HIGH TUNNEL PRODUCTION OF TOMATOES AND SNAPDRAGONS FOR

SEASON EXTENSION IN SOUTHEASTERN ALABAMA

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HIGH TUNNEL PRODUCTION OF TOMATOES AND SNAPDRAGONS FOR SEASON EXTENSION IN SOUTHEASTERN ALABAMA

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HIGH TUNNEL PRODUCTION OF TOMATOES AND SNAPDRAGONS FOR

SEASON EXTENSION IN SOUTHEASTERN ALABAMA

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THESIS ABSTRACT

HIGH TUNNEL PRODUCTION OF TOMATOES AND SNAPDRAGONS FOR SEASON EXTENSION IN SOUTHEASTERN ALABAMA

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Tomato and snapdragon production were evaluated for high tunnel production in southeastern Alabama during the spring and fall production cycles for season extension feasibility. ‘BHN 640’, ‘FLA 91’, ‘Sunleaper’, and ‘Carolina Gold’ tomato varieties were grown for early-spring production in 2004. The varieties did not differ in total marketable yields; however ‘BHN 640’ and ‘Sunleaper’ produced heavier early yields compared to the other varieties. In the fall of 2004, a study was conducted to determine the suitability of ‘BHN 640’ and ‘FLA 91’ varieties for late season extension. ‘BHN 640’ produced greater yields than ‘FLA 91’ for the large, medium, marketable and unmarketable fruit grades. In spring 2005, a planting date study was conducted to evaluate optimum planting time for season extension. Higher marketable yields were obtained from the first and second planting date studies than from the fourth planting date

study. Two growth chamber studies were conducted to evaluate cold tolerant tomato varieties along with standard varieties as suitable candidates for high tunnel production. The growth chambers were set to mimic late-fall or early-spring weather conditions in southeastern Alabama. High variation within each experiment yielded no clear indication of a best variety. However, it appeared that 'Northern Delight', 'Polar Beauty', and 'Santiam' performed well in both studies.

Snapdragons were evaluated for high tunnel production using various nitrogen fertilizer rates, plant spacings, and plastic mulch colors to determine optimum production practices in southeast Alabama. In spring 2004, a nitrogen study was completed to determine optimum rates for snapdragons grown in this system. Four rates of Polyon® 19-6-12 controlled-release fertilizer were applied at the following rates: 80, 160, 240, and 320 lbs. per acre of nitrogen. The 240 lbs./A of N rate yielded the best results for stem and inflorescence length. A snapdragon plant spacing study using 3"x 4", 4"x 4", and a 4"x 5" spacing was conducted to determine the optimum spacing for production. The 3" x 4" spacing was determined to yield a superior quality snapdragon. Various colored plastic mulches (red, white, and blue) were evaluated to determine the color mulch that resulted in optimum growth within a high tunnel in summer and fall, 2005. Inflorescence length was longer on red plastic compared to the white plastic mulch in the summer study. 'Opus Yellow' yielded longer inflorescence lengths than other varieties in this study. White plastic mulch resulted in the longest inflorescence length and 'Apollo Purple' snapdragon produced longer stems lengths than other varieties in the fall study.

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

High Tunnels are a greenhouse-like structure whereby plants are grown utilizing the soil (Wells and Loy, 1993). High tunnels have been used extensively in Europe and the Middle East for production of vegetables, cut flowers, and other horticultural plants (Wells and Loy, 1993; Wittwer and Castilla, 1995). High tunnels are an important part of vegetable production in the Middle East and increasing in importance in the Northern U.S. and Canada. The high tunnel is considered to be a less expensive alternative to a true greenhouse and yet can provide some control of environmental factors that affect plant growth and development, yields, and dates at which products are sellable. Such control is due to protection against wind, rain, weeds, and some insects and diseases as well as control of temperature and water usage (Wells and Loy, 1993). Typically, high tunnels are covered with a single layer of clear, six-mil polyethylene and are ventilated by manually rolling up the sides. There are no permanent heating or cooling systems in the high tunnel but there is a water supply for drip/trickle irrigation. High tunnels are seen as an affordable technology for season extension (Lamont et al., 2002).

Extensive research has been conducted on the use of high tunnels at Pennsylvania State University in the United States. Research at Pennsylvania State University has investigated production in high tunnels that included the production of tomatoes

(*Lycopersicon esculentum* Mill.) and snapdragons (*Antirrhinum majus* L. Peoria). Penn State subsequently established a High Tunnel Research and Educational Facility in 1999 as a part of it's Center for Plasticulture to further research and education in the area of plasticulture (Lamont et al., 2003). The Penn State system of high tunnel production is more closely related to field plasticulture than the University of New Hampshire's high tunnel system (Lamont, 1996). However, limited research has been conducted on use of high tunnels in the southeastern United States.

Normal planting dates for tomatoes in south Alabama is around March 10 (Kemble et al., 2004). Drip irrigated tomatoes with plastic mulch may yield 1,500 to 2,000, 25-pound boxes per acre. The most important time for irrigation is during fruit sizing (Kemble et al., 2004). Optimal tomato yields occur when a consistent supply of water is available (Carey, 2006). With 60 to 90 days from transplant to mature fruit, earlier planting dates allow for fruit harvest several weeks earlier than normal field production is expected in a high tunnel system (Maynard and Hochmuth, 1997). Tomatoes benefit from raised mulched beds (Carey, 2006). Raised beds are typically four to six inches high with black plastic mulch utilized in the spring to heat the soil, which will accelerate plant growth and development (Kemble et al., 2004). Typical spacing of tomatoes for field production is 18" to 24" within rows and 4' to 6' between rows to allow for machinery movement (Kemble et al., 2004). Typical spacing for high tunnel production is 18" to 24" within rows and 4' between rows (Carey, 2006).

Four to five-week-old tomato transplants can be planted in a high tunnel four to five weeks earlier in the season than field plantings (Carey, 2006). Research has shown that a tomato crop will flower and have a mature crop two to three weeks earlier in a high tunnel as compared to a low tunnel (row cover) (Waterer, 2003). In Pennsylvania, high tunnels have shown a continuous problem with frost damage. Thus, heating with a portable propane heater was advised (Lamont et al., 2002). Protection is required because tomato plants are damaged at temperatures below 10°C (50°F). High tunnels are known to extend the production season by accelerating plant growth and ripening during the colder months when field production is not possible (Gent, 1991). In New Hampshire, high tunnels advanced maturity of tomatoes by 32 days compared to unprotected field grown tomatoes (Wells, 1991). Tomatoes grown in a high tunnel can produce up to 25 lbs. of fruit per plant (Carey, 2006). According to Wells and Loy (1993), if the width of a high tunnel exceeds 20 feet then adequate ventilation is not attainable when outside temperatures rise above 30°C (86°F). Four foot row spacing allowed for five rows in a 20' wide high tunnel (Carey, 2006) requiring up to 1,100 gallons of water a week (Carey, 2006). Higher relative humidity level inside high tunnels was cited as a reason for decreased blossom-end rot incidence and an increase in bacterial spot was also reported (Waterer, 2003).

Crop support systems and pruning are important to tomato production in high tunnels. Crop support is needed during production to improve light interception, increase early yields, and to reduce the incidence of disease problems (Carey, 2006). Staking tomatoes keeps fruit off the ground and allows for improved spray coverage. Staking also increases fruit quality and makes harvesting easier (Kemble et al., 2004). Pruning tomatoes will not increase yields, but will promote early harvest (Carey, 2006). Other benefits of pruning include increased marketable fruit, ease of harvest, and reduced plant injury during multiple harvests (Kemble et al., 2004). To prune tomato plants, the axillary shoots (suckers that develop in the axils of each leaf) are removed when they are less than 4” long. All suckers are removed except the sucker below the first flower cluster (Carey, 2006). Pruning is most beneficial when a long harvest season and uniform fruit production is reguired (Kemble et al., 2004).

Fertilization is essential in tomato production. Soil testing should be used to determine proper fertilization needs. Thirty to fifty percent (30 to 50%) of the recommended nitrogen and potassium fertilizer and all phosphorus should be applied pre-plant by broadcasting or banding. The remaining recommended nitrogen (N) and potassium (K_2O) should follow a weekly schedule as described by Kemble et al (2004). Calcium is vital to tomatoes as well. Calcium (Ca) deficiency can cause blossom-end rot. One of the primary causes of blossom-end rot is fluctuations in the supply of water. Calcium levels of the soil and ph are also critical in the prevention of blossom-end rot (Kemble et al., 2004). One way of supplying the needed N, K_2O, and Ca is through use of calcium nitrate and potassium nitrate (Maynard and Hochmuth, 1997).

Optimum growing temperatures for tomatoes are 25° to 30°C (77 to 86°F) during the day and 15.6° to 20°C (60° to 68°F) at night. Temperatures greater than or equal to 35°C (95°F) or less than or equal to 10°C (50°F) will halt growth and possibly cause damage (Maynard and Hochmuth, 1997). Researchers at Penn State found that growers should be aware that early spring plantings of tomatoes in high tunnels can be damaged due to cold pockets and other similar microclimates (White et al., 2003). Growers should be conservative in choosing early planting dates because even if plants survive cold temperatures, physiological disorders can result from stress and will likely reduce yields (White et al., 2003).

For the southeast, soil-borne diseases and insects are major problems for tomato production. Methyl bromide is a widely used soil fumigant that controls most soil-borne pests. In 1990, 44 to 49 million pounds of methyl bromide were used in the U.S. for soil fumigation (USDA, 1993). Methyl bromide was slated for cancellation by 2005 in all developed countries (State, 2000). The U.S. has applied for a critical use exemption for methyl bromide which would allow continued use of 27% of pre-phase out levels (USDA, 1993). Annual losses of $350 million in tomato production have been estimated to occur with the loss of methyl bromide. Methyl bromide is critical to agriculture and phase-out alternatives are needed (USDA, 1993). According to Kelly (2005), methyl bromide is still being allowed for use on crops such as cucumber, squash, cantaloupe, pepper, tomato, and eggplant where nutsedge is a problem.

An alternative to soil fumigation is soil solarization. Soil solarization is a method of pasteurizing the soil that is practical, inexpensive, and environmentally friendly. Soil solarization can help in reducing the need for crop rotation due for management of nematodes (Hagan and Gazaway, 2000). Soil solarization was shown effective in reducing soil-borne pathogens and nematodes when the soil was irrigated, covered with transparent polyethylene plastic and the soil temperature was 50°C (122°F) for four weeks (Parmar, 2000). Porter and Meriman, (1983) reported that soil solarization reduced soil-borne pests effectively when the average maximum temperature under the plastic mulch in the soil was 50°C (122°F) or greater. Reports have shown that with the addition of chicken litter, soil temperatures were raised 2° to 6°C compared to soils solarized without chicken litter (Kurt and Emir, 2004). Soil solarization can eliminate diseases such as Verticillium wilt, Fusarium wilt, damping off (*Rhizoctonia*), phytophthora root rot, and nematodes (Hagan and Gazaway, 2000). Soil solarization has been shown to be efficacious on *Fusarium oxysporum* and *Pythium* species (Kurt and Emir, 2004). Other benefits of soil solarization include increased populations of beneficial, growth-promoting, and pathogen antagonistic bacteria and fungi which recolonize solarized soil, adding a biological control component to soil that has undergone solarization (Hagan and Gazaway, 2000). Incidence of soil-borne pathogens were found to be zero to six percent in solarized plots as compared to 10 to 21% in non-solarized plots (Parmar, 2000). Tomatoes grown in the solarized plots had up to an 87% reduction in disease incidence (Parmar, 2000). Soil solarization also had a positive effect on plant growth and vegetable yield with yields being 35 to161 % higher in solarized plots compared to unsolarized plots (Parmar, 2000). Plant heights of tomatoes grown in solarized plots were 31% higher than the tomatoes grown in unsolarized plots (Parmar, 2000).

The use of snapdragons as a cut flower is a multi-million dollar market that is underutilized by growers in the southeast (Rogers, 1992). There are four major groups of snapdragon varieties, divided into groups based on how they respond to light and temperature (Harthun, 1991). Group I cultivars are grown in the winter and early spring. Group II cultivars are grown in late winter and spring. Group III cultivars are grown in late spring and fall while Group IV cultivars are grown in the summer (Rogers, 1992). Group I cultivars are not recommended for the southeastern U. S. Group II cultivars are recommended from 1 December to 30 April in the south, while Group III cultivars are recommended for 1 May to 30 June, and 1 October to 30 November (Sanderson, 1975). Group IV cultivars are recommended from 10 June to 10 September in the south

(Sanderson, 1975). Differences in temperatures can cause snapdragons to flower too early or too late as well as decrease cut flower quality (Sanderson, 1975). Soil temperature plays an important role in the production of snapdragons. Hood and Mills (1994) showed that root zone temperature of 22°C (71.6°F) produced the greatest stem, leaf, and root dry weight for Group II varieties. However, temperatures above 29°C (84.2°F) for Group II varieties showed a decrease in major and some minor element uptake (Hood and Mills, 1994).

The average time from sowing of snapdragon seed to flowering in Alabama ranged from 84 to 102 days depending on which group was grown and season (Sanderson, 1975). Seedlings should be transplanted as soon as first true leaves are fully expanded otherwise crop stunting will occur (Sanderson, 1975). In Previous research, Group III varieties required 72 days to flower from transplanting for May to June plantings, while the same variety required only 54 days to flower from time of transplanting when transplanted for October to November flowering (Sanderson, 1975).

A major aspect of snapdragon production is disease control. *Pythium* spp. can be a problem for cool season plantings. To prevent *Pythium* infection, Sanderson (1975) recommended that a fenaminosulf (Dexon) drench be applied to seedlings. Within one week of transplanting, seedlings should be treated with qunitozene (Terrachlor) at a rate of one pound of Terrachlor per 100 gallons of water (Sanderson, 1975). Aphids, spider mites, cabbage loopers, thrips, and white flies are pest of snapdragons. Control is possible with insecticides such as malathion, resmethrin, and dipel dust (*Bacillus thuriengensis*). The garden symphilid is the most important soil-borne pest of snapdragons. Soil solarization has been shown as a possible method to control soil-borne pests (Hagan and Gazeway, 2000), but preventing diseases from the beginning is recommended (Sanderson, 1975). Fertilization is important for a high quality crop of snapdragons. Soil pH for snapdragons should be between 5.5 to 7.0. A constant fertigation of 138 mg/L N, 22 mg/L P_2O_5, and 42 mg/L K_2O produced high quality plants (Sanderson, 1975). Sanderson (1975) reported that boron deficiency was a constant problem and should be monitored carefully. Boron deficiency can be controlled with the application of Borax or Solubor (Sanderson, 1975).

Snapdragons have been shown to perform best if the first three to four weeks have an average night-time temperature of 15.6°C (60°F) (Sanderson, 1975). Snapdragons grown at lower temperatures flower later, have stronger stems, more florets, are taller, and have a heavier plant weight (Sanderson, 1975). Fluctuations in temperature during bud formation must be avoided to avoid skips in the florets. According to Sanderson (1975) short days, as opposed to long days, when plants were two to eight inches tall helped to produce more florets at the time of flowering. Research conducted at Penn State showed little to no difference in stem length of snapdragons due to various planting dates affects (White et al., 2003). The stems from snapdragons grown inside a high tunnel were twice as long as the ones grown in a field (White et al., 2003). White et al. (2003) reported high tunnel produced snapdragons higher in quality than field grown snapdragons.

The use of plasticulture was introduced in the early 1950s (Lamont, 1993). Tomatoes, okra (*Abelmoschus esculentus* L. Moench), eggplant (*Solanum melongena* L.), squash (*Cucurbita pepo* L.), and peppers (*Capsicum spp*. L) have all shown significant increases in earliness, yield, and quality when grown on plastic mulches (Lamont, 1993).

Plastic mulches provide protection from insects and weeds (Ennis, 1987). Black plastic mulch absorbs most UV, visible, and infrared solar radiation and re-radiates energy in the form of thermal radiation (Loy et al., 1989). Black plastic mulch generally provided an increase of 2.8°C (5°F) at a two inch soil depth and an increase of 1.7°C (3°F) at a four inch soil depth when compared to bare soil during the daytime (Loy et al., 1989). Clear plastic mulch transmits 85 to 95% solar radiation but absorbs very little of the solar radiation. Daytime soil temperatures under clear plastic mulch were usually 4.4 to 7.8°C (8 to 14°F) higher at a soil depth of two inches and 3.3 to 5°C (6 to 9°F) higher at a soil depth of four inches compared to bare ground (Loy et al., 1989). White plastic mulch produced a decrease of 1.1°C (2°F) at one-inch soil depth and a decrease of 0.4°C (0.7°F) at the four-inch soil depth. The reduction in temperature was due to solar radiation being reflected back into canopy of the plant, which was good for production of tomatoes in mid-summer (Loy et al., 1989). Other colored plastic mulches have been studied. Decoteau et al. (1989) reported that red colored plastic mulch resulted in increased early yields of tomatoes because of the higher ratio of red to far red light that was reflected back to the plant (Kasperbauer, 1999). The higher ratio of red to far red light resulted in increased yields, root/shoot ratio, and fruit size, when compared to black plastic mulch (Kasperbauer, 1999). Use of blue plastic mulches resulted in an increase in leaf length and higher root/shoot ratios than white plastic mulch (Lamont and Orzolek, 2004). In early spring, when light intensities were low, blue plastic mulch resulted in increased plant heights due to increased far red/red ratio of light, which promotes stem elongation. The opposite is true for the fall of the year. Csizinszky et al. (1995) reported that blue plastic mulch resulted in the highest tomato yields when compared to red, black, yellow, and gray-colored mulches. Other studies have shown red plastic mulch resulted in higher fruit yields (Orzolek et al., 2003).

High tunnel research on tomatoes conducted in other areas of the U.S. has proven successful and needs exploring in Alabama. A high tunnel production system could allow farmers to meet the demand for high valued horticultural crops for a premium price at a time of year local produce is not commonly available. Therefore, the objective of the research presented in the following pages was to evaluate the production of tomatoes and snapdragons in a high tunnel production system. Research included variety evaluations, planting dates, nitrogen rates, and soil solarization as a methyl bromide alternative in the Wiregrass area of Alabama.

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CHAPTER II

VARIETY SELECTIONS AND PLANTING DATE STUDY OF HIGH TUNNEL TOMATOES

ABSTRACT. Tomato (*Lycopersicon esculentum* Mill.) production was evaluated for high tunnel production in southeastern Alabama for spring and fall production cycles for season extension feasibility. 'BHN 640', 'FLA 91', 'Sunleaper', and 'Carolina Gold' tomato varieties were evaluated for early-spring production in 2004. The varieties did not differ in total marketable yields; however 'BHN 640' and 'Sunleaper' produced higher early yields compared to the other varieties. In the fall of 2004, 'BHN 640' and 'FLA 91' were evaluated to determine the suitability of these varieties for late season extension. 'BHN 640 had higher yields than 'FLA 91' for the large, medium, marketable, and unmarketable fruit grades. In spring 2005, a planting date study was conducted to evaluate optimum planting time for season extension. The first and second planting dates (31 Jan. and 17 Feb.) and both produced higher marketable yields than planting date four (25 Mar.). Cool temperatures and slower ripening times led to two follow-up studies to evaluate selected cold tolerant varieties compared to 'BHN 640' and 'Florida 91' in growth chambers. The growth chambers were set to mimic late-fall or early-spring weather conditions in southeastern Alabama. Varieties evaluated in the growth chamber studies were: 'BHN 640', 'Florida 91', 'Glacier', 'Legend', 'Oregon

Spring', 'Northern Delight', 'Polar Beauty', 'Santium', 'Siletz', and 'Subartic'. High variation within each experiment resulted in no clear indication of the best variety. However, it appeared, from a ranking standpoint, that 'Northern Delight', 'Polar Beauty', and 'Santiam' performed well in both studies. In summary, overall results indicated that season extension on an average of three weeks earlier in the spring and 12 weeks later in the fall occurred.

LITERATURE REVIEW

High Tunnels are a greenhouse-like structure whereby plants are grown utilizing the soil (Wells and Loy, 1993). High tunnels have been used extensively in Europe and the Middle East for production of vegetables, cut flowers, and other horticultural plants (Wells and Loy, 1993; Wittwer and Castilla, 1995). High tunnels are an important part of vegetable production in the Middle East and increasing in importance in the Northern U.S. and Canada. The high tunnel is considered to be a less expensive alternative to a true greenhouse and yet can provide some control of environmental factors that affect plant growth and development, yields, and dates at which products are sellable. Such control is due to protection against wind, rain, weeds, and some insects and diseases as well as control of temperature and water usage (Wells and Loy, 1993). Typically, high tunnels are covered with a single layer of clear, six-mil polyethylene and are ventilated by manually rolling up the sides. There are no permanent heating or cooling systems in the high tunnel but there is a water supply for drip/trickle irrigation. High tunnels are seen as an affordable technology for season extension (Lamont et al., 2002).

Extensive research has been conducted on the use of high tunnels at Pennsylvania State University in the United States. Research at Pennsylvania State University has investigated production in high tunnels that included the production of tomatoes (*Lycopersicon esculentum* Mill.) and snapdragons (*Antirrhinum majus* L. Peoria). Penn State subsequently established a High Tunnel Research and Educational Facility in 1999 as a part of it's Center for Plasticulture to further research and education in the area of plasticulture (Lamont et al., 2003). The Penn State system of high tunnel production is more closely related to field plasticulture than the University of New Hampshire's high tunnel system (Lamont, 1996). However, limited research has been conducted on use of high tunnels in the southeastern United States.

Normal planting dates for tomatoes in south Alabama is around March 10 (Kemble et al., 2004). Drip irrigated tomatoes with plastic mulch may yield 1,500 to 2,000, 25-pound boxes per acre. The most important time for irrigation is during fruit sizing (Kemble et al., 2004). Optimal tomato yields occur when a consistent supply of water is available (Carey, 2006). With 60 to 90 days from transplant to mature fruit, earlier planting dates allow for fruit harvest several weeks earlier than normal field production is expected in a high tunnel system (Maynard and Hochmuth, 1997). Tomatoes benefit from raised mulched beds (Carey, 2006). Raised beds are typically four to six inches high with black plastic mulch utilized in the spring to heat the soil, which will accelerate plant growth and development (Kemble et al., 2004). Typical spacing of tomatoes for field production is 18" to 24" within rows and 4' to 6' between rows to allow for machinery movement (Kemble et al., 2004). Typical spacing for high tunnel production is 18" to 24" within rows and 4' between rows (Carey, 2006).

Four to five-week-old tomato transplants can be planted in a high tunnel four to five weeks earlier in the season than field plantings (Carey, 2006). Research has shown that a tomato crop will flower and have a mature crop two to three weeks earlier in a high tunnel as compared to a low tunnel (row cover) (Waterer, 2003). In Pennsylvania, high tunnels have shown a continuous problem with frost damage. Thus, heating with a portable propane heater was advised (Lamont et al., 2002). Protection is required because tomato plants are damaged at temperatures below 10°C (50°F). High tunnels are known to extend the production season by accelerating plant growth and ripening during the colder months when field production is not possible (Gent, 1991). In New Hampshire, high tunnels advanced maturity of tomatoes by 32 days compared to unprotected field grown tomatoes (Wells, 1991). Tomatoes grown in a high tunnel can produce up to 25 lbs. of fruit per plant (Carey, 2006). According to Wells and Loy (1993), if the width of a high tunnel exceeds 20 feet then adequate ventilation is not attainable when outside temperatures rise above 30°C (86°F). Four foot row spacing allowed for five rows in a 20' wide high tunnel (Carey, 2006) requiring up to 1,100 gallons of water a week (Carey, 2006). Higher relative humidity level inside high tunnels was cited as a reason for decreased blossom-end rot incidence and an increase in bacterial spot was also reported (Waterer, 2003).

Crop support systems and pruning are important to tomato production in high tunnels. Crop support is needed during production to improve light interception, increase early yields, and to reduce the incidence of disease problems (Carey, 2006). Staking tomatoes keeps fruit off the ground and allows for improved spray coverage. Staking also increases fruit quality and makes harvesting easier (Kemble et al., 2004). Pruning tomatoes will not increase yields, but will promote early harvest (Carey, 2006). Other benefits of pruning include increased marketable fruit, ease of harvest, and reduced plant injury during multiple harvests (Kemble et al., 2004). To prune tomato plants, the axillary shoots (suckers that develop in the axils of each leaf) are removed when they are less than 4" long. All suckers are removed except the sucker below the first flower cluster (Carey, 2006). Pruning is most beneficial when a long harvest season and uniform fruit production is required (Kemble et al., 2004).

Fertilization is essential in tomato production. Soil testing should be used to determine proper fertilization needs. Thirty to fifty percent (30 to 50%) of the recommended nitrogen and potassium fertilizer and all phosphorus should be applied pre-plant by broadcasting or banding. The remaining recommended nitrogen (N) and potassium (K_2O) should follow a weekly schedule as described by Kemble et al (2004). Calcium is vital to tomatoes as well. Calcium (Ca) deficiency can cause blossom-end rot. One of the primary causes of blossom-end rot is fluctuations in the supply of water. Calcium levels of the soil and ph are also critical in the prevention of blossom-end rot (Kemble et al., 2004). One way of supplying the needed N, K_2O, and Ca is through use of calcium nitrate and potassium nitrate (Maynard and Hochmuth, 1997).

Optimum growing temperatures for tomatoes are 25° to 30 °C (77 to 86 °F) during the day and 15.6° to 20 °C (60° to 68 °F) at night. Temperatures greater than or equal to 35 °C (95 °F) or less than or equal to 10 °C (50 °F) will halt growth and possibly cause damage (Maynard and Hochmuth, 1997). Researchers at Penn State found that growers should be aware that early spring plantings of tomatoes in high tunnels can be damaged due to cold pockets and other similar microclimates (White et al., 2003). Growers should be conservative in choosing early planting dates because even if plants survive cold temperatures, physiological disorders can result from stress and will likely reduce yields (White et al., 2003).

The use of plasticulture was introduced in the early 1950s (Lamont, 1993). Tomatoes, okra (*Abelmoschus esculentus* L. Moench), eggplant (*Solanum melongena* L.), squash (*Cucurbita pepo* L.), and peppers (*Capsicum spp*. L) have all shown significant increases in earliness, yield, and quality when grown on plastic mulches (Lamont, 1993). Plastic mulches provide protection from insects and weeds (Ennis, 1987). Black plastic mulch absorbs most UV, visible, and infrared solar radiation and re-radiates energy in the form of thermal radiation (Loy et al., 1989). Black plastic mulch generally provided an increase of 2.8°C (5°F) at a two inch soil depth and an increase of 1.7°C (3°F) at a four inch soil depth when compared to bare soil during the daytime (Loy et al., 1989). Clear plastic mulch transmits 85 to 95% solar radiation but absorbs very little of the solar readiation. Daytime soil temperatures under clear plastic mulch were usually 4.4 to 7.8°C (8 to 14°F) higher at a soil depth of two inches and 3.3 to 5°C (6 to 9°F) higher at a soil depth of four inches compared to bare ground (Loy et al., 1989). White plastic mulch produced a decrease of 1.1°C (2°F) at one-inch soil depth and a decrease of 0.4°C (0.7°F) at the four-inch soil depth. The reduction in temperature was due to solar radiation being reflected back into canopy of the plant, which was good for production of tomatoes in mid-summer (Loy et al., 1989). Other colored plastic mulches have been studied. Decoteau et al. (1989) reported that red colored plastic mulch resulted in increased early yields of tomatoes because of the higher ratio of red to far red light that was reflected back to the plant (Kasperbauer, 1999). The higher ratio of red to far red light resulted in increased yields, root/shoot ratio, and fruit size, when compared to black plastic mulch (Kasperbauer, 1999). Use of blue plastic mulches resulted in an increase in leaf length and higher root/shoot ratios than white plastic mulch (Lamont and Orzolek, 2004). In early spring, when light intensities were low, blue plastic mulch resulted in increased plant heights due to increased far red/red ratio of light, which promotes stem elongation. The opposite is true for the fall of the year. Csizinszky et al. (1995) reported that blue plastic mulch resulted in the highest tomato yields when compared to red, black, yellow, and gray-colored mulches. Other studies have shown red plastic mulch resulted in higher fruit yields (Orzolek et al., 2003).

MATERIALS AND METHODS

Variety Yield Experiment

SPRING 2004. In the spring of 2004, a experiment was conducted to determine suitable tomato varieties for a high tunnel system in southeast Alabama. A single high tunnel (21'x 96') was constructed at the Wiregrass Research and Extension Center in Headland, AL utilizing the Penn State plan (Orzolek et al., 2003). The high tunnel had a north/south orientation and was covered with a single layer of clear 6-mil polyethylene plastic. The high tunnel was constructed with roll-up sides for ventilation. For added ventilation, two automatic vents (Ken-Bar, Reading, MA) were placed on the top of the high tunnel that opened without the use of electricity. During the study, the sides were rolled up for ventilation and to facilitate wind pollination. When night-time temperature was predicted to be less than 15.6°C (60°F), the sides were rolled down by mid-afternoon. As the season progressed and temperatures increased, sides were left open longer in the day until it was warm enough to leave open 24 hours a day. End-walls were constructed to allow opening for movement of equipment within the high tunnel.

Four selected tomato varieties (‘Florida 91’, ‘BHN 640’, ‘Sunleaper’, and ‘Carolina Gold’) were seeded at the Plant Science Research Center at Auburn University, AL. Seeds were planted in Canadian Growing Mix 2 (Conrad Fafard Inc., Agawan, MA) in 48 cell flats on 13 February 2004 and allowed to grow for four weeks. Transplants were fertilized once a week with a 20N-4.4P-16.6K water soluble fertilizer (Peter’s Water Soluble Plant Food 20-10-20) (The Scotts Co, Marysville, OH) at the rate of 265 mg/L N of N. After four weeks of growth, plants were hardened off for one week. In order to harden off the tomato plants, watering intervals were decreased from twice a day to once a day for three days and fertilizer was discontinued. The transplants were then placed outside and allowed to wilt slightly, followed by a light watering when the plants began to wilt. In addition, the plants were exposed to outside conditions such as wind, cool mornings, and late afternoon temperatures. The transplants were never exposed to temperatures below 10°C (50°F) while being hardened off.

The transplants were planted at the Wiregrass Research and Extension Center inside the high tunnel on 18 March 2004. The recommended pre-transplant fertilizer application is 30%-40% of recommended total nitrogen (N) and potassium (K_2O) and 100% of the required phosphorus (P_2O_5). The soil test (Auburn University Soil Testing Lab) recommended 240 lbs./A N, 200 lbs/A P, and 180 lbs./A K (Red Fox Fertilizer, Dothan, AL). The rate of 72 lbs/A N, 54 lbs./A K, and 200 lbs./A P was applied before the beds were formed. Prior to transplanting, four, 18” wide raised beds were formed and 1mil black plastic polyethylene mulch was laid on top of the beds inside the high tunnel utilizing a mulch bedder (Reddick Fumigants, Wilmington, NC). The beds were 90 feet long and one and a half feet wide. T-Tape® (0.45gpm/100ft) (T-Systems International, San Diego CA) was laid underneath the plastic mulch. Tomatoes were fertigated using drip tape with a Dosatron® (Clearwater, FL) fertilizer injector. Tomatoes were fertilized weekly with potassium nitrate (KNO_3) alternated with calcium nitrate $Ca(NO_3)_2$. Alternating the two fertilizers was done for the duration of the experiment and were scheduled as described by Kemble et al. (2004). During production, the plants were suckered and tied up as needed on four foot wooden stakes placed between every other plant for tying purposes (Kemble et al., 2004). Additional heat was supplied by portable, propane heaters, when needed. The experimental design was a completely randomized design (CRD) with four replications. Each row within the high tunnel was a replication. Each variety of tomato was put in a single row. Data collection included fruit weight, grades (extra large, large, medium, small, culls) and number of fruit based on USDA standards. The first harvest was on 25 May and harvest continued until 12 July on a twice weekly schedule. Fruit harvested was in the light red to red stage according to USDA standards. The harvest season was separated into three harvest periods. The early-season yields were grouped into the first five harvest dates: May 25th, May 28th, June 1st, June 4th, and June 7th The mid-season harvests were the next five harvests, which included June 10th, June 14th, June 17th, June 21st, and June 24th. The late-season harvests consisted of the following dates of June 28th, June 30th, July 6th, July 8th, and July 12th. Data was analyzed with SAS's Proc GLM procedure for ANOVA and Duncan's Multiple Range Test (P=0.05) was used to determine differences among the means (SAS Institute, Cary, NC).

FALL 2004. In the fall of 2004, a comparative yield study using tomato varieties 'Florida 91' and 'BHN 640' was conducted at the Wiregrass Research and Extension

Center in Headland, AL. The tomatoes were grown from seed at the Plant Science Research Center at Auburn University in Auburn, Al. Seeds were planted in 36 cell market flats on 30 July filled with Canadian Growing Mix 2 (Conrad Fafard Inc., Agawan, MA) and grown for three weeks. After three weeks of growth, the transplants were hardened off as described above. Tomato transplants were planted 31 August for late fall production. Each treatment consisted of nine plants in a 13.5 foot plot. There was 1.5 feet between each plot. Plants were treated with Terraclor® (Crompton Manufacturing Company, Inc. Middlebury, CT) at transplanting using labeled rates as a drench application to transplants. The plants were grown on white plastic mulched covered beds that were formed by a mulch bedder (Reddrick Fumigants, Wilmington NC) and underlain with T-Tape® (0.45gpm/100ft) (T-Systems International, San Diego CA) for irrigation. The plants were irrigated as needed to supply 1.5 acre-inches of water per week. A weekly rotation of $Ca(NO_3)_2$ and KNO_3 was applied as described above. There was a pre-plant application of fertilizer at the equivalent of 60 lbs./A N, 200 lbs./A P, and 72 lbs./A K (Red Fox Fertilizer, Dothan, AL) as described above.

During production, the plants were suckered and tied up as needed on stakes placed between every other plant for tying purposes (Kemble et al., 2004). When needed additional heat was supplied by portable, propane heaters. There were seven harvest dates for the experiment. Fruit harvested was in the light red to red stage according to USDA standards. Data collected included fruit weight, grades, number of fruit, and harvest dates. Fruit grades were recorded as extra large, large, medium, small, and cull as prescribed by USDA standards. Only ripe fruit was harvested. The two treatments (varieties) were arranged in a completely randomized design (CRD) experiment with three replications of each variety. Each row was divided in to three plots to allow for a random planting of any tomato variety in any plot in each row. Each replication was planted in a single plot. Data was analyzed with SAS's Proc GLM procedure for ANOVA and Duncan's Multiple Ranged Test (P=0.05) was used to determine differences among the means (SAS Institute, Cary, NC).

Tomato Planting Date Study

SPRING 2005. A planting date study was conducted in the spring of 2005 to determine optimum planting dates for early spring tomato production in high tunnels for southeast Alabama. In this experiment, there were four planting dates starting in late January and repeated approximately every two weeks thereafter (31 January, 17 February, 4 March, and 25 March, 2005), with each planting date consisting of two tomato varieties ('BHN 640' and 'Florida 91') with three replications for each treatment. Tomatoes were transplanted into the high tunnel at the Wiregrass Research and Extension Center.

Tomato seedlings were grown at the Plant Science Research Center at Auburn University as described above. After germination, seedlings were fertilized once a week with a 20N-4.4P-16.6K water soluble fertilizer (Peter's 20-10-20) (The Scotts Company, Marysville, OH) at the rate of 265 mg/L N. After three weeks of growth, seedlings were hardened off as described above. Black plastic mulch and drip tape were laid as described above. Additional heat was supplied by portable propane heaters, when needed.

The experiment design was a split-plot design with planting dates serving as the main effect and variety serving as the subplot. There were 9 plants per subplot that were spaced one and a half feet apart with a one and a half foot space between the subplots. There was a two-foot spacing between the plots. Each of the five rows was separated in to three plots to allow any replication of any planting date to be planted in any plot of any row. A preplant application of N, P, and K was applied at a rate of 60 lbs./A N, 200 lbs./A P, and 72 lbs/A K(Red Fox Fertilizer, Dothan, AL). Fertigation was done as described above.

Data collected included fruit weight, grades, number of fruit, and harvest dates. Fruit was harvested in the light red to red stage according to USDA standards. Data was analyzed with SAS's Proc GLM procedure for ANOVA and Fisher's T-Test (P=0.05) was used to determine differences between the means (SAS Institute Cary, NC).

Growth Chamber Study for Determining Suitable Varieties for Late Fall and Early Spring Production of Tomatoes in High Tunnels

A growth chamber study was conducted to determine suitable varieties for late fall and early spring high tunnel production in the Wiregrass region of Alabama. The varieties selected, except for 'BHN 640' and 'Florida 91', were cold tolerant varieties typically field grown in the northwestern U.S. and Alaska. The experiment was conducted at the Plant Science Research Greenhouses at Auburn University, AL. Ten varieties were selected for the study as follows: 'BHN 640', 'Florida 91', 'Glacier', 'Legend', 'Northern Delight', 'Oregon Spring', 'Polar Beauty', 'Santiam', 'Siletz', and 'Subartic'. All 10 varieties were seeded on 7 April 2005, into 36 cell market flats and were grown as previously described. After emergence, seedlings were watered as needed and fertilized once a week with a 20N-4.4P-16.6K water soluble fertilizer (Peter's Plant Food 20-10-20 (The Scotts Co, Marysville, OH) at the rate of 2.8 grams per gallon.

Transplants were hardened off four weeks after planting as described above and were then transplanted on May 11th into three-gallon pots with Canadian Growing Mix #2 (Conrad Fafard Inc., Agawan, MA) and placed into the growth chambers the same day. One plant of each variety was in each growth chamber for a total of ten plants in three growth chambers. The plants were approximately one foot from each other. The plants were staked and tied up as needed in order to maintain upright growth. Pollination was accomplished by shaking the flowers with an electric toothbrush every other day. After flowering began, the tomato plants were fertilized twice a week with a 20N-4.4P-16.6K water soluble fertilizer (Peter's Plant Food 20-10-20) (The Scotts Co, Marysville, OH) at the rate of 2.8 grams per gallon. The growth chamber was set to simulate temperatures and light duration observed in the high tunnel at the Wiregrass Research and Extension Center in Headland, AL during late fall and early spring. Data loggers had been placed in the high tunnel to record the rise and fall of temperature. The controls on the growth chamber were set to rise every hour in relation to the rise recorded in the high tunnel until temperature peaked at which time a scheduled drop in temperature was set to take place. Lights within the growth chamber were set to come on for 12 hours coinciding with the rise and fall of temperatures thus simulating morning and afternoon. The experimental design was a completely randomized block design with growth chambers serving as blocks. Once the plants began to produce fruit, the fruit was harvested at the light red to red stage according to USDA standards and weighed and graded as described above.

This study was repeated in the summer of 2005 with all factors remaining the same except planting dates. The tomatoes were seeded on 2 June at the Plant Science Research greenhouses and cared for the same as the first study. After four weeks of growth, they were hardened off as described above and transplanted on July 9th. The same fertilization schedule was maintained for this experiment as described above. Pollination was accomplished by shaking the flowers with an electric tooth-brush every other day. All fruit weights were recorded as well as harvest dates and grades; extra large, large, medium, small, and cull. Data was analyzed with SAS's PROC GLM procedure for ANOVA and Duncan's multiple Ranged Test (P=0.05) was used to determine differences between the means (SAS Institute Cary, NC).

RESULTS AND DISCUSSION

Variety Yield Experiment

SPRING 2004. Analysis of variance (ANOVA) revealed no differences in total marketable (Table 1; Figure 1) or unmarketable yields (data not shown) among the varieties tested. Some differences in yields were detected by ANOVA when the harvests were split into early, mid, and late-season harvests (Tables 2, 3, and 4).

'BHN 640' had higher total marketable yields than 'FLA 91' and 'Carolina Gold' during the early-season period (Table 2; Figure 2). 'BHN 640' also had a higher amount of extra-large fruit than 'Carolina Gold'. 'BHN 640' had greater yields of large and medium sized fruit than 'FLA 91' and 'Carolina Gold'. 'Sunleaper' was equal to 'BHN 640' in total marketable yields, extra-large, large, and medium sized yields (Table 2). There were no differences in total marketable yields, but 'BHN 640' yielded on average 20 lbs. more than 'Carolina Gold', about nine lbs. more than 'FLA 91', and three pounds less than 'Sunleaper'.

The mid-season harvest revealed no differences, except for large and medium sized tomatoes (Table 3). 'BHN 640' had a higher amount of marketable large sized fruit than ‘FLA 91’ and ‘Carolina Gold’. ‘Sunleaper’ had higher marketable large sized tomatoes than ‘Carolina Gold’. ‘Sunleaper’ also had a higher amount of medium sized marketable tomatoes than all others (Table 3; Figure 3). Overall yields increased numerically during this timeframe, which included 10 June, 14 June, 17 June, 21 June, and 24 June. ‘BHN 640’ yielded 19.98 lbs. more than ‘Carolina Gold’, and 9.33 lbs. more than ‘Florida 91’ for total mid-season yield. However, no differences were observed in total marketable category for fruit during the mid-season harvest. There were however, some differences during this mid-season harvest period in large-sized fruit (Table 3). ‘BHN 640’ was higher than ‘FLA 91’ and ‘Carolina Gold’ while ‘Sunleaper’ was also higher than ‘Carolina Gold’ (Table 3). As for the other size grades, there were no differences.

The late season harvest period revealed differences for total marketable fruit and extra-large fruit (Table 4; Figure 4). ‘FLA 91’ had more fruit weight per plant for total marketable yield than ‘BHN 640’ during the late season harvest (Table 4). ‘FLA 91’ also produced higher yields of extra-large sized tomatoes than ‘BHN 640’, with large, medium, and small size grades for all varieties all similar.

While there were no differences among the four varieties in total marketable yields for the entire season, some early season differences were noteworthy. Our study indicated that early production of tomatoes in a high tunnel system can be achieved in southeastern Alabama. Premium prices for early tomatoes can be achieved by selecting ‘BHN 640’ and to a lesser degree, ‘Sunleaper’. The total amount of fruit per plant for all varieties was very positive. Yields ranged from 11.59 lbs. per plant for ‘Sunleaper’ to 9.01 lbs. per plant for ‘Carolina Gold’. In this high tunnel we were able to plant 60 plants per 90 foot-row. An average of 11.0 lbs. per plant of marketable fruit would yield 660 lbs. of fruit per row. Early-season tomato prices are normally $2.00 per lb. (Foshee, pers.comm), which would generate approximately $1,330 per row in gross returns. Therefore five rows within this high tunnel would have generated approximately $6,650 of gross income. On a per acre basis, approximately 63,888 lbs/Ac of fruit would be produced at a gross profit of $127,776. Also, early season yields were three weeks ahead of conventional field production in the area.

Furthermore, the small amount of land required and potential gross returns appear to be very promising. Continued research is needed to refine tomato production in high tunnels for various climatic zones in Alabama.

FALL 2004. Marketable yield was affected by this late-planting date study between ‘BHN 640’ and ‘Florida 91’ varieties (Table 5). Total marketable yield for ‘BHN 640’ was 3.04 lbs. of fruit per plant, which was higher than ‘Florida 91’ at 2.09 lbs. of fruit per plant (Table 5). Only ripe fruit was harvested and not mature green fruit, which would have added greatly to the yields and were evaluated in another study. Yields of ‘BHN 640’ were 31% higher than ‘Florida 91’ for marketable fruit. There was a difference of $97.69 in gross returns at the price of $3.80 per lb., which this type fruit sold for during the fall of 2004.

Marketable fruit weights for each harvest date revealed some differences (Figure 5). On 3 December, cull weights were higher for ‘BHN 640’ than ‘Florida 91’. On 9 December, large fruit weight was higher for ‘BHN 640’ than for ‘FLA 91’. On 21 December, ‘BHN 640’ yields were higher for large, medium, marketable, and unmarketable fruit weights than yields for ‘FLA 91’. On 27 December, ‘BHN 640 yields were higher than ‘FLA 91’ in extra large, large, medium, small, and marketable weights (Table 5).

Seasonal yield totals for this experiment were all higher for ‘BHN 640’ than for ‘FLA 91’ for large, medium, small, marketable, and unmarketable fruit weights (Table 5). There was no harvest date on which ‘Florida 91’ out yielded ‘BHN 640’.

For this study, our first harvest date was on 29 November and the last harvest date was on 4 January (Table 5), which is rather extraordinary for a production system that only had heat added at times when the temperature was predicted to drop below 7.2°C (45° F) for an extended period of time within the high tunnel. It was during this time of year that the price for tomatoes was high and we received as much as $3.80 per pound from a local restaurant, due in large part to hurricane damaged Florida tomato crops. ‘BHN 640’ outperformed ‘Florida 91’ in our study by 25.71 lbs of marketable fruit and had 4.7 lbs. more unmarketable fruit than ‘Florida 91’. From our studies, we conclude that ‘BHN 640’ would be the variety of choice over ‘Florida 91’ for late fall production of tomatoes for season extension in high tunnels in southeast Alabama.

<u>Planting Date Study</u>

<u>SPRING 2005</u>. On 16 and 17 February, 2005 wind gusts as high as 19 mph occurred for several hours causing some damage to the high tunnel by tearing the plastic on one side during the night leading to severe damage and death of some tomato plants. Reduced plant density affected the first and second planting dates since the third planting was on 4 March. On 11 March, another wind event caused further damage to the end walls of the high tunnel. Harvest weights were adjusted to account for missing tomato plants from each wind event and analyzed accordingly on a per plant basis. Each

experimental unit initially had 9 plants per plot with percent survival ranging from 10% to 100% (Table 6).

Planting date affected total marketable yields (Table 7). These were differences in weekly harvest yields for the first planting date (31 Jan.) (Table 7). During the first harvest week of 31 May, fruit harvested came exclusively from the first (31 Jan.) and second (17 Feb.) planting dates (Table 7). For the second (3 June), third (9 June), and fourth harvest weeks (13 and 16 June), planting date one (31 Jan.) produced greater yields than planting date three (4 Mar.) and four (25 Mar.) (Table 7). The third harvest week resulted in a variety difference in which 'BHN 640' was higher in marketable yields than 'FLA 91' for all planting dates (Table 7). In the third, fourth, and fifth (20 and 24 June) harvest weeks, an interaction between variety and planting date was seen. 'BHN 640' of planting date one (31 Jan.) was higher in marketable yields than 'BHN 640' of planting date four (25 Mar.) (Table 7). An interaction between planting date and variety occurred during the fourth harvest week. The yield from 'BHN 640' of planting date one was higher than the yield of 'BHN 640' of planting date four (Table 7). The fifth harvest week resulted in planting date two (Feb. 17th) producing higher yields than planting date four (Table 7). An interaction between planting date and variety occurred during the sixth harvest week (27 June). 'BHN 640' yield of planting date three was greater than 'FLA 91'yield of planting date four (Table 7). There were no differences in the week seven harvest (5 July) (Table 7)

Planting date affected total marketable yields (Table 7). Differences in yields were observed for six of the seven weekly harvests for the first planting date (31 Jan.) (Table 7). During the first harvest week (31 May), fruit harvested came exclusively from the first (31 Jan) and second (17 Feb.) planting dates (Table 7). For the second (3 June), third (9 June), and fourth harvest weeks (13 and 16 June), planting date one (31 Jan) produced greater yields than planting date three (4 Mar.) and four (25 Mar.) (Table 7). During the third and sixth harvests a variety difference was seen with ‘BHN 640’ having higher marketable yields than ‘FLA 91’ for all planting dates (Table 7).

Overall, the total marketable yields for the season showed that the first planting date (31 Jan.) had greater yields than planting date four (25 Mar.). Furthermore, planting date two (17 Feb.) produced greater total marketable yields than planting date four (25 Mar.) (Table 7).

Results from this one-year study indicate that early planted tomatoes in a high tunnel system could produce marketable tomato yields; however, further investigation would be needed to develop a recommendation. Although this study experienced two major setbacks due to weather, harvest began 16 days earlier than field grown tomatoes. Local growers in the area began picking fruit on 15 June (John Aplin, pers. comm.). With the price for fresh tomatoes being higher during this timeframe, high tunnel production systems showed promise for greater profit potential for growers.

Growth Chamber Tomato Variety Trial

An interaction occurred between the two repetitions of this experiment so each individual test are described separately below.

Spring 2005. There were no differences for total yields for extra-large grade fruit (Table 8). The same trend was observed for the yield of large-grade fruit (Table 9). Differences were evident in total yields for medium-grade tomatoes (Table 10). ‘Polar Beauty’ produced greater yields for medium-grade yields than ‘Oregon Spring’, ‘Subartic’, ‘Northern Delight’, and ‘Legend’ varieties. Varieties ‘Santium’, ‘Florida 91’, ‘BHN 640’, ‘Siletz’, ‘Glacier’, ‘Oregon Spring’, ‘Subartic’, ‘Northern Delight’, and ‘Legend’ were all similar. Small-grade tomato yields had differences (Table 11). ‘Northern Delight’ had greater yields than ‘Polar Beauty’, ‘Santium’, ‘Siltez’, ‘BHN 640’, ‘Florida 91’, ‘Oregon Spring’, and ‘Legend’ (Table 11). ‘Northern Delight’ was similar to ‘Glacier’ and ‘Subartic’ in medium grade yields. ‘Glacier’ was also similar to ‘Polar Beauty’ in medium grade yields. ‘Subartic’ was also similar to ‘Polar Beauty’ and ‘Santiam’ in medium grade yields. ‘Polar Beauty’ was similar to ‘Santiam’, ‘Siletz’, and ‘BHN 640’ in medium grade yields. ‘Florida 91’, ‘Oregon Spring’, and ‘Legend’ produced the lowest yields but were similar to ‘Santiam’, ‘Siletz’, and ‘BHN 640’. ‘Siletz’ produced more culls than ‘Santium’, ‘Polar Beauty’, ‘Subartic’, ‘Glacier’, ‘Northern Delight’, ‘BHN 640’, ‘Florida 91’, and ‘Oregon Spring’ (Table 12). ‘Legend’ was similar to all treatments in cull-grade yields (Table 12).

Total marketable yield without the inclusion of the small-fruit grade did not differ (Table 13); however, marketable yield with the inclusion of the small-sized fruit was affected by variety (Table 14). ‘Northern Delight’ and ‘Polar Beauty’ had greater yields than the standard varieties of ‘BHN 640’ and ‘FLA 91’ along with cold tolerant selections of ‘Legend’ and ‘Oregon Spring’ (Table 14). ‘Glacier’ and ‘Subartic’ had greater marketable yields than ‘Legend’ and ‘Oregon Spring’ as well (Table 14). ‘Northern Delight’ was similar to ‘Polar Beauty’, ‘Glacier’, ‘Subartic’, ‘Santium’, and ‘Siletz’ in total marketable yields. Marketable yields of ‘Glacier’ was similar to ‘Subartic’, ‘Santiam’, ‘Siletz’, ‘BHN 640’, and ‘Florida 91’. The varieties ‘Santiam’, ‘Siletz’, ‘BHN 640’, ‘Florida 91’, and ‘Polar Beauty’ were all similar in terms of total marketable yields. ‘Siletz’, ‘BHN 640’, ‘Florida 91’, ‘Legend’, and ‘Oregon Spring’ were all similar in total marketable yields.

This study revealed that some of the northern type varieties of tomatoes might possibly outperform ‘BHN 640’ and ‘Florida 91’ in a high tunnel setting. As such, growers could possibly extend the season beyond that of ‘BHN 640’ and ‘Florida 91’ leading to higher potential profits.

<u>Summer 2005</u>. The ten varieties were similar in total marketable yields except where ‘BHN 640’ and ‘FLA 91’ outyielded ‘Glacier’, ‘Siletz’, ‘Subartic’, ‘Northern Delight’, and ‘Oregon Spring’ (Table 15). More differences were observed by including the small grade tomato yields (Table 16). ‘BHN 640’ outyielded ‘Glacier’, ‘Siletz’, and ‘Oregon Spring’, but was similar to all other varieties (Table 16).

Some differences were evident in the size grades for tomatoes. ‘Florida 91’ and ‘BHN 640’ had higher yields of extra-large fruit than all other treatments except ‘Legend’ (Table 17). All large-size fruit yields were similar (Table 18).

There were some differences within the medium-grade category (Table 19) with ‘BHN 640’, ‘Santiam’, and ‘Polar Beauty’ all producing more medium sized fruit as compared to ‘Glacier’, ‘Siletz’, ‘Subartic’, ‘Northern Delight’, and ‘Oregon Spring’. ‘Legend’ and ‘Florida 91’ were similar to all other varieties in terms of medium sized fruit. The small-yields revealed the most differences of any fruit grade (Table 20). ‘Northern Delight’ had greater yields than ‘Legend’, ‘Santium’, ‘BHN 640’, ‘Siletz’, ‘Florida 91’, and ‘Oregon Spring’. ‘Subartic’, ‘Glacier’, ‘Polar Beauty’, ‘Legend’ and ‘Santium’ all had similar yields. ‘Subartic’ had produced more small sized fruit than

‘BHN 640’. ‘Legend’, ‘Santium’, ‘BHN 640’, ‘Siletz’, ‘FLA 91’, and ‘Oregon Spring’ were all similar. All treatments were similar in cull yields (Table 21).

The second study indicated ‘BHN 640’ to be the best choice of the varieties evaluated for early and late season production of high tunnel tomatoes in southeast Alabama. ‘Polar Beauty’ and ‘Legend’ performed well enough to warrant more research. While other varieties were similar, they do not warrant as much attention as the ‘BHN 640’, ‘Polar Beauty’, and ‘Legend’.

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Table 1. Total marketable yields (lbs. per plant) for spring 2004 high tunnel tomato variety yield study conducted at the Wiregrass Research and Extension Center, Headland, AL.

Variety	Yield Lbs./Plant [z]
‘BHN 640’	11.13a
‘Sunleaper’	11.59a
‘Florida 91’	10.00a
‘Carolina Gold’	9.01a

[z] Means followed by the same letter are not different according to Duncan’s Multiple Range Test ($P \leq 0.05$).

Table 2. Total marketable yields (lbs. per plant) for the early-season harvest period for the high tunnel tomato variety yield study 2004 conducted at the Wiregrass Research and Extension Center, Headland, AL.

Grade Size[z]	Variety	Yield Lbs./Plant[y]
X-large	'BHN 640'	1.73a
	'Sunleaper'	1.5ab
	'Florida 91'	0.87ab
	'Carolina Gold'	0.67b
Large	'BHN 640'	0.3a
	'Sunleaper'	0.28ab
	'Florida 91'	0.11c
	'Carolina Gold'	0.14bc
Medium	'BHN 640'	0.08a
	'Sunleaper'	0.1a
	'Florida 91'	0.02b
	'Carolina Gold'	0.01b
Marketable	'BHN 640'	2.12a
	'Sunleaper'	1.85ab
	'Florida 91'	0.8c
	'Carolina Gold'	1.04bc

[z] USDA standard grades for fresh tomatoes (http://www.ams.usda.gov/standards/tomatfrh.pdf).

[y] Means followed by the same letter are not different according to Duncan's Multiple Range Test ($P \leq 0.05$).

Table 3. Total marketable yields (lbs. per plant) for the mid-season harvest period for the high tunnel tomato variety yield study 2004 conducted at the Wiregrass Research and Extension Center, Headland, AL.

Grade Size	Variety	Yield Lbs./Plant [y]
X-large	'BHN 640'	5.18a
	'Sunleaper'	5.24a
	'Florida 91'	5.06a
	'Carolina Gold'	4.21a
Large	'BHN 640'	1.54a
	'Sunleaper'	1.47ab
	'Florida 91'	1.01bc
	'Carolina Gold'	0.95c
Medium	'BHN 640'	0.33b
	'Sunleaper'	0.57a
	'Florida 91'	0.27b
	'Carolina Gold'	0.36b
Marketable	'BHN 640'	7.05a
	'Sunleaper'	7.28a
	'Florida 91'	6.33a
	'Carolina Gold'	5.51a

[z]USDA standard grades for fresh tomatoes (http://www.ams.usda.gov/standards/tomatfrh.pdf).

[y] Means followed by the same letter are not different according to Duncan's Multiple Range Test ($P \leq 0.05$).

Table 4. Total marketable yields (lbs. per plant) for the late-season harvest period for the high tunnel tomato variety yield study 2004 conducted at the Wiregrass Research and Extension Center, Headland, AL.

Grade Size [z]	Variety	Yield Lbs./Plant [y]
X-large	'BHN 640'	1.24b
	'Sunleaper'	1.55ab
	'Florida 91'	2.22a
	'Carolina Gold'	1.59ab
Large	'BHN 640'	0.77a
	'Sunleaper'	0.7a
	'Florida 91'	0.53a
	'Carolina Gold'	0.5a
Medium	'BHN 640'	0.18a
	'Sunleaper'	0.15a
	'Florida 91'	0.15a
	'Carolina Gold'	0.16a
Marketable	'BHN 640'	1.96b
	'Sunleaper'	2.45ab
	'Florida 91'	2.86a
	'Carolina Gold'	2.45ab

[z] USDA standard grades for fresh tomatoes (http://www.ams.usda.gov/standards/tomatfrh.pdf).
[y] Means followed by the same letter are not different according to Duncan's Multiple Range Test ($P \leq 0.05$).

Table 5. Yield comparison (lbs. per plant) of ‘BHN 640’ and ‘Florida 91’ in the Fall 2004 high tunnel tomato variety yield study conducted at the Wiregrass Research and Extension Center, Headland, AL.

Fruit grade [z]	Variety	29 Nov 2004	3 Dec 2004	9 Dec 2004	16 Dec 2004	21 Dec 2004	27 Dec 2004	4 Jan 2005	Total [y]
Extra large	‘BHN 640’	0.26a	0.18a	0.12a	0.17a	0.55a	0.38a	0.62a	2.11a
	‘Florida 91’	0.10a	0.07a	0.03a	0.14a	0.63a	0.21b	0.64a	1.76a
Large	‘BHN 640’	0.01a	0.01a	0.05a	0.01a	0.24a	0.19a	0.21a	0.71a
	‘Florida 91’	0.01a	0.00a	0.00b	0.02a	0.05b	0.06b	0.14a	0.28b
Medium	‘BHN 640’	0.00a	0.00a	0.01a	0.00a	0.08a	0.08a	0.03a	0.21a
	‘Florida 91’	0.00a	0.00a	0.00a	0.00a	0.02b	0.012b	0.00a	0.04b
Small	‘BHN 640’	0.00a	0.00a	0.00a	0.00a	0.01a	0.03a	0.00a	0.04a
	‘Florida 91’	0.00a	0.00a	0.00a	0.00a	0.00a	0.00b	0.00a	0.01b
Cull	‘BHN 640’	0.09a	0.02a	0.02a	0.10a	0.21a	0.05a	0.18a	0.66a
	‘Florida 91’	0.04a	0.01b	0.00a	0.06a	0.08a	0.12a	0.21a	0.52a
Marketable	‘BHN 640’	0.26a	0.19a	0.17a	0.18a	0.88a	0.66a	0.86a	3.04a
	‘Florida 91’	0.11a	0.07a	0.03a	0.16a	0.71b	0.28b	0.78a	2.08b
Unmarketable	‘BHN 640’	0.09a	0.02a	0.02a	0.11a	0.22a	0.07a	0.19a	0.69a
	‘Florida 91’	0.04a	0.01a	0.00a	0.06a	0.07b	0.12a	0.22a	0.52b

[z]USDA standard grades for fresh tomatoes (http://www.ams.usda.gov/standards/tomatfrh.pdf).

[y] Means followed by the same letter within a column and fruit grade are not different according to Fisher's t-test, alpha=0.10.

Table 6. Tomato plant deaths and percent injury in the high tunnel due to wind damage. data was taken on April 5th, 2005 at the Wiregrass Research and Extension Center, Headland, AL.

Planting date		Treatment	Replication	live plants[z]	%survival[y]	Rating(of 100)[x]
31 Jan	1	'BHN 640'	3	1	11	100
	1	'Florida 91'	3	2	22	100
	1	'Florida 91'	2	8	89	100
	1	'BHN 640'	2	6	67	100
	1	'Florida 91'	1	5	56	100
	1	'BHN 640'	1	5	56	100
17 Feb	2	'BHN 640'	2	4	44	100
	2	'Florida 91'	2	9	100	100
	2	'BHN 640'	1	6	67	100
	2	'Florida 91'	1	4	44	70
	2	'BHN 640'	3	9	100	100
	2	'Florida 91'	3	4	44	100
4 Mar	3	'Florida 91'	3	8	89	80
	3	'BHN 640'	3	8	89	65
	3	'Florida 91'	1	8	89	70
	3	'BHN 640'	1	9	10	70
	3	'Florida 91'	2	5	56	45
	3	'BHN 640'	2	5	56	60
25 Mar	4	'BHN 640'	3	7	78	20
	4	'Florida 91'	3	9	100	30
	4	'BHN 640'	1	9	100	35
	4	'Florida 91'	1	9	100	35
	4	'Florida 91'	2	5	56	20
	4	'BHN 640'	2	9	100	30

[z]The rating for live plants is out of 9.

[y]The rating for % survival is out of 100.

[x] The rating for the rating (out of 100) is a visual rating where 100 is a healthy plant and 0 is a dead plant.

Table 7. Marketable Yields (lbs. per plant) by planting date and harvest date for Spring, 2005 Planting Date Study at the Wiregrass Research and Extension Center, Headland, AL.

Planting Date	24 May	31 May-3 June	6 June-9 June	13 June-16 June	20 June-24 June	27 June	5 July	Total Marketable	Total Unmarketable[z]
Jan. 31st									
P.D. 1	0.09	0.1.8*	0.09**	3.57**	4.02**	0.96	2.46	14.58*	1.68
‘BHN 640’	(0.18)	(4.62)	(5.7)	(9.21)	(9.18)	(3.81)	(5.76)	(37.56)	(3.6)
‘Florida 91’	(0.03)	(2.67)	(5.55)	(5.58)	(7.08)	(0.42)	(4.29)	(22.47)	(3.18)
Feb. 17th									
P.D. 2	0.09	0.81	0.81	1.65*	2.34*	0.93	1.5	8.19*	1.14
‘BHN 640’		(1.98)	(2.34)	(4.11)	(3.3)	(01.8)	(3.75)	(17.67)	(2.67)
‘Florida 91’		(1.2)	(0.78)	(2.16)	(6.21)	(1.86)	(2.22)	(14.88)	(1.83)
Mar. 4th									
P.D. 3	0	0.03	0.24*	0.72**	1.41	0.99*	1.77	5.19	0.45
‘BHN 640’		(0.06)	(0.72)	(1.53)	(3.15)	(2.31)	(3.45)	(11.25)	(1.14)
‘Florida 91’		(0)	(1.83)	(1.41)	(2.49)	(1.68)	(3.63)	(9.42)	(0.63)
Mar. 25th									
P.D. 4	0	0*	0.09**	0.21**	0.66**	0.42*	1.05	2.46*	0.48
‘BHN 640’			(0.3)	(0.54)	(1.44)	(0.63)	(0.84)	(3.75)	(1.02)
‘Florida 91’			(0.09)	(0.33)	(1.26)	(1.11)	(3.45)	(6.18)	(0.9)
Planting Date	NS	**	**	**	**	*	NS	**	
Variety	NS	NS	**	NS	NS	*	NS	NS	
P.D.*Var	NS	NS	NS	NS	NS	*	NS	NS	

[z] Means followed by the same letter within a column and fruit grade are not different according to Duncan’s Multiple Range Tests.

*P≤0.01

**P≤0.05

Table 8. Statistical grouping for the yields of the extra-large-grade [z] tomatoes harvested from the first growth chamber study conducted at the Plant Science Research Center at Auburn University, AL.

Variety	Mean weight (grams) [y]
‘Florida 91’	86.79a
‘Polar Beauty’	77.11a
‘BHN 640’	75.67a
‘Siletz’	67.95a
‘Glacier’	0a
‘Oregon Spring’	0a
‘Santiam’	0a
‘Subartic’	0a
‘Northern Delight’	0a
‘Legend’	0a

[z] USDA standard grades for fresh tomatoes (http://www.ams.usda.gov/standards/tomatfrh.pdf).

[y] Means followed by the same letter are not different according to Duncan’s Multiple Range Tests ($P \leq 0.05$).

Table 9. Statistical grouping for the yields of the large-grade [z] tomatoes harvested from the first growth chamber study conducted at the Plant Science Research Center at Auburn University, AL.

Variety	Mean weight (grams) [y]
‘Siletz’	97.28a
‘Polar Beauty’	45.2a
‘Santiam’	44.57a
‘Legend’	40.14a
‘Northern Delight’	0a
‘Glacier’	0a
‘BHN 640’	0a
‘Subartic’	0a
‘Florida 91’	0a
‘Oregon Spring’	0a

[z] USDA standard grades for fresh tomatoes (http://www.ams.usda.gov/standards/tomatfrh.pdf).
[y] Means followed by the same letter are not different according to Duncan’s Multiple Range Test ($P \leq 0.05$).

Table 10. Statistical grouping for the yields of the medium-grade [z] tomatoes harvested from the first growth chamber study conducted at the Plant Science Research Center at Auburn University, AL.

Variety	Mean weight (grams) [y]
'Polar Beauty'	191.47a
'Santiam'	111.6ab
'Florida 91'	46.73ab
'BHN 640'	45.4ab
'Siletz'	25.65ab
'Glacier'	17.63ab
'Oregon Spring'	0b
'Subartic'	0b
'Northern Delight'	0b
'Legend'	0b

[z] USDA standard grades for fresh tomatoes (http://www.ams.usda.gov/standards/tomatfrh.pdf).

[y] Means followed by the same letter are not different according to Duncan's Multiple Range Test ($P \leq 0.05$).

Table 11. Statistical grouping for the yields of the small-grade [z] tomatoes harvested from the first growth chamber study conducted at the Plant Science Research Center at Auburn University, AL.

Variety	Mean weight (grams) [y]
'Northern Delight'	645.4a
'Glacier'	459.2ab
'Subartic'	435.2abc
'Polar Beauty'	301.7bcd
'Santiam'	222.6cde
'Siletz'	98.5de
'BHN 640'	75.7de
'Florida 91'	44.1e
'Oregon Spring'	0e
'Legend'	0e

[z] USDA standard grades for fresh tomatoes (http://www.ams.usda.gov/standards/tomatfrh.pdf).

[y] Means followed by the same letter are not different according to Duncan's Multiple Range Test ($P \leq 0.05$).

Table 12. Statistical grouping for the yields of the cull-grade [z] tomatoes harvested from the first growth chamber study conducted at the Plant Science Research Center at Auburn University, AL.

Variety	Mean weight (grams) [y]
'Siletz'	284.06a
'Legend'	128.66ab
'Santiam'	75.3b
'Polar Beauty'	56.97b
'Subartic'	40.05b
'Glacier'	32.68b
'Northern Delight'	7.82b
'BHN 640'	0b
'Florida 91'	0b
'Oregon Spring'	0b

[z] USDA standard grades for fresh tomatoes (http://www.ams.usda.gov/standards/tomatfrh.pdf).
[y] Means followed by the same letter are not different according to Duncan's Multiple Range
Test (P≤0.05).

Table 13. Statistical grouping for the yields of the total marketable yields [z] harvested from the first growth chamber study conducted at the Plant Science Research Center at Auburn University, AL.

Variety	Mean weight (grams) [y]
'Polar Beauty'	313.8a
'Siletz'	190.9a
'Santiam'	156.2a
'Florida 91'	133.5a
'BHN 640'	121.1a
'Legend'	40.1a
'Glacier'	17.6a
'Oregon Spring'	0a
'Northern Delight'	0a
'Subartic'	0a

[z] USDA standard grades for fresh tomatoes (http://www.ams.usda.gov/standards/tomatfrh.pdf).

[y] Means followed by the same letter are not different according to Duncan's Multiple Range Test ($P \leq 0.05$).

Table 14. Statistical grouping for yields of the total marketable yields [z] combined with the small-grade yields from the first growth chamber study conducted at the Plant Science Research Center at Auburn University, AL.

Variety	Mean weight (grams) [y]
'Northern Delight'	645.4a
'Polar Beauty'	615.5a
'Glacier'	476.8ab
'Subartic'	435.2ab
'Santiam'	378.7abc
'Siletz'	289.4abcd
'BHN 640'	196.7bcd
'Florida 91'	177.6bcd
'Legend'	40.1cd
'Oregon Spring'	0d

[z] USDA standard grades for fresh tomatoes (http://www.ams.usda.gov/standards/tomatfrh.pdf).
[y] Means followed by the same letter are not different according to Duncan's Multiple Range Test ($P \leq 0.05$).

Table 15. Statistical grouping for the yields of the total marketable yields [z] harvested from the second growth chamber study conducted at the Plant Science Research Center at Auburn University, AL.

Variety	Mean weight (grams) [y]
'BHN 640'	785a
'Florida 91'	529a
'Legend'	445.3ab
'Polar Beauty'	405.4ab
'Santiam'	348.4ab
'Glacier'	0b
'Siletz'	0b
'Subartic'	0b
'Northern Delight'	0b
'Oregon Spring'	0b

[z] USDA standard grades for fresh tomatoes (http://www.ams.usda.gov/standards/tomatfrh.pdf).
[y] Means followed by the same letter are not different according to Duncan's Multiple Range Test ($P \leq 0.05$).

Table 16. Statistical grouping for the yields of the total marketable yields [z] combined with the yields of the small-grade tomatoes harvested from the second growth chamber study conducted at the Plant Science Research Center at Auburn University, AL.

Variety	Mean weight (grams) [y]
‘BHN 640’	939.4a
‘Polar Beauty’	718.7ab
‘Legend’	669.7ab
‘Northern Delight’	559.2ab
‘Santiam’	558.2ab
‘Subartic’	535ab
‘Florida 91’	529ab
‘Glacier’	410.7bc
‘Siletz’	18.9c
‘Oregon Spring’	0c

[z] USDA standard grades for fresh tomatoes (http://www.ams.usda.gov/standards/tomatfrh.pdf).

[y] Means followed by the same letter are not different according to Duncan’s Multiple Range Test (P≤0.05).

Table 17. Statistical grouping for the yields of the extra-large-grade [z] tomatoes harvested from the second growth chamber study conducted at the Plant Science Research Center at Auburn University, AL.

Variety	Mean weight (grams)
'Florida 91'	367.1a
'BHN 640'	284.6a
'Legend'	128.8ab
'Glacier'	0b
'Polar Beauty'	0b
'Siletz'	0b
'Santiam'	0b
'Subartic'	0b
'Northern Delight'	0b
'Oregon Spring'	0b

[z] USDA standard grades for fresh tomatoes (http://www.ams.usda.gov/standards/tomatfrh.pdf).
[y] Means followed by the same letter are not different according to Duncan's Multiple Range Test ($P \leq 0.05$).

Table 18. Statistical grouping for the yields of the large-grade [z] tomatoes harvested from the second growth chamber study conducted at the Plant Science Research Center at Auburn University, AL.

Variety	Mean weight (grams) [y]
‘BHN 640’	202.75a
‘Legend’	171.37a
‘Polar Beauty’	160.67a
‘Santiam’	88.77a
‘Florida 91’	44.56a
‘Glacier’	0a
‘Siletz’	0a
‘Subartic’	0a
‘Northern Delight’	0a
‘Oregon Spring’	0a

[z] USDA standard grades for fresh tomatoes (http://www.ams.usda.gov/standards/tomatfrh.pdf).
[y] Means followed by the same letter are not different according to Duncan’s Multiple Range Test ($P \leq 0.05$).

Table 19. Statistical grouping for the yields of the medium-grade[z] tomatoes harvested from the second growth chamber study conducted at the Plant Science Research Center at Auburn University, AL.

Variety	Mean weight (grams)[y]
'BHN 640'	297.64a
'Santiam'	259.63a
'Polar Beauty'	244.76a
'Legend'	145.16ab
'Florida 91'	117.39ab
'Glacier'	0b
'Siletz'	0b
'Subartic'	0b
'Northern Delight'	0b
'Oregon Spring'	0b

[z] USDA standard grades for fresh tomatoes (http://www.ams.usda.gov/standards/tomatfrh.pdf).
[y] Means followed by the same letter are not different according to Duncan's Multiple Range Test ($P \leq 0.05$).

Table 20. Statistical grouping for the yields of the small-grade [z] tomatoes harvested from the second growth chamber study conducted at the Plant Science Research Center at Auburn University, AL.

Variety	Mean weight (grams) [y]
'Northern Delight'	559.2a
'Subartic'	535ab
'Glacier'	410.7 abc
'Polar Beauty'	313.3abc
'Legend'	224.4bcd
'Santiam'	209.8bcd
'BHN 640'	154.4cd
'Siletz'	18.9d
'Florida 91'	0d
'Oregon Spring'	0d

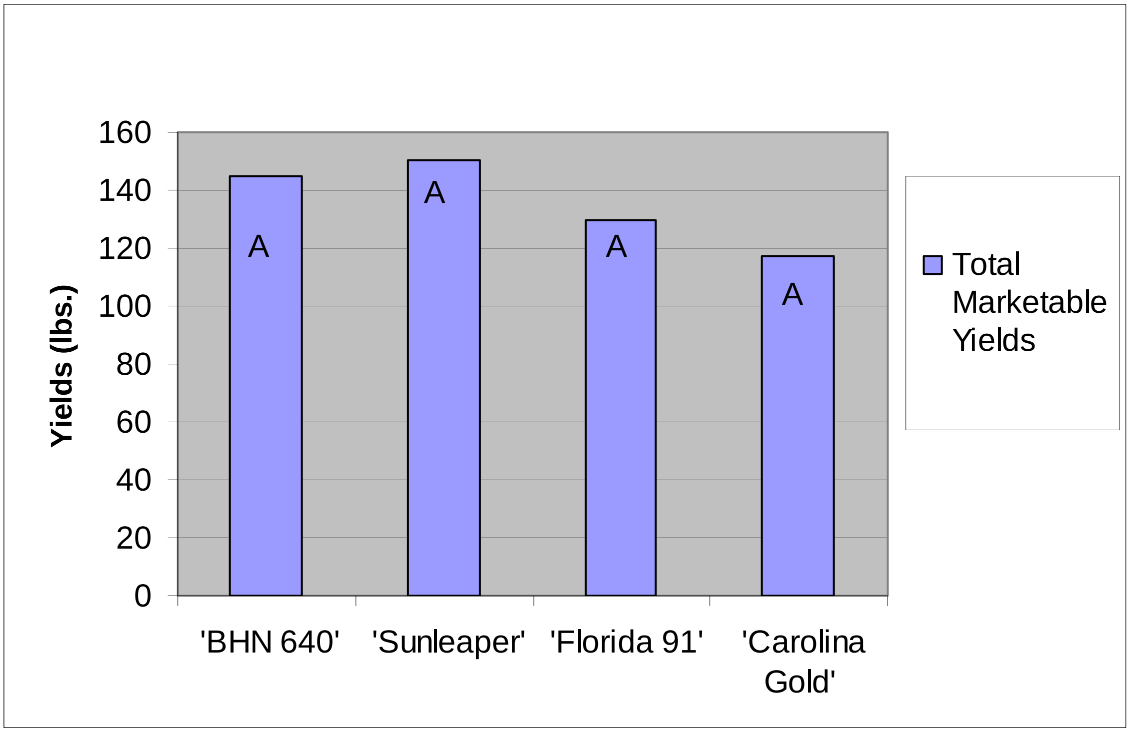
[z] USDA standard grades for fresh tomatoes (http://www.ams.usda.gov/standards/tomatfrh.pdf).
[y] Means followed by the same letter are not different according to Duncan's Multiple Range Test (P≤0.05).

Table 21. Statistical grouping for the yields of the cull-grade [z] tomatoes harvested from the second growth chamber study conducted at the Plant Science Research Center at Auburn University, AL.

Variety	Mean weight (grams) [y]
'Santiam'	256.74a
'Subartic'	59.79a
'Northern Delight'	52.52a
'Glacier'	20.86a
'Polar Beauty'	19.7a
'BHN 640'	18.67a
'Oregon Spring'	0a
'Siletz'	0a
'Florida 91'	0a
'Legend'	0a

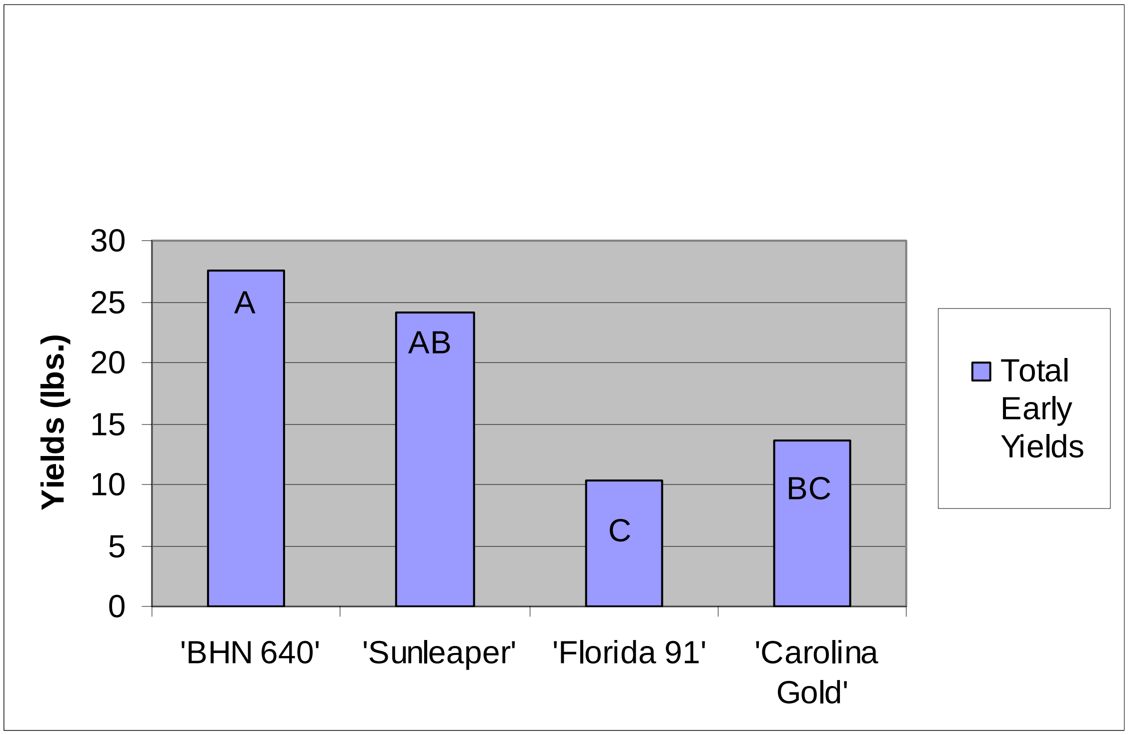
[z] USDA standard grades for fresh tomatoes (http://www.ams.usda.gov/standards/tomatfrh.pdf).
[y] Means followed by the same letter are not different according to Duncan's Multiple Range Test ($P \leq 0.05$).

Figure 1. Total marketable yields (lbs.) for selected tomato varieties planted in spring 2004 inside a high tunnel at the Wiregrass Research and Extension Center, Headland, AL.



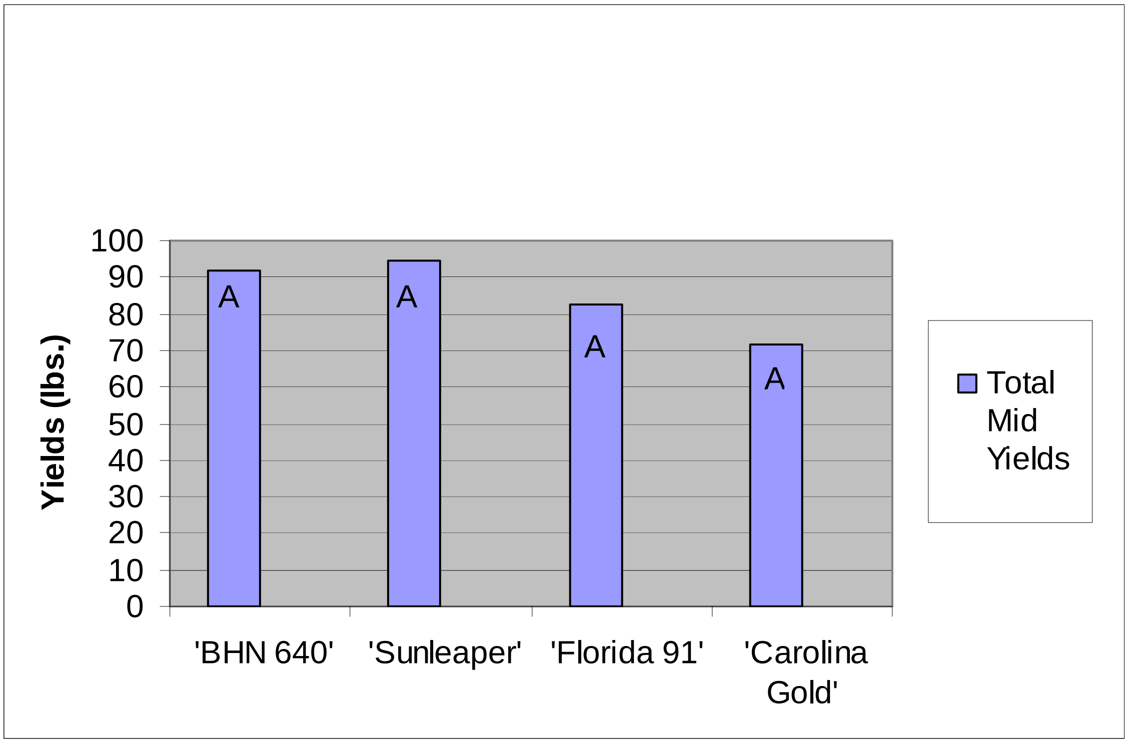
Means followed by the same letter are not different according to Duncan's Multiple Range Test (P≤0.05).

Figure 2. Total marketable yields (lbs.) for early season harvest for selected tomato varieties in spring 2004 inside a high tunnel at the Wiregrass Research and Extension Center, Headland, AL.



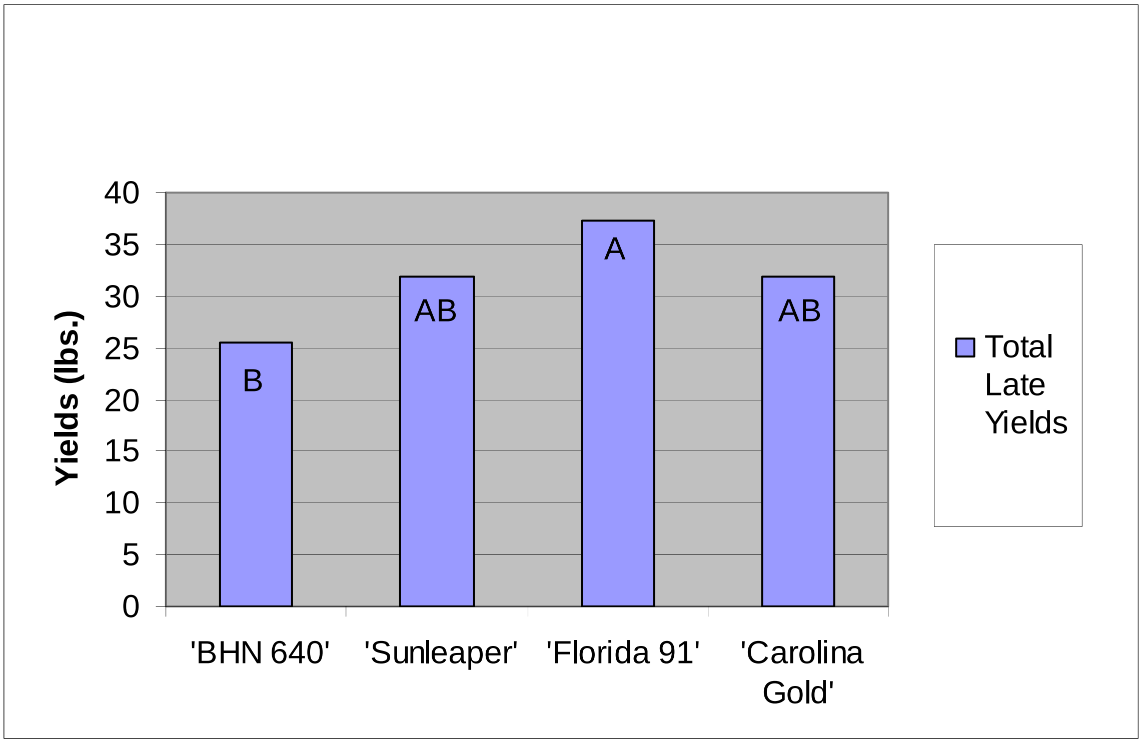
Means followed by the same letter are not different according to Duncan's Multiple Range Test (P≤0.05).

Figure 3. Total marketable yields (lbs.) for mid-season harvest for selected tomato varieties planted in spring 2004 inside a high tunnel at the Wiregrass Research and Extension Center, Headland, AL.



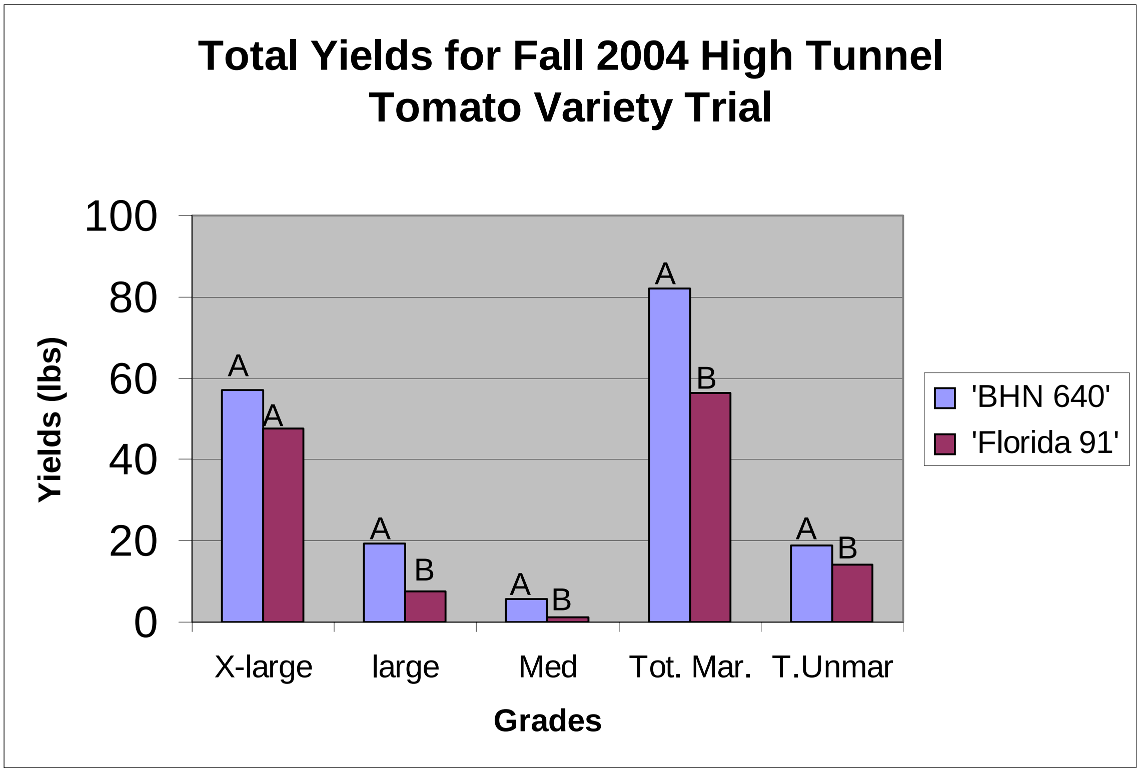
Means followed by the same letter are not different according to Duncan's Multiple Range Test ($P \leq 0.05$).

Figure 4. Total marketable yields (lbs.) for late-season harvest for selected tomato varieties planted in spring 2004 inside a high tunnel at the Wiregrass Research and Extension Center, Headland, AL.



Means followed by the same letter are not different according to Duncan's Multiple Range Test (P≤0.05).

Figure 5. Total yields (lbs.) for selected tomato varieties for fall 2004 inside a high tunnel at the Wiregrass Research and Extension Center, Headland, AL.



USDA standard grades for fresh tomatoes (http://www.ams.usda.gov/standards/tomatfrh.pdf).
Means followed by the same letter within a column and fruit grade are not different according to Fisher's t-test, alpha=0.10.

CHAPTER III

EFFECTS OF FERTILITY, PLANT SPACING, AND PLASTIC MULCH COLOR ON SNAPDRAGON PRODUCTION IN A HIGH TUNNEL PRODUCTION SYSTEM

ABSTRACT. Snapdragons (*Antirrhinum majus* (L.) Peoria) from response groups II, III, and IV were evaluated in a series of studies to determine production practices for cut flower production in a high tunnel production system. A nitrogen (N) study with 'Monaco Yellow' (Group III) evaluated the following rates: 80, 160, 240, and 320 lbs./A N from a slow release fertilizer (Polyon® 19-6-12). Higher quality snapdragons were produced with the 240 lbs./A N equivalent rate. In a plant spacing study the 3" x 4" spacing produced better quality snapdragons than the 4" x 4" or 4" x 5" spacings. A seasonal (summer and fall) plastic mulch color (red, blue, and white) was evaluated in combination with selected varieties. Snapdragon quality was improved by red plastic mulch in summer production and by white plastic mulch in fall production.

LITERATURE REVIEW

High Tunnels are a greenhouse-like structure whereby plants are grown utilizing the soil (Wells and Loy, 1993). High tunnels have been used extensively in Europe and the Middle East for production of vegetables, cut flowers, and other horticultural plants (Wells and Loy, 1993; Wittwer and Castilla, 1995). High tunnels are an important part of vegetable production in the Middle East and increasing in importance in the Northern U.S. and Canada. The high tunnel is considered to be a less expensive alternative to a true greenhouse and yet can provide some control of environmental factors that affect plant growth and development, yields, and dates at which products are sellable. Such control is due to protection against wind, rain, weeds, and some insects and diseases as well as control of temperature and water usage (Wells and Loy, 1993). Typically, high tunnels are covered with a single layer of clear, six-mil polyethylene and are ventilated by manually rolling up the sides. There are no permanent heating or cooling systems in the high tunnel but there is a water supply for drip/trickle irrigation. High tunnels are seen as an affordable technology for season extension (Lamont et al., 2002).

Extensive research has been conducted on the use of high tunnels at Pennsylvania State University in the United States. Research at Pennsylvania State University has investigated production in high tunnels that included the production of tomatoes (*Lycopersicon esculentum* Mill.) and snapdragons (*Antirrhinum majus* L. Peoria). Penn State subsequently established a High Tunnel Research and Educational Facility in 1999 as a part of it's Center for Plasticulture to further research and education in the area of plasticulture (Lamont et al., 2003). The Penn State system of high tunnel production is more closely related to field plasticulture than the University of New Hampshire's high tunnel system (Lamont, 1996). However, limited research has been conducted on use of high tunnels in the southeastern United States.

The use of snapdragons as a cut flower is a multi-million dollar market that is underutilized by growers in the southeast (Rogers, 1992). There are four major groups of snapdragon varieties, divided into groups based on how they respond to light and temperature (Harthun, 1991). Group I cultivars are grown in the winter and early spring. Group II cultivars are grown in late winter and spring. Group III cultivars are grown in late spring and fall while Group IV cultivars are grown in the summer (Rogers, 1992). Group I cultivars are not recommended for the southeastern U. S. Group II cultivars are recommended from 1 December to 30 April in the south, while Group III cultivars are recommended for 1 May to 30 June, and 1 October to 30 November (Sanderson, 1975). Group IV cultivars are recommended from 10 June to 10 September in the south (Sanderson, 1975). Differences in temperatures can cause snapdragons to flower too early or too late as well as decrease cut flower quality (Sanderson, 1975). Soil temperature plays an important role in the production of snapdragons. Hood and Mills (1994) showed that root zone temperature of 22°C (71.6°F) produced the greatest stem, leaf, and root dry weight for Group II varieties. However, temperatures above 29°C (84.2°F) for Group II varieties showed a decrease in major and some minor element uptake (Hood and Mills, 1994).

The average time from sowing of snapdragon seed to flowering in Alabama ranged from 84 to 102 days depending on which group was grown and season (Sanderson, 1975). Seedlings should be transplanted as soon as first true leaves are fully expanded otherwise crop stunting will occur (Sanderson, 1975). In Previous research, Group III varieties required 72 days to flower from transplanting for May to June plantings, while the same variety required only 54 days to flower from time of transplanting when transplanted for October to November flowering (Sanderson, 1975).

A major aspect of snapdragon production is disease control. *Pythium* spp. can be a problem for cool season plantings. To prevent *Pythium* infection, Sanderson (1975) recommended that a fenaminosulf (Dexon) drench be applied to seedlings. Within one week of transplanting, seedlings should be treated with qunitozene (Terrachlor) at a rate of one pound of Terrachlor per 100 gallons of water (Sanderson, 1975). Aphids, spider mites, cabbage loopers, thrips, and white flies are pest of snapdragons. Control is possible with insecticides such as malathion, resmethrin, and dipel dust (*Bacillus thuriengensis*). The garden symphilid is the most important soil-borne pest of snapdragons. Soil solarization has been shown as a possible method to control soil-borne pests (Hagan and Gazeway, 2000), but preventing diseases from the beginning is recommended (Sanderson, 1975). Fertilization is important for a high quality crop of snapdragons. Soil pH for snapdragons should be between 5.5 to 7.0. A constant fertigation of 138 mg/L N, 22 mg/L P_2O_5, and 42 mg/L K_2O produced high quality plants (Sanderson, 1975). Sanderson (1975) reported that boron deficiency was a constant problem and should be monitored carefully. Boron deficiency can be controlled with the application of Borax or Solubor (Sanderson, 1975).

Snapdragons have been shown to perform best if the first three to four weeks have an average night-time temperature of 15.6°C (60°F) (Sanderson, 1975). Snapdragons grown at lower temperatures flower later, have stronger stems, more florets, are taller, and have a heavier plant weight (Sanderson, 1975). Fluctuations in temperature during bud formation must be avoided to avoid skips in the florets. According to Sanderson (1975) short days, as opposed to long days, when plants were two to eight inches tall helped to produce more florets at the time of flowering. Research conducted at Penn State showed little to no difference in stem length of snapdragons due to various planting dates affects (White et al., 2003). The stems from snapdragons grown inside a high tunnel were twice as long as the ones grown in a field (White et al., 2003). White et al.

(2003) reported high tunnel produced snapdragons higher in quality than field grown snapdragons.

The use of plasticulture was introduced in the early 1950s (Lamont, 1993). Tomatoes, okra (*Abelmoschus esculentus* L. Moench), eggplant (*Solanum melongena* L.), squash (*Cucurbita pepo* L.), and peppers (*Capsicum spp*. L) have all shown significant increases in earliness, yield, and quality when grown on plastic mulches (Lamont, 1993). Plastic mulches provide protection from insects and weeds (Ennis, 1987). Black plastic mulch absorbs most UV, visible, and infrared solar radiation and re-radiates energy in the form of thermal radiation (Loy et al., 1989). Black plastic mulch generally provided an increase of 2.8°C (5°F) at a two inch soil depth and an increase of 1.7°C (3°F) at a four inch soil depth when compared to bare soil during the daytime (Loy et al., 1989). Clear plastic mulch transmits 85 to 95% solar radiation but absorbs very little of the solar readiation. Daytime soil temperatures under clear plastic mulch were usually 4.4 to 7.8°C (8 to 14°F) higher at a soil depth of two inches and 3.3 to 5°C (6 to 9°F) higher at a soil depth of four inches compared to bare ground (Loy et al., 1989). White plastic mulch produced a decrease of 1.1°C (2°F) at one-inch soil depth and a decrease of 0.4°C (0.7°F) at the four-inch soil depth. The reduction in temperature was due to solar radiation being reflected back into canopy of the plant, which was good for production of tomatoes in mid-summer (Loy et al., 1989). Other colored plastic mulches have been studied. Decoteau et al. (1989) reported that red colored plastic mulch resulted in increased early yields of tomatoes because of the higher ratio of red to far red light that was reflected back to the plant (Kasperbauer, 1999). The higher ratio of red to far red light resulted in increased yields, root/shoot ratio, and fruit size, when compared to black plastic mulch (Kasperbauer, 1999). Use of blue plastic mulches resulted in an increase in leaf length and higher root/shoot ratios than white plastic mulch (Lamont and Orzolek, 2004). In early spring, when light intensities were low, blue plastic mulch resulted in increased plant heights due to increased far red/red ratio of light, which promotes stem elongation. The opposite is true for the fall of the year. Csizinszky et al. (1995) reported that blue plastic mulch resulted in the highest tomato yields when compared to red, black, yellow, and gray-colored mulches. Other studies have shown red plastic mulch resulted in higher fruit yields (Orzolek et al., 2003).

MATERIALS AND MEHTODS

Nitrogen Study on Snapdragons

In spring, 2004, a N rate study was initiated to determine optimum growth in utilizing a slow release fertilizer (one-time application) in growing snapdragons on black plastic mulch within a high tunnel. 'Monaco Yellow' snapdragons were planted at the Patterson Greenhouse Complex at Auburn University, AL on 21 January. Seed were germinated in plug-flats using Fafard #2 Mix (Conrad Fafard Inc., Agawan, MA) which were placed in one-gallon plastic bags and placed in a germination room set at 21.1°C (70°F). Time from seeding to germination was five days. Plug-flats were removed from the germination room and seedlings were grown for approximately four weeks. Watering and fertigation were accomplished by placing flats in a container filled with water to allow for wicking. Fertilizer used was a mixture of a 14N-1.76P-11.62K fertilizer (Total Gro Premium Grade Plant Food 14-4-14) (SDT Industries Inc., Winnsboro, LA) and a

15N-2.2P-12.45K fertilizer (Jack's Professional Water Soluable Fertilizer 15-5-15) (The Scotts Co) at a rate of 150mg/L N.

After four weeks, seedlings were transferred to market flats and Fafard 3B Mix (Conrad Fafard Inc., Agawan MA) was the media used. For the next three weeks, the snapdragons were fertigated with a 14N-1.76P-11.63 fertilizer (Total Gro Premium Grade Plant Food 14-4-14) (SDT Industries Inc., Winnsboro, LA) mixed with a 15N-2.2P-12.45K fertilizer (Jack's Professional Water Soluable Fertilizer 15-5-15) (The Scotts Co) at 150mg/L N at each watering (once per day). Fertilizer was mixed in a five-gallon bucket and delivered using a Dosatron® (Dosatron, Clearwater, FL) fertilizer injector.

A 19N-2.64P-9.96K six month slow-release fertilizer (Sta-Green with Polyon® 19-6-12) (Pursell's Technologies, Inc., Sylacauga, AL) was selected as the fertilizer to be used. One row was used within the high tunnel for this experiment. Each experimental unit consisted of a two-foot plot planted with 18 snapdragon seedlings on black plastic mulch. There were four treatments with three replications of each treatment. Treatments consisted of a one-time application equivalent of 80, 160, 240, and 320 lbs./A N applied on the soil surface under the black plastic mulch. Treatments were assigned to experimental units using a completely randomized design. Snapdragons were watered via T-Tape® (0.45gpm/100ft) (T-Systems International, San Diego, CA) on the soil surface under black plastic mulch. On 13 May, the snapdragons were harvested and measured for stem length, stem diameter, and inflorescence length. Response to fertilizer rates was determined using linear and quadratic orthogonal polynomials (P=0.05).

After data was collected, snapdragons were given to three local florists in the Auburn area for a quantitative non-scientific evaluation of cut-flower quality to determine their economic value (see Appendix B).

Snapdragon Spacing Study

In fall 2004, a plant spacing study was conducted to determine the effects on cut flower quality of snapdragons grown in a high tunnel production system. The study was conducted at the Wiregrass Research and Extension Center in Headland, AL. ‘Overture Red II’ (Group II) was selected for this study. Snapdragon seed were sown on October 23rd, 2004 at the Patterson Greenhouse Complex at Auburn University, AL. Seed were germinated as described above in a germination room with a temperature of 21.1°C (70°F) and seeded into plug flats as describe above. The germinating mix that was used was Fafard 2 Mix (Conrad Fafard Inc., Agawan, MA). Water and fertigation were accomplished by placing flats in a container filled with water to allow for wicking. The fertilizer used was a mixture of a 14N-1.76P-11.62K fertilizer (Total Gro Premium Grade Plant Food 14-4-14) (SDT Industries Inc., Winnsboro, LA) and a 15N-2.2P-12.45K fertilizer (Jack’s Professional Water Soluable Fertilizer 15-5-15) (The Scotts Co, Marysville, OH). After four weeks in the plug flats, the seedlings were transplanted into market flats on 20 November, 2004. The seedlings were grown in market flats using Fafard 3B Mix (Conrad Fafard Inc., Agawan MA) for another four weeks. The snapdragons were fertigated as previously stated. At the end of a three week period, transplants were hardened off for seven days as described previously.

One row within the high tunnel was used for this experiment. Each experimental unit consisted of a two-foot plot planted with snapdragons on white plastic mulch.

Mulched beds were formed and plastic was laid by a mulch bedder (Reddick Fumigants, Wilmington NC) and underlain with T-Tape® (0.45gpm/100ft)(T-Systems International, San Diego, CA). Irrigation was applied at a rate of an acre-inch per week. Treatments consisted of 3"x 4", 4"x 4", and 4"x 5" spacing for a total of 18 plants per plot. There were three replications of each treatment. Before planting, 39g of a 19N-2.64P-9.96K fertilizer (Sta Green 19-6-12 with Polyon) (Pursell's Technologies, Inc., Sylacauga AL) was applied to the soil surface of each plot for an equivalent of 240 lbs./A N. Snapdragons were allowed to grow for two months before harvest. Data gathered was: stem length, stem diameter, and inflorescence length. Data were analyzed with SAS's Proc GLM procedure for ANOVA and Duncan's Multiple Range Test were used for means separation (SAS Institute, Cary, NC).

Effects of Plastic Mulch Color and Selected Varieties on Snapdragon Production

In the summer and fall of 2005, two separate studies were conducted to determine the effects of plastic mulch color and selected varieties on growth and flowering of snapdragons. Plug-grown seedlings in a 384 cell flat were obtained from Ball Seed (Ball Seed Co, West Chicago, IL) and grown at Patterson Greenhouse Complex at Auburn University, AL. Upon receipt, the seedlings were transplanted into 36 cell market flats. Media used to grow the transplants was Fafard 3B Mix (Conrad Fafard Inc., Agawan, MA). Plugs were transplanted to market flats on 25 May. Snapdragons were allowed to grow for four weeks and were watered with a 14N-1.76P-11.62K fertilizer solution of Total Gro Premium Grade Plant Food14-4-14 (SDT Industries Inc., Winnsboro, LA) and Jack's Professional Water Soluble Fertilizer 15-5-15 (The Scotts Co., Marysville, OH). Two pounds and four ounces of each fertilizer were placed into a five-gallon bucket, filled with water, and mixed into solution. A Dosatron® (Dosatron, Clearwater, FL) fertilizer injector was used to deliver the 150mg/L N of N at each watering. Five selected varieties of snapdragons were used in the experiment. ‘Monaco Red’, ‘Monaco Violet’, ‘Opus Yellow’, ‘Opus Rose’, and ‘Potomac Early White’ were varieties selected for the summer study. ‘Apollo Purple’, ‘Apollo Yellow’, ‘Monaco Red’, ‘Monaco Rose’, and ‘Potomac Early Orange’ were selected for the fall study. The varieties consisted of group III and group IV types. The two ‘Monaco’ varieties and ‘Potomac Early White’ are Group III types and the two ‘Opus’ varieties are Group IV types. The snapdragons were planted in a high tunnel located at the Wiregrass Research and Extension Center in Headland, AL on 22 June. The high tunnel allowed for six rows. Red, white, and blue plastic mulches were selected for use and two rows of each color were laid. Snapdragons were planted in three rows in each plot on a 4”x 5” spacing for a total of 21 plants per two-foot long plot. There was a one-foot spacing between each plot. The mulched bed rows were formed and plastic was laid by a mulch bedder (Reddick Fumigants, Wilmington NC) and underlain with T-Tape® (0.45gpm/100ft) (T-Systems International, San Diego CA) for irrigation.

Experimental units were assigned utilizing a split-plot design experiment. Mulch color (red, blue, white) served as the main effect and the subplot effects were selected varieties (‘Monaco Red’, ‘Opus Yellow’, ‘Opus Rose’, and ‘Potomac Early White’ in the summer study; and ‘Apollo Purple’, ‘Apollo Yellow’, ‘Monaco Red’, ‘Monaco Rose’, and ‘Potomac Early Orange’ in the fall study). Each treatment was replicated three times. Snapdragons from summer study were harvested on 12 July. Snapdragons from fall study were harvested on 1 December. Data collected were total stem length, stem diameter, and inflorescence length. Data was analyzed with SAS's Proc GLM procedure for ANOVA and Duncan's Multiple Range Test (P=0.05) was used to determine differences between the means (SAS Institute, Cary, NC).

RESULTS AND DISCUSSION

Snapdragon Fertility Study Spring 2004.

There was a quadratic response to increasing N rate supplied with the slow-release fertilizer (Polyon® 19-6-12). Inflorescence length and stem length was highest at the 240 lbs./A N rate (Table 1; Figure 1). Stem diameter was the greatest for the 160 lbs./A. N application, the 320 lbs./A. N was the second longest and 240 lbs./A. N was the third largest stem diameter (Table 1).

Snapdragons from the 240 lbs/A N rate were delivered to three different florists in the Auburn, AL area for evaluation. All three florists responded favorably to these snapdragons and communicated an interest in purchasing locally grown snapdragons of similar quality year round (data not shown).

This one-year study demonstated that high quality cut-flower snapdragons grown inside a high tunnel in the spring at 240 lbs./A N rate with a 19N-2.64P-9.96K (19-6-12) slow-release fertilizer can be grown successfully. Furthermore, our non-scientific survey with local florists revealed a high demand for fresh snapdragons.

Evaluation of Snapdragon Plant Spacing.

'Overture Red II' had the longest stem and inflorescence length, and the largest stem diameter when produced at the 3" x 4" spacing (Table 2; Figure 2). Therefore, the highest quality snapdragons were produced at the closest spacing, thus allowing a greater number of snapdragons to be grown in the high tunnel on the plastic mulched beds. The 3 x 4" spacing would allow for 1,800 snapdragons to be grown on a single 90' long by 18" wide mulched bed within a high tunnel. Our high tunnel was 21'x 96' and would accommodate five rows and allow for a total of 9,000 snapdragons to be grown in a single production cycle. Depending on the market, snapdragon prices have been documented at 60 cents per cut (Stanley Sistruck, Flower Store Auburn, AL per comm). If only 75% of the snapdragons were marketable, a grower could sell 6,750 snapdragons at an estimated gross return of $4,050. If the growing cycle were repeated at least four more times inside the high tunnel allowing for an annual gross return of $20,250.

Production of snapdragons in high tunnels on a 3" x 4" spacing appears to be promising. More research to validate this spacing is needed.

Colored Mulch Study for Snapdragons Summer 2005.

Inflorescence length was affected by mulch color (P=0.0532), however other variables such as stem length and stem diameter were not effected by mulch color (data not shown). Stem length, inflorescence length, and stem diameter ($P \leq 0.001$) (Figure 3, 4, and 5 respectively) varied by variety. Also, an interaction for mulch*variety was observed for stem diameter (P=0.0050).

Varietal differences were observed in stem length. 'Opus Rose', 'Potomac Early White', and 'Opus Yellow' were all similar, but greater than 'Monaco Red' in stem length (Figure 6).

Inflorescence lengths were affected by variety. 'Opus Yellow' had longer inflorescence lengths than all other varieties (Figure 7). 'Potomac Early White' and

‘Opus Rose’ were similar in inflorescence lengths. ‘Monaco Red’ had lower inflorescence lengths than ‘Opus Yellow’ and ‘Potomac Early White’ (Figure 7).

Stem diameters varied by variety. ‘Opus Yellow’ and ‘Opus Rose’ were similar to each other and ‘Monaco Red’ and ‘Potomac Early White’ were similar to each other (Figure 8). ‘Opus Yellow’ and ‘Opus Rose’ where larger than ‘Monaco Red’ and ‘Potomac Early White’ in stem diameter (Figure 8).

In the colored plastic mulch study there was no difference in stem length and stem diameter among the plastics, however a difference was observed for inflorescence lengths. Inflorescence lengths did not differ from plants produced on blue and red plastic mulch, however inflorescences produced on red plastic mulch were longer than those produced on white plastic mulch. The varieties, ‘Opus Rose’, ‘Potomac Early White’ and ‘Opus Yellow’, performed well in these studies and appear promising varieties for production. However, ‘Monaco Red’ performed poorly in our study with inferior stem and inflorescence lengths. ‘Opus Yellow’ produced the longest inflorescence lengths of all varieties evaluated. Inflorescence length is very important in the marketability of snapdragons, without which, a high quality cut flower is impossible. For this reason, ‘Opus Yellow’ would be the cut flower of choice when longer inflorescence lengths are required. For stem diameter, ‘Opus Yellow’ had a higher stem diameter than ‘Monaco Red’ and ‘Potomac Early White’. Stem diameter is also important because stem diameter makes the stem strong and able to hold up the inflorescence. When considering the quality aspects of stem length, inflorescence length, and stem diameter, ‘Opus Yellow’ was the best performing variety in the study. The ‘Opus’ series is a Group IV and the other two varieties examined were Group III snapdragons. These results were not a surprise because Group IV is recommended for summer production in Alabama. However, more research needs to be done to conclude which snapdragon varieties from which series do best because florists will desire more than one color of snapdragon for use.

Colored Mulched Study For Snapdragons Fall 2005.

Inflorescence length was affected by mulch color (P=0.0217), however other variables such as stem length and stem diameter were not affected by mulch color (P=0.1788; P=0.3045, respectively) (Figure 9). Varieties differed for stem length and inflorescence length (P<0.0001; P<0.0001, respectively). No interactions for mulch*variety were observed for any of the variables tested.

'Apollo Purple' had longer stem lengths than all other varieties evaluated in the experiment (Figure 10). 'Potomac Early Orange', 'Monaco Red', and 'Monaco Rose' were all similar in stem lengths. These three had longer stem lengths than 'Apollo Yellow', which had the shortest stem length (Figure 10). 'Apollo Purple' had longer inflorescence lengths than 'Potomac Early Orange' and 'Apollo Yellow' (Figure 11). No differences were observed between 'Apollo Purple', 'Monaco Rose', and 'Monaco Red' (Figure 11). No difference was observed between 'Monaco Rose', 'Monaco Red', and 'Potomac Early White' either. 'Apollo Yellow' had shorter inflorescence lengths than all other treatments (Figure 11). 'Apollo Yellow' was greater than 'Monaco Red' in stem diameter. 'Apollo Yellow', 'Apollo Purple', 'Potomac Early White' and 'Monaco Rose' were all similar in stem diameter (Figure 12). The only difference observed for stem diameter was that 'Apollo Yellow' had greater stem diameter than 'Monaco Red' (Figure 12).

As in the first study, there were no differences for stem length and stem diameter between the various colored plastic mulches, and like the first study, there were differences in inflorescence lengths. In this study, however the longest inflorescence length was produced on the white plastic mulch. The ‘Apollo’ series seems to be the best choice for stem length, inflorescence length, and stem diameter for fall production of snapdragons. Because all varieties chosen were Group III snapdragons, the Apollo series seems to be superior for high tunnel production in southeast Alabama.

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Table 1. Effect of fertilizer N rate on growth and flower development of 'Monaco Yellow', Group III snapdragons grown inside a high tunnel, March 2004.

Treatment (lbs. N/A)	Inflorescence length (cm)	Total stem length (cm)	Stem diameter (mm)
80	14.4	83.9	7.2
160	16.9	87.2	8.2
240	18.4	89.9	8.0
320	16.6	87.7	8.1
Significance	L*Q**	L***Q**	L***Q**

[z] Orthogonal polynomial trend analysis (L) or quadratic (Q) at P≤0.05 (*), 0.01 (**) or 0.01 (***).

Table 2. Effect of plant spacing on 'Overture II' Group II snapdragons grown inside a high tunnel on white plastic mulch, transplanted on 4 Nov. 2004.

Treatment	Inflorescence length (cm)	Total stem length (cm)	Stem diameter (mm)
3x4 inch spacing	17.5a [z]	91.25a	5.2a
4x4 inch spacing	10.5b	66b	4.0b
4x5 inch spacing	10.75b	68.5b	4.4b

[z] Means within columns followed by the same letter are not different according to Duncan's Multiple Range Test ($P \leq 0.05$).

Figure 1. Effects of N rate on total stem length, inflorescence length, and stem diameter for snapdragons grown inside a high tunnel at the Wiregrass Research and Extension Center, Headland, AL.

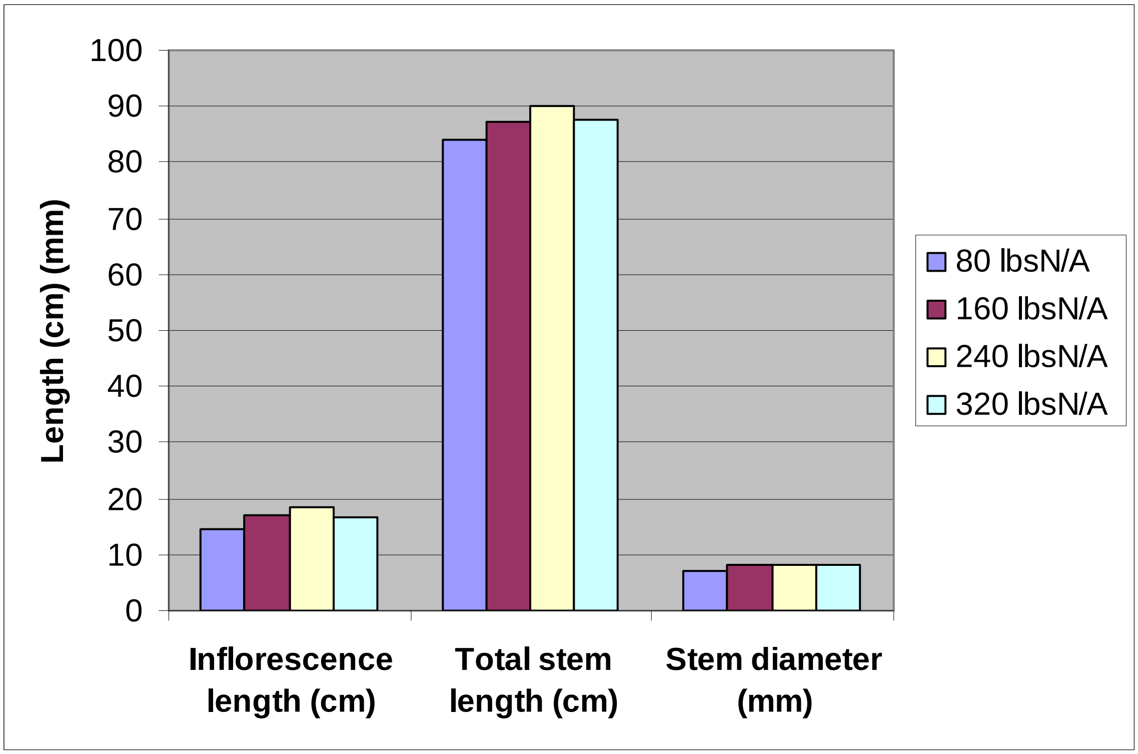


Figure 2. Effects of plant spacing on total stem length, inflorescence length, and stem diameter for snapdragons grown inside a high tunnel at the Wiregrass Research and Extension Center, Headland, AL.

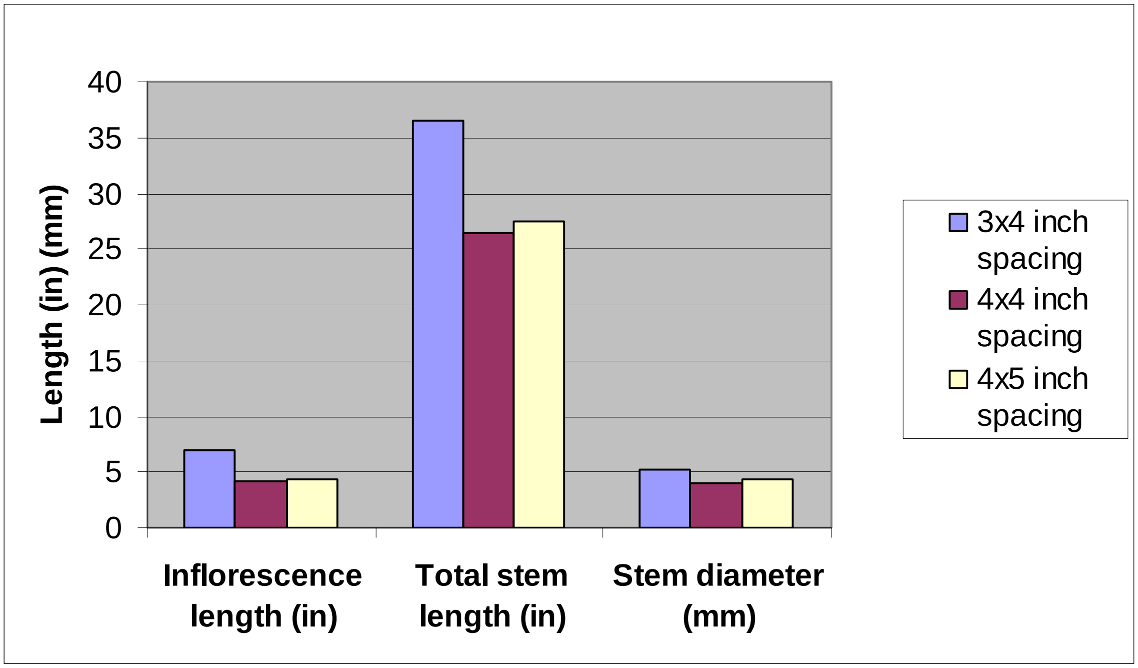
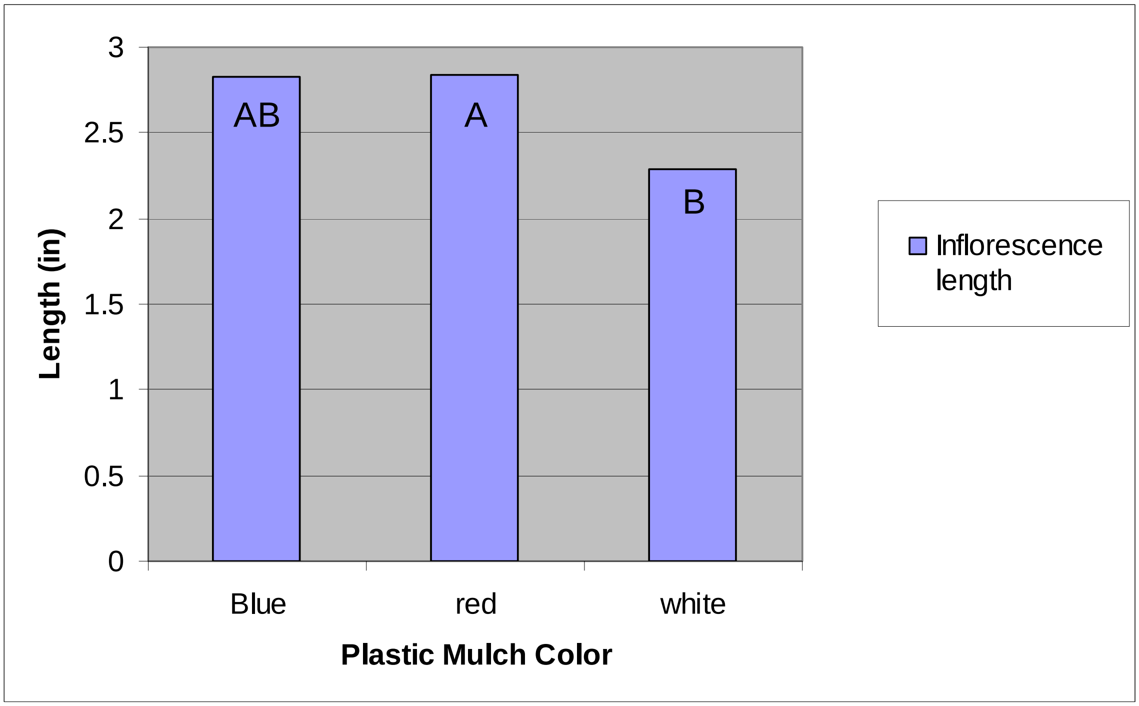


Figure 3. Effect of plastic mulch color on snapdragon stem length grown inside a high tunnel, summer, 2005 at the Wiregrass Research and Extension Center, Headland, AL.

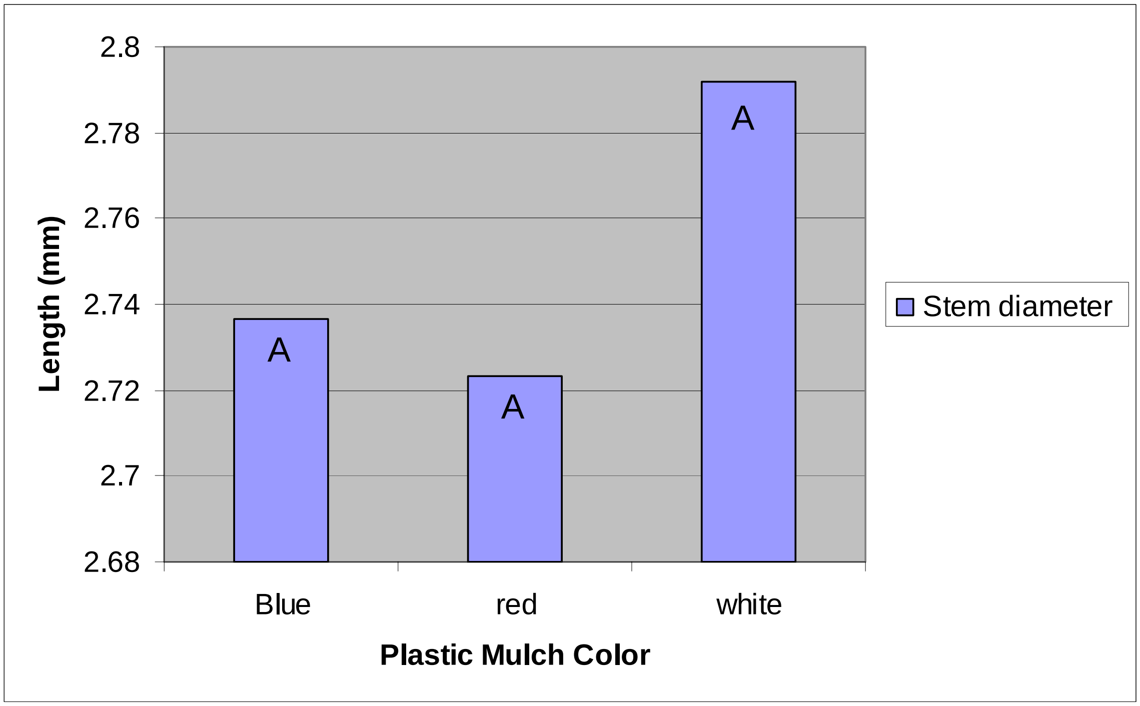
Means with same letter are not different according to Waller-Duncan K-ratio t Test ($P \leq 0.05$).

Figure 4. Effect of plastic mulch color on snapdragon inflorescence length grown inside a high tunnel, summer, 2005 at the Wiregrass Research and Extension Center, Headland, AL.



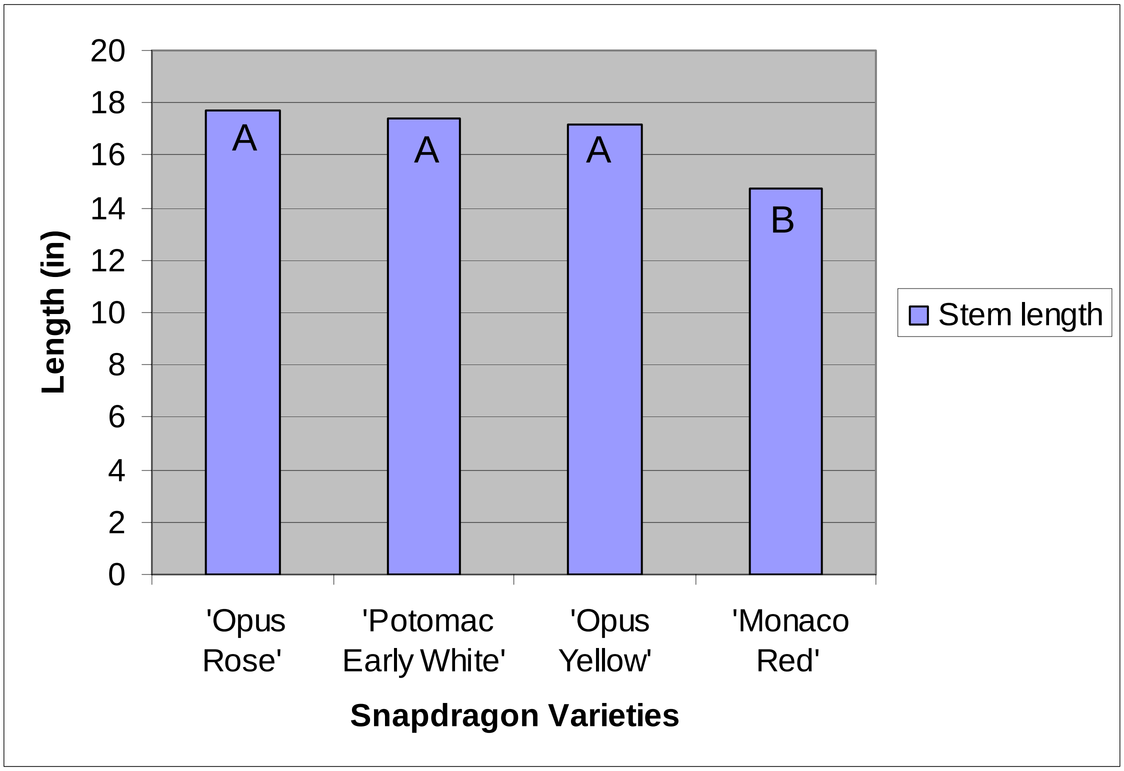
Means with same letter are not different according to Waller-Duncan K-ratio t Test ($P \leq 0.05$).

Figure 5. Effect of plastic mulch color on snapdragon stem diameter grown inside a high tunnel, summer, 2005 at the Wiregrass Research and Extension Center, Headland, AL.



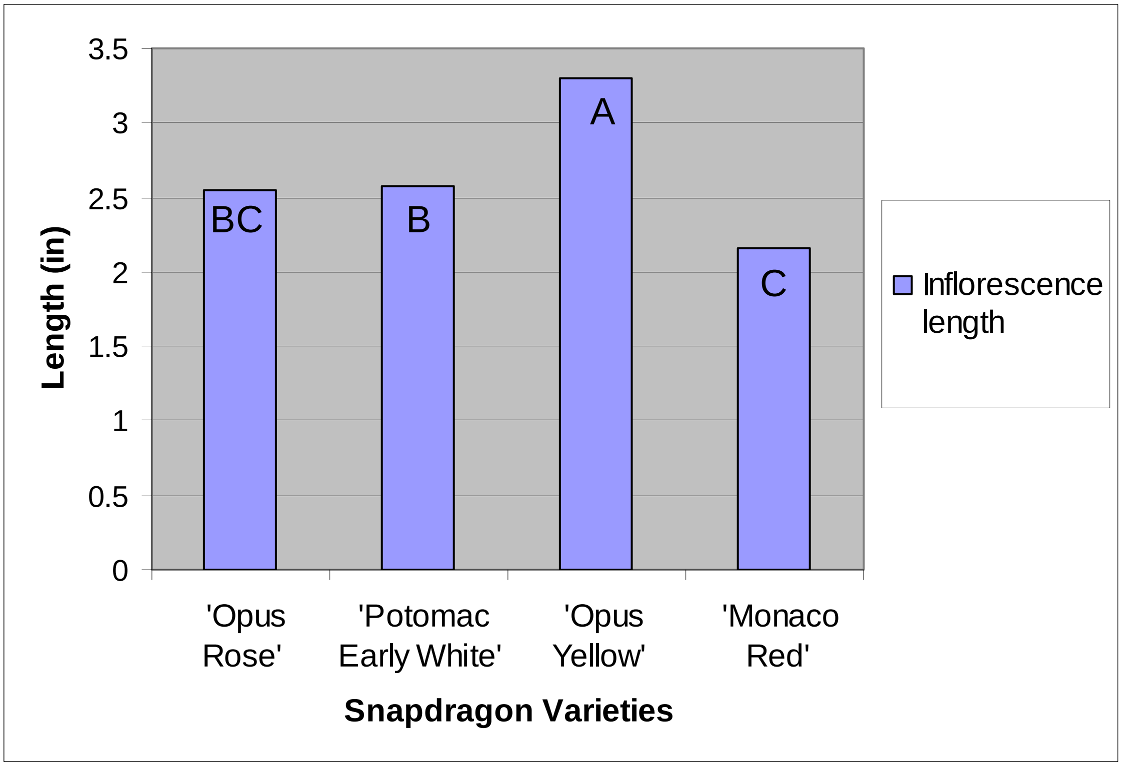
Means with same letter are not different according to Waller-Duncan K-ratio t Test ($P \leq 0.05$).

Figure 6. Average stem lengths of snapdragon varieties grown inside a high tunnel, summer, 2005 at the Wiregrass Research and Extension Center, Headland, AL.



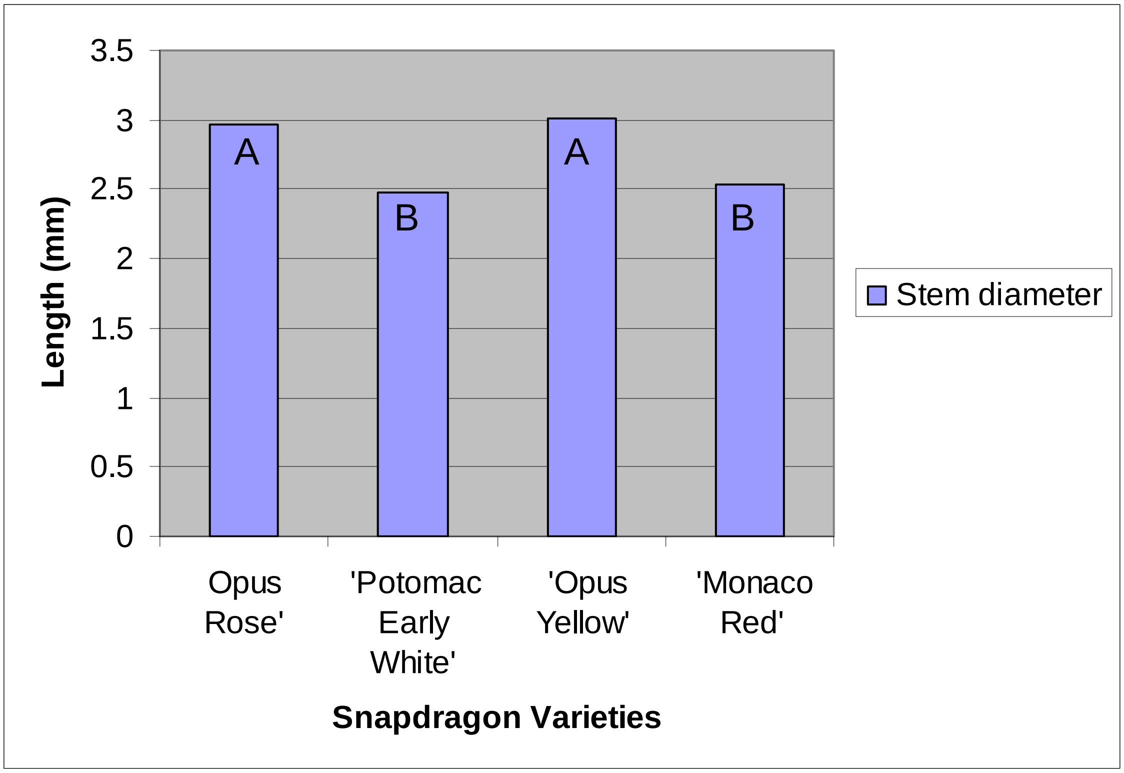
Means with same letter are not different according to Waller-Duncan K-ratio t Test ($P \leq 0.05$).

Figure 7. Average inflorescence lengths of snapdragon varieties grown inside a high tunnel, summer, 2005 at the Wiregrass Research and Extension Center, Headland, AL.



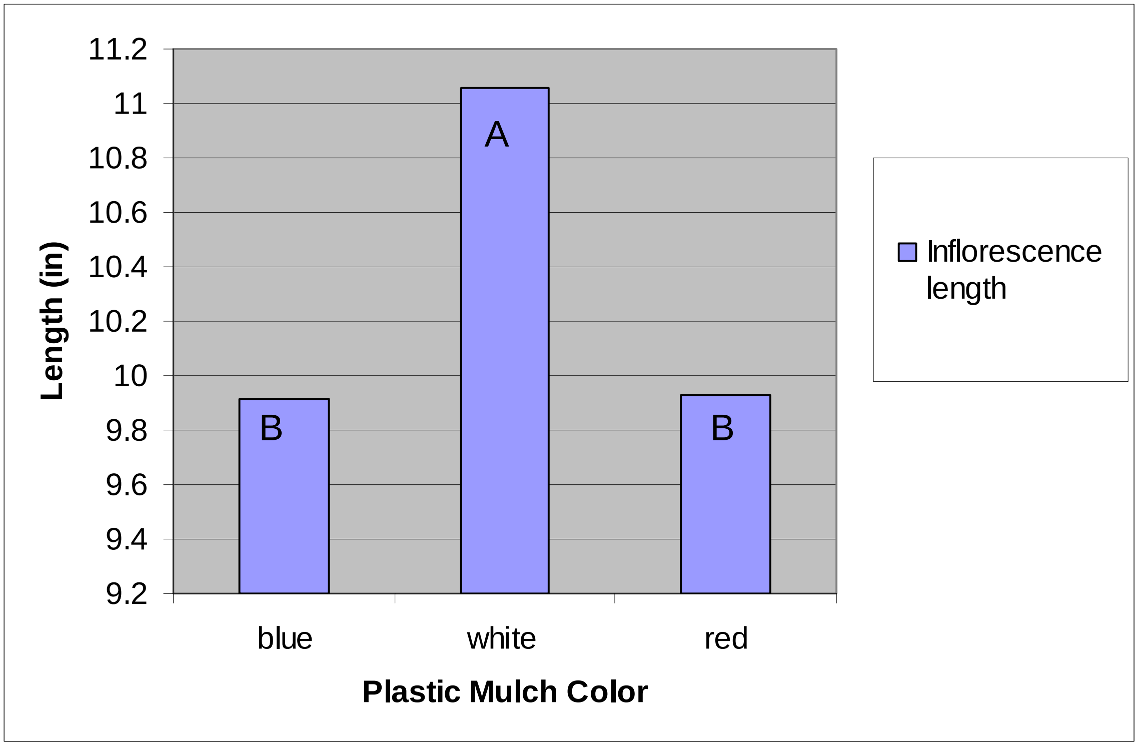
Means with same letter are not different according to Waller-Duncan K-ratio t Test (P≤0.05).

Figure 8. Average stem diameters of snapdragon varieties grown inside a high tunnel, summer, 2005 at the Wiregrass Research and Extension Center, Headland, AL.



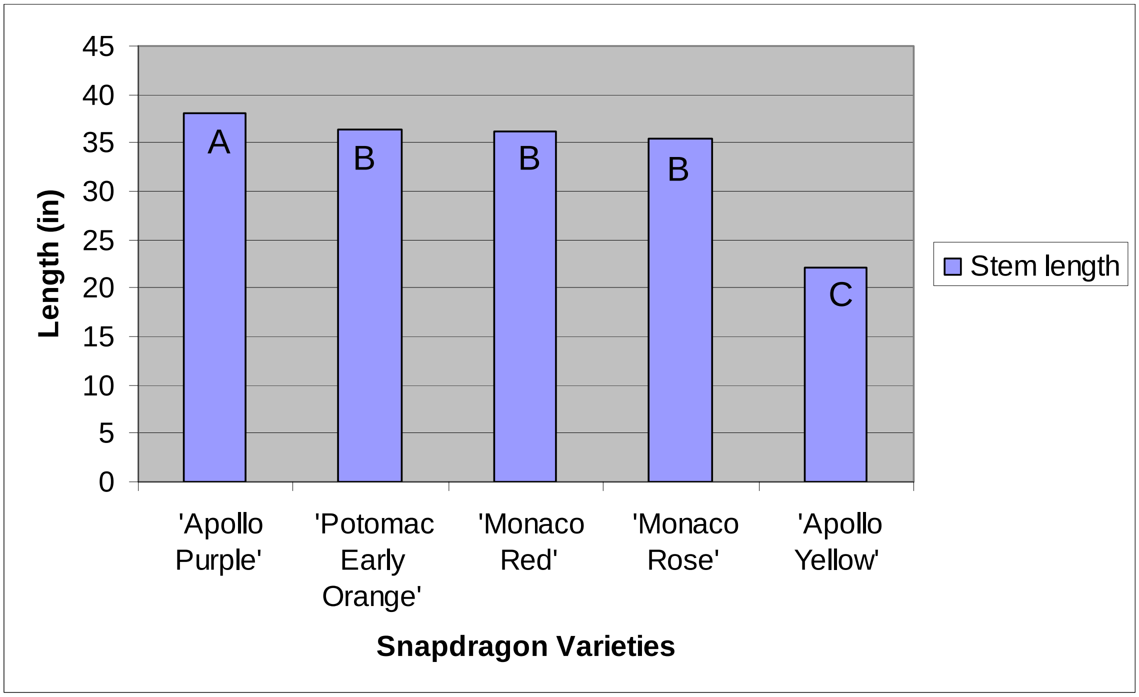
Means with same letter are not different according to Waller-Duncan K-ratio t Test ($P \leq 0.05$).

Figure 9. Effect of plastic mulch color on snapdragon inflorescence length of snapdragons grown inside a high tunnel in fall, 2005 at the Wiregrass Research and Extension Center, Headland, AL.



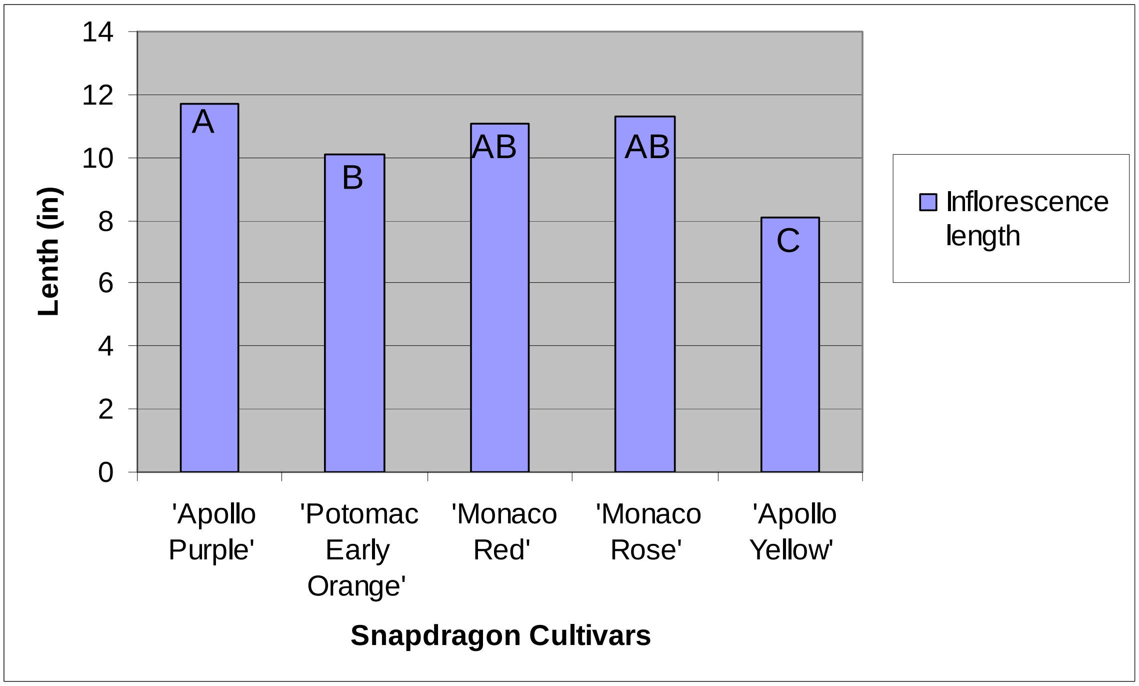
Means with same letter are not different according to Waller-Duncan K-ratio t Test ($P \leq 0.05$).

Figure 10. Effect of plastic mulch color on snapdragon stem length for snapdragons grown inside a high tunnel, fall, 2005 at the Wiregrass Research and Extension Center, Headland, AL.



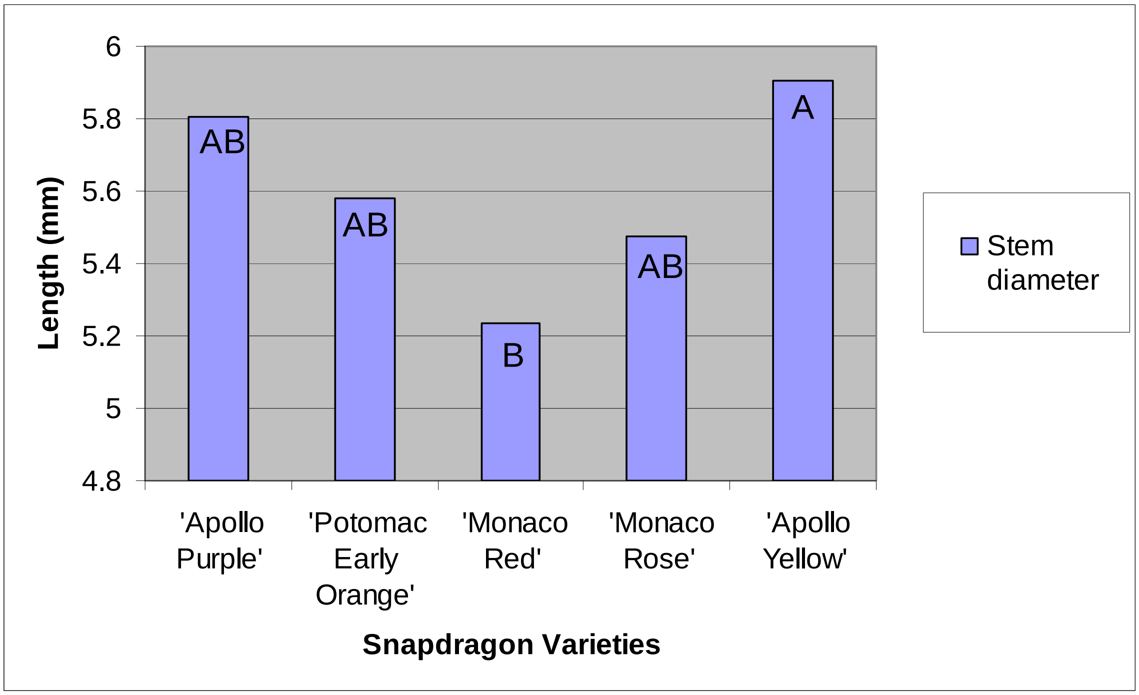
Means with same letter are not different according to Waller-Duncan K-ratio t Test ($P \leq 0.05$).

Figure 11. Effect of plastic mulch color on snapdragon inflorescence length for snapdragons grown inside the high tunnel, fall, 2005 at the Wiregrass Research and Extension Center, Headland, AL.



Means with same letter are not different according to Waller-Duncan K-ratio t Test ($P \leq 0.05$).

Figure 12. Effect of plastic mulch color on snapdragon stem diameters for snapdragons grown inside the high tunnel, fall, 2005 at the Wiregrass Research and Extension Center, Headland, AL.



Means with same letter are not different according to Waller-Duncan K-ratio t Test ($P \leq 0.05$).

CHAPTER IV

FINAL DISCUSSION

Prior to these experiments, only one other study had been conducted on the production of tomatoes in a high tunnel for season extension in Alabama. That study was being conducted at the same time as the one discussed here. Our study is the first documentation of production of snapdragons inside high tunnels in the southeast. High tunnel production is possible with many crops, but we chose to use tomatoes and snapdragons because there are market opportunities for both in the Wiregrass area. Experiments conducted here provide valuable data for future research into high tunnel production systems for tomatoes and snapdragons in southeast Alabama.

During these experiments, high tunnel production of tomatoes led to season extension for the crop. Season extension allowed for a higher price received for marketable tomatoes. There was evidence that 'BHN 640' is a better choice for season extension in a high tunnel production setting than 'Florida 91'. 'BHN 640' produced more marketable tomatoes earlier in the spring and later in the fall. From our work, a planting date of late January to mid-February can provide up to a one month earlier harvest for fresh market tomatoes compared to traditional field grown tomatoes in the area. Earlier tomatoes will command higher prices.

Little to no disease was observed during of these studies. 'BHN 640' is resistant to tomato spotted wilt virus. Tomato spotted wilt virus inside the high tunnel appeared fairly low because the susceptible varieties in the study were not affected by tomato spotted wilt virus. Cold damage was also a concern for the early spring and late fall studies. Caution must always be observed in managing tomatoes during cold weather because the plants are susceptible to damage and even death at temperatures below 10°C (50° F). There was some cold damage to our spring, 2005 study. However, surviving plants still produced well.

Several of the cold tolerant tomato varieties showed promise for high tunnel production and could possibly lead to even greater yields. Of the varieties from the growth chamber studies, the five that seemed to be the best choices were 'Northern Delight', 'Polar Beauty', 'Santium', 'BHN 640', and 'Legend'. While 'Legend' and 'BHN 640' did not do as well in the first study, their performance in the second study was impressive. Each of the tomato varieties listed need further research into the prospect of high tunnel production. 'FLA 91', 'Siletz', 'Subarctic', and 'Glacier' are probably not good choices for high tunnel production. 'Oregon Spring' would definitely not be recommended for high tunnel production as it performed the poorest in each study.

Snapdragons can be a valuable cut-flower crop and high tunnel production yielded the high quality stems florists demand. Red plastic mulch gave the best overall results from the summer study. There were no differences in stem length and stem diameter, but inflorescence length was greater with red plastic mulch. White plastic mulch appeared to give the best overall results for snapdragon production in the fall study. While no statistical differences were seen in stem length and stem diameter, inflorescence length was greater with the white plastic mulch. Snapdragons grown in a high tunnel system showed a response to the use of a 19N-2.64P-9.96K (19-6-12) controlled release fertilizer at a rate of 240 lbs./A N with the production of the longest stem length and the longest inflorescence length. While this rate resulted in the production of only the third greatest (out of four) stem diameter, it was only 0.1mm and 0.2 mm less than the two larger stem diameter means. It is believed that fertigation of the crop would produce a higher quality cut flower than controlled release fertilizers applied pre-plant. The injection of a 20N-4.4P-16.6K (20-10-20) fertilizer through the drip system did produce high quality cut flowers at 150 mg/L of N. These cut flowers were given an excellent rating by florists for marketability, stem length, stem diameter, and inflorescence length. Snapdragon spacing is also very important for maximizing production. The 3"x 4" spacing that produced the best results for stem length, inflorescence length, and stem diameter. This close spacing is very important to growers because at this spacing more snapdragons can be produced per high tunnel which can increase profit potential.

In conclusion, high tunnel production of tomatoes and snapdragons appears very promising from results obtained from these experiments. Furthermore, soil solarization as a sustainable approach to soil pest management appeared promising from our empirical observations. High tunnel production systems can allow producers to grow tomatoes for a fresh market when no other local tomatoes are available and premium prices can be obtained. Percent marketable fruit was very high (>90%) and few disease problems were observed. Snapdragons can be grown successfully in high tunnels with fewer disease problems and more marketable cut-flowers due to the protection from the environment (i.e. wind, rain, etc). With fewer pesticides used and more marketable cut-flowers, profit potential appears promising. Profitable traditional farming on a small acreage basis has become rare and farm families need options to better compete in today's market. While the high tunnel production system needs more research, the experiments conducted here provide great promise for growers. More research is needed to identify optimum varieties of both tomatoes and snapdragons for high tunnel production, along with optimum planting dates and preferred plastic mulch colors for southeast Alabama.

APPENDICES

APPENDIX A

EMPIRICAL OBSERVATIONS

Evaluation of Snapdragons In the spring of 2004, after we collected the data from the snapdragon fertility study we allowed three florists in the Auburn area to evaluate the snapdragons for their quality and marketability. Each florist was asked to evaluate the snapdragons on the evaluation sheets that asked the florists to rate the snapdragons (on a 1-5 scale with 1 being very poor and 5 being very good in respect to their current supply) on stem length and strength, inflorescence color and length, marketability, and their interest in purchasing a snapdragon of such quality bring grown locally. The florists were also questioned about the price they would pay for such a cut flower, how often they would purchase the snapdragons, and what season(s) of the year they would purchase locally grown snapdragons.

The florists gave the ‘Monaco Yellow’ snapdragons a very good rating for all categories with prices they were willing to pay for such a product being in the range of 60 to 75 cents per cut flower, or $6 to $7.50 per bunch of 10. Two of the florist said they would buy the snapdragons twice a week while the other said he would purchase them weekly.

In the fall of 2005, we again had florists evaluate the snapdragons we had grown. This time we used the snapdragons from the fall colored mulch study for the evaluation. Instead of using florists in Auburn however, florists from the Wiregrass region were utilized. Five florists were used for this empirical study. The conclusions were once again very positive. The same questionnaire (Appendix B) was used from the spring 2004 study. Once again, the snapdragons produced in the high tunnel were rated as being much better than those that the florists were currently getting. The prices ranged from 75 cents to 85 cents per stem. The florists stated they would purchase the cut flowers twice a week and year round if available.

This is very promising for potential growers of snapdragons as cut-flowers. It is believed from these observations that great market potential exists in Alabama for the sale of snapdragons as cut flowers.

Soil Solarization Another non-scientific study that was conducted was the solarization of the soil within the high tunnel. Soil solarization, as outlined by Hagan and Gazeway (2000), and Kurt and Emir (2004), was conducted as an alternative means to methyl bromide to treat for soil pathogens in the high tunnel. This was a non-replicated study. After the tomato study was discontinued, 2000 lbs./A of chicken litter was applied inside the high tunnel and the soil was tilled with a rototiller. The soil was irrigated with a sprinkler for several hours. Hobo temperature data loggers (Onset Manufacturers, Bourne MA) were placed in the middle of the high tunnel with one measurement being taken at soil level while another was taken at the soil depth of six inches. Another data logger was at three feet above the ground and at about six feet above the ground. White plastic was spread over the ground inside the high tunnel. The sides were let down, the ends were closed and the high tunnel was sealed up for four weeks to allow for the soil solarization process to occur. After four weeks of solarization, the high tunnel was opened up. Plastic was removed along with temperature data loggers and soil samples were collected. The soil samples were taken to the Auburn University Plant Diagnostic Lab to be tested for major soil borne pathogens and nematodes. This was a nonreplicated study.

This study was promising for high tunnel production. Soil temperatures reached a high of 46.7°C (116°F) down to the four inch soil depth. These temperatures are known to be detrimental to weed seeds and disease pathogens (Gazeway, 2004). Soil analysis revealed that no harmful disease pathogens were found in the soil. However, one pest did survive, yellow nutsedge. While yellow nutsedge is a continuing problem, it can be controlled with herbicides such as halosulfuron. More work must be done in order to determine if soil solarization is a feasible option to soil fumigation in high tunnels.

APPENDIX B

(Sample copy of questionnaire used for quality assessment of snapdragons)

Please rate these snapdragons compared to your current supply (circle your response).

Date_______________
Location_______________
Type of florist____________

(Please score these as 1-very poor; 2-poor; 3-about the same; 4-better; 5- much better)

1. Stem length and strength:

   1 2 3 4 5

2. Inflorescence color and length:

   1 2 3 4 5

3. Marketability:

   1 2 3 4 5

4. If snapdragons of this quality could be grown locally, how interested would you be in purchasing them?

   1 2 3 4 5

5. What price per cut would you be willing to pay for such a snapdragon:_________

6. If you purchased snapdragons grown locally, how often would you need them (i.e. daily, twice-a-week, weekly, monthly, etc):___________________________________

7. What seasons of the year would you purchase locally grown snapdragons (check all that apply): _____winter _____spring _____summer _____fall