon, Mooresville, NC). A granular 13N-13P-13K fertilizer was applied pre - plant to all plots at the rate of 56 kg nitrogen per hectare (5.6 g/m^2). Calcium nitrate ($CaNO_3$), with an analysis of 15% N and 19% Ca, was applied weekly beginning four weeks after planting through the drip irrigation at a rate of 10 kg/ha (1 g/m^2). Five cm (606) plastic cell-packs (164 cm^3 per cell) with Pro-Mix BX® (Premier Peat Co. (75-85% peat by volume, perlite, vermiculite, macro- and micro - nutrients and wetting agent)) were used to start seed in the University of Missouri Horticultural Greenhouses. Seedlings were grown at 22ºC daytime temperature and 20ºC night temperature for eight weeks prior to transplanting.

Tomato plants in all treatments were spaced 0.6 m in rows with 0.9 m between rows. Tomatoes were trellised using the string weave method, with two tomato plants between each stake and approximately 4 strings to support the plants.

Tomato plants (*Lycopersicon esculentum* Mill.) were grown to evaluate their early season yield characteristics when grown using different mulch types with and without row cover. Six treatments were evaluated: clear plastic mulch without row cover, clear plastic mulch with row cover, black plastic mulch without row cover, black plastic mulch with row cover, bare ground without row cover, bare ground with row cover (Table 1).

Table 1. Mulch and Row Cover Treatments

Mulch Type	With Row cover
Bare Ground	yes
Bare Ground	
Black Plastic	yes
Black Plastic	
Clear Plastic	yes
Clear Plastic	

There were four replications for each treatment arranged in a completely randomized block design. A one- way analysis of variance (ANOVA) was computed for all data and differences were determined using Fisher's Least Significant Difference (LSD). Plants were set into rows of 16 plants, with each row being split into a row cover, and a no row cover treatment. Each treatment contained 8 plants. Plants in the row cover treatments were covered continuously, with a double layer, until first flowers appeared. During and after flowering, row covers were removed when daytime temperatures exceeded 15ºC, and replaced when night temperatures dropped below 13ºC. Pollination was accomplished by natural insect populations and air movement. Tomato transplants were planted in the tunnels on March 21, 2002.

Fruit harvest on spring tomatoes began on June 12, 2002, and continued through July 18, 2002. Yields were recorded on a per - plant basis, and fruit was graded according to USDA grade standards (USDA, 1966).

Fall plantings were made on August 10, 2001, and August 1, 2002. Treatments were made up of two rows (16 plants per row) of plants in each of four high tunnels. One row was covered with row cover, and the other was not. Tomato fruit did not have enough time to ripen in both season and a harvest was never accomplished. On November 3 of 2001, and 2002 necrotic tissue due to cold damage was removed from plants grown with and without row cover. Necrotic tissue that was damaged immediately following freezing temperatures were considered to be cold damaged. Weights of necrotic tissue were recorded separately for each treatment.

Results

Total marketable yield and yield of US number1 fruit (USDA, 1966) from clear plastic mulch without row cover treatments was significantly greater than yield from bare ground without row cover (Table 2). Yield of grade 2 fruit from bare ground with row cover was significantly greater than that of clear plastic mulch with row cover. No significant difference existed between any other treatments for full season yield. Both mulch types (clear and black) use solar energy to heat the soil. Black mulch heats the soil by conduction of heat from the plastic to the soil. Clear mulch heats the soil through transmission of solar radiation through the plastic and onto the soil surface. The soil warming effects of mulches are important early in the season because cool soil temperatures have a number of adverse effects on plant root growth such as reduced nutrient uptake (Nielsen, 1974). Based on light intensity readings taken during this project, a double layer of AG 19 row cover blocked an average of 40% of incoming solar radiation from the plants and the soil surface. Mulch under row cover was not able to heat the soil as effectively as mulch without row cover because it did not receive as much solar radiation. However, row covers retained heat, resulting in more vigorous plant growth early in the season. Filtration of solar radiation to the mulch surface and heat retention by the row cover lead to similar yield from mulched treatments with and without row cover.

Table 2. Total Yield of Mulch Treatments

Treatment	Total yield g/plant	USDA # 1 fruit g/plant	USDA#2 fruit g/plant
Bare Ground	2953b[1]	2357b	710ab
Bare Ground row cover	3777ab	2925ab	823a
Black Plastic	3720ab	2925ab	710ab
Black Plastic row cover	3720ab	2896ab	681ab
Clear Plastic	4004a	3322a	624ab
Clear Plastic row cover	3663ab	3038ab	568b

[1]Means within the same column followed by the same letter are not significantly different at the 5% level based on LSD

Early marketable yield from clear plastic mulch without row cover was significantly greater than yield from black plastic mulch with row cover, and bare ground with and without row cover (Table 3). Early yield of grade 1 fruit from clear plastic was significantly greater than all other treatments except clear plastic with row cover. Black plastic mulch with row cover yielded no grade 2 fruit early in the season, and no significant difference existed for early yield of grade 2 fruit among all other treatments. Greater early yield from clear plastic mulch treatments could be attributed to the fact that clear plastic mulch heated the soil more than black plastic mulch or bare ground, resulting in more favorable growing conditions early in the growing season.

Table 3. Early Yield of Mulch Treatment (Before July 4)

Treatment	Total yield g/plant	USDA #1 fruit g/plant	USDA #2 fruit g/plant
Bare Ground	1051b[1]	795b	454a
Bare Ground row cover	1079b	852b	369a
Black Plastic	1164ab	880b	426a
Black Plastic row cover	1079b	880b	0b
Clear Plastic	1704a	1363a	369a
Clear Plastic row cover	1221ab	1079ab	284a

[1]Means within the same column followed by the same letter are not significantly different at the 5% level based

Row covers significantly reduced the amount of necrotic foliage due to cold exposure on plants in 2001, and eliminated damage in 2002 (Table 4). Damage under row cover in 2001 occurred only at points in which the plants contacted the row cover.

Table 4. Necrotic Tissue Due to Cold Damage

Treatment	Necrotic Tissue Fall 2001/g	Necrotic Tissue Fall 2002/g
Row cover	1925b[1]	0b
No Row Cover	5955a	2131a

[1]Means within the same column followed by the same letter are not significantly different at the 5% level based on LSD

Discussion

Row covers did not significantly increase total, or US number 1 yield of high tunnel tomatoes. Row covers did provide added frost protection in addition to the protection afforded by a high tunnel. Row covers, however, required extra capital for their purchase, and extra labor to put them on and remove them when plants were flowering and when daytime temperatures were high. When using black or clear plastic mulch, row covers were only useful for frost protection during times when the temperature within the high tunnel dropped below freezing. When plants were small, it was advantageous to support row covers over the plants to avoid direct contact of the plant and row cover. Tissue damage on plants at the point of contact with the row covers was designated as frost damage due to the absence of disease or insects that may have caused the damage, and appearance of the damaged tissue immediately following a frost. Using high tunnels and row covers for frost protection on full-grown plants, damage was localized to the points on the plants that were in direct contact with the row cover.

Early yield from bare ground with row cover treatments did not differ significantly from any of the mulch treatments except clear plastic. Treatments grown without mulch required one thorough hand cultivation during the season. Hand cultivation was labor intensive, but was the only feasible way to eliminate weeds in the tightly spaced high tunnel. Clear and black plastic mulches were effective enough at suppressing weeds that no cultivation was necessary. There was, however, capital required to purchase plastic mulch, and labor involved with applying plastic mulch. The total cost of purchasing and applying the mulch was comparable to the cost of labor involved with cultivating weeds by hand. Therefore, growing tomatoes on bare ground in high tunnels with the use of floating row cover is more economical than using black plastic mulch.

Clear plastic mulch significantly increases early yield of grade 1 fruit over all other treatments. This increase in production occurs at a time when tomato prices are high because field tomatoes have not yet come onto the market.

Chapter 4

Evaluation of Yield Potential in High Tunnels for Eight Tomato Cultivars

Abstract

Many popular tomato cultivars are used for field production in Missouri. Growing conditions within a high tunnel can be quite different from growing conditions typically encountered in outdoor production. Tomatoes grown in a high tunnel are exposed to high relative humidity, lower light, and more extreme temperature fluctuations than field- grown tomatoes. The effect of environmental factors within high tunnels on yield of popular field- grown tomato cultivars is unknown. The objective of this research was to determine yield characteristics throughout the growing season for several popular tomato cultivars commonly grown in Missouri. Total early yields from BHN 543, and Merced were significantly greater than all other cultivars (Table 2). Early yield of number one fruit from BHN 543 was significantly greater than most other cultivars, and was equal to that of Merced, and Florida 91. Full season yield of grade 1 and 2 fruit combined was significantly greater for Merced than any other cultivar (Table 2). Total yield of grade 1 fruit was greater for Merced than all other cultivars except Florida 47, and Florida 91.

Introduction

High tunnels are unheated plant forcing structures covered with clear plastic and made of metal bows connected to pipes that are driven into the ground and come in various shapes. The end-walls are enclosed, and can be equipped with doors wide enough to allow for entry of small equipment. High tunnels have no electric or gas hookups and therefore have no supplementary heat or ventilation. A water line for drip irrigation is the only connection needed for crop production in high tunnels. Although high tunnels have not been used extensively in the United States, they have, and are, being used extensively in Southern Europe, the Middle-East, and Asia (Wells, 1991).

High tunnels must be manually ventilated during cool and sunny weather to remove excess heat and humidity (Wells and Loy, 1993). Ventilation is facilitated by the use of a three to five foot high role-up side-wall that extends the length of the structure on both sides, allowing for cross ventilation (Wells and Loy, 1993). The width of a high tunnel cannot exceed twenty feet without suffering from inadequate ventilation (Wells and Loy, 1993). Excessive humidity caused by less -than -optimal ventilation within high tunnels is a factor that can negatively impact plant growth (Castilla, 1992). When humidity is too high, water will condense in droplets on the inner surface of the tunnel's plastic covering. Condensation on the plastic covering has a negative effect on the transmission of solar radiation if the droplets persist during daylight hours (Jaffrin et al., 1990). Relative humidity levels above 90% can also cause developmental disorders related to localized calcium deficiency, promote outbreak of fungal diseases, and decrease flower pollination (Cockshull, 1988).

In Connecticut, tomatoes transplanted into tunnels on May 1 ripened three weeks earlier than tomatoes planted into the field on the same date (Gent, 1991). Gent (1991) reported that tomatoes transplanted into high tunnels on April 3, ripened 13 days earlier than plants transplanted into tunnels on April 17. April 13 transplants yielded less than six pounds of fruit per plant after seven weeks of harvest, compared to nine pounds of fruit per plant for April 17 plantings. In this study, Gent also found that ventilation at 30°C within the tunnels was optimum during spring production. As a general rule for spring tomato production, tunnels should be vented on sunny days when the outside temperature reaches 10°C (Gent, 1991). Conversely, for fall production Gent found that reducing ventilation to achieve warm days reduced marketable percentage and size of fruit, and increased disease levels. Ventilation for fall production should take place when the inside temperature reaches 14°C to achieve the highest yield, fruit size, and fruit quality (Gent, 1991). Each two week delay in planting after July 15 delayed ripening by one month and reduced yields (Gent, 1991). However, the July 15 planting ripened throughout September, which was in direct competition with field production. Therefore, a late July planting in high tunnels may be the best compromise between yields and timing, to come into the market when field production has ceased (Gent, 1991). The objective of this research was to determine yield characteristics throughout the growing season for several popular tomato cultivars commonly grown in Missouri.

Materials and Methods

Four high tunnels (HT) were constructed in June, 2001 at the University of Missouri Bradford Research and Education Center located near Columbia, Missouri (Lat. 38N, Long. 92W). The experiments were carried out during fall of 2001, and the spring and fall of 2002. The soil, a fine Mexico silt loam, montmorillonitic, mesic Mollic Endoaqualf, was tilled, graded, and leveled prior to construction. Soil samples were taken prior to planting and analyzed by the University of Missouri soil-testing laboratory. Soil pH was 6.0, with 1.9% organic matter (see Appendix I). Each HT was 6mx11mx3m, giving 66 m^2 of total planting space (Stuppy Greenhouse Mfg., Inc., Kansas City, MO). Bows were spaced 1.2 meters apart, and one purlin was used for each tunnel. For ventilation, a 1m high roll-up sidewall was used. The roll-up sidewall extended the length of both sides of the high tunnels and was rolled up manually. Tunnels were built with the long axis oriented east-west to intercept the areas prevailing south by southwest wind. Each tunnel was covered with a single layer of clear 6 mil plastic (K-50, Klerk's Plastic Products Manufacturing Inc., Richburg, SC). Plots were irrigated with 2.54 cm of water weekly through 8mm t- tape with 12" emitter spacing and a flow rate of 0.450 gpm (TSX-508, T-Systems International, San Diego, CA). Row cover treatments were covered with a double layer of Agribon AG-19 row cover, which weighs 19g/m^2 (Agribon, Mooresville, NC). A granular 13N-13P-13K fertilizer was applied pre plant to all plots at the rate of 56 kg nitrogen per hectare (5.6 g/m^2). Calcium nitrate (CaNO3) was applied weekly through the drip irrigation at a rate of 10 kg/ha (1 g/m^2).

Five cm (606) plastic cell-packs (164 cm^3 per cell) with Pro-Mix BX® (Premier Peat Co., Quebec) 75-85% peat by volume, perlite, vermiculite, macro and micro nutrients and wetting agent)) were used to start seed in the University of Missouri Horticultural Greenhouses. Seedlings were grown at 22ºC daytime temperature and 20ºC night temperature for eight weeks prior to transplanting.

Tomato plants in all treatments were spaced 0.6 m in rows and 0.9 m between rows. Tomatoes were trellised using the string weave method, with two tomato plants between each stake.

Tomato (*Lycopersicon esculentum* Mill) cultivars that are commonly grown as field crops were grown to evaluate their performance as an early season crop in high tunnels. Tomato cultivars included: Florida 47, Florida 91, Floralina, Merced, Carolina Gold, Brandywine, BHN 543, and Mt. Fresh.

Florida 47 is a vigorous, determinate tomato that ripens mid-season with very large fruit (Sieger, 2000). Florida 91 is medium-tall determinate, heat tolerant, early to mid-season cultivar with large fruit (Sieger, 2000). Floralina is a medium-tall determinate cultivar that bears large fruit that ripens early to mid-season (Tomato Growers Supply Co., Fort Myers). Merced is an early-ripening, determinate cultivar with large fruit (Grant, 1997). Carolina Gold is a tall determinate cultivar that ripens mid-season with large, yellow- colored fruit (Syngenta Seeds Inc., Basal). Brandywine is an heirloom cultivar with an indeterminate growth habit and large fruit that ripen late in the season (Tomato growers supply Co., Fort Myers). BHN 543 is a medium-tall, determinate cultivar with large fruit ripening early to mid-season (Sieger, 2000). Mt. Fresh is a tall, determinate cultivar with large fruit that ripen mid-season (Sieger, 2000).

There were four replications for each cultivar arranged in a completely randomized block design. A one- way analysis of variance (ANOVA) was computed for all data and differences were determined using Fisher's Least Significant Difference (LSD). Plants were set into rows of sixteen plants, with four plots per row. Each plot contained four plants. Plants were grown using black plastic mulch, and were covered with row cover continuously until the first flowers appeared. During flowering, row covers were removed in the morning and replaced in the afternoon. When the weather began warming, row covers were only used on evenings when the temperature dropped below 10°C. Pollination was accomplished by natural insect populations and air movement. Tomato transplants were planted in the high tunnels on March 24, 2002.

Fruit harvest began on June 12, 2002, and continued through July 18, 2002. Yields were recorded on a per plant basis, and fruit was graded according to USDA grade standards (USDA, 1966).

Results

Total early yields from BHN 543, and Merced were significantly greater than all other cultivars (Table 5). No significant difference existed for early yield of any other cultivars. Early yield of number one fruit from BHN 543 was significantly greater than most other cultivars, and was equal to that of Merced, and Florida 91. Twenty Two percent of the early fruit collected from the cultivar BHN 543 were culls (Table 5), most of which were attributed to rabbit damage. Rabbits were attracted to the high tunnels due to their warm conditions, food source and thick cover afforded by the tomato plants. BHN 543 set fruit very low to the ground, which made it easy for the rabbits to get to the fruit. The heirloom tomato cultivar Brandywine produced significantly less early total and grade 1 (USDA, 1966) fruit per plant than Merced or BHN 543. Brandywine yielded an equal amount of early grade 2 fruit as Merced and BHN 543, even though it produced significantly less marketable fruit than either variety. Forty- one percent of the fruit picked from Brandywine before July 4 were culls. Culls from Brandywine were mostly attributed to fruit cracking and surface blemishes (Table 6).

Table 5. Early Yield for Cultivar Trial (Before July 4)

Cultivar	Total yield g/plant	USDA #1 fruit g/plant	USDA #2 fruit g/plant	% Culls
BHN 543	2045 a[1]	1477 a	540 ab	22
Merced	2016 a	1420 ab	710 a	13
Carolina Gold	1278 b	1022 bdc	341 b	16
Florida 91	1278 b	1164 bac	284 b	19
Florida 47	1221 b	880 dc	483 ab	17
Brandywine	1193 b	795 dc	625 a	41
Floralina	1164 b	682 d	625 a	23
Mt. Fresh	1022 b	852 dc	284 b	5

[1]Means within the same column followed by the same letter are not significantly different at the 5% level based on LSD.

Table 6. Percent Culls Due to Applicable Reason

Cultivar	% BER[1]	% Rabbit	% Fruit Worm	% Crack	% Surface Blemish
BHN 543	0	70	24	0	2
Brandywine	0	2	11	33	38
Carolina Gold	8	12	56	0	24
Floralina	23	18	23	0	11
Florida 47	5	40	23	3	0
Florida 91	9	27	32	0	32
Merced	22	14	14	28	14
Mt. Fresh	23	7	23	38	0

[1]Blossom End Rot

Full season yield of grade 1 and 2 fruit combined was significantly greater for Merced than any other cultivar (Table 7). Total yield of grade 1 fruit was greater for Merced than all other cultivars except Florida 47, and Florida 91. Florida 47, and Florida 91 were bred to perform well in hot weather, although their yield throughout the season was not significantly greater than any variety other than Brandywine. Merced also produced a significantly greater number of grade 2 fruits than any other cultivar, which could be attributed to the fact that overall yields for Merced were also significantly greater than most other cultivars.

Table 7. Yield Data for Cultivar Trial

Cultivar	Total Yield g/plant	USDA #1 fruit g/plant	USDA #2 fruit g/plant	% Culls
Merced	5992 a[1]	4374 a	1562 a	14
Floralina	4516 b	3181 b	1051 b	15
Florida 47	4316 b	3380 ab	852 bc	18
Mt. Fresh	3976 b	3096 bc	710 bc	9
Florida 91	3976 b	3408 ab	540 c	14
BHN 543	4004 b	3096 bc	852 bc	19
Carolina Gold	3976 b	3209 b	653 bc	16
Brandywine	3266 c	2130 c	1051 b	30

[1]Means within the same column followed by the same letter are not significantly different at the 5% level based on LSD.

Discussion

Central Missouri experienced an unusually wet spring in 2002. Because of the wet weather, field tomatoes were late coming onto the market and farmer's market tomato prices stayed over $2.00 per pound through the middle of July. While wet spots did exist near the edges of the high tunnels, conditions in the high tunnels were much drier and therefore more conducive to plant growth. Protecting the plants from rain with the high tunnels allowed for early harvest of high quality fruit even though field conditions were poor.

Merced and BHN 543 are both excellent choices for early season tomato production in high tunnels. Merced also carried a large fruit load throughout the season. BHN 543 would be a good choice for growers who wish to produce an early crop of tomatoes that will be pulled out early in the summer and followed by another crop. During harvest it was noted by a three person panel of judges that fruit from BHN 543 had better flavor than Merced. Early in the season flavor would not limit sales of Merced because demand for tomatoes at that time exceeds supply, although later in the season retail consumers may choose other more flavorful cultivars as they become available.

Results from this research indicate that controlling rabbit populations in and around high tunnels would have lead to a higher percentage of marketable fruit. The number of culls attributed to fruit worm damage could have been reduced by scheduled applications of BT (*Bacillus thuringiensis*).

Carolina Gold had good yield, excellent flavor, and is recommended for producers of yellow tomatoes. Yield from the heirloom tomato cultivar Brandywine did not compare to newer hybrid cultivars, although, Brandywine had extremely flavorful fruit that is popular with many consumers. Brandywine would only be profitable to produce if a market exists in which producers could charge a premium for the heirloom tomato even though the fruit is not as blemish free as other cultivars. Mt. Fresh produced very few culls and a low number of grade 2 fruit. Mt. Fresh was an extremely vigorous growing and bushy plant. It was noted that the thick vegetative growth restricted airflow within the plant and led to greater levels of powdery mildew on Mt. Fresh than on other varieties. Therefore, a fungicide application could have led to lower fungal disease rates on the Mt. Fresh cultivar.

Chapter 5

SUMMARY AND CONCLUSIONS

Tomato plants (*Lycopersicon esculentum* Mill) were grown to evaluate their early season yield characteristics when grown using different mulch types with and without row cover. Mulch treatments included plants grown on clear and black plastic mulch and a control group of plants grown on bare ground. Half of the plants in each experimental plot were covered with row cover and half were not. In a similar experiment, eight field tomato cultivars were grown in high tunnels in order to evaluate their yield potential throughout the growing season. Plants in the cultivar experiment were grown on black plastic mulch and covered with row cover. Row covers did not significantly increase total, or US number 1 yield of high tunnel tomatoes. When using black or clear plastic mulch, row covers were only useful for frost protection during times when the temperature within the high tunnel dropped below freezing. Early yield from bare ground with row cover treatments did not differ significantly from any of the mulch treatments except clear plastic. Clear plastic mulch significantly increases early yield of grade 1 fruit over all other treatments. This increase in production occurs at a time when tomato prices are high because field tomatoes have not yet come onto the market.

Total early yields from BHN 543 and Merced were significantly greater than all other cultivars. Twenty- Two percent of the early fruit collected from the cultivar BHN 543 were culls, most of which were attributed to rabbit damage. Controlling rabbit populations in and around high tunnels could lead to a higher percentage of marketable fruit. Due to early fruit ripening characteristics, BHN 543 could fit into a double cropping system for growers wanting to replant their high tunnels with a fall crop. Full season yield of grade 1 and 2 fruit combined was significantly greater for Merced than any other cultivar. The heirloom tomato cultivar Brandywine produced significantly less early total and grade 1 fruit per plant than Merced or BHN 543.

Chapter 6

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Appendix I: Soil Test Results

Soil Test Results Using Bray 1 Test

Sample	pH	N.A. Meq/100g	O.M. %	P Lbs/A	Ca Lbs/A	Mg Lbs/A	K Lbs/A
High Tunnel 1	6.3	1	3.6	95	5849	523	198
High Tunnel 2	5.9	2.5	3.4	84	5581	530	178
High Tunnel 3	6.1	1.5	2.9	65	5846	549	169
High Tunnel 4	5.9	2.5	3	57	5739	611	194