EVALUATION OF SOILLESS MEDIA, CONTAINER TYPES AND IN-ROW DISTANCES ON BELL PEPPER GROWTH AND YIELD

BY

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Bell pepper (*Capsicum annuum*) production in protective structures improves fruit quality and yield. Bell pepper under this system is typically grown in soilless culture to reduce problems associated with poor physical soil properties and soilborne diseases. However, cost, local variability, growing conditions and practices are often main concerns for choosing a specific substrate and planting density. Therefore, it is important to understand the physical and chemical properties of media and cultural practices that influence crop yield and fruit quality.

High planting densities are common under protected culture for determinate and indeterminate pepper culture but cultivars tend to differ in the way they respond to in-row spacing and light interception. The goal of this project was to determine the response of bell pepper cultivars in protective structures to different in-row spacing and diverse soilless conditions. A first experiment determined the effect of media (i.e. coconut coir, pine bark, and potting mix) and container types (i.e. boxes, bags, and pots) on the growth and yield of determinate bell pepper. A second experiment evaluated the effect of in-row spacings (i.e. 20, 25, and 30 cm) on bell pepper cultivars (i.e. 'Crusaider', 'Lafayette', and 'Maria').

For the first experiment, the combination of potting mix with bags, pots, or boxes increased bell pepper total marketable fruit weight, number and plant height compare to pine bark and coconut coir.

The second experiment, there was no difference in total marketable fruit number and weight for bell pepper planted at 20, 25, and 30 cm of in-row space.

CHAPTER 1
INTRODUCTION

In the USA, bell pepper sales were around $634 million and production reached around 715,000 Mg in 2010. Florida bell pepper production was slightly below 185,000 Mg and gross sales were $295 million (USDA, 2011). Protected structures, such as greenhouses, screen houses, and high tunnels, are known worldwide as production systems for high quality bell pepper. Greenhouses are completely enclosed permanent structures, covered by transparent glass or plastic (Santos et al., 2010). High tunnels are a low-cost version of greenhouses with passive ventilation (MSU, 2010). These structures can be moved from one place to another, which often gives an advantage for rotating to new soils and trying to avoid pests, disease build-up, and nutrient depletion (New York State Agricultural Experiment Station, 2008). Screen houses are structures with a function comparable to that of a greenhouse, aiming to reduce the incidence of sunlight during the day and moderate temperatures during cold nights through the use of white, black or colored nets (Santos et al., 2010).

A common practice inside protective structures is the use of non-mineral growing media or substrates. Soilless culture is spread throughout the world (Rodriguez et al., 2006). The advantages of substrates ranges from efficient use of water and fertilizer due to its large water holding capacity and homogeneity to reduce populations of soilborne pathogens, which leads to less application of soil fumigants (Ansorena Miner, 1994; Rodriguez et al., 2006). Soilless culture may also enhance crop yield compared to soil culture due to the more adequate pore distribution in the medium, large nutrient holding capacity, and buffer potential, which also gives the possibility of growing crops in areas where the soil condition normally will not allow it (Rodriguez et al., 2006). The container shape also may influence water movement, which affects medium water retention (Ansorena Miner, 1994). Factors influencing the selection of media are cost, local availability and grower knowledge on handling media (Del Amor and Gomez, 2009). Some commonly-used media in Florida are perlite, pine bark, potting mix, and coconut coir (Del Amor and Gomez, 2009; Jovicich et al., 2004). Many substrates are imported and their cost is high compared to local ones (Del Amor and Gomez, 2009). Growers may save money and exploit the benefits of soilless culture with the use of locally-available media (Rodriguez et al., 2006). Identification of appropriate soilless media and container types for bell pepper in needed to improve yield and fruit quality.

Light interception by the crop is an essential factor for high fruit yield (Jovicich et al., 2004). Photosynthesis provides the biochemical energy for crop growth. The efficiency of photosynthesis is related to the interception of the photosynthetic active radiation (PAR). For crops, leaf area distribution is a major factor that influences PAR interception and it is achievable by changing the crop density (Papadopoulos and Pararajasingham, 1997). There is a large diversity of pepper cultivars and each cultivar differs in growth habit (determinate or indeterminate), fruit size, and market characteristics, thus cultural practices requirements might be different (Montsenboker, 1996). Several in-row spacing studies in open fields and greenhouses with bell pepper cultivars resulted on higher fruit yield when pepper were between 0.2 to 0.5 m apart (Jovicich et al., 1999; Jovicich et al., 2004; Locascio and Stall, 1994). Nevertheless, under high tunnel conditions, local environment, seasonal changes, and type of cultivar may affect crop response (Jovicich et al., 1999).

Limited research has been conducted on bell pepper in-row distances under high tunnel conditions. Production under protective structure requires high investment, needing the appropriate selection on plant densities that make efficient use of the available space (Rodriguez et al., 2007). The overall goal of these experiments was to determine the response of bell pepper under protective structures to soilless media, irrigation volumes, and in-row spacing.

The specific objectives were:

- Determine the effect of media and container types on growth and yield of bell pepper under a screen house.
- Assess the effect of in-row spacing and cultivars on bell pepper growth and yield under a high tunnel.

CHAPTER 2
LITERATURE REVIEW

The genus *Capsicum* is native to the tropics of northern Latin America. In the 20th century, there were five domesticated pepper species (*C.annuum* var. *annuum, C. chinense*, *C. frutescens*, *C. baccatum* var. *pendulum,* and *C. pubescens*) (Eshbaugh, 2012). The most widely cultivated species is *C.annuum* var. *annuum*, probably because it was the first species discover and taken to Europe from the New World. (Eshbaugh, 1976, and 1993). The non-pungent form, bell pepper, belongs to the *C.annuum* var. *annuum* species. The crops in the *Capsicum* genus from the *Solanaceae* family are among the more consumed in USA (Eshbaugh, 1993; ERS, 2012). Bell pepper (*C. annuum*) is a small shrub, 2 m height with white flowers, most often one per node and short calyx teeth, rarely exceeding 0.5 mm. The base chromosome number for the genus is 2n = 24, but recent research had shown that there are two basal chromosome numbers in the genus X = 12 and X = 13. Species confined to southern Brazil and the Atlantic coastal zone tend to have chromosome number of X = 13, whereas anywhere else chromosome number of species is based upon X = 12 (2n = 24) (Eshbaugh, 2012). Leaves are oblong and glabrous with solitary flowers, rarely in pairs; the fruit are green changing when ripen to yellow, orange, red, brown or purple with variable sizes (up to 20 cm long and 10 cm in diameter). Fruit shape is sometimes lobed; the seed are white to yellow, thin, almost circular, with long placental connections (Krishna, 2003). Pepper root system consists of a strong tap root and numerous lateral roots. The bulk of water absorption occurs in the superficial 30 cm of the soil. Sweet pepper is a perennial plant native from tropical climates but cultivated as an annual in the USA (Weaver and Bruner, 1927). Plant growth and development are influenced by light, temperature, air, water and nutrients (Eshbaugh, 2012). The combination of these factors creates a phytoclimate for cultivation (Wyzgolik et al., 2008).

Photosynthetic active radiation (PAR) refers to the wavelength of solar radiation that an organism can use to fulfill the photosynthesis process. The measuring unit for PAR is photosynthetic photo flux density (PPFD).This unit express the photon flux per unit area between 400 to 700 nm of solar radiation (Hall and Rao, 1999; Takehiko, 1999). For any plant, the range of optimum PAR goes from 400 to 700 nm.

Chlorophyll absorbs light mainly in the red and blue spectrum, reflecting most of the green wavelengths. The amount of light reaching the plant canopy is directly related to yield, and as light increases, pepper yields increase (Sysoeva et al., 2010). An increase of light intensity can stimulate biomass production and growth rate (Wyzgolik et al., 2008). Lin and Salteveit (2012) stated that a 1% increase in light enhanced harvestable production by 0.8%. Bell pepper is sensitive to extreme temperatures at any growth stage. Seed germination decreases with temperatures below 25°C and heat stress can take place above 32°C. Optimum seed germination occurs between 25 and 28°C. Plants respond with acceptable yields to day/night temperatures of 24-30/18-12°C. Extreme high temperatures (above 38°C) can reduce fruit set, pollination, yields, and quality (Hartz et al., 2008; Lin and Salteveit, 2012).

Pepper Production Systems

The world leader pepper producer is China with 1.25 million ha, exporting between 45 to 90 Mg of hybrid seed to the USA, South Korea and other countries (Timothy and Webster, 2012). In 2011, there were over 21,000 ha of bell pepper harvested in the U.S. (NASS, 2011). Florida is the second largest producing state of bell pepper with 7000 ha in 2011 just behind California (NASS, 2011). Florida is the main winter supplier to the northeastern and midwestern markets of the U.S., with a season from November to May (Cantliffe et al., 2008). Bell pepper production represents about 18% of the state vegetable production (Zotarelli et al., 2011). Major regions of bell pepper production in Florida are Hillsborough, Manatee, Miami-Dade and Palm Beach Counties for winter cultivation. Depending on the county, the harvesting season may extend from November through June and plants could be harvested up to five times for determinate cultivars (Mossler et al., 2009).

In field conditions, peppers are commonly grown on elevated polyethylene-mulched beds with drip irrigation and harvested at the mature green stage. In protective structures, the environmental conditions are modified, maintaining a higher temperature during the cool season to protect fruit from chilling and freeze damage, while producing shadow during the warm season to lower temperatures. In this condition, pepper fruit will reach full maturation and ripening before harvested and fruit yield will be higher with improved quality (Jovicich et al., 2004).

Seedlings for transplants are produced to obtain a well developed shoot and strong root system before going into the greenhouse (Timothy and Webster, 2012). Some advantages of seedlings are uniformity, precocity, and minimum risk of diseases (Casanova et al., 2007). Seeds are germinated in soilless media at appropriate temperatures until plants emerge (Lin and Salteveit, 2012). Pepper plants will take between 32 to 36 days to be ready for transplant (Casanova et al., 2007).

Indeterminate cultivars are common in greenhouse production and required high labor for their management. Training techniques for indeterminate cultivars are classified in two systems: the Spanish and the “V shape” trellis systems. In the Spanish trellis system, plants are allowed to grow without pruning. This system saves about 75% in labor with great extra-large production (Jovicich et al., 2004). The “V shape” trellis consists of a plant with two main stems. The young transplants naturally branch into two or three shoots and after about 4 weeks of planting, the two strongest shoots are selected to become the two main stems, all side shoots beyond the first or second leaves are pruned (Jovicich et al., 2004).

Cultivar Description

Cultivar selection is related to the market, yield, pest and disease resistance, and the grower ability the exploit the genotype potential (Cantliffe et al., 2008). There is diversity of sweet pepper cultivars, such as cherry, cubanelle, and bell pepper. The most commonly-used sweet pepper cultivars for greenhouses are bell-shape or blocky-type fruit hybrids (Casanova et al., 2007; Contreras, 2004; Jovicich et al., 2004). Fruit and leaf shape, size, color, uniformity, and plant habit are important characteristics defined by the genotype and environmental factors (Cruz-Huerta et al., 2011; Stommel and Albrecht, 2012). Over 290 genes are involved in developing those unique horticultural characteristics. Growers get premium prices for mature colored peppers (Cantliffe et al., 2008). Commercial bell pepper fruit colors are red, purple, brown, white, orange or yellow when they are mature, depending on the genotype. White, purple and brown cultivars are less demanded (Jovicich et al., 2004; Stommel and Albrecht, 2012).

In some genotypes, fruit shape definition occurs before the pollination, while in other cultivars, shape is defined during and after anthesis (Cruz-Huerta et al., 2011). A single locus has been designated for the dominant gene (*O*), which determines the round fruit characteristic of pepper. There are approximately 30 genes that modify the gene *O* to cause an elongated fruit shape. A long fruit pedicel allows the expansion of the developing fruit for large fruit cultivars. The dimensions of the pedicel are controlled by multiple genes, with long pedicels being partially dominant over short ones. Two specific sets of genes, *p*-1 and *up*-2, define upright pedicels and fruit orientation (Stommel and Albrecht, 2012).

Bell pepper is a dicotyledonous, open-pollinated plant, with between 8% and 68% of its flowers available for cross pollination, allowing the production of hybrids. Pollen germination and self-pollination are partially genotype-dependent and are related to the position of the stigma and the anthers. Hybrids are preferred because of their vigor, uniformity, disease resistance, and stress tolerance (Contreras, 2004; Grey and Webster, 2012). Seed production begins with flower formation. About 85% of flower anthesis starts before dawn and continue throughout the morning with almost no occurrence in the afternoon. Flower bud initiation and fruit set are sensitive to temperature. Low night temperatures could increase fruit set compared to high temperatures but seedless or seed deficient could occur due to poor pollen quality (Grey and Webster, 2012). High day temperatures could affect fruit set and pollen germination inducing flower abscission. Resistance to low and high temperatures could occur depending on the genotype (Hartz et al., 2008; Lin and Salteveit, 2012; Saha et al., 2010)

Bell pepper cultivars can be differentiated by their growing habit. A determinate pepper is genetically programmed to limit its growth when the flower organs start to develop. Indeterminate cultivars show no predetermined limit to their growth with flower opening and fruit setting as long as the growing resources allow. Several genes have been described influencing pepper growing habits. The indeterminate growth habit is defined by the dominant *Dt*$^{+}$ gene and the recessive *ct*$^{+}$ gene (Stommel and Albrecht, 2012). Indeterminate cultivars are mainly used in greenhouse production. This type of cultivar allows growers to extend the growing season and to be more profitable in time. A dominant gene *(su)* suppresses the epistatic action of *ct*$^{+}$ on indeterminate cultivars. The dominant form of *ct*, recesive fasciculate gene (*fa*), recessive *brl* gene, and *dw*1 and *dw*2 cause shortened internodes and stems, compact, bushy plants and more concentrated fruit set (Stommel and Albrecht, 2012). Indeterminate cultivars are commonly used in protective structures with acceptable results on yield and quality. Some growers had cultivate determinate pepper in greenhouse conditions, trying to reduced labor expenses and to obtain yields similar to indeterminate cultivars (Jovicich et al., 2004), but there is still little information over the performance of this type of cultivars under protective conditions.

Radiant Energy Interception and Plant Density

Plant density and spatial arrangement had been a case of study for many years. The plant density recommendation for peppers varies due to a number of factors that affect this decision (Huerta et al., 2009; Kahn and Leskovar, 2006; Ortega and Gutierrez, 2004). Solar radiation interception is directly related to plant biomass production and yield. Factors such as growing system, distance between rows, in-row spacing, fertility and cultivar selection have an effect on light interception and planting density. Greenhouse production profits are highly dependent of yield and quality per unit area. Wider space between rows could increase plant yield while reducing yield per unit area. The main cost related to increasing plant density is the higher seed number (Jovicich et al. 1998).

Plants are affected by changes in resources supply as well as the effect of other plants over resources. This phenomenon is called interference. Limited supply of light, nutrients, water, and space can changes the competitive interactions between plants. Light plays an important role in plant competition (Santos et al., 2004). During the photosynthesis process, light, CO_2, nutrients and water are utilized to convert inorganic compounds to organic molecules. When irradiation levels are reduced or light quality changes, significant changes in plant responses can be observed. These changes could be expressed as redistribution of dry matter, alteration and reduction of leaf anatomy and decrease respiration and photosynthetic rate (Santos et al., 2004). Green plants utilized light mainly in a range between 400 to 700 nm. Under high tunnels, the environment is influenced by solar radiation, and other factors interacting together. Light intensity and temperature could either improve or limit sweet pepper yields. Modern polyethylene films to cover high tunnels are made of multiple layers and which alter temperature and light refraction (Wyzgolik et al., 2008). Siwek and Libik (1999) reported that radiation transmittance was between 300-1100 nm and 400-700 nm for eight different plastic covers, resulting in different plant foliages. Sweet pepper is sensitive to changes and deterioration of light, resulting in reduced foliage area, low flowering and fruit set. Under acceptable light conditions, pepper plants grown under tunnel conditions developed higher leaf number and larger biomass (Siwek and Libik, 1999).

Photomorphogenesis is a process where plant growth and development is mediated by light. Phytochrome is a blue protein pigment that promoted rapid changes in most plants, in responses to light. There are two major forms of phytochromes: red light-adsorbing form (Pr) and red light to far red light-adsorbing form (Pfr). These forms are photoreversible; Pr is transformed to Pfr by far red light, while Pfr can be reconverted to Pr by red light. The Pfr is the physiologically-active form of phytochrome (Taiz and Zeiger, 2010). One of the functions of phytochromes is to allow the plant to sense other plants shading. Plants that are normally grown in open-field conditions exhibit a response called shade avoidance. When they are submitted to plant shade, there is a response increasing stem extension (Taiz and Zeiger, 2010). This phenomenon is related to the red to far red ratio (R/FR). Under canopy shade, chlorophyll from green leaves is absorbed most of the red light allowing far red light to reach under the canopy. This condition stimulates the conversion of Pfr to Pr, which induces allocation of more resources to grow taller, reducing leaf area and branching (Taiz and Zeiger, 2010). Leaf area index has a direct influence in light interception and it is also mainly determine by plant density (Ortega and Gutierrez, 2004). Most authors reported that fruit number is affected by plant density in pepper with no effect on fruit size (Ortega and Gutierrez, 2004). Inadequate plant population can lead to low yield and quality (Maboko et al., 2012).

Huerta et al. (2009) reported that for Spanish pruning on indeterminate pepper, the most common plant density used by growers is between 2 and 4 plants/m^2. Ortega and Gutierrez (2004) indicated that plant densities between 10 and 12 plants/m^2 are adequate for high marketable yield for determinate sweet pepper. These results are related to the increased number of plants per area and increased PAR interception of plant canopies, without plant shading. Cavero et al. (2001) reported that plant densities between 15 and 20 plants/m^2 were optimal in terms of fruit yield for paprika pepper in the open field.

Maboko et al. (2012) reported that 3 plants/m^2 increased indeterminate sweet pepper yield, compared to 2.5 and 2 plants/m^2 inside shade net. Cebula (1995) reported that plant densities of 3 and 4 plants/m^2 reduced early yield per plant in sweet pepper and productivity is inversely proportional to the increasing density. Jovicich et al. (1998) indicated that 4 plants/m^2 pruned to four stems increased marketable and extra-large fruit yield for indeterminate bell pepper under greenhouse conditions.

Jovicich et al. (2004) reported that the Spanish trellis system at a density of 3.8 plants/m^2 resulted in greater yield of extra-large fruit yield for indeterminate bell pepper under greenhouse conditions. Kahn and Leskovar (2006) reported significant difference between determinate bell pepper cultivar 'King Arthur' and 'X3R' yield, indicating a different response between cultivars to plant density. In spite these results, more research is needed to characterized bell pepper cultivars responds to in-row spacing in high tunnels.

Soilless Culture

In past years a series of pesticides, including methyl bromide, has been phased out of the market due to their hazardous environmental impact on the ozone layer. This has reduced the options for nematode, insect, weed, and soil disease control. It is necessary to find suitable options for vegetable growers for avoiding soilborne pest. Soilless culture might be an alternative to soil-based production, especially in small scale, and situations where suitable chemical control is not possible. Soilless culture is an artificial system design to provided support and storage of nutrients and water to plants (Hunter, 1985). Also known as hydroponic culture, soilless culture is commonly-used in greenhouse production, maintaining crops long season without the need of fumigation (Hochmuth and Hochmuth, 2003). This system allows growers to take advantages of production sites with undesirable characteristics (Nelson, 1998). Soilless culture has been around for centuries. Some commonly-used media for greenhouse vegetable production are rockwool, perlite, expanded clay, pine bark, coconut coir, rice hulls, and composted plant materials (Hochmuth and Hochmuth, 2003). Some advantage of soilless culture are adequate water and nutrient holding capacity, low weight, medium and containers can be reuse for several seasons, and containers are easily installed (Hunter, 1985).

Barks from pine, fir cypress, and redwood have been used productively as growing media in greenhouses (Hunter, 1985). Pine bark characteristics differ greatly from soil. Native pine bark pH is generally 4.5 or lower, while most production soils are between 6 and 7. Pine bark substrates generally contain no aluminum, allowing to growth plants at lower pH without the toxic effect of soluble aluminum. Nutrient holding sites in pine bark are related to the organic fraction of the medium. Most of the exchangeable sites are negatively charged, holding nutrients such as calcium (Ca), magnesium (Mg) and potassium (K), and allowing the runoff of anions such as phosphorus (P) species (Tucker, 1995). Pine bark pore structure is approximately 40% and 45% internal pore and 40% intra particle pore space. The approximately 20% remaining consist of solid matter (Krewer and Ruter, 2009). Particle sizes range generally between 1 to 10 mm in diameter (Hunter, 1985). Depending on the age and level of decomposition of the medium, specific surface area will change. Fresh pine bark has a water holding capacity of about 13% by volume, while aged pine bark retains 21% of the water by volume (Krewer and Ruter, 2009).

Peat moss is the result of the decomposition of sphagnum, mosses, and sedges under acid and wet anaerobic conditions. Some of their characteristics are high water holding capacity, high cation exchange capacity, and good porosity (Gianquinto, 2005). Peat is preserved in a high acid environment, such as bogs and fens where thick layers of decomposed sphagnum peat have been accumulated. For commercial potting mixes production a weakly decomposed peat, mainly of sphagnum mosses, is preferred. Most of the peat produced is sold to the horticultural industry or for domestic use; the rest is used for soil mixes by adding nutrients and other materials (The Canadian Sphagnum Peat Moss Association, 2012). Peat moss has a high water holding capacity and is extremely stable, with a slow decomposition rate. Canada is the larger peat moss producer in the world and although the Canadian bogs are extensive, peat moss recovery rate is extremely slow, leading to environmental concert and uncertainty about its availability (Pelczar, 2003). Potting mixes can contain organic ingredients such as peat moss, coconut coir, compost, and bark. Some frequently-used mixes are composite of half sphagnum peat moss and half horticulture-grade vermiculite or perlite. Other commercially-available substrates contain sand or perlite in addition to peat moss and vermiculite (Nelson, 1998). Mixtures of spaghnum peat and horticultural vermiculite are broadly-used because of the desirable characteristics as growing medium (Abad et al., 2005). In response to new environmental regulations, substrate shortages, and increasing cost, alternatives to peat moss are needed (Abad et al., 2005; Jackson et al., 2008).

Coconut coir is a natural by product from the coconut fiber industry. Their characteristics are similar to peat moss for water holding capacity, and cation exchange capacity. Some of its advantages are neutral pH, little negative effect on environment, availability and cost effective (Gianquinto, 2005). The major coconut coir producers are Sri Lanka, India, Philippines, Indonesia, Mexico, Costa Rica, and Guyana. Coconut coir substrate comes from the mesocarp tissue or husk of the coconut fruit. The husk is first softened with water and then grind. After grinding, the long fibers are removed and the remaining material is screened. After screened the coconut coir is allowed to dry to specific moisture, depending of the specifications of the grower and then compressed and shipped (Konduru et al. 1999).

Substrates have four basic functions: plant support, root oxygenation, nutrient retention, and moisture retention. These conditions have to be taking into account when selecting and mixing media (Nelson, 1998). By mixing media the physical and chemical characteristics of the substrate are altered. Water holding capacity can be improved in big particle sizes media, such as coarse bark, by adding a second source of organic matter with smaller particles, or clay. On the other hand, in some mixes, sand, perlite, polystyrene, or any big particle aggregate are added to improve aeration (Nelson, 1998).

The most used containers for soilless culture are bags, pots, and troughs, allowing a simple and economic way to manage media. In the USA, bags and pots are the most common container systems filled with pine bark or peat moss. Nutrients are supplied from a fertilizer tank directly to the surface of the medium in a sufficient amount to moisten the medium (Hunter, 1985). In case of an excessive leaching, holes in the base of the container will allow the water and fertilizer to leach. The volume of medium per container can range between 2.5 liters in pots to 56 liters in lay-flat bags (Hunter, 1985). Water does not move the same way in every containers. The same volume of media will hold more water as wider the base (Ansorena Miner, 2004).

There are several fundamental phenomena related to particle size that influence soil and substrates properties. As surface increase, the larger the water and nutrient holding capacity. Weathering of minerals and organic matter takes place at the surface of the particles, thus releasing elements into the soil solution. Colloids electromagnetic charge and water polar condition help maintain the soil or media particles together in a coherent mass, or as discrete aggregates. Microbial reactions are greatly affected by the specific surface area. Microorganisms are affected by media cation exchange capacity (CEC), oxygen and water levels (Brady and Well, 2007).

The basic source of media CEC is organic matter. Organic matter is composed of living biomass, dead roots, other recognizable plants residues, and an amorphous complex of no longer identifiable tissue with colloid nature, called humus. Organic matter CEC is related to humus structure (Brady and Well, 2007). Humus is composed of a complex series of carbon (C) chains and ring structures, with several chemically active functional groups.

Humus specific surface area is very high, with three main types of (-OH) groups associated to the charge: carboxyl, phenolic hydroxyl and alcoholic hydroxyl groups (Brady and Well, 2007). Lost or gained of H^+ ions of these groups create charges on the colloid surface. Both cations and anions are attracted and adsorbed by humus with an outcome of negative charges. Organic matter retains very large amounts of water per unit mass due to their high specific surface area and hydrophilic nature. Humus micelles adsorbed nutrients, such as Ca^+, H^+, Mg^+, and K^+ from the soil solution. Organic matter can be decomposed outside their natural environment by composting (Brady and Well, 2007). This practice is used to created organic materials similar to humus by mixing, piling or storing the organic material under aerobic conditions. Microbes slowly break down the organic material into simple compound by decomposition and mineralization. In these processes, the lignin is broken down into their phenolic subunits. Nitrogen immobilization can occur due to a high C: N ration of the material (Brady and Well, 2007).

Substrates with a high portion of wood have a tendency to become deficient as a result of N sequestration. Wood contains long C chains, with a small amount of available nutrients, resulting in a draw of resources, mainly N. The extraction of N and other nutrients from the substrate solution into the colloid surface lower the availability for plants, leading to deficiencies (Jackson et al., 2009).

Several studies have evaluated sphagnum peat water and nutrient holding capacities compare to coconut coir with contradictory results (Abad et al., 2005). Hanson et al. (2004) reported that pine bark substrate top section dried to near zero plant available volumetric water 6 days after irrigation for 5-L containers with different volumes. Hanson et al. (2004) stated that containers with large volumes maintained higher available water in the middle sections than smaller container sizes. Jovicich et al. (2004) reported that bell pepper marketable fruit yields were similar in plants grown in bags and pots. Hochmuth et al. (2010) reported yields above 110,000 kg/ha for bell pepper produced in soilless culture under shade house conditions.

Importance of the Study

Bell pepper production under protective structures improves fruit quality and yield. Peppers under this system are typically grown in soilless culture to reduce problems associated with poor physical soil properties and soilborne pets. However, cost, local variability, growing conditions and practices are often main concerns for choosing a specific substrate, irrigation program, and planting density.

Growers may save money and exploit the benefits of soilless culture with the use of locally-available media (Rodriguez et al., 2006). Identification of appropriate soilless media and container types for bell pepper in needed to improved yield and fruit quality. For irrigation management purposes, in any soilless media within protective structure condition, it is important to determine the required water volume to obtain the highest yield (Pardossi et al., 2011). Little research has been conducted on bell pepper in-row spacing under tunnel conditions. Protective structure production requires a high investment, needing appropriate selection on plant densities to make an efficient use of the available space (Rodriguez et al., 2007). This study assesses the response of bell pepper to different soilless media, and in-row spacing conditions in protective structures.

CHAPTER 3
EFFECTS OF SOILLESS MEDIA AND CONTAINER TYPES ON BELL PEPPER GROWTH AND YIELD IN A NETHOUSE

Overview

Methyl bromide has been phased out due to its hazardous environmental impact on the ozone layer. This regulation has reduced the number of options for efficient nematodes, weed, and soilborne disease control. Suitable alternatives to soil culture are needed for vegetable growers to avoid soilborne pests. Soilless culture might be an alternative to soil-based production, especially at small scale and in situations where suitable chemical control is not possible. The advantages of soilless culture ranges from efficient use of water and fertilizer, due to the high water holding capacity and cation exchange capacity of the media, to reduction of populations of soilborne pests, which leads to less application of soil fumigants (Ansorena Miner, 1994; Rodriguez et al., 2006). Some commonly-used media in greenhouse production are rockwool, perlite, expanded clay, pine bark, coconut coir, rice hulls, and composted plant materials (Hochmuth and Hochmuth, 2003). Many substrates are imported and their cost is high compared to local ones (Del Amor and Gomez, 2009). Growers may save money and exploit the benefits of soilless culture with the use of locally available media.

Local substrates have the potential to produce equal or higher yield than imported ones (Rodriguez et al., 2006). Identification of appropriate soilless media and container types is needed to improve bell pepper yield and fruit quality inside protective structures. The objective of this study was to determine the effect of media and container types on the growth and yield of bell pepper in a nethouse.

Materials and Methods

Two trials were conducted from February to June (spring) and August to December (fall) 2011 at the Gulf Coast Research and Education Center of the University of Florida, located in Balm, Florida. Experiments were conducted under a closed 1050 m2 nethouse structure with 50 mesh white antivirus insect net (30 m width by 35 m length by 3.5 m height) (American Farm System, Jemison, Alabama, USA) oriented north-south. The structure was built using 4 m tall wooden poles in the center for support and 2.5 m tall at the sides.

Nine medium and container combinations resulted from three containers and three media: 1) potting mix in bags, 2) potting mix in boxes, 3) potting mix in pots, 4) coconut coir in bags, 5) coconut coir in boxes, 6) coconut coir in pots, 7) pine bark in bags, 8) pine bark in boxes, and 9) pine bark in pots. Pine bark particle size was between 1 to 2.5 cm in diameter (Elixson Wood Products, Starke, Florida, USA). Coconut coir was fine-grade coconut fiber (Botanicoir, London, United Kingdom). Potting mix was Farfard 2 mix, combination of sphagnum peat moss (65%), perlite, vermiculite, and dolomitic limestone (Fafard, Agawam, Massachusetts, USA). Media physical and chemical analyses are described in Tables 3-1 and 3-2.

Containers types were 102-L wooden boxes (20 cm height by 30 cm width by 170 cm length), 40-L white plastic bags (10 cm height by 20 cm width by 200 cm length), and 5.6-L black plastic pots (21 cm top diameter by 18 cm bottom diameter by 21 cm height). Wooden boxes, plastic bags, and plastics pots provided 6.6, 5, and 5.6 L of medium per plant respectively. Treatments were arranged in a randomized complete block design with four replications. Experimental units were 1.7 m long (16 plants per plot). Rows were 50 cm wide by 20 m long, separated 150 cm apart on center. Plot size was 0.5 m2 with a separation between plots of 60 cm within the row. In-row spacing was 22 cm with double rows separated 25 cm apart, corresponding to a plant density of 5.6 plants/m2.

Determinate ‘Revolution’ bell pepper (Harris Seeds, New York, USA) seedlings (5 week-old) were transplanted on 23th Feb. and 8th Aug. Preplant nitrogen (N) was applied at a rate of 50 kg/ha using calcium nitrate (9% N) as the N source throughout the irrigation system. Media electrical conductivity (EC) ranged from 2.5 to 4.0 mS/cm, after preplant application. Irrigation emitters had a flow of approximately 160 mL/min (John Deere, California, USA). Irrigation was used 8 h/day for 10 days for the spring season and 7 days for the fall season, to establish bell pepper seedlings.

After establishment, irrigation was adjusted according to the crop requirement, stage of growth, and evaporative demand in terms of reference potential evapotranspiration (ETo) from the historical daily averages of Penman for west-central Florida (Olson et al., 2011). Irrigation cycles were of 125 mL delivered in 60 seconds, three to seven times per day according to the historical ETo and rain fall occurrence. Plots received approximately 400 kg/ha of N through the irrigation system during a 4-month season in a daily injection with the last irrigation cycle. One fertilizer proportional injectors (model D14MZ2; Dosatron International Inc., Clearwater, Florida, USA) were used to pump concentrated stock solution into the irrigation water using a dilution rate of, 1:50 (v/v). After establishment, seedlings were fertigated using a solution with nutrient levels of 2.27% N; 1% P; 6.48% K; Ca, 2%; Mg, 0.4%; B, 0.02%; Mn, 0.04%; Zn, 0.02%; Cl, 4.5%. Media pH ranged from 6.5 to 8.0, and EC ranged from 0.5 to 4 mS/cm throughout the season. Plants were horizontally tied every two weeks starting 4 weeks after transplanting (WAT) with no pruning. Pesticides were applied weekly or biweekly to control insects and diseases depending on pest population.

Plant height was measured at 4, 8, and 12 WAT using five randomly selected plants per plot avoiding border plants. The same five plants per plot were sampled during the three height observations. Plants were measured from the ground level to the newest top leaf. Leaf greenness was measured at 4, 8, and 12 WAT with a handheld color meter (SPAD-502; Minolta, Ramsey, New Jersey, USA), which provides a numerical soil plant analysis development (SPAD) value, ranging from 0 to 80, where 0 = white and 80 = dark green. Five readings were taken from five of the newest mature leaves on the top of plant canopies. The same plants used for plant height were used to obtain the greenness data.

Marketable fruit weight and number were determined throughout five harvests and fruit were classified using the United States Department of Agriculture (USDA) vegetable product sheet standards (USDA, 2011). Fruit were harvested weekly for 5 weeks, starting on 10th March on the spring season, and 31th October (12 WAT) on the fall season. A marketable fruit was defined as a fruit without visible damage with at least 30% red skin, with a diameter and length not less than 6.25 cm, without deformations or physiological disorders. Any fruit that did not meet these requirements was considered unmarketable. Weight per fruit was determined by dividing the marketable fruit weight of each treatment by its corresponding fruit number.

Root and shoot dry weights were taken at the end of the fall season. Shoot samples were measured using five randomly selected plants per plot avoiding border plants. The same five plants per plot were sample for root dry weight. After the last harvest, shoots were cut at grown level and weighed. Root samples were extracted from the container and washed with water to remove the excess of media. Root samples were dried out at 80°C for five days and then weighed.

Volumetric water content (VWC) was measured during bell pepper harvesting stage, with a time domain reflectometer (TDR) (Spectrum Technologies, Inc. Plainfield, Illinois, USA). VWC was taken four times per plot, 20 cm from the plant crown within the row and averaged. VWC measurements were taken five times during the fall season.

Collected data was analyzed using the analysis of variance procedure (Statistix Analytical Software, Tallahassee, Florida, USA) to determine factors main effect and interactions between season, media and containers ($P < 0.05$). Treatments means were separated with Fisher's-protected least significant (LSD) at the 5% significant level.

Results and Discussion

There was a significant season by treatment interaction for plant height at 4 WAT, and leaf greenness at 4 and 8 WAT, thus data from the two seasons were analyzed separated. No significant season by treatment interaction was found for the rest of the variables, thus data from the two seasons were combined for analysis.

There was a significant media by container interaction for plant height at 4 WAT in spring 2011. Data showed no significant difference between pine bark in bags and pots, potting mix in boxes and pots, and coconut coir in boxes, with a plant height ranging between 32.1 and 35.8 cm. The lowest plant height was obtained in treatments of coconut coir in bags and pine bark in boxes (Table 3-3). In fall 2011, there was no significant media by container interaction for plant height at 4 WAT (Table 3-3). Container types had a significant effect on bell pepper height at 4 WAT. There was no significant difference between bags and pots, with 18.2 and 18.1 cm respectively. The lowest plant height was found in boxes, with 15.4 cm (Table 3-4).

At 8 WAT, there was a media by container interaction for bell pepper height. Data indicated no significant difference between potting mix in bags, pots and boxes, coconut coir in boxes and pots and pine bark in pots, with values ranging between 48.1 and 54.9 cm, where as the lowest plant height was found in pine bark in boxes with 15.4 cm (Table 3-5). At 12 WAT, there was a significant effect of media on bell pepper height. Potting mix resulted in the tallest plants with 61.1 cm, whereas, there was no significant difference between pine bark and coconut coir with 51.6 and 53.9 cm respectively (Table 3-6).

In the spring season, leaf greenness was significantly affected by media at 4 WAT (Table 3-7). There was no significant difference between pine bark and potting mix, with SPAD values of 48.1 and 46.3 respectively, whereas coconut coir resulted in the lowest leaf greenness with a SPAD value of 41.5 (Table 3-7). In the fall, there was a significant effect of media and container type for leaf greenness. Pine bark and coconut coir showed no significant difference with SPAD values of 47.9 and 49.1 respectively. Potting mix resulted in the lowest SPAD value with 44.1 (Table 3-7). There was no significant difference between bags and pots for bell pepper leaf greenness at 4 WAT, with SPAD values of 49.5 and 49.4 respectively (Table 3-8). Boxes treatments resulted in the lowest leaf greenness with a SPAD value of 42.2.

Data showed no significant effect of container types on leaf greenness in spring 2011 (Table 3-8). In spring 2011, there was a significant media by container interaction for bell pepper leaf greenness at 8 WAT. Pine bark in pots resulted in the highest leaf greenness with a SPAD value of 57.8. Potting mix in bags, pots and boxes, and pine bark in bags resulted in no significant difference. The lowest leaf greenness resulted in treatments of pine bark in boxes and coconut coir in bags at 8 WAT (Table 3-9). Leaf greenness at 8 and 12 WAT was unaffected by media and container type in fall 2011 (Table 3-9). Container type had a significant effect of on leaf greenness at 12 WAT. There was no significant difference between bags and boxes, with SPAD values of 60.0 and 60.9 respectively (Table 3-10). Bell peppers in pots resulted in the highest leaf greenness, with a SPAD value of 64.1 at 12 WAT (Table 3-10).

There was no significant media by container interaction for media VWC, where as there was a significant main effect of media and container (Fig. 3-1 and 3-2). Potting mix resulted in a significantly higher VWC with 44.1%, compared to coconut coir (36.6%) and pine bark (18.6%). Potting mix resulted in 57.7% higher water content than pine bark (Fig. 3-1). There was a significant effect of container for media VWC. The highest VWC was found in bags with 40.5%, whereas the lowest VWC was found in boxes with 26.54% (Fig. 3-2).

There was a significant media by container interaction for dry root biomass. No significant difference resulted between coconut coir and pine bark in bags and pots (Fig. 3-3). The lowest dry root biomass weight was obtained in potting mix in bags, boxes and pots, and coconut coir in pots (Fig. 3-3).

Shoot biomass was significantly affected by media and container type interaction. There was no significant difference between coconut coir in bags and boxes and potting mix in bags (Fig. 3-4). The lowest shoot biomass weight was obtained in pine bark in boxes (Fig. 3-4).

No significant media by container interaction resulted for total marketable fruit number. Potting mix resulted in the highest total marketable fruit number with 285,863 fruit/ha (Fig. 3-5). There was no significant difference between bell pepper produced in coconut coir and pine bark for fruit number, with values of 237,841 and 217,800 fruit/ha respectively (Fig. 3-5). Potting mix resulted in 23.8% higher fruit number than pine bark, and 16.8% higher than coconut coir. Total marketable fruit weight was significantly affected by media and container interaction. Data showed no significant difference between potting mix in bags, pots and boxes (Fig. 3-6). Pine bark in boxes resulted in the lowest total marketable fruit weight (Fig. 3-6). Potting mix in boxes resulted in 60.9% and 18.6% higher marketable fruit weight than pine bark and coconut coir in boxes. Potting mix in pots resulted in 33.7% and 28.9% higher fruit weight that coconut coir and pine bark in pots. Coconut coir in bags resulted in 21.5% less marketable fruit weight than potting mix in bag. Pine bark in bags obtained 17.0% less marketable fruit weight than potting mix in bags. There was a significant media by container interaction for weight per fruit. Potting mix in bags, pots and boxes, pine bark in bags and pots, and coconut coir in bags and pots showed no significant difference (Fig. 3-7). The lowest weight per fruit was found in treatment of pine bark in boxes (Fig. 3-7).

Data indicated that the use of potting mix in bags, pots, or boxes increased bell pepper total marketable number, weight and plant height compared to pine bark and coconut coir. These results may be influenced by a combination of two factors interacting collectively. First, data supported that there is a different patter on water retention among media and container types, which influenced plant available water. The capacity of a media for water holding is mostly determined by their particle size and arrangement (Haman and Izuno, 2003), but is also influenced by container height. Media analysis showed that pine bark water retention at field capacity is lower than coconut coir and potting mix; due to it lower water-filled pore percentage and reduced capillarity (Table 3-1). Furthermore, shallow containers, such as boxes, could influence the fast water movement throughout media with low water retention such as pine bark. The combination of low capillarity of the pine bark (32.6%) and shallowest of boxes could restrict water lateral movement and therefore its availability for the plant, affecting plant growth and development, while high water retention of potting mix helped retain more water for longer time, allowing bell pepper plants to uptake water during moments of high evapotraspiration requirement. Potting mix treatments resulted in 57.7% higher water content than pine bark and 17.0% higher than coconut coir (Fig. 3-6) while boxes and pots resulted in 26.5% and 32.3% less volumetric water content than bags.

Mayoral et al. (2000) reported that bell pepper relative growth rate, leaf area index, net assimilation rate and photosynthetic rate significantly decreased under water stress. Hanson et al. (2004) reported that pine bark substrate top (5 cm) section dried to near zero plant available volumetric water for five different volume containers. Increased in fruit yield in potting mix treatment could be related to the high available water content. However, potting mix high prices restrict their use at big scale for high value crops such as bell pepper and tomato. Further research is needed to evaluated bell pepper rate of response and economical profitability to media mixes in protective structures.

Second, nutrient availability could affect bell pepper development. Coconut coir water content was higher than pine bark, but there was no significant difference between both media in bags for marketable fruit weight. Pine bark analysis showed

NO3, Ca+, K+, and Mg+ levels higher than for coconut coir (Table 3-2). At the same time, potting mix analysis showed even higher levels of NO3, Ca+, K+, Mg+, and P2O5 compared to pine bark and coconut coir. Higher nutrient levels related to the high water content of media could explain the higher SPAD values for pine bark and potting mix, compared to coconut coir during the first 4 weeks after transplanting. The same way, higher nutrient concentration of potting mix could affect fruit number compare to pine bark and coconut coir (Fig. 3-1). Jovicich et al. (2007) reported that increasing available water in perlite has been shown to increased plant acquisition of nutrient, and that low water and nutrient supply to the roots can reduce plant growth and total yield. Several studies have evaluated sphagnum peat water and nutrient holding capacities compare to coconut coir with contradictory results (Abad et al., 2005).

Bell pepper root system is also affected by water deficit (Taiz and Zeiger, 2010).The larger root biomass of pine bark in pots, and bags, and coconut coir in bags could be related to the preferential root growth into areas that remain moist. Taiz and Zeiger (2010) reported that deeper root growth into wet soil can be considered a line of defense against drought. Inhibition of leaf expansion reduces the consumption of carbon and energy, and greater proportion of the plant assimilates can be redistributed to the root system, where they can support further root growth. The greater water content of potting mix in bags, pots and boxes, and coconut coir in pots could restrict the redistribution of carbohydrates, while pine bark in pots and bags was enhancing this redistribution. Further research is needed to characterize the photosynthetic rate of bell pepper related to media and container type as well as the nutrients uptake and losses in interaction with media and containers.

There was no significant difference between coconut coir and pine bark in pots or bags for bell pepper total marketable fruit weight. Besides the low water retention of pine bark compared to coconut coir, an adequate container such as bags or pots can restrict water losses from the media allowing the plant to have available water. Simonne et al., (2011) reported that mulches, such as plastic bags, are highly effective in reducing ETo requirements with a reduction between 10% and 30% of water losses. This research may lead to a better use of locally available soilless media for vegetable production in Florida. In conclusion, the combination of potting mix with bags, pots, or boxes increased bell pepper total marketable fruit weight, number and plant height compare to pine bark and coconut coir.

Table 3-1. Physical analysis of pine bark, coconut coir, and potting mix for bell pepper production in a nethouse at Balm, Florida, in fall 2011.

Media	Media physical analysis							
	Saturated hydraulic conductivity (cm/h)	Porosity (%)			Bulk density (g/cm^3)	Water retention at field capacity (%)	Organic matter (%)	Inorganic matter (%)
		Non-capillary (air filled)	Capillary (water filled)	Total				
Pine bark	13.5	48.8	32.6	81.4	0.19	171.6	93.4	6.6
Coconut coir	191.2	46.9	42.8	89.7	0.08	535.0	87.6	12.4
Potting mix	101.2	40.0	43.8	83.8	0.12	365.0	65.3	34.7

Table 3-2. Chemical analysis of pine bark, coconut coir, and potting mix for bell pepper production in a nethouse at Balm, Florida, in fall 2011.

Media	Soluble salts (mmhos/cm)	pH	Media chemical analysis mg/L							
			Ca	K	Mg	Mn	NH_4-N	NO_3-N	P	Zn
Pine bark	0.2	5.5	4.7	21.9	1.5	<0.05	0.6	0.8	4.7	0.6
Coconut coir	0.2	7.2	1.0	18.4	0.7	<0.05	0.7	0.4	<0.0	0.2
Potting mix	1.0	6.8	57.9	46.2	67.4	<0.05	0.8	34.0	7.1	0.2

Table 3-3. Effects of media and container types interaction on plant height at 4 weeks after transplanting in a nethouse at Balm, Florida, in spring and fall of 2011.

Media	Containers	Plant height cm	
		Spring	Fall
Coconut coir	Bag	29.7 D	17.9
Pine bark	Bag	32.8 ABCD	18.0
Potting mix	Bag	32.1 BCD	18.3
Coconut coir	Box	33.4 ABC	15.5
Pine bark	Box	29.7 D	13.8
Potting mix	Box	35.8 A	17.0
Coconut coir	Pot	31.3 CD	18.0
Pine bark	Pot	34.5 ABC	18.5
Potting mix	Pot	35.1 AB	18.3
Significance ($P < 0.05$)		0.0121	NS

[Z] Values followed by different letters represent significant differences among treatments.
[NS] Not significant at $P < 0.05$ analysis of variance.

Table 3-4. Effects of container types on plant height at 4 weeks after transplanting in a nethouse at Balm, Florida in spring and fall of 2011.

Containers	Plant height cm	
	Spring	Fall
Bag	31.5	18.1 A
Box	32.9	15.4 B
Pot	31.6	18.2 A
Significance (P < 0.05)	NS	0.0019

[Z] Values followed by different letters represent significant differences among treatments.
[NS] Not significant at P< 0.05 analysis of variance.

Table 3-5. Effects of media by containers types interaction on bell pepper height at 8 weeks after transplanting in a nethouse in Balm, Florida in spring and fall of 2011.

Media	Containers	Height cm
Coconut coir	Bag	46.7 BC
Pine bark	Bag	43.3 CD
Potting mix	Bag	51.7 AB
Coconut coir	Box	48.9 ABC
Pine bark	Box	38.8 D
Potting mix	Box	53.1 AB
Coconut coir	Pot	48.1 ABC
Pine bark	Pot	54.9 A
Potting mix	Pot	53.7 AB
Significance (P < 0.05)		*0.0265*

[Z] Values followed by different letters represent significant differences among treatments.
[NS] Not significant at P< 0.05 analysis of variance.

Table 3-6. Effects of media on bell pepper height at 12 weeks after transplanting in a nethouse at Balm, Florida in spring and fall of 2011.

Containers	Plant height cm Spring
Coconut coir	53.9 B
Pine bark	51.5 B
Potting mix	61.0 A
Significance (P < 0.05)	*0.0002*

[Z] Values followed by different letters represent significant differences among treatments.
[NS] Not significant at P< 0.05 analysis of variance.

Table 3-7. Effects of media on plant leaf greenness at 4 weeks after transplanting in a nethouse at Balm, Florida in spring and fall of 2011.

Media	Leaf greenness SPAD values	
	Spring	Fall
Coconut coir	41.5 B	49.1 A
Pine bark	48.0 A	47.8 A
Potting mix	46.2 A	44.1 B
Significance (P < 0.05)	*<0.0001*	*0.0242*

[Z] Values followed by different letters represent significant differences among treatments.
[NS] Not significant at P< 0.05 analysis of variance.
[SPAD] Soil plant analysis development

Table 3-8. Effects of container types on plant leaf greenness at 4 weeks after transplanting in a nethouse at Balm, Florida in spring and fall of 2011.

Containers	Leaf greenness SPAD values	
	Spring	Fall
Bag	50.8	49.5 A
Box	49.9	42.2 B
Pot	52.3	49.3 A
Significance (P < 0.05)	*NS*	*0.0004*

[Z] Values followed by different letters represent significant differences among treatments.
[NS] Not significant at P< 0.05 analysis of variance.
[SPAD] Soil plant analysis development

Table 3-9. Effects of media by container types interaction on bell pepper leaf greenness at 8 weeks after transplanting in a nethouse at Balm, Florida in spring and fall of 2011.

Media	Container	Leaf greenness SPAD values Spring	Fall
Coconut coir	Bag	40 D	55.1
Pine bark	Bag	46 BC	55
Potting mix	Bag	43.9 BC	60.7
Coconut coir	Box	42.2 CD	49.6
Pine bark	Box	40.7 D	57.3
Potting mix	Box	47.2 B	60.7
Coconut coir	Pot	42.3 CD	62.7
Pine bark	Pot	57.4 A	61.3
Potting mix	Pot	47.7 B	58.5
Significance (P < 0.05)			*NS*

[Z] Values followed by different letters represent significant differences among treatments.
[NS] Not significant at P< 0.05 analysis of variance.
[SPAD] Soil plant analysis development

Table 3-10. Effects of container types on bell pepper leaf greenness at 12 weeks after transplanting in a nethouse at Balm, Florida in spring and fall of 2011.

Containers	Chlorophyll content SPAD value
Bag	60.9 B
Box	60.0 B
Pot	64.1 A
Significance (P < 0.05)	*0.0268*

[Z] Values followed by different letters represent significant differences among treatments.
[NS] Not significant at P< 0.05 analysis of variance.
[SPAD] Soil plant analysis development

Table 3-11. Effects of media and container types interaction on bell pepper total dry root biomass and total shoot biomass in a nethouse at Balm, Florida in fall of 2011. [Z] Values followed by different letters represent significant differences among treatments.

Media	Container	Root biomass	Shoot biomass
Pine bark	Bag	84.8 AB	1,021.5 CD
	Box	58.8 BC	652.6 D
	Pot	87.5 AB	1,049.9 CD
Coconut coir	Bag	102.7 A	1,617.4 A
	Box	62.9 BC	1,475.5 AB
	Pot	37.2 C	993.1 C
Potting mix	Bag	46.8 C	1,447.1 AB
	Box	41.8 C	1,197.8 BC
	Pot	48.3 C	1,135.0 BC

Table 3-12. Effects of media and container types interaction on bell pepper marketable fruit weight and weight per fruit in a nethouse at Balm, Florida in spring and fall of 2011. Z Values followed by different letters represent significant differences among treatments.

Media	Container	Fruit weight	Weight per fruit
Pine bark	Bag	39,832 BC	166.2 AB
	Boxes	18,624 D	96.5 C
	Pot	36,202 C	167 AB
Coconut coir	Bag	37,705 C	153.5 AB
	Boxes	38,816 C	146.3 B
	Pot	33,799 C	163.5 AB
Potting mix	Bag	48,025 AB	177.9 A
	Boxes	47,695 AB	166.9 AB
	Pot	50,985 A	177.2 A

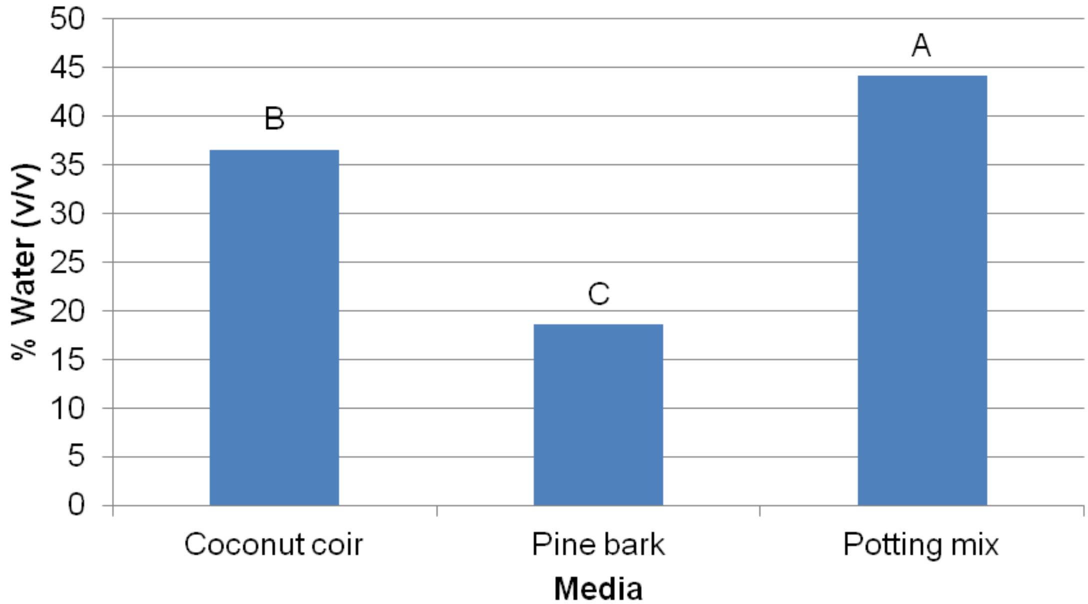


Figure 3-1. Effects of media on volumetric water content for bell pepper production in a nethouse at Balm, Florida in spring of 2011. [Z] Values followed by different letters represent significant differences among treatments.

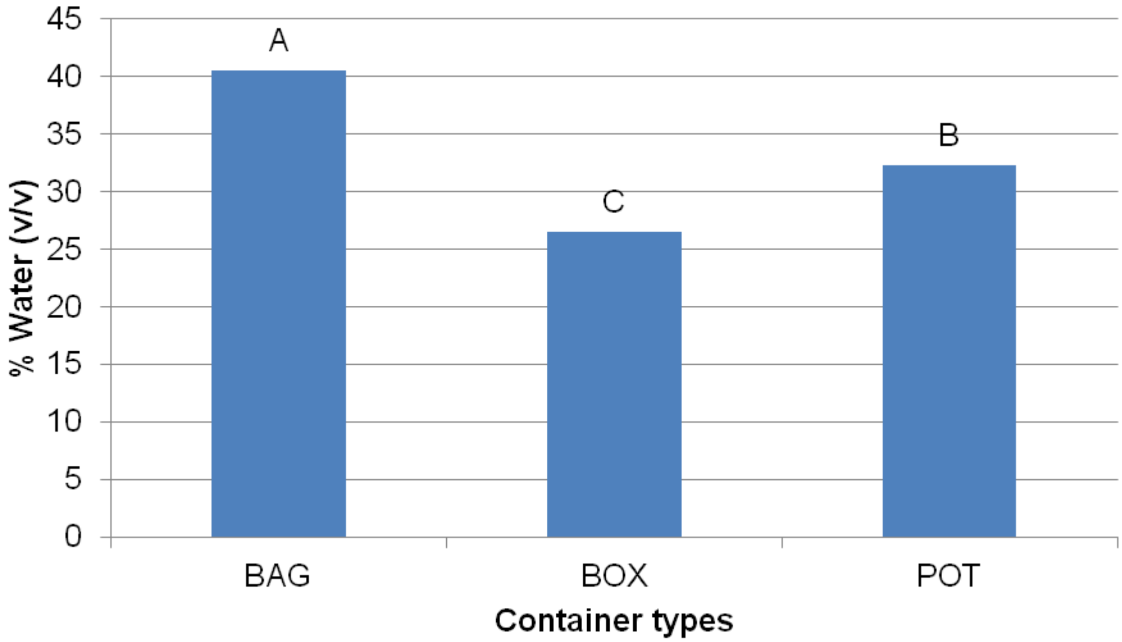


Figure 3-2. Effects of container types on volumetric water content for bell pepper production in a nethouse at Balm, Florida in spring of 2011. [Z] Values followed by different letters represent significant differences among treatments.

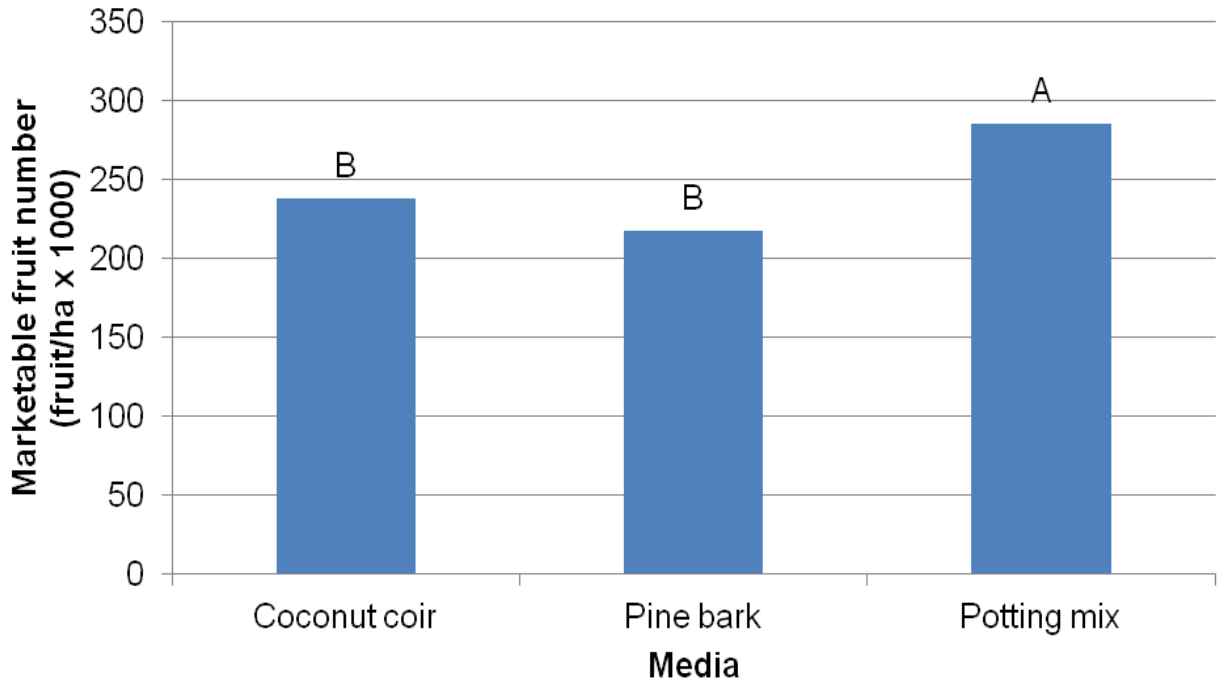


Figure 3-3. Effects of media on bell pepper marketable fruit number in a nethouse at Balm, Florida in spring and fall of 2011. [Z] Values followed by different letters represent significant differences among treatments.

CHAPTER 4
EFFECTS OF IN-ROW DISTANCES ON THE GROWTH AND YIELD OF BELL PEPPER CULTIVARS IN HIGH TUNNELS

Overview

The process of photosynthesis provides the biochemical energy for crop development. The efficiency of photosynthesis is related to the interception of the photosynthetic active radiation (PAR). Leaf area distribution is a major factor influencing PAR interception and an adequate distribution is achievable by changing crop density (Papadopoulos and Pararajasingham, 1997). There is a large diversity of pepper cultivars. Each cultivar differs on fruit size, growth habit (determinate or indeterminate), and marketable characteristics, thus cultural practices requirements might be different (Montsenboker, 1996). Several in-row spacing studies for different bell pepper cultivars agreed that the highest fruit yield is achievable between 0.2 to 0.5 m (Jovicich et al., 1999; Jovicich et al., 2004; Locascio and Stall, 1994). Nevertheless, in tunnel conditions, the local environment, seasonal changes, and type of cultivar may affect the crop response (Jovicich et al., 1999).

Limited research has been conducted on bell pepper in-row spacing in high tunnel conditions (Rodriguez et al., 2007). Recommendations of plant spacing varied among cultivars and production sites due to the number of factors affecting plant density (Huerta et al., 2009; Kahn and Leskovar, 2006; Ortega and Gutierrez, 2004). Protective structure production requires high investment, needing an appropriate selection of plant density to make an efficient use of the available space (Rodriguez et al., 2007). The objective of this study was to assess the effects of in-row spacing and cultivars on bell pepper growth and yield in high tunnel.

Materials and Methods

A field experiment was conducted from August 2011 to April 2012 at the Gulf Coast Research and Education Center of the University of Florida, located in Balm, Florida. The experiment was conducted in a passively ventilated high tunnel of 459 m^2 (7.57 m width by 60.60 m length by 5.50 m height) (Haygrove Tunnels, Redbank, United Kingdom) oriented north-south. The structure was built using galvanized steel with plastic roof (0.2-mm thick, 35% light-reduction polyethylene; Haygrove Tunnels, Redbank, United Kingdom). For freeze protection, the sides and ends of the unit were covered up to 24 h before the forecast freeze with a single layer of the same film used on the roof. The units were ventilated by lowering the sides and ends as soon as the air temperature reached 10^oC, provided that another freeze event was not forecast for the following night.

Determinate ‘Crusader’ and ‘Lafayette’ bell peppers (Syngenta seeds, Boise, Idaho, USA) and indeterminate bell pepper ‘Maria’ (Zeraim Gedera LTD, Israel) (5 week-old) seedlings were transplanted in a single row with either 20, 25 or 30 cm between plants on 16th August 2011. A second season of ‘Crusader’ and ‘Lafayette’ were replanted four months later (10th February 2012) overlapping the first season of the indeterminate ‘Maria’, after freezing events were unlikely in 2012 (Appendix A-1).

Planting trenches were 50 cm wide, 25 cm deep and spaced 150 cm apart on centers with a semicircular shape (Santos and Salame, 2012). Growing medium was aged pine bark with a particle size between 1 to 2.5 cm in diameter (Elixson Wood Products, Starke, Florida, USA). Constant drip irrigation was allowed to moisten the medium for 3 weeks before transplanting (Santos and Salame, 2012). Pre-plant nitrogen (N) was applied at a rate of 50 kg/ha using calcium nitrate (9% N) as the N source through the drip lines. Media electrical conductivity (EC) ranged from 0.7 to 3.0 mS/cm throughout the season. Treatments were arranged in a randomized complete block design with four replications. There was a light gradient oriented north-south in the tunnel (Fig. 4-9), so replications were oriented east-west to eliminate the effect of the gradient.

Experimental units were 3.6, 3.0, and 2.4 m long, corresponding to 30, 25, and 20 cm of in-row spacing (12 plants per plot). Drip irrigation was used 8 h/day for 7 days to establish pepper seedlings in 2011. After establishment, irrigation was adjusted according to the crop requirement, stage of growth, and evaporative demand in terms of reference potential evapotranspiration (ETo) from the historical daily averages of Penman for west-central Florida (Olson et al., 2011). Drip tape emitters were 30 cm apart with a flow of approximately 21.6 mL/min (Netafim, Israel) with 69 cbar of pressure. Irrigation cycles were 10 min long three to five times per day according to the historical ETo. Determinate ‘Crusader’ and ‘Lafayette’ bell pepper received approximately 400 kg/ha of N through the drip lines during a 4-month season in daily injections with the last irrigation cycle. Indeterminate ‘Maria’ received approximately 740 kg/ha of N during a 9-month season. One fertilizer proportional injectors (model D14MZ2; Dosatron International Inc., Clearwater, Florida, USA) were used to pump concentrated stock solution into the irrigation water, using a dilution rate of 1:50 (v/v). After establishment, seedlings were fertigated using a solution with nutrient levels of 2.27% N; 1% P; 6.48% K; Ca, 2%; Mg, 0.4%; B, 0.02%; Mn, 0.04%; Zn, 0.02%; Cl, 4.5%. Media pH ranged between 5.5 and 8.0. Because pepper cultivars of different growing habits were utilized in this study, growing practices for each type followed recommended for both pepper types. Two weeks after transplanting, the crown flower of each stem of indeterminate 'Maria' was removed and plants were tied with the Spanish trellis system. Determinate 'Crusader' and 'Lafayette' were horizontally tied with no pruning. Plants were horizontally tied every two weeks starting 4 weeks after transplanting (WAT). Pesticides were applied weekly or biweekly depending on pest population. In March 2012, plants were highly affected by trips (*T. tabaci*) corresponding to the end of the strawberry season (first week of March), damaging the surface of the developing fruit and resulting in curling and distortion of the calyxes and fruit scars. Some visually spotted symptoms were small, distorted leaves, and reduced flower production. This condition forced to end the trial a month before planed and harvesting all the commercial fruit at once.

Plant height was measured at 4, 8, 12, 31, and 35 WAT using five randomly selected plants per plot avoiding border plants. The same five plants per plot were sampled during the five height observations. Plants were measured from the ground level to the newest top leaf. Leaf greenness was measured at 4, 8, 12, 31, and 35 WAT with a handheld color meter (SPAD-502; Minolta, Ramsey, New Jersey, USA), which provides a numerical soil plant analysis development (SPAD) value, ranging from 0 to 80, where 0 = white and 80 = dark green. This variable is directly correlated to chlorophyll content (Azia and Stewart, 2001; Himelrick et al. 1992). Five readings were taken from five of the newest mature leaves on the top of the plant canopy. The same plants used for plant height were used to obtain the greenness data.

Marketable fruit weight and number were determined throughout six harvests of the determinate cultivars. Indeterminate bell pepper marketable fruit weight and number were obtained throughout 14 harvests. Fruit were classified using the United States Department of Agriculture (USDA) vegetable product sheet standards (USDA, 2011). Fruit harvest started on 2 November 2011, and ended on 4 May 2012. A marketable fruit was defined as a fruit without visible damage with at least 30% red skin, with a diameter and length not less than 6.2 cm, and without deformations or physiological disorders. Any fruit that did not meet these requirements was considered unmarketable. Weight per fruit was determined by dividing the marketable fruit weight of each treatment by their corresponding fruit number.

Plant tissue samples were taken at the end of each season of determinate cultivars during the harvesting stage to assess the nutrient status of the plants. Plant tissue samples were taken using five randomly selected plants per plot avoiding border plants. Five of the newest mature leaves were sample avoiding the oldest leaves. Plant tissue samples were dried out at 80°C for five days and then sent a commercial laboratory for N, P, K, Ca and Mg analysis (Waters Agricultural Laboratories, Camilla, Georgia, USA).

Collected data were analyzed using the analysis of variance procedure (Statistix Analytical Software, Tallahassee, Florida, USA) to determine factors main effect and interactions among factors ($P<0.05$). Treatments means were separated with Fisher's-protected least significant (LSD) at the 5% significant level. In-row distance was treated as a continuous variable, and main effect was analyzed with linear regression analysis. Differences between means were compared using standard errors.

Results and Discussion

There were no significant cultivars by in-row distance interactions for all examined variables. Cultivars did not significantly affected plant height at 4 and 8 WAT, whereas there was a significant effect at 12, 21, and 35 WAT. At 12 WAT, data showed no difference between ‘Maria’ and ‘Lafayette’ with a plant height of 73.8 and 70.4 cm, respectively (Table 4-1). ‘Crusader’ showed the smallest plant height at 12 WAT (Table 4-1). At 31 and 35 WAT, ‘Maria’ had the tallest plants with 106.4 and 125.6 cm (Table 4-1). At 31 WAT, there was a significant difference between cultivars ‘Lafayette’ and ‘Crusader’. ‘Lafayette’ resulted on the tallest plants with a height of 54.9 cm compared to ‘Crusader’ that showed a plant height of 45.8 cm (Table 4-1). There was no difference between ‘Lafayette’ and ‘Crusader’ height at 35 WAT (Table 4-1).

Cultivars affect on leaf greenness at 12 and 31 WAT (Table 4-2). At 12 WAT, data showed no difference between ‘Lafayette’ and ‘Crusader’, with SPAD values ranging between 66.8 and 66.9 (Table 4-2). ‘Maria’ resulted on the lowest leaf greenness at 12 WAT with a SPAD value of 61.4 (Table 4-2). At 31 WAT, ‘Maria’ obtained the highest leaf greenness with a SPAD value of 65.7, whereas there was no difference between ‘Lafayette’ and ‘Crusader’ with SPAD values of 62.1 and 62.4 (Table 4-2). There was no effect of the cultivars at 4, 8 and 35 WAT.

Cultivars and in-row spacing did not affect N, P and Mg concentrations at 12 and 35 WAT. There was an effect of cultivars on plant tissue analysis for K and Ca at 12 WAT. No difference resulted for ‘Maria’ and ‘Lafayette’ K concentration with levels of 5.5 and 5.4% (Table 4-3). The lowest concentration was found in ‘Crusader’ with 5.8% of K (Table 4-3). For Ca concentration, there was no significant difference between ‘Maria’ and ‘Crusader’ with of 2.8 and 2.7% (Table 4-3), where as ‘Lafayette’ showed the highest Ca concentration with 3.0% (Table 4-3).

Cultivars had an effect of on total marketable fruit number per plant. ‘Maria’ resulted on the highest marketable fruit number per plant with 14.9 fruit per plant (Fig. 4-1). There was no difference between ‘Lafayette’ and ‘Crusader’ with 7.7 and 8.8 fruit per plant respectively (Fig. 4-1).

Bell pepper cultivars had an effect of on total marketable fruit number. ‘Maria’ resulted on the highest marketable fruit number with 492,139 fruit/ha (Fig. 4-2). Data showed no difference between ‘Lafayette’ and ‘Crusader’ with 317,122 and 322,405 fruit/ha respectively (Fig. 4-2). In-row spacing did not have an effect on bell pepper total marketable fruit number, weight, fruit number per plant and weight per fruit. Total marketable fruit number ranged between 320,310 and 434,832 fruit/ha (Fig. 4-3), whereas total marketable fruit weight ranged between 54,243 and 74,832 kg/ha (Fig. 4-4). Bell pepper fruit number per plant ranged between 9.2 and 11.0 fruit/plant for all in-row distances (Fig. 4-5), whereas weigh per fruit ranged between 239.8 and 269.9 g/fruit (Fig. 4-6).

Cultivars affected bell pepper weight per fruit. ‘Lafayette’ resulted on the highest weight per fruit with 325 g/fruit, while ‘Maria’ showed the lowest weight per fruit with 239 g/fruit (Fig. 4-7). ‘Lafayette’ obtained 21.9% higher weight per fruit than ‘Crusader’ and 47.0% higher than cultivar ‘Maria’ (Fig. 4-7). There was no difference on marketable fruit weight for bell pepper cultivars (Fig. 4-8)

Establishing plants at in-row distances from 20 to 30 cm produced no clear determination of the most beneficial in-row spacing to maximize marketable yield. Furthermore, the variability inside each treatment of in-row spacing was very high as reflected by the coefficients of variation for total marketable fruit number, and weight, fruit number per plant and weight per fruit.

The data indicated that plants could be placed at 30 cm without reducing marketable yield in high tunnels. This value is within the standard distances range of 25 and 60 cm between plants for bell pepper in open field. These results are similar to previous research reported by Russo (2008) who indicated that pepper plants could be planted at 32 and 48 cm of in-row spacing. Maboko et al. (2012) reported that 3 plants/m^2 (corresponding to 30 cm of in-row spacing) increased indeterminate sweet pepper yield, compared to 2.5 and 2 plants/m^2 inside shade net, whereas Jovicich et al. (2004) reported that a density of 3.8 plants/m^2 resulted in greater yield of extra-large fruit for indeterminate bell pepper in greenhouse.

In contrast, Ortega and Gutierrez (2004) indicated that plant densities between 10 and 12 plants/m2 are adequate for high marketable yield of determinate sweet pepper, while Cebula (1995) reported that plant densities of 3 and 4 plants/m^2 to reduced early yield per plant in sweet pepper and productivity is inversely proportional to the increasing density. These results suggested that growers may have the option of either using fewer plants on the same amount of land or more plants on less land without much reduction of quantity or quality of yield.

From the cultivars standpoint this results support that there is no difference for total marketable fruit weigh between indeterminate ‘Maria’ and determinate ‘Lafayette’ and ‘Crusader’. ‘Maria’ resulted in the smallest fruit weight, compared to ‘Lafayette’ and ‘Crusader’ (Fig 4-6). These suggest ‘Lafayette’ and ‘Crusader’ higher weight per fruit allowed then to compensate the high fruit set of indeterminate ‘Maria’. This research may lead to savings growers in the bell pepper greenhouse industry. Indeterminate cultivars required a high investment in seeds, labor, and time in order to optimize yield. These force growers to spend high amounts of money in crop maintenance on top of the investment of the structure. Determinate bell pepper cultivars required less labor and investment for crop maintenance compared to indeterminate varieties, due to their less expensive seeds and potential savings in labor by avoiding practices such as tiding and pruning. This could represent savings up to $23,040/ha, assuming a labor cost of $8/h in an 8-month season. These results support that growers could obtain same fruit yield with two seasons of determinate bell pepper compared to one season of indeterminate bell pepper in protected structures. Furthermore, average fruit weight is enhanced by determinate genotypes which could allow growers to obtain higher profits for higher quality fruit. Further research is necessary to evaluate the economic viability of substituting the indeterminate cultivars for determinate cultivars in protective structure conditions.

In conclusion, there is no difference in total marketable fruit number and weight for bell pepper planted at 20, 25, and 30 cm of in-row spacing. ‘Lafayette’ resulted in the higher weight per fruit, while ‘Maria’ resulted in the lower weight per fruit. ‘Maria’ showed the higher total fruit number. There was no difference in total marketable fruit yield between two seasons of determinate bell pepper compared to one season of indeterminate bell pepper in high tunnel conditions.

Table 4-1. Effects of ‘Maria’, ‘Lafayette’ and ‘Crusader’ on plant height at 4, 8, 12, 31, and 31 weeks after transplanting (WAT) in high tunnel at Balm, Florida in fall of 2011 and spring of 2012.

Cultivars	Plant height cm				
	4 WAT	8 WAT	12 WAT	31 WAT	35 WAT
Maria	30.8	59.5	73.8 A	106.3 A	125.6 A
Lafayette	29.3	55.6	70.3 A	54.8 B	63.3 B
Crusader	28.7	54.5	63.8 B	45.7 C	55.8 B
Significance (P < 0.05)	*NS*	*NS*	*0.0025*	*<0.0001*	*<0.0001*

[Z] Values followed by different letters represent significant differences among treatments.
[NS] Not significant at *P* < 0.05 analysis of variance.

Table 4-2. Effects of 'Maria', 'Lafayette' and 'Crusader' on leaf greenness at 4, 8, 12, 31, and 31 weeks after transplanting (WAT) in high tunnel at Balm, Florida, in fall of 2011 and spring of 2012.

Cultivars	Leaf greenness SPAD value				
	4 WAT	8 WAT	12 WAT	31 WAT	35 WAT
Maria	49.6	63.8	61.3 B	65.7 A	54.1
Lafayette	50.1	65.7	66.7 A	62.1 B	52.5
Crusader	50.3	67.4	66.9 A	62.4 B	54.5
Significance (P < 0.05)	*NS*	*NS*	*0.0128*	*0.0115*	*NS*

[Z] Values followed by different letters represent significant differences among treatments.
[NS] Not significant at P < 0.05 analysis of variance.
[SPAD] Soil plant analysis development.

Table 4-3. Effects of ‘Maria’, ‘Lafayette’ and ‘Crusader’ on plant tissue analysis at 12 weeks after transplanting in high tunnel at Balm, Florida in fall of 2011 and spring of 2012.

Cultivars	Plant analysis %				
	N	P	K	Ca	Mg
Maria	4.1	0.3	5.5 AB	2.7 B	0.8
Lafayette	4.3	0.3	5.3 A	3.0 A	0.9
Crusader	4.3	0.3	5.8 B	2.7 B	0.9
Significance (P < 0.05)	*NS*	*NS*	*0.0251*	*0.0309*	*NS*

[Z] Values followed by different letters represent significant differences among treatments.
[NS] Not significant at $P < 0.05$ analysis of variance.

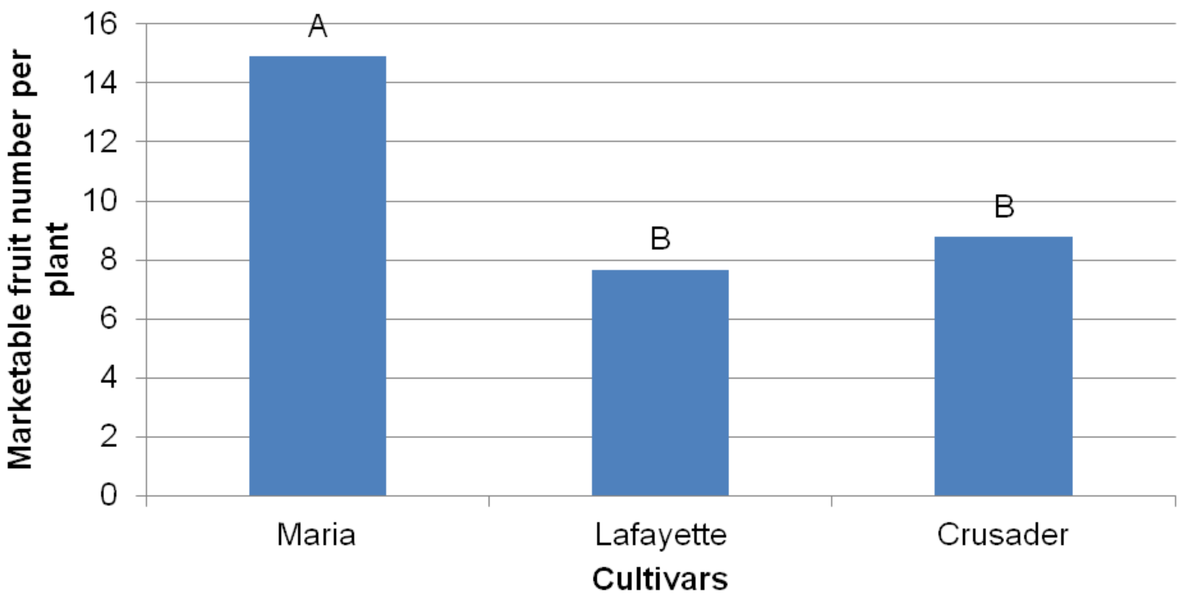


Figure 4-1. Effects of cultivars on bell pepper marketable fruit number per plant in high tunnel at Balm Florida in fall of 2011 and spring of 2012. [Z] Values followed by different letters represent significant differences among treatments.

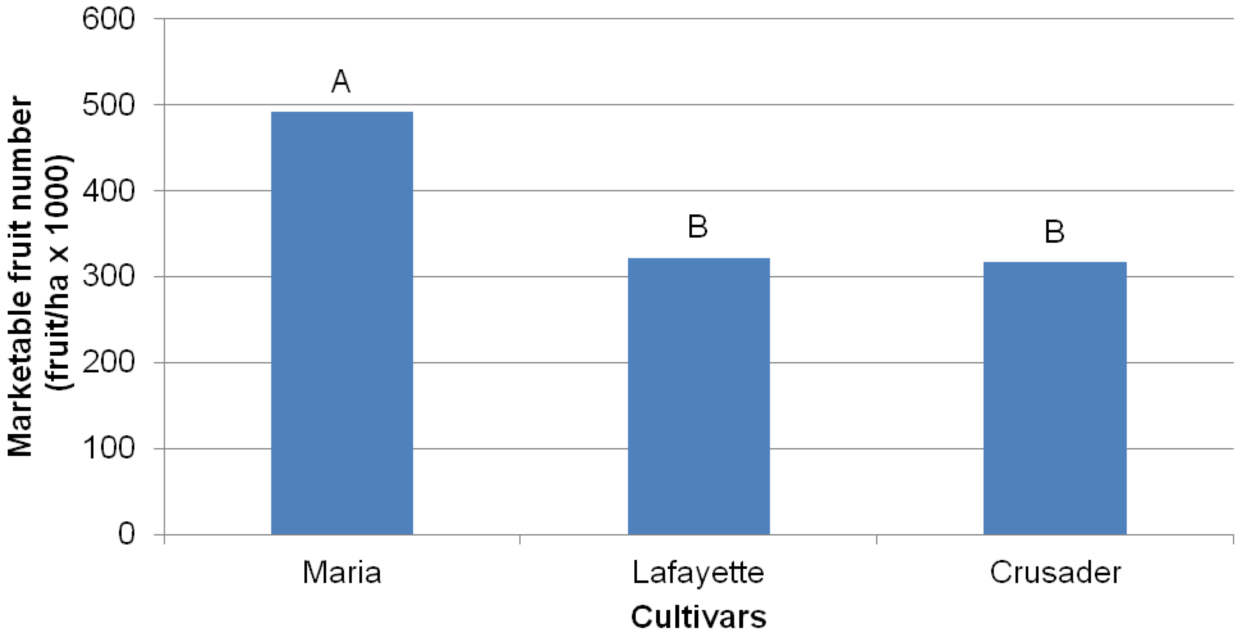
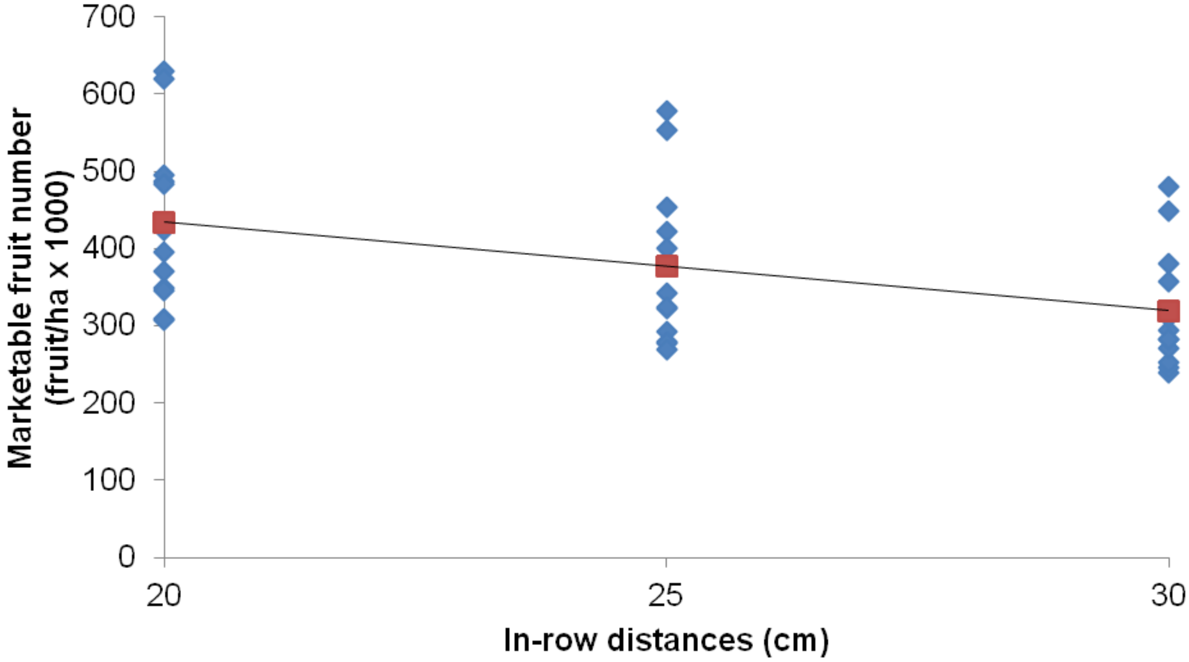
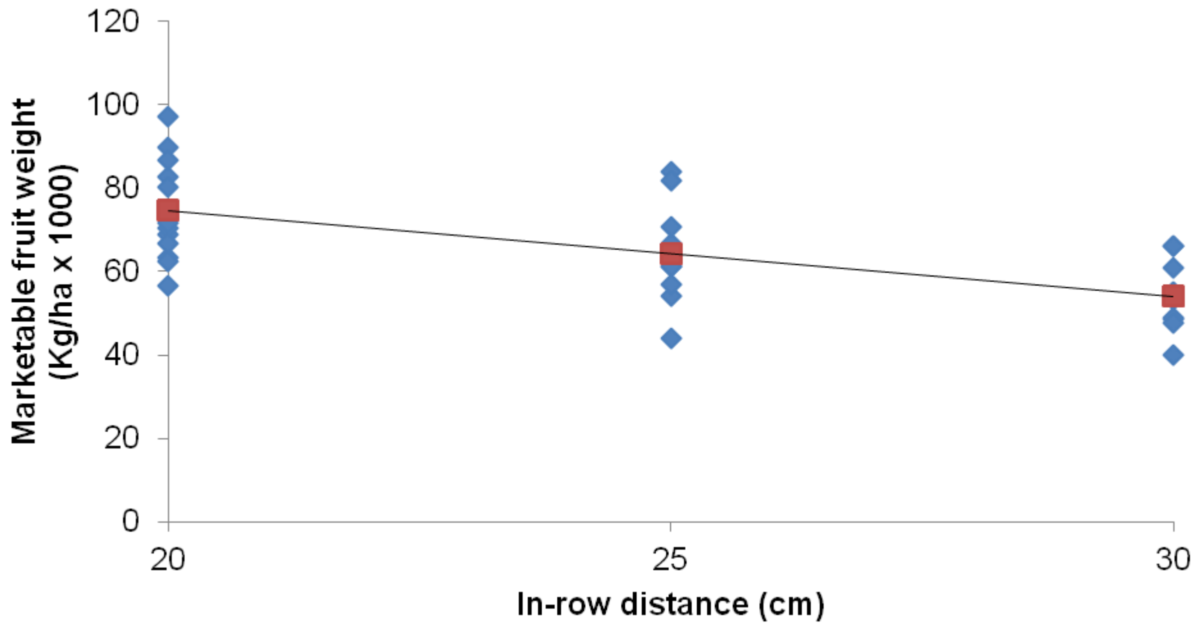


Figure 4-2. Effects of cultivars on bell pepper marketable fruit number in high tunnel at Balm, Florida in fall of 2011 and spring of 2012. Z Values followed by different letters represent significant differences among treatments.



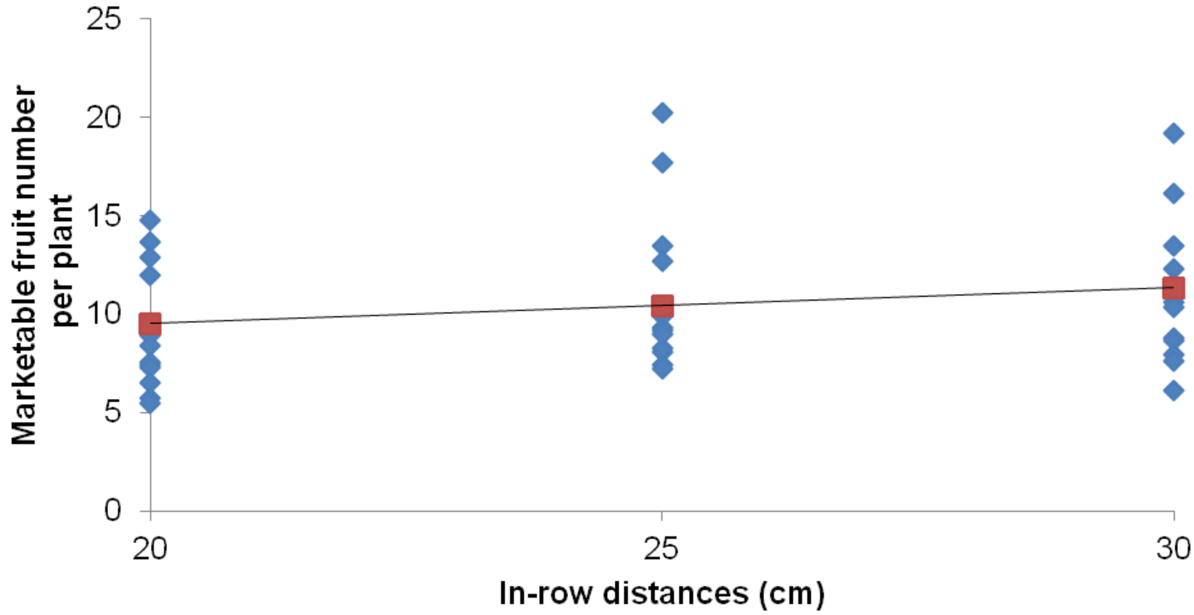
P = 0.0072; r^2 = 0.19

Figure 4-3. Effects of in-row distances on bell pepper marketable fruit number per hectare in high tunnel at Balm, Florida in fall of 2011 and spring of 2012.



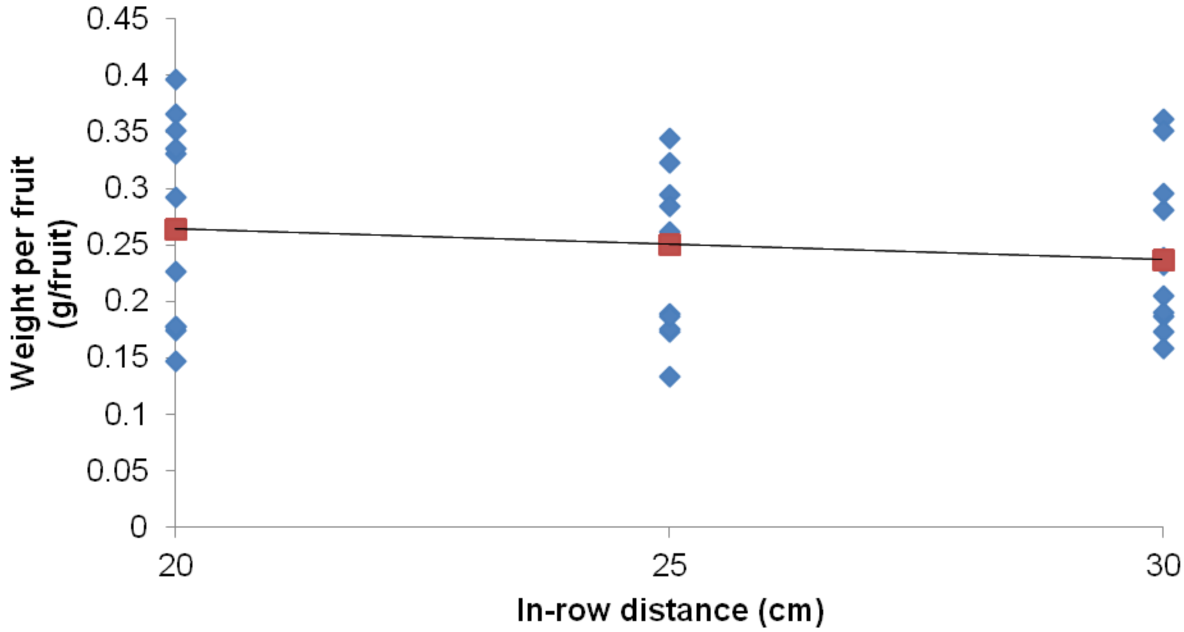
P = < 0.0001; r^2 = 0.41

Figure 4-4. Effects of in-row distances on bell pepper marketable fruit weight in high tunnel at Balm, Florida in fall of 2011 and spring of 2012.



P = 0.2373; r^2 = 0.041

Figure 4-5. Effects of in-row distances on bell pepper marketable fruit number per plant in high tunnel at Balm, Florida in fall of 2011 and spring of 2012.



P = 0.3684; r^2 = 0.0239

Figure 4-6. Effects of in-row distances on bell pepper fruit weight in high tunnel at Balm, Florida in fall of 2011 and spring of 2012.

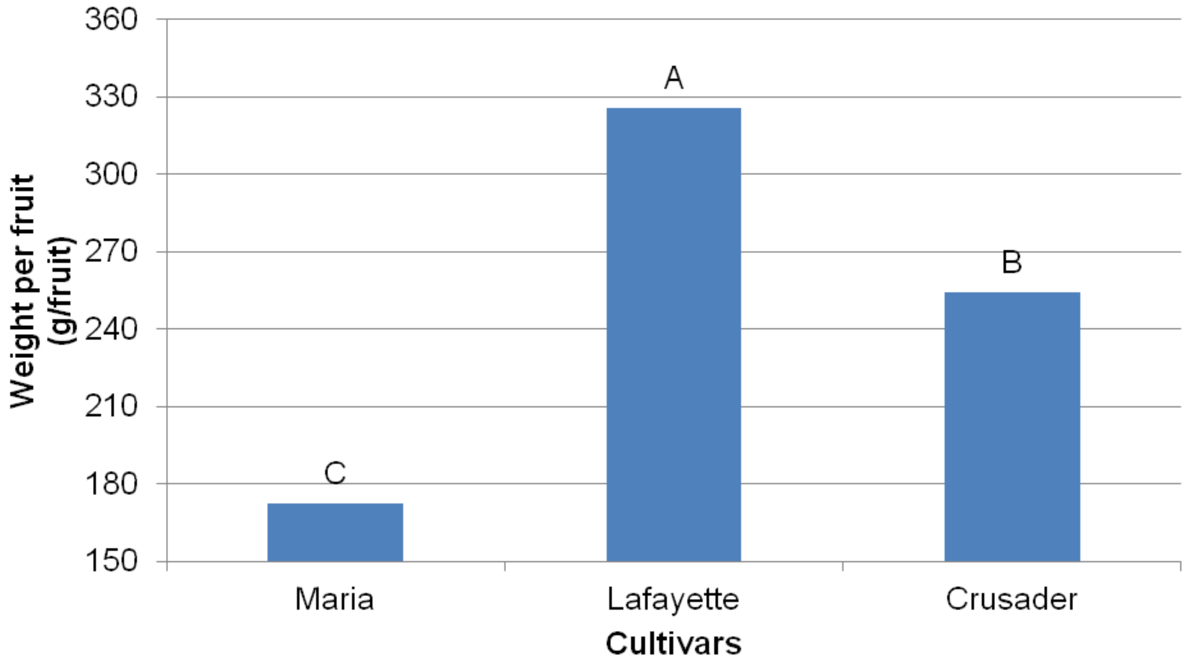


Figure 4-7. Effects of bell pepper cultivars on weight per fruit in high tunnel at Balm, Florida in fall of 2011 and spring of 2012. Z Values followed by different letters represent significant differences among treatments.

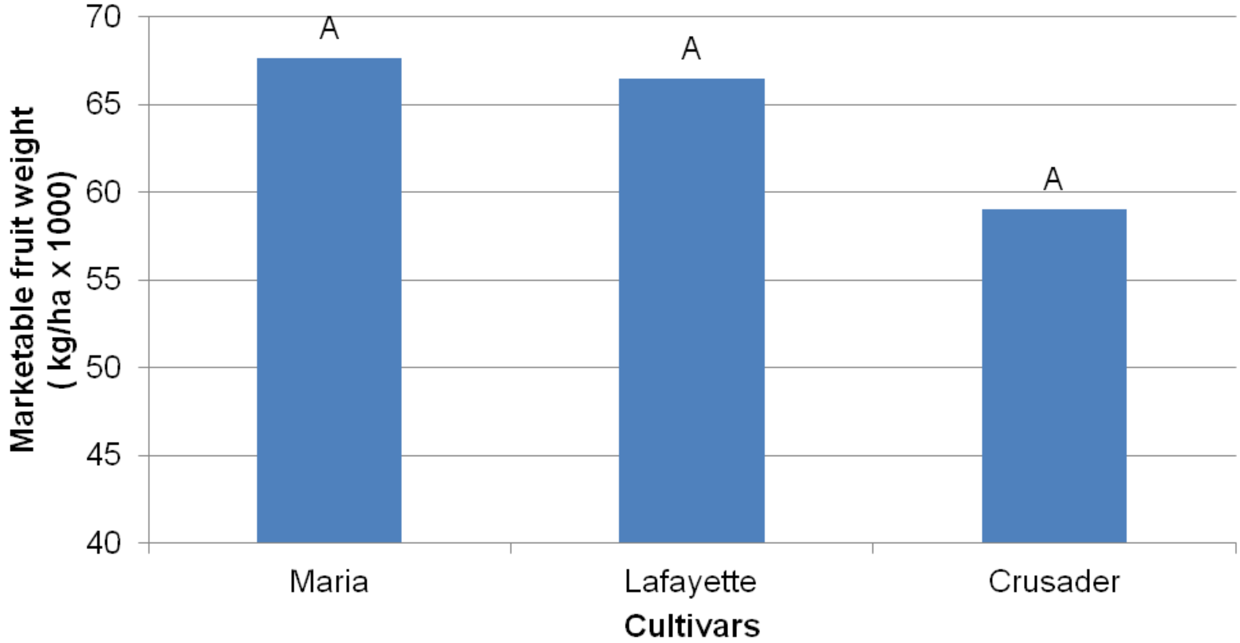


Figure 4-8. Effects of bell pepper cultivars marketable fruit weight per hectare in high tunnel at Balm, Florida in fall of 2011 and spring 2012. Z Values followed by different letters represent significant differences among treatments.

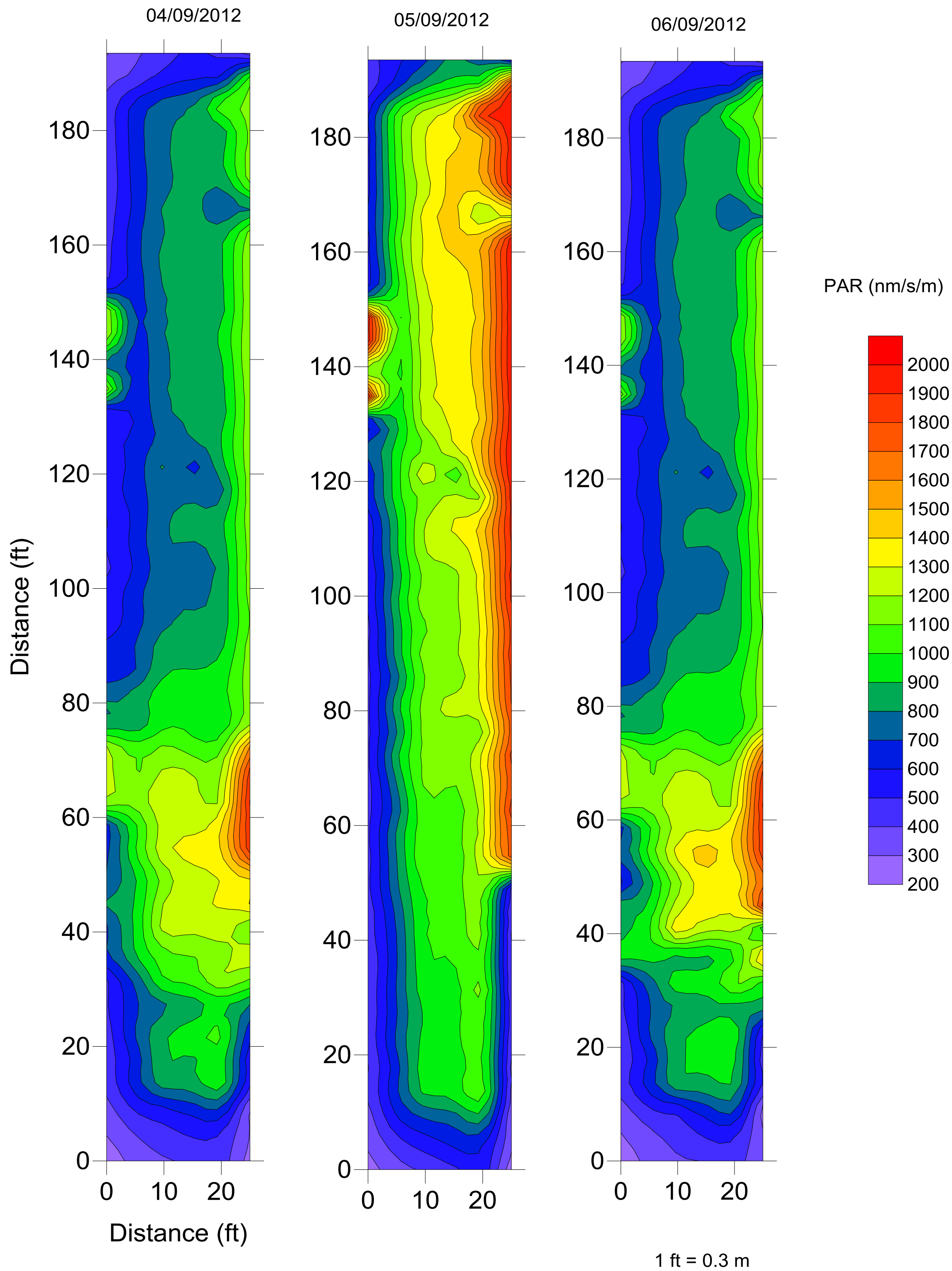


Figure 4-9. Effects of high tunnel roof on photosynthetic active radiation (PAR) levels at Balm, Florida in spring 2012.

CHAPTER 5
CONCLUSIONS

These studies on production systems and cultural practices provided basic information on media, container types, cultivars and in-row distances for bell pepper growth and yield in protective structures. On the container by soilless media study, the combination of potting mix with bags, pots, or boxes increased bell pepper total marketable fruit weight, number and plant height compared to pine bark and coconut coir. The data supported that there is a different pattern on water retention among media and container types, which influenced plant available water. Media analysis showed that pine bark water retention at field capacity is lower than coconut coir and potting mix, due to it lower water-filled pore percentage and reduced capillarity. Potting mix treatments resulted in 57.7% higher water content than pine bark and 17.0% higher than coconut coir while boxes and pots resulted in 26.5% and 32.3% less volumetric water content than bags. Furthermore, shallow containers, such as boxes, could influence the fast water movement throughout media with low water retention such as pine bark. The combination of low capillarity of the pine bark (32.6%) and shallowest of boxes could restrict water lateral movement and therefore its availability for the plant, affecting plant growth and development, while high water retention of potting mix helped retain more water for longer time, allowing bell pepper plants to uptake water during moments of high evapotraspiration requirement.

There was no significant difference between coconut coir and pine bark in pots or bags for bell pepper total marketable fruit weight. Besides the low water retention of pine bark compared to coconut coir, an adequate container such as bags or pots can restrict water losses from the media allowing the plant to have more available water.

For bell pepper in-row spacing, there was no difference in total marketable fruit number and weight for bell pepper planted at 20, 25, and 30 cm of in-row spacing. Data indicated that plants could be place at 30 cm without loss of marketable yield in high tunnels. These results suggested that growers may have the option of either using fewer plants on the same amount of land or more plants on less land without much reduction of quantity or quality of yield.

From the cultivars stand point this results support that there was no difference for total marketable fruit weigh between indeterminate ‘Maria’ and determinate ‘Lafayette’ and ‘Crusader’. ‘Maria’ resulted in the smallest fruit weight, compared to ‘Lafayette’ and ‘Crusader’. These suggested that ‘Lafayette’ and ‘Crusader’ higher weight per fruit allowed then to compensate the high fruit set of indeterminate ‘Maria’. These results supported that growers could obtain same fruit yield with two seasons of determinate bell pepper compared to one season of indeterminate bell pepper in protected structures. Indeterminate cultivars required a high investment in seeds, labor, and time in order to optimize yield. These force growers to spend high amounts of money in crop maintenance on top of the investment of the structure. Determinate bell pepper cultivars required less labor and investment for crop maintenance compared to indeterminate varieties, due to their less expensive seeds and potential savings in labor by avoiding practices such as tiding and pruning. Furthermore, average fruit weight is enhanced by determinate genotypes which could allow growers to obtain higher profits for higher quality fruit.

LIST OF REFERENCES

Abad, M., F. Fornes, C. Carrion, V. Noguera, P. Noguera, A. Maquieira and R. Puchades. 2005. Physical properties of various coconut coir dust compared to peat. HortScience 40 (7):2138-2144.

Ansorena Miner, J. 1994. Sustratos propiedades y caracterización. 1st ed. Ediciones Mundi-Prensa, España.

Azia, F., and K. A. Stewart. 2001. Relationships between extractable chlorophyll and SPAD values in muskmelon leaves. Journal of plant nutrition, 24(6), 961-966.

Brady, C. B. and R. R. Well. 2007. The nature and properties of soils. Thirteenth edition. Pearson Education, Inc. India. P. 245-255.

The Canadian Sphagnum Peat Moss Association. 2012. Harvesting Peat in Canada. 8/26/12. http://www.peatmoss.com/pm-harvest.php

Casanova, S C., F.R. Rupo. 2007. Manual para la producción protegida de hortalizas. Segunda Edición. Editorial Liliana. La habana, Cuba.

Cavero, J., R. G. Ortega, and M. Gutierrez. 2001. Plant density affects yield, yield components, and color of direct-seeded paprika pepper. HortScience 36(1):76-79.

Cebula, S. 1995. Optimization of plant and shoot spacing in greenhouse production of sweet pepper. Acta Horticulturae 412.

Contreras, S. 2004. Tomato and Pepper, Hybrid seed production in vegetables. Departamento de Ciencias Vegetales. Pontificia Universidad Católica de Chile. Santiago. Chile.

Cruz-Huerta, N., J. G. Williamson, and R. L. Darnell. 2011.Low night temperature increases ovary size in sweet pepper cultivars. HortScience 46(3):396–401.

Del Amor, F.M. and M.D. Gómez López. 2009. Agronomical response and water use efficiency of sweet pepper plants frown in different greenhouse substrates. HortScience 44:810-814.

De Pascale, S., L. Dalla Costa, S. Vallone, G. Barbieri, and A. Maggio. 2011. Increasing water use efficiency in vegetable crop production: from plant to irrigation systems efficiency. HortTechnology 21: 301-308.

Diaz-Perez, J. C., D. Granberry, K. Seebold, D. Giddings and D. Bertrand. 2004. Irrigation levels affect plant growth and fruit yield of drip-irrigated bell pepper. HortScience, Vol. 39 (4).

Dukes, M. D., E. H. Simone, W. E. Davis, D. W. Studstill and R. Hochmuth. 2003. Effect of sensor-based high frequency irrigation on bell pepper yield and water use. 2nd International conference on irrigation and drainage. pp. 665-674.

Economic Research Service (ERS), 2012. Bell Peppers and Chile Peppers, Vegetables and Melons, USDA. <http://www.ers.usda.gov/topics/crops/vegetables-pulses.aspx>

Eshbaugh, W.H. 1976. Genetic and biochemical systematic studies of chili peppers (Capsicum-Solanaceae). Bulletin of the Torrey Botanical club. Vol. 102, No. 6, pp.396-403.

Eshbaugh, W.H. 1993. History and exploitation of a serendipitous new crop discovery. p. 132-139. In: J. Janick and J.E. Simon (eds.), New crops. Wiley, New York.

Eshbaugh, W.H., 2012. The Taxonomy of the genus Capsicum. P. 14-28 In: Peppers botany, production and uses. 2012. Russo, V.M. USDA/ARS Wes Watkins Agricultural Research Laboratory, Lane, Oklahoma, USA.

Fuentes Yague, J. L. 2003. Técnicas de riego. 4ta edición. Ediciones mundi-prensa. Madrid, España.

Gianquinto, G. P. 2005. Soilless culture information system. Orticoltura, dip. agronomia Ambientale e produzioni vegetali, Universita di padova. 8/26/12. http://www.fao.org/hortivar/scis/scis.htm?TRX= Redirect&TO=DOC&ID=0

Grey, T.L., and T.M. Webster. 2012. Pepper fertilization and irrigation management. P. 57-72 In: Peppers botany, production and uses. 2012. Russo, V.M. USDA/ARS Wes Watkins Agricultural Research Laboratory, Lane, Oklahoma, USA.

Hall, D.O., and K.K. Rao. 1999. Photosynthesis. 6th edition. Institute of biology, Cambridge University, United Kingdom.

Haman, D. Z., and Izuno, F. T. 2003. Soil water relationships. Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida

Hanson, A. M., J. R. Harris, R. Wright, and A. Niemiera. 2004. Water content of a pine-bark growing substrate in a drying mineral soil. HortScience 39 (3):591-594.

Hartz, T., M. Cantwell, M. Lestrange., R. Smith., and J. Aguiar., 2008. Bell pepper production in California. University of California, Davis. Vegetable Research & Information Center. Vegetable Production Series. Oakland, California.

Hepler, P. K. 2005. Calcium: A central regulator of plant growth and development. The plant cell vol 17 N. 8 2142-2155.

Himelrick, D. G., C. W. Wood, W. A. Dozier JR. 1992. Relationship between SPAD-502 meter values and extractable chlorophyll in strawberry. Advances in strawberry research, Volume 11.

Hochmuth, G., and R. Hochmuth. 2003. Open-field soilless culture of vegetables. IFAS publ., Univ. of Florida, Gainesville, FL. University of Florida.

Hochmuth, R. C., D. D. Treadwell, E. H. Simonne, L. B. Landrum, W. L. Laughlin, and L. L. Davis. 2010. Growing bell peppers in soilless culture under open shade structures. IFAS publ., Univ. of Florida, Gainesville, FL. University of Florida.

Huerta, N.C., F. Sánchez del Castillo, J. O. Cereceres and M. del Carmen Mendoza Castillo. 2009. Altas densidades con despunte temprano en rendimiento y periodo de cosecha en chile pimiento. Agricultura Técnica en México Vol. 35 Num.1.

Hunter, J. J. 1985. Soilless culture of greenhouse vegetables. UC Davis, Vegetable research and information center. University of California. 8/26/12. http://vric.ucdavis.edu/pdf/hydroponics_soillesscultureofgreenhouse%20vegetables.pdf

Jackson, B. E., J. F. Browder, R. D. Wright, J. R. Harris, and A. X. Niemiera. 2008. Effect of fertilizer rate on growth of azalea and holly in pine bark and pine tree substrates. HortScience 43 (5): 1561-1568.

Jackson, B. E., M. Alley, R. D. Wright, M. 2009. Comparison of fertilizer nitrogen availability, nitrogen immnobilization substrate carbon dioxide efflux, and nutrient leaching in peat-lite, pine bark, and pine tree substrates. HortScience 44(3):781-790.

Jovicich, E., D. J. Cantliffe and G. J. Hochmuth. 1998. Plant density and shoot pruning on yield and quality of a summer greenhouse sweet pepper crop in Northcentral Florida. <http://www.hos.ufl.edu/protectedag/pdf/pepperpruning-elio.pdf>

Jovicich, E., D.J. Cantliffe, and G.J. Hochmuth. 1999. Plant density and shoot pruning on yield and quality of a summer greenhouse sweet pepper crop in Northcentral Florida. HortScience 34: 532.

Jovicich, E., D.J. Cantliffe, S. A. Sargent, and L.S. Osborne. 2004. Production of greenhouse-grown peppers in Florida. 14 July 2011. <http://edis.ifas.ufl.edu/hs228>

Jovicich, E., D.J. Cantliffe, and P.J. Stoffella. 2004. Fruit yield and quality of greenhouse-grown bell pepper as influenced by density, container, and trellis system. HortScience 14: 507-513.

Jovicich, E., D.J. Cantliffe, P.J. Stoffella, and D.Z. Haman. 2007. Bell pepper fruit yields and quality as influenced by solar radiation-based irrigation and container media in a passively ventilated greenhouse. HortScience 42: 642-652.

Kahn, B. A., D. I. Leskovar. 2006. Cultivar and plant arrangement effects on yield and fruit quality of bell pepper. HortScience 41(7): 1565-1570.

Krewer, G., J. Ruter. 2009. Fertilizing highbush blueberries in pine bark beds. Cooperative extension. The University of Georgia.

Krishna, A. D., 2003. Capsicum: The Genus Capsicum. P. 9-10. Taylor & Francis. London, United Kingdom.

Konduru, S., M. R. Evans, and R. H. Stamps. 1999. Coconut husk and processing effects on chemical and physical properties of coconut coir dust. HortScience 34(1):88-90.

Maboko, M.M., C.P. Du plooy, and S. Chiloane. 2012. Effect of plant population, stem and flower pruning on hydroponically grown sweet pepper in a shadenet structure. African Journal of Agricultural Research Vol. 7(11), pp.1742-1748.

Lin, W.C. and M. Saltveit, 2012. The Greenhouse production. P. 57-72 In: Peppers botany, production and uses. 2012. Russo, V.M. USDA/ARS Wes Watkins Agricultural Research Laboratory, Lane, Oklahoma, USA.

Locascio, S. J. and W. M. Stall. 1994. Bell pepper yield as influenced by plant spacing and row arrangement. J. Amer. Soc. Hort. Sci. 119: 899-902.

Mayoral, J.A., E. T. Dieguez., M. Toyota., B. M. Amador. 2000. Effects of salt and wáter stress on the growth and photosynthesis rate of bell pepper (Capsicum annuum L.) HortScience vol. 35 no. 3 427.

Moller, M. and S. Assouline. 2007. Effects of shading screen on microclimate and crop water requirements. Irrig Sci 25:171-181.

Mossler, M., M. J. Aerts, and O. N. Nesheim. 2009. Florida Crop/Pest Management Profiles: Bell PeppersHorticultural Sciences Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida.

Motsenbocker, C.E. 1996. In-row plant spacing affects growth and yield of pepperoncini pepper. HortScience 31:198-200.

MSU, Mississippi State University. 2010. High Tunnel Crop Production Project. 20 October 2011. <http://msucares. com/crops /hightunnels/index.html>

NASS, National Agricultural Statistics Service. 2012. Vegetables 2011 Summary January 2012. 13 August 2012. <www.nass.usda.gov>

Nelson, P. V. 1998. Greenhouse operation & management. Fifth edition. Prentice Hall. Upper Saddle River, New Jersey. United States.

New York State Agricultural Experiment Station. 2008. SARE grant ONE04-028, High Tunnel Tomato Variety Trial, Final Report. 4 August 2011. <http://web.pppmb.cals.cornell. edu/dillard/pdf/SAREFinal Report.pdf>

Olson, S.M., E.H. Simonne, W.M. Stall, G.E. Vallad, S.E. Webb, E.J. McAvoy, S.A. Smith, M. Ozores-Hampton, and B.M. Santos. 2011. Pepper production in Florida. p. 215-234. In: Vegetable production handbook for Florida, 2011-2012. S.M. Olson and B.M. Santos. IFAS Publ., Univ. of Florida, Gainesville, FL. University of Florida.

Ortega, R.G., and M. Gutierrez. 2004. Plant density influences marketable yield of directly seeded 'Piquillo' pimiento pepper. HortScience 39(7):1584-1587.

Papadopoulos, A.P. and S. Pararajasingham. 1997. The influence of plant spaicing on light interception and use in greenhouse tomato (*Lycopersicon esculentum* Mill.): A review. Elsevier Science B.V. 69: 1-29.

Pardossi, A. and L. Incrocci. 2011. Traditional and new approaches to irrigation scheduling in vegetable crops. HortTechnology 21(3): 309-313.

Pelczar, R. 2003. Potting Soil and Mixes: Properties and Priorities. the American Gardener 8/26/12. http://www.ahs.org/publications/the_american_gardener/pdf/09/03/Green Garage.pdf

Rehm, G., and M. Schimitt. 1997. Potassium for crop production. Extesion. University of Minesota. http://www.extension.umn.edu/distribution/cropsystems/dc6794.html. 22th September, 2012.

Rodriguez, J.C., D.J. Cantliffe, N.L. Shaw, and Z. Karchi. 2006. Soilless media and containers for greenhouse production of 'Galia' type muskmelon. HortScience 41:1200-1205.

Rodriguez, J.C., N.L. Shaw, and D.J. Cantliffe. 2007. Influence of plant density on yield and fruit quality of greenhouse-grow Galia muskmelons. HortTechnology 17: 580-585.

Santos, B.M. 2012. Pepper fertilization and irrigation management. P. 57-72 In: Peppers botany, production and uses. 2012. Russo, V.M. USDA/ARS Wes Watkins Agricultural Research Laboratory, Lane, Oklahoma, USA.

Santos, B. M., J. A. Dusky, W. M. Stall, T. A. Bewick, D. G. Shilling. 2004. Mechanisms of interference of smooth pigweed (*Amaranthus hybridus*) and common purslane (*Portulaca oleracea*) on lettuce as influenced by phosphorus fertility. Weed Science, 52:78-82.

Santos, B. M., H. A. Obregón-Olivas, and T. P. Salamé-Donoso. 2010. Producción de hortalizas en ambiente protegido: Estructuras para la agricultura protegida. 20 June 2011. <http://edis.ifas.ufl.edu/hs1182>.

Santos, B. M., and T. P. Salame-Donoso. 2012. Protected culture for vegetable and small fruit crops: The soilless trench system. Horticultural Sciences Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida.

Simonne, E. H., M. D. Dukes, and L. Zotarelli. 2011. Principles and practices of irrigation management for vegetables. p. 17-27. In: Vegetable production handbook for Florida, 2011-2012. S.M. Olson and B.M. Santos. IFAS Publ., Univ. of Florida, Gainesville, FL. University of Florida.

Siwek, P., A. Libik. 1999. The impact of tunnel covers type on growth and yield of sweet pepper. Int. Agrophysics, 13, 119-124.

Stommel, J., and E. Albrecht. 2012. Pepper fertilization and irrigation management. P. 57-72 In: Peppers botany, production and uses. 2012. Russo, V.M. USDA/ARS Wes Watkins Agricultural Research Laboratory, Lane, Oklahoma, USA.

Sysoeva, M.I., E. F. Markovskaya, and T.G. Shibaeva. 2010. Plants under continuous light: a review. Plants Stress 4 (1) 5-17.

Tanaka, J.S., Y. Nakagawa, and R. Sakuoka. 1997. Bell pepper. Cooperative Extension Service CTAHR Fact Sheet. Home Garden Vegetable no. 3. CTAHR Department of Horticulture

Taiz, L.and E. Zeiger, 2010. Plant Physiology. 5th edition, Sinauer Assoc., Inc.

Takehiko, H. 1999. The unit concerning the light in the plant production. Tokai University. Shizuoka Japan.

Timothy, L. G., and T. M. Webster. 2012. Transplant production. P. 87-99 In: Peppers botany, production and uses. 2012. Russo, V.M. USDA/ARS Wes Watkins Agricultural Research Laboratory, Lane, Oklahoma, USA.

Tucker, M. R. 1995. Chemical characteristics of pine bark. NCDA&CS agronomic division. North Carolina. United States. 8/26/12. www.ncagr.gov/agronomi

USDA, National Food Service Management Institute, the University of Mississippi. 2011. 20 June 2011. <http://www.fns.usda.gov/TN/Resources/quality_veg.pdf>

Weaver, J. E., and W. E. Bruner. 1927. Root Development Of Vegetable Crops. First Edition. McGraw-Hill Book Company, Inc. New York. United State.

Wyzgolik, G., J. Nawara, and M. Leja. 2008. Photosynthesis and some growth parameters of sweet pepper grown under different light conditions. Department of Plant Physiology, Faculty of Horticulture. Lithuanian Institute of Horticulture and Lithuanian University of Agriculture. Sodininkyste ir Darzininkyste.

Zhao, X. and E. E. Carey. 2005. Microclimate and reference crop evapotranspiration in high tunnels and open field during summer lettuce production. HortScience, Vol. 40(4).

Zotarelli, L., M. D. Dukes, J. M. S. Scholberg, K. Femminella and R. Muñoz-Carpena. 2011. Irrigation Scheduling for green bell peppers using capacitance soil moisture sensors. J. Irrig. Crain Eng. 137:73-81.

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