EVALUATING NUTRIENT MANAGEMENT SYSTEMS FOR ORGANICALLY-PRODUCED GREENHOUSE COLORED BELL PEPPER (*CAPSICUM ANNUUM* L.)

By

ALLISON LEIGH BEYER

A THESIS PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE

UNIVERSITY OF FLORIDA

2012

To my father, mother, sister, husband and all others who unconditionally supported me

ACKNOWLEDGMENTS

I would first and foremost like to thank my husband, Joey Cassata Jr., for his undying love and support during my masters education and all the years leading up to it, and for the many times he spent his days off from work to assist me in the field. I could not imagine experiencing it all without my soul mate by my side. Similarly, I am forever indebted to my parents and sister for everything they have done and continue to do for me to help me achieve my goals. I would like to express my sincere gratitude to my advisor, Dr. Danielle Treadwell, for her unparalleled kindness and encouragement and for being a wonderful source of inspiration for me, professionally, educationally and personally, throughout the last two years. I would like to thank my committee member, Dr. Daniel Cantliffe, for supporting me before, during and after my masters education, and imparting invaluable knowledge and wisdom to me in the process that have made me a better student and scientist. I would also like to thank my committee member, Dr Michael Gunderson, and also Dr. Alan Hodges for inciting my interest in the economic side of horticulture and assisting me in the economic analysis of my project. I thank Dr. Peter Stoffella, Dr. Salvador Gezan, Dr. Lance Osborne and James Colee for their assistance with the statistical aspects of my research.

I must thank biologist, Michael Alligood, a billion and one times for his incredible expertise in building the ingenious fertigation and irrigation system, without which my research could not have been done, not to mention his willingness to spend many tedious hours with me collecting harvest data. I would also like to thank Dr. Rebecca Darnell, Libby Rens, Wenjing Guan, Bee Ling Poh, Angelos Deltsidis, Maggie Goldman, Brandon Cassata and the entire Citra crew for their assistance with my research.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Abstract of Thesis Presented to the Graduate School
of the University of Florida in Partial Fulfillment of the
Requirements for the Degree of Master of Science

EVALUATING NUTRIENT MANAGEMENT SYSTEMS FOR ORGANICALLY-PRODUCED GREENHOUSE COLORED BELL PEPPER (*CAPSICUM ANNUUM* L.)

By

Allison Leigh Beyer

August 2012

Chair: Danielle D. Treadwell
Major: Horticultural Science

A potentially lucrative market opportunity for growers is presented by high price premiums associated with greenhouse, organic, red bell pepper. The objective of this project was to identify the organic greenhouse nutrient management system that produces the greatest yield, quality and economic returns from determinate red bell pepper plants (*Capsicum annuum* L.). Treatments that varied in compost amendments to container growing media (three levels) and fertilizer source (five levels) were arranged in a randomized complete block design replicated four times at the University of Florida's greenhouses near Citra, Florida in Fall of 2010 and Spring of 2011. The three compost amendment treatments in a 1 peat : 1 pine bark container media were: 1) no compost; 2) 30% yard waste compost; or 3) 30% poultry litter compost (by volume). The four organic fertilizer treatments included: 1) dry granular sources only; 2) a nutrient solution delivered through the irrigation system only; 3) granular sources applied at transplanting and nutrient solution beginning at sidedress; and 4) nutrient solution beginning at transplanting and granular sources applied at sidedress. The organic systems were compared to the fifth fertilizer treatment that represented conventional hydroponic systems of mineral-based nutrient solution applied regularly through the

irrigation system. Throughout the experiment, data were collected on plant height, relative leaf nitrogen status, and the pH, electrical conductivity and nitrate concentration of media leachate. At harvest, data were collected on whole plant dry weight, leaf percent total kjeldahl nitrogen, and fruit yield, quality and nitrogen use efficiency. The media amended with poultry litter compost combined with the organic fertilizer treatments that derived at least half of total season nutrients from granular sources produced the highest organic marketable yields of 57-138% of the conventional hydroponic control. A sensitivity analysis was conducted based on the yields and input costs in this study. Compared to greenhouse-grown red bell pepper produced conventionally, producing organically resulted in a 30% average increase in estimated partial net returns due to a 35% reduction in nutrient management input costs and an average increase in market price of 75%, even with an average reduction in yield of 30%.

CHAPTER 1
LITERATURE REVIEW

Bell Pepper Production in the U.S. and World

Bell peppers (*Capsicum annuum* L.) are a member of the Solanaceae family and originated from Mexico and Central America with evidence of its use by early inhabitants as many as 12,000 years ago. A phenolic compound called capsaicin is responsible for the pungency in peppers and different cultivars differ markedly in their content of the chemical, resulting in many different kinds of pepper, including sweet bell, cherry, jalapeno, habaneros, cayenne and Scotch Bonnet. In 2007, over 26 million metric tons of peppers were produced globally (U.S. Dept. of Agriculture, 2008a). China ranked first, producing more than 50% of the world's peppers, while the United States (U.S.) ranked sixth with about 855,000 metric tons produced (U.S. Dept. of Agriculture, 2008a). However, the majority of pepper produced in the U.S. is the sweet bell pepper, accounting for nearly 78% of all peppers produced in the U.S. in 2007 (665,000 metric tons on 25,237 hectares) (U.S. Dept. of Agriculture, 2008b). Within the U.S., Florida is the second leading producer of bell peppers behind California, producing 197,000 metric tons for a value of $183 million in 2007, accounting for 30% of total U.S. bell pepper production volume and 39% of total U.S. bell pepper production value (U.S. Dept. of Agriculture, 2008b). In 2008, bell pepper production in Florida accounted for 7,822 hectares of cropland and $267 million in value (U.S. Dept. of Agriculture, 2009a).

Bell pepper plants are managed as annuals in temperate climates. Peppers are particularly sensitive to low temperatures and are relatively slow to establish compared to other solanaceous crops. Peppers are traditionally grown in the field, and in the Southeast, they are typically grown on plastic mulched beds and irrigated through subsurface or drip irrigation systems (Olson and Santos, 2013). Field-grown peppers are typically determinate cultivars, where the plants grow to a certain size, produce fruit and senesce, with a season length of about 5-6 months from seeding and one to three harvests of mature green peppers for a period of approximately one month. Greenhouse production has increased over the past couple of decades, and bell pepper has become a popular crop in protected systems along with tomato, cucumber, strawberry, lettuce, herbs, ornamentals and transplants (Greer and Diver, 2000; Jovicich et al., 2005). Compared to the field, bell peppers grown in the greenhouse are typically indeterminate cultivars, where the plants continually develop and grow from new meristems that produce new stems, leaves, flowers and fruit. Season length is 10-11 months from seeding and weekly harvests of colored pepper continue for a period of up to 6-7 months. All peppers start out green and gradually mature to typically a red, orange or yellow color. Consumer demand for colored bell peppers has increased their market price by almost two times that of green pepper (Cantliffe et al., 2008; Jovicich et al., 2005).

U.S. production of fresh bell pepper has been continually on the rise, tripling in the span of time between 1978 and 2003 from approximately 227,000 to 680,000 metric tons per year (Kelley and Boyhan, 2009). During this same time-frame, there has been a 3.5-fold increase (from 272,000 to 953,000 metric tons) and 2.5-fold increase (from 1.3 to 3.2 kg per year per person) in domestic consumption and per capita use, respectively (Kelley and Boyhan, 2009). Despite the considerable rise in domestic production, the U.S. imports a substantial amount of its peppers to supplement the ever-increasing domestic demand. U.S. import of peppers exceeds its export of peppers, with the import-export gap steadily widening over time (Kelley and Boyhan, 2009). In 2007, imported peppers accounted for 40% of the peppers on the domestic market (Kelley and Boyhan, 2009). The majority of these imports come from Mexico, Canada, the Netherlands, Dominican Republic, Israel and Spain. Part of the reason why some of these countries are dominating the retail industry of pepper is because they are providing high-quality greenhouse-grown colored fresh pepper during those seasons when field production is reduced or non-existent due to non-optimal natural weather conditions (Cantliffe et al., 2008; Jovicich et al., 2005). Because states in southeastern U.S. have such mild climate, there is a large economically-viable opportunity for southeast growers to fulfill this winter market for greenhouse-grown peppers, thereby reducing the need for imports from abroad.

Greenhouse Production

Greenhouses are permanent structures that have metal or wood structural supports, roof and sides made of glass, plastic and/or mesh netting and a structural design that allows for either active or passive ventilation. They are built to create a protective shell around a crop in which:

- Environmental extremes can be avoided leading to growing season extension and uninterrupted labor;
- The surrounding growing environment can be optimized and synchronized with the demands and requirements of the particular crop by modifying, fine-tuning and automating environmental factors such as temperature and light levels based on sensors built into the greenhouse system;
- Yield per unit area of land and produce quality can be increased by creating a protected, intensive, high-density and high-efficiency crop growing environment, which is advantageous as our rising population and urbanization limits suitable agricultural land;

- Inputs such as water, fertilizer and pest control products can be precisely applied, controlled, contained, recycled and adjusted according to plant demands, resulting in reduction of waste and conservation of resources and money; and
- There is an opportunity and flexibility to produce specialty crops, on a small or large scale, during non-peak production times, using a variety of different systems and materials and thus earn premium prices in the absence of market competition.

There are many advantages associated with greenhouse production that contribute to its increase in popularity as a production system, particularly for relatively challenging and nutrient-demanding crops like bell pepper. The result is a value-added product for which there is high demand. For example, greenhouse-grown colored bell peppers are typically priced 3 to 5 times greater than field-grown (Jovicich et al., 2005). Colored bell peppers are more difficult to grow because they have to remain on the plant longer (two to three weeks) to ripen for color-development, making them more susceptible to disease and quality problems, so growing them under the protection of a greenhouse increases their yield potential (Cantliffe et al., 2008; Jovicich et al., 2003; Jovicich et al., 2004; Jovicich et al., 2005; Jovicich et al., 2007; Shaw and Cantliffe, 2002). Furthermore, the phase out (and, as a result, increasing cost) of methyl bromide for soil fumigation of field-grown crops emphasizes the considerable market opportunity for greenhouse growers in Florida due to the development of Integrated Management Practices (IPM), soilless media, and other technologies that eradicate the need for soil fumigation products and reduce the need for pesticides (Jovicich et al., 2004; Osborne and Barrett, 2005; Saha and Cantliffe, 2009; Shaw and Cantliffe, 2002). The main disadvantage associated with greenhouse production is high start-up and production costs, mostly associated with the infrastructure, technology and heating systems in cold climates (Greer and Diver, 2000; Jovicich et al., 2005). Therefore, high-value crops must be produced in order to keep the operation profitable.

While our neighbors, Canada and Mexico, have increased their greenhouse vegetable production area by 39% and 105%, respectively, from 2002 to 2006, the U.S. has increased greenhouse vegetable production area by only 25% in that same time range (Zbeetnoff Agro-Environmental Consulting, 2006). In 2006, greenhouse vegetable production in Canada, Mexico and the U.S. accounted for 1100, 2300 and 450 hectares, respectively. Furthermore, only 5% of U.S. greenhouse vegetable production is devoted to bell pepper and this number remained constant between 2002 and 2006, while the fraction of bell pepper grown in greenhouses rose by 60% and 67% in Canada and Mexico, respectively (Zbeetnoff Agro-Environmental Consulting, 2006). In 2006, greenhouse bell pepper production in Canada, Mexico and the U.S. accounted for 279, 350, and 20 hectares, respectively. The increased global expansion of greenhouse area highlights an obvious opportunity for U.S. growers to expand into this market and reduce reliance on pepper imports.

While a wide variety of media, fertilization and irrigation systems exist in greenhouse production, a large proportion of conventional greenhouse systems (especially for colored bell peppers) use hydroponics. In this system, mineral-based soluble fertilizers are metered out in small quantities at a regular frequency through low-volume irrigation systems (such a drip or micro-jet) to plants growing in soilless media with low cation exchange capacity (CEC) (Jovicich et al., 2004). The concentration of nutrients in the stock solution and the duration and frequency of fertigation events are adjusted as the crop progresses through its growth stages and according to crop needs throughout the season. Since the goal of each fertigation event is to deliver only what the plant can take up, nutrient leaching and water waste is minimized and nutrient and water levels can be quickly and easily adjusted, resulting in synchronicity of nutrient and water availability with plant demand. As a result of the long-term health, productivity and quality of hydroponic crops, greenhouse production has in many cases become synonymous with hydroponics.

Organic Production

Traditionally, organic production emphasizes long-term soil management strategies that rely on natural inputs and cultural practices that enhance the ecological processes, beneficial microorganisms and organic matter content in order to maintain or improve the physical, chemical and biological condition of the soil. Organic nutrient management philosophy typically refers to field production and involves cover crops, crop rotation and application of organic-compliant inputs. In general, chemical and synthetic inputs (including synthetic fertilizers and pesticides, growth regulators, antibiotics and genetically modified organisms) are prohibited, and allowable inputs are derived from plant, animal or natural deposits as defined by the Organic Foods Production Act of 1990 (Greer and Diver, 2000). Producers rely on private organizations such as the Organic Materials Review Institute (OMRI) that service the organic industry by determining what products are compliant with the United States Department of Agriculture (USDA)'s National Organic Standards Final Rule (U.S. Dept. of Agriculture, 2012b). These organizations publish generic material and product name lists of approved inputs. Compliant organic farming systems are certified by an agency accredited by the USDA.

Organic vegetable acreage in the U.S. averaged a 15% annual increase between 2000 and 2008 and increased a total of 150% in that time span to an area of nearly 65,000 hectares in 2008 (not including beans, grains, fruits, potatoes and herbs - based on information from USDA-accredited State and private organic certifiers) (U.S. Dept. of Agriculture, 2008c). In 2008, Florida ranked 5th in certified organic vegetable acreage with 1,465 hectares (U.S. Dept. of Agriculture, 2008c). From 1997-2008, there was a four-fold increase in U.S. retail sales of organic fruits and vegetables, accounting for $8 billion in 2008 (Nutrition Business Journal, 2009; U.S. Dept. of Agriculture, 2009b) and rising to $10.6 billion in 2010 (Organic Trade Association, 2011). Fresh organic produce has been the most popular organic category during this rise in demand for organic products, with the top fresh organic vegetables in cropland being lettuce (12% of all vegetable acreage), tomatoes (7%) and carrots (6%). (U.S. Dept. of Agriculture, 2009b). In 2008, certified and exempt organic bell pepper production in the U.S. accounted for 352 harvested hectares, 5485 metric tons in production, and $8,088,912 in sales (U.S. Dept. of Agriculture, 2009a). In 2008, certified and exempt organic bell pepper production in Florida accounted for 37 harvested hectares and $1,081,821 in sales (U.S. Dept. of Agriculture, 2009a).

The increasing consumer demand for organic foods is due to a variety of reasons. Research studies have demonstrated higher nutritional quality and enhanced flavors associated with some organic foods (del Amor, 2007; del Amor et al., 2008; U.S. Dept. of Agriculture, 2009b). Because organic production prohibits the use of chemical or synthetic inputs, consumers recognize organic foods as potentially healthier and safer alternatives to conventionally-grown foods not just in terms of human health but also in terms of the environmental and ecological benefits that the organic standards encourage. The USDA's National Organic Program (NOP) federally regulates certified organic farming systems in way that requires them to: 1) use management practices that maintain or improve the natural resources of the farm, including soil and water quality; 2) use preventative management practices to manage pests; and 3) undergo a rigorous annual oversight and certification process (U.S. Dept. of Agriculture, 2012b).

Due to double-digit growth in consumer demand, the increase in organic acreage still cannot keep up with this demand (U.S. Dept. of Agriculture, 2009b). Organic vegetable acreage only represents 9% of total vegetable cropland in the U.S (U.S. Dept. of Agriculture, 2009b). The low supply and high demand coupled with the fact that organic produce can be priced more than double that of conventional produce (U.S. Dept. of Agriculture, 2012a) highlights organic production as a potentially lucrative market for growers to expand into. Furthermore, as research exposes the negative environmental impacts associated with traditional commercial agriculture, governmental agencies such as the Environmental Protection Agency (EPA), Department of Agriculture and Consumer Services (DACS), and Water Management Districts (WMD) are focusing on legislative actions to ameliorate these negative impacts. As a result, they are creating laws to phase out some products that have traditionally been heavily relied upon (e.g. Chloropicrin, methyl bromide, etc.) and to enforce Best Management Practices (BMPs) that focus on reducing fertilizer and water waste and minimizing contamination of surrounding natural water bodies by fertilizer and pesticides. Therefore, transitioning into the organic production market may be a way for growers to comply with these legal trends and expand into an environmentally and economically sustainable market niche. The major downfalls of organic production are that it can be expensive to become certified, rules and regulations are strict and inflexible, and products approved for organic use can be expensive and vary widely in their efficiency.

Furthermore, the 2002 USDA National Organic Standards regulation in most cases requires an agricultural area (whether it be open-field or greenhouse) to produce organically according to a certifier-approved plan for 3 years before its products can be labeled as organic (U.S. Dept. of Agriculture, 2009b).

Greenhouse Organic Production

Theoretically, combining organic and greenhouse production together could prove more profitable and environmentally sustainable than either system on its own. This could be a potentially viable, scale-neutral opportunity for growers throughout the U.S. However the ability to produce year round due to the mild climate and opportunity for crop diversification may give southeastern region growers a competitive edge in the agricultural market and provide supplemental income when fields are out of production. It can be difficult to control diseases, weeds and other pests in field organic production because chemical pesticides are prohibited and allowed products are relatively expensive and less effective. Bringing organic production into the greenhouse will likely facilitate pest control because the greenhouse offers: 1) protection from the unfavorable weather conditions that lead to diseases; 2) use of soilless media that can minimize the threat of soil-borne pathogens and weeds; and 3) use of biological control of pests which can introduce and maintain beneficial insect populations within the structure. All this could potentially translate to better yields and quality of organic produce. However, successful nutrient management remains an important and challenging issue for organic greenhouse production. Historically, the nutrient management philosophies associated with greenhouse and organic production are different and attempting to combine them can be quite challenging. The three most important factors to consider in order to create a successful and economically practical organic greenhouse nutrient management system for fresh-market production include media, fertilizer source, and application strategy.

Organic Media

Plants cannot uptake organic forms of nutrients. For example, bacteria and fungi around the root system must first mineralize organic nitrogen into ammonium which can then be taken up by the plant or, with the addition of oxygen, can be nitrified by bacteria into nitrate, which is more easily taken up by plants (Evanylo and McGuinn, 2009; Sanchez and Richard, 2009; Treadwell et al., 2007). Therefore, mineralizing and nitrifying microorganisms are essential for the transformation of organic forms of nutrients into plant-available forms. Media must be optimal not just for the plant health, but also for sustaining microbial activity and growth throughout the season (Evanylo and McGuinn, 2009; Succop and Newman, 2004; Treadwell et al., 2007). Although soil-based media may be used, the advantages to using soilless media for organic greenhouse production are: 1) it minimizes the risk of soil-borne pathogens, nematodes and weeds for which there are few effective non-chemical control methods approved for organic production; 2) it avoids any environmental pollutants or residual fertilizers that are prohibited in organic production; and 3) it allows growers to custom make media with properties that may be more optimal than local soil type (Greer and Diver, 2000; Kuepper and Everett, 2004). Media properties that must be considered include percent moisture (water holding capacity), percent oxygen (aeration and drainage capacity), nutrient-holding capacity (cation exchange capacity), chemical properties (pH, soluble salt levels and electrical conductivity), temperature buffering capacity, organic matter content, carbon to nitrogen ratio (C:N), and bulk density (Evanylo and McGuinn, 2009; Kuepper and Everett, 2004; Succop and Newman, 2004; Treadwell et al., 2007). All of these factors interact with each other and with the media microorganism populations to determine the highly variable and unpredictable rates of mineralization and nitrification. In general, these rates will be slower at lower media temperatures, in dry or waterlogged media conditions and if organic nutrient sources are incorporated too deep into the media where oxygen levels are lower (Sanchez and Richard, 2009).

Organic greenhouse crops grown in soil are typically grown in bare-ground greenhouses and lower-cost, less permanent protected agriculture structures. Organic greenhouse crops grown in soilless media are grown in above-ground containers such as pots, lay-flat bags or troughs in, typically, more modern greenhouse systems. The most common soilless media ingredients used in greenhouse production include peat, pine bark, coconut coir, perlite and vermiculite. Combinations of these media ingredients are often mixed together in different proportions to create a mix with properties that are optimal for the specific crop. For example, peat moss has high water-holding capacity and low pH which, as the sole media source, may not provide enough oxygen-filled pore space to sustain the transforming aerobic bacteria and may render certain nutrients unavailable for plant uptake due to the low pH (Sanchez and Richard, 2009; Treadwell et al., 2007). Therefore, pine bark or perlite is often added to increase air space and improve drainage, and limestone is added to increase the pH to more acceptable levels for nutrient availability (Kuepper and Everett, 2004; Succop and Newman, 2004). Many companies manufacture soilless mixes with synthetic wetting agents and starter charges which are prohibited in organic production, therefore it is important to choose media products that do not contain these additives and are approved for use in organic production (Greer and Diver, 2000; Kuepper and Everett, 2004; Sanchez and Richard, 2009; Treadwell et al., 2007).

Organic compost can be added to a soilless mix in organic greenhouse systems to: 1) provide and help sustain populations of mineralizing/nitrifying microorganisms; 2) provide micronutrients; 3) enhance the temperature buffering capacity of the media; and 4) cut down on media costs since it tends to be less expensive than other soilless media such as peat moss (Kuepper and Everett, 2004; Lee et al., 2004; Marinari et al., 2000; Sanchez and Richard, 2009; Treadwell et al., 2007). Composts can also improve porosity and water-holding capacity of the media mix and contribute to the suppression of diseases, all of which can affect nutrient management (Celik et al., 2004; Kuepper and Everett, 2004; Marinari et al., 2000; Sanchez and Richard, 2009; Zinati, 2005). The most common composts are derived from either plant sources (e.g. yard waste, spent mushroom substrate) or animal sources (e.g. poultry litter, dairy manure, vermicompost). Properties vary among different compost sources and will affect the suitability of the media for optimal nutrient uptake and plant growth (Treadwell et al., 2007). For example, compost with a high carbon to nitrogen (C:N) ratio (>30) will typically tie up (immobilize) nitrogen in a media mix, making it unavailable for plant uptake, while those with a low C:N ratio (<20) will mineralize organic nitrogen into plant-available form at a faster rate (Evanylo and McGuinn, 2009; Paul and Clark, 1996; Sanchez and Richard, 2009; Zhai et al., 2009;). Also, animal-based composts tend to have higher pH than plant-based composts, and so they will have different effects on the micro-organisms and nutrient availability. Due to the high porosity of most compost, the soluble salt levels are often high and they can create nutrient imbalances (Kuepper and Everett, 2004). Compost is not recommended for use alone as a media. Previous research report favorable results with media mixes containing anywhere between 20-50% compost (Chang et al., 2007; Kraus and Warren, 2000; Kuepper and Everett, 2004; Succop and Newman, 2004; Treadwell et al., 2007; Zhai et al., 2009).

Organic Fertilizer and Application Strategies

Composts are considered an organic nutrient source because many will provide adequate amounts of micronutrients and (depending on source) have variable amounts of phosphorus, potassium, magnesium and calcium (Kuepper and Everett, 2004; Sanchez and Richard, 2009). However, typically, total nitrogen content is too low (0.5-2.5%) and becomes available too slowly (10-50% per year) to be able to sustain plant growth on its own without the addition of other organic nutrient sources (Sanchez and Richard, 2009; Zhai et al., 2009). Fertilizers approved for use in organic production are available in granular, powder and liquid forms, and include plant-based products (e.g. kelp and seaweed extract [19% K], soybean meal [7% N]), animal-based products (e.g. blood meal, bone meal [13% P], feather meal [13% N], hydrolyzed fish protein [10% N], bat guano [11% N]) and natural deposits (e.g. rock phosphate, potassium sulfate, gypsum, sodium nitrate) (Organic Materials Review Institute, 2010). Sodium (or Chilean) nitrate is the only allowed source of nitrogen that is a salt (and not a complex organic composite) and may provide no more than 20% of the crop's total nitrogen requirement, however caution must be exercised with its use because its high sodium content can be detrimental to plant health (Organic Materials Review Institute, 2010; Sanchez and Richard, 2009). Citing increasing concerns of salt accumulation in soil, and to facilitate trade with countries who prohibit use of sodium nitrate in their country's organic program, the USDA NOP is slated to remove sodium nitrate by November 2014

(Treadwell et al., 2007). OMRI-approved limestone and elemental sulfur can be used to adjust pH of soil/media and also provide a source of calcium, magnesium or sulfur (Organic Materials Review Institute, 2010; Sanchez and Richard, 2009).

While conventional hydroponic greenhouse fertigation systems are designed to deliver an optimal balance of elements to the crop and allow for quick and precise adjustments throughout the season, this synchronicity is difficult to achieve using organic nutrient sources. For example, many animal-based composts and fertilizers have an excess of phosphorus and potassium relative to plant demand for nitrogen (Sanchez and Richard, 2009). Therefore, it is advantageous to use different organic fertilizers from a variety of sources to attempt to provide enough of one element without creating an accumulation or deficiency of another element (Greer and Diver, 2000; Sanchez and Richard, 2009). It is wise to test the nutrient content of the media as well as the potential organic fertilizer/compost inputs in order to make a more informed decision about the types and relative amounts of organic nutrient sources that will be needed to achieve this balance of elements (Sanchez and Richard, 2009). However, different nutrients within the same organic nutrient source and between different organic nutrient sources are transformed into plant-available forms at variable rates, and at much slower rates compared with inorganic fertilizers (some research claims that only 50% of total organic nutrients applied will become available by the end of the season). Moreover, different organic fertilizer sources have their own unique effects on the activity and health of the mineralizing and nitrifying microorganism populations in the media (Chang et al., 2007; Marinari et al., 2000). Therefore, it is extremely difficult to maintain the optimal balance among elements to avoid element interactions that can lead to deficiencies or toxicities. And this proves to be particularly challenging in organic production of crops, such as bell pepper, which are particularly N:K ratio (regulating vegetative vs. generative growth) sensitive.

In conventional greenhouse production, mineral-based fertilizers are often dissolved in water to create a nutrient solution that is then injected into the drip irrigation system with an automated proportional dosing pump and delivered to the plants with each irrigation event (known as fertigation). Liquid-based organic fertilizers are relatively expensive, and both dry solution-grade and liquid organic fertilizers do not dissolve completely in water. Nutrient solutions made with these products are primarily organic particles suspended in solution and cause clogging if delivered through the drip irrigation system (Greer and Diver, 2000; Miles and Peet, 2002; Rippy et al., 2004; Zhai et al., 2009). However, fertigating would make use of greenhouse growers' existing hydroponic infrastructure and could potentially allow for quicker/easier adjustment of individual element levels and more precise control over nutrient delivery to meet plant demand throughout the season. Granular organic fertilizers, on the other hand, are less expensive and can be applied directly to the media thus avoiding clogging problems. However, they represent less control over nutrient delivery and could cause the electrical conductivity (EC) of the media to increase to levels detrimental to the plant (Rippy et al., 2004). Granular organic nutrient sources should be incorporated into the top 6-8 inches of the media because this is where most of the transforming microorganisms reside (Sanchez and Richard, 2009). Other delivery methods of organic fertilizers in the greenhouse include a media drench, foliar sprays and sub-irrigation.

All factors considered, a variety of different organic fertilizers and their associated nutrient release rates and application strategies may be more successful than any one fertilizer or application strategy on its own. For example, organic sources of phosphorus are highly insoluble and so by incorporating high-phosphorus-containing granular sources directly into the media, relatively more soluble organic nutrients may be delivered through the irrigation system at dilute concentrations with less clogging issues (Miles and Peet, 2002; Rippy et al., 2004).

Other Organic Amendments

There are other products approved for use in organic production that could prove beneficial for organic greenhouse nutrient management. Inoculating media with biological amendments like plant growth-promoting bacteria (Rhizobacteria) and fungi (Mycorrhizae) has been shown to enhance nutrient uptake and utilization in organic transplant production (Kokalis-Burelle et al., 1999; Ortas et al., 2009; Russo, 2006). However, its usefulness in long-term production has been debatable as it is still unclear if the benefits they provide translate into higher yields that justify the extra production cost. These biological amendments are either already incorporated into organic fertilizers or sold separately to be applied by foliar spray or soil drench (Organic Materials Review Institute, 2010).

Fulvic acid is an amendment that is marketed to increase nutrient-holding capacity of media, chelating ability and plant uptake of micronutrients. Other products marketed as increasing plant health, plant flowering, media microbial activity and/or disease suppression are chitin, humic acid, enzymes and molasses.

Fertigation System Strategies

Due to insolubility of organic fertilizers, attempting to deliver them through the greenhouse hydroponic drip irrigation systems will commonly result in clogging of the irrigation lines and emitters. Therefore, it may be advantageous to use irrigation lines with larger diameter and emitters with higher flow rate than what is typically used in conventional greenhouse irrigation systems in an attempt to avoid (or at least reduce the severity of) future clogging issues (Miles and Peet, 2002; Rippy et al., 2004).

In conventional fertigation systems, it is recommended to periodically deliver only water through the lines for a short time period in order to flush the lines and dislodge mineral deposits. It may be even more important to do this in organic fertigation systems to help alleviate clogging issues by flushing any particulates, algae or microbial sludge deposited in the lines (Rippy et al., 2004).

Solubility of some conventional mineral fertilizers can be enhanced by changing the pH or temperature of the nutrient solution. Typically, acidification can improve the solubility of organic nutrient sources. While there are several acidic products that can be added to nutrient solutions in conventional production, there are very few acidic products that are OMRI-approved in organic production, the most common of them being citric acid (Organic Materials Review Institute, 2010). However, growers must be careful to balance the pH in the nutrient solution and root environment so as to prevent nutrient imbalances and maintain the health of the crop and transforming bacteria.

Organic nutrient solution should be made more frequently and more dilute than conventional fertilizer nutrient solution in order to avoid excess precipitates in the solution that can clog the filters on the fertigation pumps (Miles and Peet, 2002; Rippy et al., 2004).

Previous Organic Greenhouse Production (Commercial and Research)

Because of the inherent difficulties in organic greenhouse nutrient management, previous research studies and commercial operations have focused on crops that compared to bell pepper are less demanding (e.g. tomato) or shorter-season (e.g. tomato, herbs, lettuce and transplants), and it is difficult to extrapolate these finding to other crops and systems (Treadwell et al., 2007). However, previous published research on organic greenhouse production, in general, is limited and is particularly scarce for intensive, nutrient-demanding, N:K ratio-sensitive, relatively long-season crops such as bell pepper. And while practices of organic greenhouse production in soil have been documented, specific practices for preparing organic fertilizer mixes for hydroponic systems, injecting the mix through the drip irrigation lines and adding composts to soilless media for crop production are not adequately described (Rippy et al., 2004, Zhai et al. 2009). The fact is there are few, if any, turnkey protocols for successful organic greenhouse production. However, the USDA's Fruit and Vegetable Market News Portal began reporting on U.S. imports of organic greenhouse-grown colored bell peppers from Israel in December 2004, and currently the site reports on this commodity being imported into the U.S. from the Netherlands, Mexico, Spain, the Dominican Republic, and Canada as well (U.S. Dept. of Agriculture, 2012a). Therefore, successful organic greenhouse production of bell pepper is possible and it can potentially be a very lucrative market for U.S. growers.

Results of previous organic greenhouse research are variable. Amending soil or soilless media with organic composts derived from yard, dairy, poultry, swine, worms or greenhouse operation wastes can improve porosity, water-holding capacity and biological activity of the media, however the nutrient content of these composts were typically too low and became available too slowly to sustain plant growth and productivity without added fertilizer sources. (Chang et al., 2007; Kraus and Warren, 2000; Zhai et al., 2009). Zhai et al. (2009) produced organic greenhouse tomato yields of 80-100% of the conventional hydroponic greenhouse control using peat and perlite media amended with 40-50% swine, yard waste or mushroom compost and organic plant-based liquid feed mixed with organic potash, calcium carbonate and dolomitic lime delivered through the irrigation system starting at transplant or 30 days after transplant. This study showed that compost type did not affect yield, but plant-based organic liquid feed produced higher organic yields than fish-based organic liquid feed, and low liquid feed concentrations produced higher yields and less disease incidence than high liquid feed concentrations (Zhai et al., 2009). This study also showed higher biological activity in compost-amended media compared to the no compost control, and in the organic liquid feeds compared to the hydroponic conventional feed (Zhai et al., 2009).

Heeb et al. (2006) showed lower yields from organic compared to conventional treatments in both field and greenhouse tomato crops. Rippy et al., 2004 used various liquid organic fertilizers, comprised of bat guano, Norwegian sea kelp, natural sulfate of potash, feather meal, oat bran, blood meal, steamed bone meal, Chilean sea bird guano, rock phosphate, wheat malt, molasses, yeast, kelp meal, seaweed, poultry compost tea and calcium phosphate. These fertilizers were hydroponically fertigated to organic greenhouse tomato plants grown in peat and pine bark substrate amended with various amounts of vermicompost, blood meal, bone meal, potassium sulfate, dolomitic lime and elemental sulfur, producing variable results from year to year and substantial clogging problems, but some organic regimes produced yields comparable to conventional in the final year of the experiment (Miles and Peet, 2002; Rippy et al, 2004). Organic, greenhouse-grown, mature-green, indeterminate (214-day season from transplant) bell pepper plants grown in soil amended with horse manure as the only source of nutrients produced variable results as well (del Amor, 2007; del Amor et al., 2008) In 2007, Del Amor showed decreased plant biomass and [NO_3-N] but similar marketable yields from organic bell pepper plants compared to conventionally-fertilized plants. Organic greenhouse basil planted in either perlite or peat/perlite/compost media and fertigated with an organic nutrient solution made of fermented poultry compost, hydrolyzed fish emulsion, kelp extracts, and soft rock phosphate produced yields comparable to that of greenhouse basil plants grown conventionally (Succop and Newman, 2004).

Schwankl and McGourty (1992) demonstrated successful fertigation and minimal clogging with organic spray-dried fish and poultry protein fertilizers injected through drip and micro-sprinkler systems, and Greer and Diver (2000) claimed liquid organic fertilizers made of fish and seaweed blends were popular among organic growers using drip systems. Hartz et al. (2010) found that fish, guano and plant-based liquid organic fertilizers mineralized/nitrified under an incubation study and were made plant-available in an organic soil-based greenhouse-bioassay study with fescue at a much faster rate than dry organic fertilizers and composts. In this sense, they functioned similarly to conventional nitrogen fertilizers and Chilean nitrate. However they found these liquid organic fertilizers to be cost-prohibitive and unsuitable for application through drip irrigation systems due to clogging and so could not form the basis for an organic nitrogen fertility plan.

Organic Greenhouse Production of Red Bell Pepper Economic Analysis

There are oftentimes high costs associated with modern greenhouse technology (Cantliffe et al., 2008; Jovicich et al., 2005), many organic inputs and USDA certification of organic systems. Furthermore, the list of products approved for use in organic production are limited and variable in effectiveness (Organic Materials Review Institute, 2010), the USDA regulations are ever-changing, and the yields of produce from organic production systems are often lower compared to yields from conventional systems. However, as demand for and price premiums associated with colored, greenhouse-grown and organic bell pepper increase, combining these aspects into a successful organic greenhouse-grown red bell pepper operation presents itself as a potentially lucrative fresh-market niche for growers to expand into. As a result, economic analysis of organic greenhouse production of red bell pepper is needed to determine if the benefits of the system outweigh the costs.

Prices of colored bell pepper can be two times higher than green bell pepper, greenhouse-grown bell pepper can be three to five times higher than field-grown pepper and organic produce can be more than two times higher than conventional produce (Jovicich et al., 2005; U.S. Dept. of Agriculture, 2012a). The yield and quality increases associated with growing in a greenhouse compared to the open field will be especially important in attempting to offset the typically lower yields associated with organic production. Organic greenhouse-grown red bell peppers in the U.S. are typically imported from Israel, the Netherlands, Mexico, Spain, the Dominican Republic, and Canada, with only a very small proportion supplied from domestic operations (U.S. Dept. of Agriculture, 2012a). The steadily high market prices, the increases in consumer demand for this product and the lack of domestic supply highlights the potential for U.S.

growers to expand into this market niche, especially for growers in Florida where climate is mild and protected agriculture area is increasing.

Because many conventional greenhouse growers use soilless hydroponic systems, it may be beneficial to use their existing hydroponic infrastructure and materials and modify it for successful organic greenhouse production. By adapting the existing greenhouse system, the costs of transitioning from conventional to organic production would be minimized. Greenhouse systems vary considerably in size, technology and infrastructure, and there are studies that explore the economic viability of conventional red bell pepper grown in different greenhouse structures. However, to our knowledge, there have been few studies examining how organic nutrient management systems directly affect the viability of organic production of red bell pepper in these greenhouse structures, in terms of both costs and returns.

Florida growers interested in organic greenhouse production of red bell pepper need information based on local production systems. While many organic nutrient and media inputs can be expensive, it will important for growers to use sources that are relatively less expensive and, in keeping with organic philosophy, use resources that are local and available in enough supply to be used in large commercial greenhouse operations in order to cut down on costs and keep the operation profitable. The purpose of this study was to determine the nutrient management costs in producing organic red bell pepper in a mid-level Florida greenhouse for fresh market and estimate the economic return with expected yields for growers interested in this market. Sensitivity analyses were performed to assess and compare the economic feasibility of growing organic vs. conventional greenhouse red bell pepper. These analyses were developed using fruit yield information from the greenhouse trials of red bell pepper grown under different organic and conventional greenhouse nutrient management systems.

Objectives and Hypothesis

Certification agencies across the U.S. are certifying greenhouses for organic transplant and specialty crop production, due primarily to the requirement for organic transplants in the Final Rule of the USDA National Organic Standards (U.S. Dept. of Agriculture, 2012b). Because of the inherent complexities and costs, very little research has been dedicated to discovering the most effective combinations of media, fertilizer source and application strategies for successful organic greenhouse production of bell pepper. By managing for nitrifying bacteria, selecting plant- and animal-based fertility amendments, and using locally-sourced materials to the fullest extent possible, we anticipate an increased profit potential for growers of organic greenhouse bell pepper. Four organic greenhouse nutrient management regimes and their associated application strategies were developed, assessed and compared with one another and with conventional greenhouse nutrient management regime in terms of their production potential and economic practicality. We propose that these media and fertilizer combinations will significantly contribute to our confidence in recommending nutrient management strategies for sustainable, organic greenhouse colored bell pepper production.

The objectives of this project were to:

1. Identify the combination of media, fertilizer source and application strategy that will grow organically-managed greenhouse colored bell pepper plants which produce the quantity and quality of fruit similar to conventionally-managed hydroponic greenhouse colored bell pepper plants.
2. Conduct a partial cost-benefit analysis of the best-performing conventional and organic treatments in order to determine their economic practicality for growers.

In support of these objectives, two hypotheses were developed and are:

1. An organic greenhouse colored bell pepper nutrient management strategy that can produce yields comparable to that of a crop grown under conventional greenhouse hydroponic systems will include: a) an organic-compliant soilless media mix amended with animal-based compost to sustain essential transforming microbes; and b) a combination of several organic-compliant nutrient sources applied both granularly and through the irrigation system.

2. Potential yield reductions associated with organic production methods will be offset and exceeded by: a) high price premiums for bell pepper that is greenhouse-grown, organically-grown and harvested red; and b) using a variety of organic media and fertilizer inputs that are relatively low-cost and locally-sourced.

CHAPTER 2
EVALUATION OF GROWING MEDIA, FERTILIZER SOURCE AND NUTRIENT APPLICATION STRATEGIES FOR AN EFFECTIVE ORGANIC GREENHOUSE BELL PEPPER NUTRIENT MANAGEMENT SYSTEM

Materials and Methods

Site Description

The experiment was conducted in Fall 2010 and Spring 2011 in a multi-bay, 2023 m^2, passively-ventilated, saw-tooth style greenhouse (Top Greenhouses Ltd., Barkan, Israel) located at the University of Florida's (UF) Plant Science Research and Education Unit (PSREU) in Marion County, near Citra, FL (Figure 2-1). The high-roof structure is covered with UV-absorbing polyethylene film, the ventilated side walls and roof vents are covered with 50-mesh insect screen and the floors are covered in white landscape fabric. The experiment was established in one bay of the greenhouse, where 0.15-m diameter polyvinyl chloride (PVC) pipes were placed in four rows (1.2 m apart) down the north-south length of the greenhouse to serve as a drainage system (Figure 2-2). Because the experiment contained a conventional fertilizer treatment for comparison, the greenhouse was not certified organic. Pest management was achieved using biological control methods as described below, and no prohibited pesticides were applied in the greenhouse for six months prior to and during the course of the experiment.

Experimental Design

Overview

An experiment was arranged as a randomized complete block design with treatments replicated four times to evaluate the effects of fertilizer and media source and form on the yield and quality of 'Red Knight' bell pepper (Osborne Seed Company, Mount Vernon, WA) in Fall 2010 and Spring 2011. Treatments were a factorial combination of five fertilizer treatments (one conventional hydroponic and four organic-compliant) and three compost treatments (no compost, 30% yard waste compost or 30% poultry litter compost) for a total of 15 treatments.

‘X3R Red Knight F1’ was used because it is a top-yielding and top-quality determinate variety well adapted to Florida climate (Shuler, 2003) which could potentially be grown in three crops per year (spring, summer and fall); it is resistant to Bacterial Leaf Spot (*Xanthomonas axonopodis* pv. *vesicatoria* races 1-3), Tobacco Mosaic Virus and Potato Virus Y strain which is important in an organic-compliant growing system that does not use chemicals for disease suppression; and it is an early-mid maturing variety which would allow growers to target specific market windows.

On 13 Sept. 2010 and 9 Mar. 2011, bell pepper seedlings were transplanted into 11.4-L black polyethylene nursery pots (C1200, BWI Co Inc., Apopka, FL) with two 1.5-cm diameter drainage holes drilled equidistant from each other and 3.8 cm from the bottom of the pot to create a reservoir (Figure 2-3a). Cut squares of nylon screen covered the holes from the inside of each pot to prevent media loss. Pots were placed on the four rows of PVC pipe, and each row of pipe comprised one block of the experiment (Figure 2-3b). Plots contained six plants (one plant per pot) arranged in rows, for a total of 60 plots and 360 plants. Plants within each row were 30 cm apart and between-row spacing was 120 cm from center to center for a plant density of three plants per m^2. The center four plants in each plot were harvested by hand on 2 and 9 Dec 2010 [80 and 87 days after transplant (DAT), respectively] and 18 May, 25 May and 7 June 2011 (70, 77 and 90 DAT, respectively).

Fertilizer treatments

The conventional hydroponic fertilizer (“Convtl”) consisted of a custom-mix of mineral-based fertilizers (Table 2-1) and was injected through the irrigation system throughout the season based on a nutrient levels and irrigation schedule formulated for hydroponic greenhouse-grown bell peppers (Table 2-2) (Jovicich et al., 2004). The organic granular fertilizer (“Gran”) consisted of a custom mix of four OMRI-approved sources (Table 2-1) and was incorporated directly into the media either at transplant or at sidedress depending on the treatment. The organic fertilizer solution (“Soln”) consisted of a custom-mix of three OMRI-approved sources (Table 2-1) and was injected through the irrigation system beginning either at transplant or at sidedress depending on the treatment. Sidedress fertilizers were applied on 13 October 2010 (30 DAT) and 9 April 2011 (31 DAT). The five fertilizer treatments were as follows:

- Convtl: mineral-based; “Convtl” beginning at transplanting and applied throughout the season (Table 2-2)
- Gran-Gran: organic; “Gran” applied at transplanting, “Gran” applied at sidedress (Table 2-3)
- Gran-Soln: organic; “Gran” applied at transplanting, “Soln” beginning at sidedress (Table 2-3)
- Soln-Gran: organic; “Soln” beginning at transplanting, “Gran” applied at sidedress (Table 2-3)
- Soln-Soln: organic; “Soln” beginning at transplanting and applied throughout the season (Table 2-3)

Total season applications of nitrogen (N), phosphorus (P), potassium (K) and calcium (Ca) were consistent across all treatments (i.e., 10,220, 3513, 13,365 and 11,692 mg per plant, respectively).

In conventional greenhouse hydroponic fertigation production systems, all nutrients are typically metered out via the irrigation system with each irrigation event throughout the season allowing precise control over nutrient applications, and calcium is usually injected separately from phosphorus and sulfur because they precipitate when mixed together. In field production systems that utilize fertigation, most, if not all, of the phosphorus is applied in granular form at planting because it is relatively less soluble (especially if it is derived from organic sources), and can clog the irrigation system if injected. In field systems, at least half of the nitrogen and potassium are applied in granular form at planting, but the other half is injected through the irrigation system so that the nutrient supply can be controlled and adjusted according to plant demand during the season. An advantage shared by both the greenhouse and field fertigation methods is the reduced risk of fertilizer leaching and salt toxicity in young plants because these methods supplant heavy fertilizer applications early in the season. The application timing and strategies of the organic fertilizer treatments in this study (Table 2-2, Table 2-3) were based on these basic principles in addition to the goal of keeping total season N, P, K and Ca consistent across treatments.

Application of “Convtl” fertilizer. Two fertilizer proportional injectors (MiniDos 2.5%, Dosmatic U.S.A., Inc, Carrollton, TX) placed in series were used to pump mineral-based stock solution into the irrigation water (dilution rate 1:50; v/v) from two 18.9-L buckets according to conventional hydroponic greenhouse practices that keep calcium separate from both phosphorus and sulfur to prevent precipitation (Figure 2-4).

Application of “Gran” fertilizer. At transplanting, the “Gran” fertilizer was incorporated into the top 15 cm of the media in the pots. The depth was chosen because it is the most biologically active zone for transforming organic sources of nutrients into plant-available forms. At sidedress, the “Gran” fertilizer was incorporated into the top 8 cm to avoid damaging plant roots.

Application of “Soln” fertilizer. A fertilizer proportional injector was used to pump organic stock solution into irrigation water (dilution ratio 1:50; v/v) from an 18.9-L bucket for each of the three fertilizer treatments involving “Soln” (Figure 2-4). To reduce the incidence of clogging, new organic stock solutions were made weekly, emitters were frequently checked for clogging and flushed out, the dilution ratio of 1:50 was chosen to feed a less concentrated fertilizer solution and all filters were cleaned at least twice a week (Rippy et al., 2004; Zhai et al., 2009).

Compost treatments

All pots received a media base-mix of 1 peat : 1 pine bark (by volume). The OMRI-approved peat (Sunshine Peat Moss; Sun Gro Horticulture Canada Ltd, Orlando, FL) was custom-mixed with dolomitic limestone for a target pH between pH 5.5 and pH 6.5. The OMRI-approved pine bark (Elixson Wood Products, Starke, FL) was screened to a size less than 2.5 x 2.5 cm. The three compost treatments were as follows:

- NC: no compost
- YW: 30% yard waste compost by volume
- PL: 30% poultry litter compost by volume

The OMRI-approved yard waste compost was locally-sourced (Gainesville Wood Resource and Recovery, Gainesville, FL) and screened to 0.95 cm. The poultry litter compost was sourced from a local organic farm (Hoover’s Organic Farm, Live Oak, FL, certified by Quality Certification Services, Gainesville, FL) and was composed of 100% poultry manure and pine sawdust from a neighboring poultry producer. The compost was screened to 1.27 cm. Relevant chemical and physical properties of the peat, pine bark, yard waste compost and poultry litter compost media components are presented in Table 2-4. Relevant properties of the NC, YW and PL custom-made media mixes that represent the compost treatments are presented in Table 2-5.

Irrigation system

Untreated well water was used for irrigation. Water was delivered through black 1.9-cm diameter polyethylene pipe (John Deere Landscapes, Gainesville, FL) with or without fertilizer depending on the treatment. Previous studies (Rippy et al., 2004; Zhai et al., 2009) have found that typical hydroponic greenhouse emitters with a flow rate of 1.9 L/h or less are readily clogged by fertilizer solutions made from organic sources; therefore, in this study, each plant received the irrigation through a 7.6 L/h pressure-compensated emitter on the end of a 60-cm long spaghetti tube (Figure 2-5). Other measures taken to avoid clogging issues included using polyethylene pipe and spaghetti tubing with diameters larger than normal for hydroponic greenhouse operations, incorporating three filters before the fertilizer proportional injectors in order to filter out particulates from the well water and drawing each stock solution up through its own filter.

Irrigation duration and frequency was automated using a timer, was consistent across all treatments and was increased over the course of the season to meet plant demand (ranging from 300 to 1500 mL/plant/day). Although the fertilizer proportional injectors were all operated on the same timer, each was connected to its own solenoid and separate program on the timer to allow them to run individually and avoid reductions in pressure (Figure 2-4).

Crop Seasonal Management

Transplant production

Untreated ‘X3R Red Knight F1’ bell pepper seeds were sown in Sunshine organic planting mix (Sun Gro Horticulture Canada Ltd, Tampa, FL) in plastic 72-cell transplant flats. The seedlings were grown in two controlled environment chambers (width x depth x height: 183 x 76 x 102 cm; Conviron, Controlled Environments Limited, Winnepeg, Manitoboa, Canada) fitted with fluorescent and incandescent bulbs on the main campus of UF beginning on 16 July 2010 and 6 January 2011. The photoperiod was set at 14:10 day/night and the temperature was set at 25°C until germination and then used 22°C/20°C day/night and 25°C/22°C day/night programs until transplant (Cruz-Huerta, 2010; Saha and Cantliffe, 2009). The seedlings were fertigated as needed after the expansion of the first true leaf using a nutrient solution made with 20-8.8-16.6 (%N-%P-%K) Multipurpose Professional Water Soluble Plant Food (Plant Foods, Inc., Vero Beach, FL).

Temperature control and trellising

Throughout the season, the greenhouse polyethylene side curtains were manually lowered when air temperatures were less than 18°C or during periods of rainfall and were raised when air temperatures were greater than 25°C. Thermal tubes (Polyon, Barkai, Israel) and aluminized thermal screens were used when air temperatures were less than 10°C (Jovicich et al., 2005; Jovicich et al., 2007). In high temperatures, fans were used to improve air circulation. All plants were trellised in a modified “Spanish” system as the plants were a determinate growth structure (Jovicich et al., 2004; Saha and Cantliffe, 2009). Pairs of vertical poles and horizontal twine supported the plants on both sides of the rows, and twine was placed every vertical 20 cm as the plants grew.

Integrated pest management practices

No chemical means of pest control were used in this study. Plants were scouted on a weekly basis or more often as needed to identify disease occurrence and increasing pest thresholds. Pests were controlled using integrated pest management (IPM) practices, including biological control with banker plant systems and alternate hosts that help to sustain beneficial insect populations but do not negatively affect bell pepper crops (Jovicich et al., 2004; Osborne and Barrett, 2005; Saha and Cantliffe, 2009; Shaw and Cantliffe, 2002). Alternate host grain aphids were reared on sorghum banker plants in order to sustain the beneficial parasitic wasp colonies (*Aphidius colemani*) that control the aphid pests. Alternate host papaya whiteflies were reared on papaya banker plants in order to sustain the beneficial parasitic wasp colonies (*Encarsia formosa* and *Eretmocerus eremicus*) that control the whitefly pests. Alternate host grass mites were reared on sorghum banker plants in order to sustain the beneficial predatory mite colonies (*Amblyseius swirskii*, *Neoseiulus cucumeris* and *Neoseiulus californicus*) that control mite and thrip pests. Additionally, sticky cards were used to trap winged pests such as fungus gnats, and diligent sanitation habits were observed during the course of the season. Bumblebees (*Bombus impatiens*) were introduced for supplementary pollination to aid in fruit set; one bee hive per season serviced 650 to 1115 m^2 (Jovicich et al., 2004; Saha and Cantliffe, 2009; Shaw and Cantliffe, 2002). Beneficials (i.e., Aphipar, Enermix, Swirski-Mite, Thripex-V and Spical) and bumblebees (i.e., NATUPOL – class B) were acquired from Koppert Biological Systems in Romulus, Michigan.

The seedlings were transplanted to the depth of the cotyledonary node level and the emitter placed at the base of the seedling at transplant was gradually moved back from the base of the plant over the course of 4 weeks. These IPM measures were taken to prevent a physiological basal stem disorder known as “Elephant’s Foot” disorder which could predispose the plants to a Fusarium infection (Jovicich and Cantliffe, 2004)

Data Collection

Measurements during the growing season

Inside the greenhouse, air temperature at a height of 1 meter and the temperature of each of the three media/compost mixes was measured with thermocouples (PR-T-24 Omega Engineering, Stamford, Conn.) and recorded every 15 minutes using HOBO data loggers (CR10X; Campbell Scientific, Logan, Utah) beginning on 12 Oct. 2010 (Jovicich et al., 2007; Saha and Cantliffe, 2009) (Figure 2-6). Only Fall 2010 temperature data are presented. The equipment malfunctioned in Spring 2011 and the data could not be retrieved from the recorder.

On 30 Sept. and 23 Oct. 2010 (17 and 40 DAT, respectively) and on 30 Mar., 22 Apr., 4 May and 6 June 2011 (21, 44, 56 and 89 DAT, respectively), plant height was measured from the media surface to the last node of the tallest stem on each of the four center plants in each plot (Tables 2-12 and 2-13 and Figures 2-18 and 2-19).

On 30 Sept., 23 Oct., 12 Nov. and 8 Dec. 2010 (17, 40, 60 and 86 DAT, respectively) and on 30 Mar., 22 Apr., 4 May and 6 June 2011 (21, 44, 56 and 89 DAT, respectively), a SPAD value from the most recently fully expanded leaf of the four center plants in each plot was measured using a SPAD-502Plus chlorophyll meter (Spectrum Technologies, Plainfield, IL) (Tables 2-12 and 2-13 and Figure 2-20). The SPAD values are relative numbers that estimate leaf “greenness” – a representation of leaf nitrogen status.

Leachate sampling and analysis

On 12 Oct., 11 Nov., and 14 Dec. 2010 (29, 59 and 92 DAT, respectively) and on 8 Apr., 30 Apr. and 21 May 2011 (30, 52 and 73 DAT, respectively), leachate samples were collected from one of the center four plants in each plot by the pour-through nutrient extraction procedure (Rippy et al., 2004). At the time of collection, the pH and electrical conductivity (EC) of the samples were measured using a Hanna Waterproof pH/Conductivity/TDS tester (HI 98129 and HI 98130; Hanna Instruments, Smithfield, RI). Each sample was then transferred to a 20 mL scintillation vial, filtered and acidified with a 50% sulfuric acid solution to between pH 1 and pH 2, and frozen at 4°C (Florida Dept. of Environmental Protection, 2010; Mylavarapu et al., 2010) until analyzed for nitrate (NO_3-N) concentration by the University of Florida's Analytical Research Laboratory using standard procedures (EPA Method 353.2) (Mylavarapu and Kennelley, 2002). Leachate pH, EC and nutrient analyses are presented in Tables 2-14 and 2-15 and Figure 2-21.

Tissue sampling and analysis

At harvest, tissue samples of the most recently fully expanded leaves were collected from the four center plants in each plot and combined into one composite leaf sample per plot. Also at harvest, one bell pepper was randomly selected from each of the four center plants in each plot, cores and seeds were removed and the flesh was diced and combined into one composite fruit sample per plot. Leaf and fruit tissue samples were dried at 70°C until a constant weight was measured, ground in a Wiley mill (Thomas Scientific, Swedesboro, NJ) to pass through a 20-mesh sieve, and analyzed for total kjeldahl nitrogen (TKN) concentration using a Bran+Luebbe

Technicon AutoAnalyzer II segmented flow analysis system (EPA Method 351.2) (Hochmuth et al., 1991).

Fresh and dry weights of the fruit samples were recorded and used with the fruit TKN analysis data to determine fruit nitrogen use efficiency (NUE). In the experiment, NUE is defined as the percentage of applied nitrogen that was removed at the end of the season by the harvested bell peppers. NUE was calculated using Equation 1-1 described by Zvomuya et al. (2003):

$$NUE = 100 * (N_{treat} / N_{applied}) \quad (1\text{-}1)$$

In Equation 1-1, N_{treat} represents the amount of nitrogen removed in the fruit sample of a given treatment (i.e., fruit nitrogen uptake), and $N_{applied}$ is the amount of nitrogen applied as fertilizer in that treatment (i.e., N rate). Calculations of N_{treat} used total yield values.

After all peppers were harvested, whole plant samples were collected by removing the center four plants of each plot at the media surface, dried at 70°C until a constant weight was measured and weighed to determine aboveground biomass accumulation per plant.

Leaf percent TKN, whole plant dry weight and pepper fruit fresh weight, dry weight, percent TKN and percent NUE at harvest are presented in Tables 2-16 and 2-17 and Figures 2-22 and 2-23.

Harvest

Bell pepper fruit were harvested by hand on 2 and 9 Dec 2010 (80 and 87 DAT, respectively) and 18 May, 25 May and 7 June 2011 (70, 77 and 90 DAT, respectively). Using a slide ruler, all peppers on the center four plants of each plot were graded by size according to a fresh-market diameter scale used for imported greenhouse-grown bell peppers (Jovicich et al., 2004; Saha and Cantliffe, 2009). Marketable fruit were graded as extra large (XL diameter ≥ 84 mm), large (L = 75 to 83.9 mm), medium (M = 65 to 74.9 mm) or small (S = 55 to 64.9 mm) with no serious external defects. Unmarketable fruit were less than 55 mm in diameter or had at least one of the six major bell pepper external defects: blossom end rot, sunscald, radial cracking, flat shape, misshapen or russeting. Weight and number of fruit in each of the five size categories and six cull categories were recorded per plant. The number of lobes was counted on each pepper harvested and averaged per plant (Tables 2-16 and 2-17 and Figure 2-24). The four sample peppers per plot collected for TKN analysis were sliced at their equator where pericarp thickness was measured using a Venier caliper (Bel-Art Products, Pequannock, NJ) (Tables 2-16 and 2-17).

Total and marketable pepper yield data in kg/m^2 are presented in Tables 2-6 and 2-7 and Figures 2-7 through 2-10. Pepper quality data in kg/m^2 are presented in Tables 2-8 and 2-9 and Figures 2-11 and 2-12. Pepper yield and quality data in number of fruit per m^2 and percent of total yield by weight are presented in Tables 2-10 and 2-11 and Figures 2-13 through 2-17.

Statistical Analysis

Combined analyses of variance (ANOVA) among years (Fall 2010 and Spring 2011) indicated significant treatment and year interactions. This may have been attributed to the seasonal variation in growing conditions and the resulting differences in irrigation scheduling as well as to the minor adjustments made when the study was repeated in Spring 2011. Therefore separate statistical analyses for each year were conducted to evaluate the effect of fertilizer treatment, compost treatment and their interaction on organic greenhouse-grown bell pepper production. Statistical analyses to evaluate main and interaction effects were performed using SAS General Linear Model

(GLM) software (V.9.2 SAS Institute, Cary, N.C.). Fisher's least significance difference (LSD) tests with $P \leq 0.05$ were employed for means separation among treatments. Significant interaction effects were sliced by fertilizer treatment to enable the comparison of the compost treatments among each of the fertilizer treatments, and were sliced by compost treatment to enable the comparison of the fertilizer treatments among each of the compost treatments.

Although plant height, plant SPAD values, plant dry weight at harvest, lobe number, pericarp thickness and yield and quality data were collected per plant, the values were averaged per plot before statistical analyses in order to reduce within treatment variation. Composite fruit sample fresh and dry weight, leaf and fruit percent TKN and the pH, EC and [NO_3-N] of leachate data were measured per plot.

Results and Discussion

Cultivar Selection

Just as cultivar performance changes with climate (i.e. cultivars performing better in one region than another) different cultivars may perform better than others under organic greenhouse nutrient management. X3R Red Knight F1 was chosen for this experiment because of its demonstrated adaptation to Florida climate and to containerized greenhouse growing environments, its disease resistance (which is important since there is limited available/effective products for pest/disease control in organic production), and its market desirability and mature red color which will demand high premiums (Shuler, 2003). Of the different mature bell pepper colors, red was chosen because research has demonstrated that red bell pepper plants achieve higher yields than the other colors (Cantliffe et al., 2008). While indeterminate bell pepper cultivars with 10-month-long seasons are often grown in greenhouses, a determinate cultivar was chosen for this study for the following reasons:

- Clogging of the hydroponic greenhouse fertigation systems by organic nutrient sources worsens with time, so using a determinate variety creates shorter crop seasons (less liability), between which the fertigation lines can be thoroughly cleaned and reused for the next crop season.
- Since it is a three to four-month crop from transplant to harvest, growers could potentially produce three bell pepper crops per year corresponding to spring, summer and fall, reusing materials such as media, pots and irrigation lines; or it could serve as a way for growers to create revenue in their “off-season” or during non-peak production times in the absence of market competition.

Therefore, it is important to keep in mind that the yields discussed in this study reflect those of a determinate 4-month-long crop per season with one to two harvests and so will naturally be lower than typical yields reported for greenhouse bell pepper production of an indeterminate 10-month-long crop per season with up to 30 harvests.

Air and Compost Treatment Temperature and Chemical/Physical Properties

The physical and chemical properties of the four media components (peat, pine bark, yard waste compost and poultry litter compost) and of the three custom media mixes that represent the compost treatments (NC, YW and PL) are shown in Table 2-4 and 2-5, respectively). The physical and chemical characteristics of the substrate can potentially affect plant yield. Poultry litter compost had substantially higher soluble salt, sodium and potassium content than the peat, pine bark and yard waste compost, resulting in higher soluble salt and potassium content of the PL compost treatment. This could potentially result in high EC and salt salinity stress which could negatively affect bell pepper yields (Zhai et al., 2009). Ideal EC range for bell pepper is 1.5 to 2.5 mS/cm. Poultry litter compost also had higher phosphorus content resulting in higher phosphorus concentration in the PL compost treatment, which could potentially limit calcium availability through precipitation reactions (Zhai et al., 2009). Bulk density is the mass of soil/media per unit of volume and includes air space and mineral plus organic materials, and is used to determine if soil/media layers are too compact to allow root penetration or adequate aeration (Evanylo and McGuinn, 2009). Similar to results reported by Zhai et al. (2009) and Treadwell et al. (2007), bulk density of the YW and PL compost treatments (0.37 and 0.33 g/cm^3, respectively) was about twice that of the NC control (0.19 g/cm^3), most likely because of the lower percent organic matter and fine particle size of the poultry litter and yard waste compost compared to the peat and pine bark base media components. However, all are within acceptable range. Percent cation exchange capacity (CEC) of the NC, YW and PL compost treatments was 55, 38 and 32%, respectively, and represents their nutrient-holding capacity. Media with higher organic matter and CEC and lower bulk density improves the media quality (Bulluck et al., 2002).

Although PL and YW compost treatments had higher pH than NC (similar to results reported by Zhai et al., 2009), it was still in acceptable media pH range for bell pepper production (pH 5.5 – pH 7.0). Reflecting the lower carbon to nitrogen (C:N) ratio of the organic treatments compared to the conventional hydroponic control in Zhai et al. (2009), C:N ratio of the peat, pine bark, yard waste compost and poultry litter compost was 64:1, 121:1, 25:1, and 7:1, respectively. Since peat and pine bark have a high C:N ratio (>30), the NC treatment could have led to nitrogen immobilization in the media mix, making it unavailable for plant uptake, and rendering any of the combinations of organic fertilizer treatment with NC compost treatment ineffective in terms of yield (Paul and Clark, 1996; Sanchez and Richard, 2009). Microbes will compete with plants for nitrogen when media is amended with products having C:N ratios higher than 25:1 or 30:1 (Evanylo and McGuinn, 2009; Sanchez and Richard, 2009). Since the poultry litter compost has a lower C:N ratio than the yard waste compost (<20), it could potentially mineralize organic nitrogen into plant-available form at a faster rate, resulting in higher yields for organic fertilizer x PL compost treatment combinations (Sanchez and Richard, 2009). However, C:N ratio of the media mix would not likely be a yield-determining factor in compost treatments paired with the conventional hydroponic fertilizer treatment because the mineral-based fertilizer is providing plant-available forms of nutrients with every fertigation event. Percent water holding capacity of NC, YW and PL compost treatments was 56, 71 and 91%, respectively. Ideal water holding capacity (or water-filled pore space) is considered to be within the range of 50-70%. Because the poultry litter compost increased the water-holding capacity of the media to 90%, it is important to not over-irrigate, reducing the oxygen-filled pore spaces that are necessary for nitrification reactions (Evanylo and McGuinn, 2009; Treadwell et al., 2007). In general, poultry litter compost had higher nutrient concentrations than yard waste compost, and both composts had higher nutrient concentrations than the peat and pine bark base media components. As a result, compost/media treatment nutrient concentrations followed the pattern PL > YW > NC. However, the organic sources of nutrients in composts are relatively low (e.g. only 0.3% and 1% total nitrogen in the yard waste and poultry litter compost, respectively) and mineralized into plant-available forms at such a slow rate (10-20% per year for nitrogen is commonly assumed), that it is unlikely these nutrient content differences in the media treatments directly affected yield (Sanchez and Richard, 2009).

The high temperature, low temperature and average temperature of the air inside the greenhouse at a height of 1 m and the NC, YW and PL compost treatments throughout the Fall 2010 season beginning at 29 DAT is presented in Figure 2-6. Optimum soil temperature is considered to be within the range of 25-35°C, but substrates tend to reach higher temperatures than soil. These graphs show the temperature buffering capacity afforded by the composts, with YW and PL substrates maintaining lower temperatures than the air and NC in the high temperature graph, and YW and PL substrates maintaining higher temperatures than air and NC in the low temperature graph. Of the two composts, poultry litter seems to have slightly greater temperature buffering capacity than yard waste compost. The temperature buffering capacity of the YW and PL compost treatments could be partly due to the higher water-holding capacity of the composts and could potentially give plants a growing advantage by keeping the environment surrounding the roots more stable. The ideal day air temperature for bell pepper plants during fruit set is 18-22°C. However night temperatures are more crucial and must stay above 10°C during fruit set.

Bell Pepper Yield and Size Distribution (kg/m^2)

Total and marketable yields were significantly influenced by treatment in both Fall 2010 and Spring 2011 (Table 2-6 and 2-7, respectively). In Fall 2010, total yields ranged from 0.96 to 4.49 kg/m^2 and marketable yields ranged from 0.88 to 4.01 kg/m^2 (in both cases, these extremes were recorded from Soln-Soln x NC and Convtl x YW treatment combinations, respectively). In Spring 2011, total yields ranged from 0.74 to 3.93 kg/m^2 (recorded in Soln-Soln x NC and Convtl x YW treatment combinations, respectively) and marketable yields ranged from 0.29 to 2.91 kg/m^2 (recorded in Soln-Soln x PL and Convtl x YW treatment combinations, respectively). Total and marketable bell pepper yields recorded in Fall 2010 were relatively higher than the yields recorded in Spring 2011. In both years, the Soln-Soln fertilizer treatment produced the lowest yields, in part due to the organic nutrient solution clogging the irrigation lines and emitters, resulting in the plants receiving inadequate supply of nutrients and water (Rippy et al., 2004). While the Gran-Soln and Soln-Gran treatments also utilized organic nutrient solution fertigation, the solution was more dilute compared to the Soln-Soln treatment because these treatments involved granular nutrient sources incorporated into the media as well. Therefore the clogging issues from these treatments were not nearly as severe as those experienced in the Soln-Soln treatment, resulting in better yields. Although other research and commercial operations have claimed success with fertigating with organic spray-dried fish protein fertilizers (Schwankl and McGourty, 1992) (which made up a large proportion of my organic nutrient solution mix), this study shows that these materials will still clog the irrigation system if its concentration in the stock solution is too high. The P in the hydrolyzed spray-dried fish protein could have precipitated with the Ca in the calcium sulfate component of the organic nutrient solution, contributing to clogging issues as well.

Fall 2010

Fertilizer x Compost interaction effect significantly influenced total yield (P = 0.0014) (Figure 2-7). Within the Gran-Gran, Soln-Gran and Soln-Soln fertilizer treatments, PL compost treatment produced higher total yield than NC and YW (by 1 and 17, 70 and 56, 163 and 108%, respectively). Within NC compost treatment, fertilizer treatment total yields followed the pattern Convtl > Gran-Gran = Gran-Soln > Soln-Gran > Soln-Soln. Within YW compost treatment, Convtl fertilizer treatment achieved higher total yield than all others (by 92-271%) and Gran-Gran produced greater total yield than Soln-Soln (by 93%).

Fertilizer main effect significantly influenced marketable yield ($P < 0.0001$) (Table 2-6). Gran-Gran, Gran-Soln and Soln-Gran treatments produced similar marketable yields that were significantly higher than that of Soln-Soln, but lower than that of the Convtl treatment, producing 67, 63 and 54%, respectively, of the 3.47 kg/m^2 marketable yield achieved by Convtl. This is in contrast to a greenhouse-grown, mature-green, indeterminate (214 DAT) bell pepper experiment in which marketable yield of organic bell peppers grown in horse-manure amended soil was not significantly different from yield of conventionally-grown bell peppers (del Amor, 2007). Although the interaction was not significant, the Gran-Gran, Gran-Soln and Soln-Gran fertilizer treatments combined with PL compost treatment produced the highest organic marketable yields of 2.34, 2.37 and 2.44 kg/m^2, respectively, corresponding to 67-71% of the Convtl x NC marketable yield of 3.49 kg/m^2, 58-61% of the Convtl x YW marketable yield of 4.01 kg/m^2, and 80-84% of the Convtl x PL marketable yield of 2.92 kg/m^2.

Some research suggests that only 50% of the total applied nitrogen in organic nutrient sources is made available in a given season. As a result, organic production guidelines often suggest applying organic nitrogen at a rate two times that of conventional inorganic nitrogen. However, this was not done in this study because it was important to keep applied nutrient (especially nitrogen) levels consistent across treatments for comparison purposes (in both the production and economic analysis studies), and also because other research has shown higher disease incidence and leachate/substrate EC (and therefore lower marketable yields) from higher nitrogen (organic or inorganic) fertilizer rates (Miles and Peet, 2002; Rippy et al, 2004; Zhai et al., 2009). It was also important to keep organic nutrient management input costs down to help ensure positive partial net returns in the subsequent economic analysis.

The majority of non-culled peppers fell within the XL, L and M size classes for the Convtl, Gran-Gran, Gran-Soln, and Soln-Gran fertilizer treatments, while the majority of non-culled peppers fell within the M size class for the Soln-Soln fertilizer treatment (Table 2-6). Fertilizer main effect significantly influenced yield of XL size peppers ($P < 0.0001$) with means separation paralleling that of marketable yield. Fertilizer x Compost interaction effect significantly influenced yield of L and M size peppers ($P = 0.0092$ and $P = 0.0433$, respectively) (Figure 2-8 and 2-9, respectively).

Spring 2011

Fertilizer main effect significantly influenced total and marketable yield ($P < 0.0001$ and $P = 0.0003$, respectively) (Table 2-7). Gran-Gran, Gran-Soln and Soln-Gran treatments produced total yields that were significantly higher than that of Soln-Soln, but lower than that of the Convtl treatment, producing 56, 63 and 46%, respectively, of the total yield of 3.55 kg/m^2 achieved by Convtl. Gran-Gran and Gran-Soln treatments produced marketable yields that were significantly higher than that of Soln-Soln and comparable to that of Convtl, producing 63 and 87%, respectively, of the marketable yield of 2.21 kg/m^2 achieved by Convtl. Additionally, Gran-Soln resulted in significantly higher total and marketable yields than Soln-Gran. Although the interaction was not significant, the Gran-Gran x YW, Gran-Soln x NC and Gran-Soln x PL treatment combinations produced the highest organic marketable yields of 1.65, 1.86 and 2.45 kg/m^2, respectively, corresponding to 93, 104 and 138% of the Convtl x NC marketable yield of 1.78 kg/m^2, 57, 64 and 84% of the Convtl x YW marketable yield of 2.91 kg/m^2, and 85, 96 and 126% of the Convtl x PL marketable yield of 1.94 kg/m^2.

The majority of non-culled peppers fell within the XL, L and M size classes for Convtl, the L, M and S size classes for Gran-Gran and Gran-Soln, and the M and S size classes for Soln-Gran and Soln-Soln fertilizer treatments. Fertilizer main effect significantly influenced yield of XL, L, and U size peppers (*P* = 0.0137, 0.0044 and 0.0322, respectively) (Table 2-7). The yield of XL size peppers from Gran-Soln was comparable to that from Convtl, and the yield of L size peppers from Gran-Gran and Gran-Soln was comparable to that from Convtl, with significantly lower yields of these size classes from the other fertilizer treatments. Fertilizer and Compost main effects significantly influenced yield of M size peppers (*P* = 0.0007 and 0.0231, respectively), with Soln-Soln fertilizer and PL compost treatments yielding less M size peppers than all other fertilizer or compost treatments. Fertilizer x Compost interaction effect significantly influenced yield of S size peppers (*P* = 0.0442) (Figure 2-10).

The greenhouse utilized for this experiment was not hooked to a back-up generator. Several times during the Spring 2011season, at crucial plant and fruit development stages, storms caused power outages in the greenhouse, which caused the irrigation system to turn off. During these times, all plants did not receive water (and in some cases nutrients, depending on the treatment) for 1-2 days at a time in hot Florida spring temperatures. This caused a reduction in yields compared to Fall 2010 yields. This situation was compounded in the organic treatments because dry media conditions would have slowed down the mineralization rate, depriving the organic plants of much-needed nitrogen during stages of high vegetative and reproductive growth

(Sanchez and Richard, 2009). Also, the transplant date of 9 March is relatively late. Yields could very likely have been higher for the Spring 2011 trial if the seedlings were transplanted into the greenhouse in January or early February, so that harvest occurred before the high Florida temperatures could stress the plants and contribute to decreased fruit quality.

Bell Pepper Quality (kg/m^2)

Fall 2010

Fertilizer and Compost main effects significantly influenced yield of fruit with external defects (Table 2-8). The Convtl fertilizer treatment resulted in higher yields of total culls (P = 0.0165) and blossom end rot peppers (P = 0.0026), and both Convtl and Soln-Gran treatments resulted in higher yields of flat shape peppers (P = 0.0066) than all other fertilizer treatments. The PL compost treatment resulted in higher yields of total culls (P = 0.0084) and sunscald peppers (P = 0.0029), and PL resulted in higher and YW resulted in lower yields of blossom end rot peppers (P = 0.0003) compared to the other compost treatments.

Spring 2011

Fertilizer x Compost interaction effect significantly influenced yield of culls (P = 0.0204) and blossom end rot peppers (P = 0.0143) (Figure 2-11 and 2-12, respectively). Within all five fertilizer treatments, PL compost treatment resulted in higher yield of total culls and blossom end rot peppers than NC and YW. Within all three compost treatments, Convtl fertilizer treatment resulted in higher yield of total culls and blossom end rot peppers than all other fertilizer treatments. Within PL compost treatment only, Gran-Soln resulted in lower yield of total culls than Gran-Gran and lower yield of blossom end rot peppers than all other fertilizer treatments. Fertilizer main effects significantly influenced yield of flat shape and misshapen peppers (Table 2-9). The Convtl and Gran-Gran treatments resulted in higher yields of flat shape fruit ($P < 0.0001$) and Soln-Soln resulted in higher yields of misshapen fruit ($P = 0.0287$) compared to all other fertilizer treatments.

Bell Pepper Fruit Counts and Percent Yields

Bell pepper fruit counts and percent yields were significantly influenced by treatment in both Fall 2010 and Spring 2011. In Fall 2010, total yields ranged from 10 to 35 fruit/m^2 and marketable yields ranged from 9 to 30 fruit/m^2 (in both cases, these extremes were recorded in Soln-Soln x NC and Convtl x NC treatment combinations, respectively). Percent marketable yield by weight ranged from 77.2% in Soln-Soln x PL to 95.7% in Gran-Gran x YW. Total culls ranged from 0.6 fruit/m^2 and 1.8% in Gran-Gran x YW to 7 fruit/m^2 and 17.9% in Convtl x PL. Blossom end rot ranged from 0 fruit/m^2 and 0% in all organic fertilizer treatments paired with YW compost to 5 fruit/m^2 and 13.1% in Convtl x PL. In Spring 2011, total yields ranged from 17 to 85 fruit/m^2 (from Soln-Soln x NC and Convtl x PL, respectively) and marketable yields ranged from 6 to 31 fruit/m^2 (from Soln-Soln x PL and Convtl x YW, respectively). Percent marketable yield by weight ranged from 21.7% in Soln-Soln x PL to 88.9% in Gran-Soln x NC. Total culls ranged from 3 fruit/m^2 in Soln-Soln x YW and 7.6% in Gran-Soln x YW to 51 fruit/m^2 and 55.9% in Convtl x PL. Blossom end rot ranged from 0 fruit/m^2 and 0% in Soln-Gran x YW, Soln-Soln x YW and Soln-Soln x NC to 46 fruit/m^2 and 49.2% in Convtl x PL.

Fall 2010

Fertilizer x Compost interaction effect significantly influenced number of total and marketable fruit per square meter ($P < 0.0001$ and $P < 0.0001$, respectively) (Figure 2-

13 and 2-14, respectively). Within Convtl fertilizer treatment, PL compost treatment produced less marketable fruit than NC and YW. Within Gran-Gran fertilizer treatment, PL compost treatment produced more total fruit than YW, and within Gran-Soln fertilizer treatment, NC compost treatment produced more total and marketable fruit than YW. Within Soln-Gran and Soln-Soln fertilizer treatments, PL compost treatment produced more total and marketable fruit than NC and YW. Within NC and YW compost treatments, Convtl fertilizer produced significantly more total and marketable fruit than all other fertilizer treatments. Within NC compost treatment, Gran-Gran and Gran-Soln fertilizer treatments produced more total and marketable fruit than the other two organic fertilizer treatments. Within YW compost treatment, Soln-Soln produced less total and marketable fruit than the other three organic fertilizer treatments. Within PL compost treatment, number of total and marketable fruit is statistically similar among all fertilizer treatments.

Fertilizer main effect significantly influenced number of culled fruit and blossom end rot fruit per square meter and percent blossom end rot yield (P = 0.0167, 0.0125 and 0.0195, respectively) (Table 2-10). Convtl fertilizer treatment resulted in higher number of culled and blossom end rot fruit than all other fertilizer treatments. While the percent blossom end rot yield was statistically similar across the four organic fertilizer treatments, Convtl fertilizer resulted in a higher percentage than Soln-Gran and Soln-Soln treatments. Compost main effect significantly influenced number of culled fruit and blossom end rot fruit per square meter and percent marketable, culled and blossom end rot yield (P = <0.0001, 0.0002, 0.0218, 0.0074 and <0.0001, respectively) (Table 2-10). PL compost treatment resulted in higher number of culled and blossom end rot fruit and percent blossom end rot yield compared to the other compost treatments, and lower percent marketable yield and higher percent culled yield compared to YW compost treatment.

Spring 2011

Fertilizer x Compost interaction effect significantly influenced number of total and blossom end rot fruit per square meter and percent blossom end rot yield by weight (P = 0.0004, 0.0050 and 0.0038, respectively) (Figure 2-15, 2-16 and 2-17, respectively). Within all fertilizer treatments except for Soln-Gran, PL compost treatment resulted in higher total fruit count than NC and YW. Within all three compost treatments, Convtl fertilizer resulted in higher total fruit count than all other fertilizer treatments. Within NC and YW compost treatment, Soln-Soln resulted in significantly lower total fruit count. Within all fertilizer treatments except for Gran-Soln, PL compost treatment resulted in significantly more blossom end rot (both in count and percent by weight) compared to NC and YW. Within NC and YW compost treatments, Convtl fertilizer resulted in more blossom end rot (both in count and percent by weight) than the other fertilizer treatments, and within PL compost treatment, Gran-Soln fertilizer resulted in less blossom end rot than the other fertilizer treatments.

Fertilizer main effect significantly influenced marketable and culled fruit count and percent yield by weight (P = <0.0001, <0.0001, 0.0004 and <0.0001, respectively) (Table 2-11). Convtl, Gran-Gran and Gran-Soln produced more marketable fruit and Gran-Soln produced higher percent marketable yield compared to the other fertilizer treatments. The culled fruit count results of Convtl > Gran-Gran > Soln-Gran = Soln-Soln > Gran-Soln is generally reflected in percent culled yield with Convtl producing significantly higher percentage and Gran-Soln lower percentage compared to the other fertilizer treatments. Compost main effect also significantly influenced these four variables (*P* = 0.0272, <0.0001, <0.0001 and <0.0001, respectively) (Table 2-11). YW produced higher marketable fruit count than PL, both YW and NC produced higher percent marketable yield than PL, and PL produced higher culled fruit count and culled percent yield than YW and NC.

Although, in general, plants in Spring 2011 produced more fruit per square meter than plants in Fall 2010, most of this fruit was unmarketable because of blossom end rot. The water stress that the Spring 2011 plants experienced due to the storm surges that turned off the irrigation system resulted in the physiological disorder called blossom end rot (Bar-Tal et al., 1999). Also, due to the high temperatures in Spring 2011, most of the water was most likely drawn up into the mature leaves to maintain functional transpiration rate, resulting in a lack of calcium reaching the actively growing cells of the young fruits (Marcelis and Ho, 1999). This calcium deficiency in the fruit led to blossom end rot. Of the fertilizer treatments, Convtl resulted in the most blossom end rot, partly because all of its nutrients were being fertigated through the irrigation system, so when the irrigation shut off, the plants were not receiving nutrients either, which may have caused a calcium deficiency that led to blossom end rot as well. The high incidence of blossom end rot from the PL compost treatment may have been due to the relatively high phosphorus content in the poultry litter compost, which could have potentially limited calcium availability through precipitation reactions. However, the advantageous properties of the PL compost treatment such as the low C:N ratio, high water-holding capacity and temperature-buffering capacity offset this disadvantage enough to still result in higher marketable yields of the organic fertilizer x PL compost treatment combinations compared to other organic treatments.

Plant Height and Leaf SPAD values

Fall 2010

Plant height generally reflects yield results. Compost main effect significantly influenced plant height at 17 DAT (P = 0.0041) (Table 2-12). Plants grown with PL compost treatment were taller than plants grown with NC or YW. At 40 DAT, Fertilizer x Compost interaction effect significantly influenced plant height (P = 0.0029) (Figure 2-18). Within Gran-Gran fertilizer treatment, PL produced taller plants than YW; within Soln-Gran fertilizer treatment, PL produced taller plants than YW which produced taller plants than NC; and within Soln-Soln fertilizer treatment, PL produced taller plants than both YW and NC. Within NC compost treatment, Convtl and Gran-Gran produced taller plants than Soln-Gran and Soln-Soln; within YW compost treatment, Convtl produced taller plants than all other fertilizer treatments; and within PL compost treatment, Gran-Soln produced shorter plants than all other fertilizer treatments.

Fertilizer main effect significantly influenced relative leaf SPAD values at all four sampling dates (P = 0.0155, 0.0002, <0.0001 and <0.0001, respectively) (Table 2-12). Gran-Soln resulted in lower leaf SPAD values at 17 DAT and Convtl resulted in higher leaf SPAD values at 40, 60 and 86 DAT compared to all other fertilizer treatments. At 60 DAT, leaf SPAD values were higher from the Gran-Gran compared to the Gran-Soln fertilizer treatment. At 60 and 86 DAT, the Soln-Gran fertilizer treatment produced higher leaf SPAD values than the Gran-Soln and Soln-Soln fertilizer treatments. Compost main effect significantly influenced relative leaf SPAD values at 17 and 40

DAT (*P* = 0.0027 and <0.0001, respectively) (Table 2-12). At both sampling dates, YW produced lower leaf SPAD value than NC or PL.

Spring 2011

Plant height generally reflects yield results. Fertilizer and Compost main effects significantly influenced plant height at 21 DAT (*P* = 0.0059 and 0.0015, respectively) (Table 2-13). Convtl produced taller plants than all other fertilizer treatments, and PL produced taller plants than all other compost treatments. At 44 DAT, Fertilizer x Compost interaction effect significantly influenced plant height (*P* = 0.0267) (Figure 2-19). Within Gran-Soln and Soln-Gran fertilizer treatments, PL produced taller plants than NC or YW compost treatments. Within NC and YW compost treatments, Convtl, Gran-Gran and Gran-Soln produced similar size plants that were taller than those produced by the other fertilizer treatments; and within PL compost treatment, Convtl and Gran-Soln produced plants of comparable size that were taller than those produced by the other fertilizer treatments. Fertilizer and Compost main effects also significantly influenced plant height at 56 and 89 DAT (Table 2-13). At 56 DAT, Convtl and Gran-Soln produced similar size plants that, along with those produced by Gran-Gran, were taller than those produced by Soln-Gran and Soln-Soln (*P* <0.0001). At 89 DAT, Convtl produced taller plants than all other fertilizer treatments and Gran-Soln produced taller plants than Soln-Gran and Soln-Soln (*P* <0.0001). At both 56 and 89 DAT, YW and PL compost treatments produced taller plants than NC (*P* = 0.0017 and 0.0002, respectively).

Fertilizer x Compost interaction effect significantly influenced relative leaf SPAD values at 21 DAT (*P* = 0.0061) (Figure 2-20). Within Convtl fertilizer treatment, PL compost treatment resulted in higher leaf SPAD values than NC; within Gran-Soln fertilizer treatment, NC compost treatment resulted in higher leaf SPAD values than PL; and within Soln-Gran fertilizer treatment, both NC and PL compost treatments produced higher leaf SPAD values than YW. Within NC compost treatment, Convtl fertilizer produced higher leaf SPAD values than Soln-Gran; within YW compost treatment, Convtl and Gran-Gran fertilizers produced comparable leaf SPAD values that were higher than those produced by the other fertilizer treatments; and within PL compost treatment, Convtl fertilizer resulted in higher leaf SPAD values and Gran-Soln resulted in lower leaf SPAD vales compared to the other fertilizer treatments. At 44, 56 and 89 DAT, Fertilizer main effect significantly influenced leaf SPAD values (P = 0.0009, <0.0001 and <0.0001, respectively) (Table 2-13). At 44 DAT, Convtl fertilizer produced higher leaf SPAD values than all other fertilizer treatments. At 56 DAT, Convtl and Soln-Gran produced comparably higher leaf SPAD vales and Gran-Soln produced lower leaf SPAD values than the other fertilizer treatments. At 89 DAT, Convtl and Soln-Soln produced the comparably highest leaf SPAD values and Gran-Gran and Gran-Soln produced the comparably lowest. At 44, 56 and 89 DAT, Compost main effects also significantly influenced leaf SPAD values (P = <0.0001, 0.0382 and 0.0241, respectively) (Table 2-13). At 44 DAT, PL compost treatment produced higher leaf SPAD values than NC, which produced higher leaf SPAD values than YW. At 56 DAT, NC compost treatment produced leaf SPAD values that were comparable to those of PL and higher than those of YW. At 89 DAT, NC compost treatment produced leaf SPAD values that were comparable to those of YW and higher than those of PL.

Leachate pH, EC and Nitrate Concentration

For hydroponic greenhouse bell pepper, optimum leachate pH is between 5.5 and 7.0 pH (the range in which macronutrients are most readily available for plant uptake)

(Rippy et al., 2004) and optimum leachate EC is between 1.5 and 2.5 mS/cm. In both Fall 2010 and Spring 2011, the first leachate sampling date occurred the day before sidedress fertilizers were applied.

Fall 2010

There were no significant Fertilizer main effects for leachate pH at 29 DAT (ranging from pH 6.7 to pH 7.3), however Fertilizer main effect did significantly influence leachate pH at 59 and 92 DAT (P = <0.0001 and <0.0001, respectively) and leachate EC at 29, 59 and 92 DAT (P = 0.0025, <0.0001 and <0.0001, respectively) (Table 2-14). At both 59 and 92 DAT, the leachate pH was lower (pH 6.5 and pH 6.4, respectively) and, at all three sampling dates, leachate EC was higher (1.9, 2.9 and 3.7 mS/cm, respectively) from the Convtl treatment than from all other fertilizer treatments. The Convtl fertilizer treatment includes phosphoric acid which lowers the pH; however, the organic fertilizer treatments do not have a component that is as acidic, which explains their higher leachate pH, similar to results reported by Rippy et al. (2004). The higher leachate EC of the Convtl treatment is due to the fact that its components are salt-based, whereas the organic fertilizers are slowly mineralized into salts throughout the season. At 59 DAT, the leachate pH was lower and leachate EC was higher from the Soln-Gran treatment (pH 7.0 and 1.7 mS/cm, respectively) than from the Gran-Gran treatment (pH 7.3 and 0.9 mS/cm, respectively). At 92 DAT, the leachate pH was higher from the Gran-Soln treatment (pH 7.3) and leachate EC was higher from the Gran-Gran and Soln-Gran treatments (2.5 and 2.6 mS/cm, respectively) than from all other fertilizer treatments. The pH and EC levels were acceptable throughout the season for the Convtl fertilizer treatment (although EC was a little high at the end of the season). However, pH was either at the high end of acceptable range or slightly higher for the organic treatments; and EC was lower than acceptable range for all the organic treatments throughout the season accept for Soln-Gran at 59 DAT (1.7 mS/cm) and Gran-Gran and Soln-Gran at 92 DAT (2.5 and 2.6 mS/cm, respectively). The acceptable EC at the end of the season for these two organic treatments perhaps was due to their granular fertilizer sidedress, and could have contributed to their higher yields compared to the other organic fertilizer treatments. However, the relatively higher than optimal pH and lower than optimal EC of the organic fertilizer treatments most likely contributed to their lower yields compared to the Convtl treatment.

At all three sampling dates, Compost main effect significantly influenced leachate pH and EC (P <0.0001 in all cases) (Table 2-14). At 29 DAT, leachate pH followed the pattern NC < PL < YW (pH 6.5, pH 7.1 and pH 7.5, respectively), and leachate EC followed the pattern PL > YW > NC (2.1, 1.0 and 0.6 mS/cm, respectively). At 59 DAT, leachate pH was lower from the NC compost treatment (pH 6.6) than from PL or YW (pH 7.1 and pH 7.3, respectively) and leachate EC was higher from the PL compost treatment (2.4 mS/cm) than from YW or NC (1.4 and 1.0 mS/cm, respectively). At 92 DAT, leachate pH followed the same pattern as it did at 29 DAT, NC < PL < YW (pH 6.5, pH 7.1 and pH 7.3 respectively), and leachate EC followed the same pattern as it did at 59 DAT, PL > YW = NC (3.4, 1.6 and 1.5 mS/cm, respectively).

In general, NC compost treatment displayed lowest leachate pH and within optimal range, while YW and PL displayed leachate pH higher than optimal range, with YW having higher pH than PL. These results reflect the pH levels of the compost media mixes presented in Table 2-5. Because the organic fertilizer treatments already result in relatively high leachate pH, pairing them with the PL compost treatment is a better option than the YW because of its relatively lower pH, resulting in greater yields. Although the NC compost treatment results in the best leachate pH levels, the low yields from its pairing with the organic fertilizer treatments is most likely due to the lack of compost in the NC media mix and its high C:N ratio, which results in a media environment that is not optimal for mineralizing and nitrifying microorganisms. The lack of compost in the NC treatment also results in low leachate EC, making it an unfavorable media for the already low EC organic fertilizer treatments. On the other hand, because of the higher soluble salt, sodium, potassium and other nutrient content in the poultry litter compost, the PL compost treatment results in higher leachate EC than the YW or NC treatments and so can help to offset the low EC from the organic fertilizers, resulting in favorable yields from the organic fertilizer x PL compost pairing.

In the study conducted by Rippy et al. (2004), the organic treatments experienced much higher than optimal leachate EC early in the season because the organic media was amended with large amounts of organic composts and fertilizers all at once at transplanting. This situation leads to salt toxicity in the young plants and can negatively affect yields; this situation was avoided in my study by using lower amounts of amendments and splitting them into two applications.

At all three sampling dates, Fertilizer main effect significantly influenced leachate NO_3-N concentration (P <0.0001 in all cases) (Table 2-14). At all three sampling dates, leachate [NO_3-N] was higher from Convtl than from all other fertilizer treatments due to the soluble mineral-based calcium nitrate fertilizer ingredient in the Convtl treatment. At 92 DAT, Soln-Gran produced higher leachate [NO_3-N] than Gran-Soln or Soln-Soln fertilizer treatments, and Gran-Gran produced higher leachate [NO_3-N] than Soln-Soln fertilizer treatment, perhaps due to the organic granular fertilizer sidedress in the Soln-Gran and Gran-Gran treatments. At 29 and 92 DAT, Compost main effect significantly influenced leachate NO_3-N concentration (P = 0.0163 and 0.0004, respectively) (Table 2-14). At both sampling dates, PL produced higher leachate [NO_3-N] than NC or YW compost treatments. The poultry litter compost had the lowest C:N ratio (Table 2-4) allowing the microorganisms to mineralize organic nitrogen into plant-available forms at a faster rate compared to the yard waste compost, peat and pine bark, resulting in higher leachate [NO_3-N] from the PL compost treatment compared to NC and YW (Sanchez and Richard, 2009). This could also explain why the organic fertilizers x PL compost treatment produced the highest organic yields. Because the NC treatment had no compost, it could have had less nitrifying microorganisms, and its high C:N ratio could have contributed to a slower rate of nitrification, resulting in the lower yields produced form the organic fertilizers x NC treatment combinations (Chang et al., 2007; Sanchez and Richard, 2009; Zhai et al., 2009).

In general, leachate from PL compost treatment had lower (more optimal) pH compared to YW, higher (more optimal) EC compared to NC and YW, and higher (more optimal) [NO_3-N] compared to NC and YW. This explains why the organic fertilizer treatments paired with PL compost treatment achieved higher fruit yields compared to other organic treatment combinations. In general, leachate from the all-granular (Gran-Gran) and combinations of granular and solution (Gran-Soln and Soln-Gran) organic fertilizer treatments resulted in higher (more optimal) EC by end of season and the higher [NO_3-N] throughout the season, compared to the all-organic-solution (Soln-Soln) treatment. This could be partly explained by the clogging problems experienced in the

Soln-Soln treatment. As a result, Gran-Gran, Gran-Soln and Soln-Gran fertilizer treatments achieved higher fruit yields compared to Soln-Soln, especially when paired with PL compost treatment. Although conventional hydroponic fertilizer systems are not often paired with a media amended with compost, the Convtl fertilizer treatment paired with YW compost treatment achieved the highest yields. The high pH and low EC of the leachate from the YW treatment is offset by the Convtl fertilizer, so the Convtl x YW treatment combination could have benefited from the media-enhancing properties of yard waste compost such as the higher water holding capacity, temperature-buffering capacity, etc., resulting in higher yields from the Convtl x YW treatment combination compared to Convtl x NC control.

Spring 2011

Fertilizer x Compost interaction effect significantly influenced leachate EC at 30 DAT (P = 0.0017) (Figure 2-21). Within all fertilizer treatments except for Gran-Soln, PL compost treatment produced significantly higher leachate EC (ranging from 3.6 to 4.0 mS/cm, which is higher than optimal EC) than NC or YW, and YW compost treatment produced higher leachate EC than NC treatment. In most cases, any fertilizer treatment paired with NC or YW resulted in below optimal EC. Within NC compost treatment, Convtl, Gran-Gran and Gran-Soln fertilizer treatments resulted in higher leachate EC than the other treatments, however all were below optimal EC range. Within YW compost treatment, Gran-Gran produced higher leachate EC (2.2 mS/cm, within optimal EC range) than all other fertilizer treatments (which showed EC levels below optimal range). Within PL compost treatment, there were no significant differences among fertilizer treatments, and all exhibited higher than optimal leachate EC except for Gran-Soln.

There were no significant Fertilizer main effects for leachate pH at 30 and 52 DAT (ranging from pH 6.4 to pH 6.7), however Fertilizer main effect did significantly influence leachate pH at 73 DAT (P = 0.0065) and leachate EC at 52 and 73 DAT (P < 0.0001 on both dates) (Table 2-15). At 52 DAT, leachate EC from Gran-Gran fertilizer treatment (3.3 mS/cm) was comparable to that of Soln-Gran (2.4 mS/cm) and higher than EC from the other fertilizer treatments, potentially due to the organic granular fertilizer sidedress applied in both these treatments. Leachate EC from Soln-Gran was comparable to that of Convtl (2.2 mS/cm), both of which were higher than EC from Gran-Soln fertilizer treatment (1.0 mS/cm). At 73 DAT, leachate pH was lower from Convtl (pH 6.1) than from all other fertilizer treatments, reflecting Fall 2010 results. Leachate EC from Gran-Gran (2.5 mS/cm) was comparable to that of Convtl (3.3 mS/cm) and Soln-Gran (2.1 mS/cm), all of which were higher than EC from Gran-Soln and Soln-Soln, reflecting Fall 2010 results.

Compost main effect significantly influenced leachate pH at all three sampling dates (P = 0.0214, 0.0010 and 0.0004, respectively) and leachate EC at 52 and 73 DAT (P <0.0001 on both dates) (Table 2-15). At all three sampling dates, leachate pH from YW and PL compost treatments were comparable (ranging from pH 6.6 to pH 6.7) and higher than leachate pH from NC, similar to Fall 2010 results. At 52 and 73 DAT, leachate EC was higher from PL compost treatment (3.3 and 3.4 mS/cm, respectively) than from NC or YW, reflecting Fall 2010 results.

Across treatments, the leachate pH levels were lower in Spring 2011 compared to Fall 2010 and all within optimum range. However, on average, the leachate EC levels were higher, especially from treatments paired with Convtl fertilizer or PL compost. The

Convtl fertilizer treatment utilizes all salt-based nutrients and the poultry litter compost has substantially higher soluble salt, sodium and potassium content. When the irrigation system shut off due to storm surges, the lack of water could have caused the salts to build up in the media of plants under the Convtl fertilizer treatment or PL compost treatment. This extra salinity stress could have compounded the water stress, resulting in the higher incidence of blossom end rot from these treatments compared to all others.

Fertilizer main effect significantly influenced leachate NO_3-N concentration at all three sampling dates (P = 0.0242, <0.0001 and <0.0001, respectively) (Table 2-15). At 30 DAT, Convtl showed higher leachate [NO_3-N] than all other fertilizer treatments except for Soln-Gran. At 52 DAT, Convtl, Gran-Gran and Soln-Gran resulted in comparable leachate [NO_3-N] that was higher than those from the other two organic fertilizer treatments. At 73 DAT, Convtl produced higher leachate [NO_3-N] than all other fertilizer treatments, and Gran-Gran and Soln-Gran produced higher leachate [NO_3-N] than the other two organic fertilizer treatments. Compost main effect significantly influenced leachate NO_3-N concentration at all three sampling dates (P = <0.0001, 0.0003 and 0.0131, respectively) (Table 2-15). On all sampling dates, PL produced significantly higher leachate [NO_3-N] than NC or YW compost treatments. All these results reflect those in Fall 2010.

Plant Biomass and Nutrient Content at Harvest

Fall 2010

Fertilizer x Compost interaction effect significantly influenced whole plant dry weight at harvest (P=0.0048) (Figure 2-22), reflecting yield results. Within Gran-Gran fertilizer treatment, PL compost treatment produced greater plant biomass than YW; within Gran-Soln fertilizer treatment, PL and NC compost treatments produced greater plant biomass than YW; and within Soln-Gran and Soln-Soln fertilizer treatments, PL compost treatment produced greater plant biomass than NC and YW. Within NC compost treatment, plant biomass followed the patter Convtl > Gran-Gran = Gran-Soln > Soln-Gran > Soln-Soln. Within YW and PL compost treatments, Convtl produced significantly greater plant biomass than all other fertilizer treatments.

Fertilizer and Compost main effect significantly influenced leaf percent TKN at harvest (P = <0.0001 and 0.0031, respectively) (Table 2-16). Convtl fertilizer treatment produced higher leaf percent TKN than all other treatments, and Soln-Gran and Soln-Soln produced higher leaf percent TKN than the other two organic fertilizer treatments. NC compost treatment produced higher leaf percent TKN than YW or PL.

These results agree with a greenhouse-grown bell pepper experiment by del Amor (2007) in which leaf [NO_3-N] was lower and shoot and leaf fresh weight were reduced by 32.6 and 35%, respectively, in the organic treatments compared to the conventional treatment. The leachate [NO_3-N] results in my study indicate that a smaller percentage of plant-available nitrogen is present at any given time in the organic treatments, compared to conventional, due to the fact that organic nitrogen must be mineralized into plant-available forms by microbes. This would result in lower leaf percent TKN and slower leaf expansion and plant growth rate and, therefore, the lower whole plant dry weight from the organic treatments at the end of the season (del Amor, 2007; Martinez et al., 2005; Van Delden, 2001). However, nitrogen pools in the stems could have acted to regulate and maintain fruit yield at the expense of vegetative growth (del Amor, 2007). On the other hand, these results are in contrast to the studies by Rippy et al. (2004) and Zhai et al. (2009) in which greenhouse-grown tomato leaf nitrogen content at mid-season and 132 DAT, respectively, was comparable among organic and conventional systems.

Spring 2011

Fertilizer and Compost main effects significantly influenced whole plant dry weight at harvest (*P* < 0.0001 for both effects) (Table 2-17), reflecting yield results. Convtl fertilizer treatment produced greater plant biomass than all other treatments, and Gran-Gran and Gran-Soln produced greater plant biomass than the other two organic fertilizer treatments. PL compost treatment produced greater plant biomass than NC or YW. Across all treatments, whole plant dry weight was almost twice that of plants from the Fall 2010 trial, indicating that while the plants might have been healthier, it did not translate into higher yields due to the blossom end rot problems and perhaps more nutrients were being allocated to vegetative growth as opposed to reproductive growth, indicating the ratio of available nitrogen to potassium was not optimal for bell pepper yield.

Fertilizer main effect significantly influenced leaf percent TKN at harvest (*P* < 0.0001) (Table 2-17). Convtl fertilizer treatment produced higher leaf percent TKN than all other treatments Soln-Soln produced higher leaf percent TKN than Soln-Gran and both produced higher leaf percent TKN than the other two organic fertilizer treatments, reflecting Fall 2010 results.

Fruit Characteristics and Nutrient Content/Efficiency at Harvest

Fall 2010

Fertilizer main effect significantly influenced fruit pericarp thickness, fresh weight, dry weight and percent NUE at harvest (*P* < 0.0001 in all cases) (Table 2-16), reflecting yield and quality results. Convtl fertilizer treatment produced thicker pericarps than all other fertilizer treatments, and Gran-Gran and Soln-Gran produced thicker pericarps than Soln-Soln. Thicker pericarps are desirable because they may be less susceptible to cracking during handling and they may create heavier fruit, requiring less fruit to fill a 5-kg carton (Shaw and Cantliffe, 2002). Fruit from Gran-Gran fertilizer treatment had fresh weight comparable to fruit from Convtl, and fruit from Gran-Gran, Gran-Soln and Soln-Gran had fresh weight comparable to one another and higher than fruit fresh weight from Soln-Soln fertilizer treatment. Convtl, Gran-Gran, and Soln-Gran produced similar fruit dry weights that were greater than that of Gran-Soln fertilizer treatment, and all fertilizer treatments produced fruit dry weights greater than Soln-Soln. Convtl fertilizer treatment resulted in higher fruit percent NUE than all other treatments, and Gran-Gran, Gran-Soln and Soln-Gran resulted in higher fruit percent NUE than Soln-Soln.

Compost main effect significantly influenced fruit lobe number and percent NUE at harvest (P = 0.0208 and 0.0028, respectively) (Table 2-16), reflecting yield and quality results. PL compost treatment produced fruit with higher lobe number than NC, and resulted in higher fruit percent NUE than NC and YW compost treatments.

Fertilizer x Compost interaction effect significantly influenced fruit percent TKN at harvest (P = 0.0001) (Figure 2-23), reflecting yield and quality results. Within Convtl fertilizer treatment, PL compost treatment produced higher fruit percent TKN than NC or YW; within Gran-Gran fertilizer treatment, YW compost treatment produced higher fruit percent TKN than PL; within Soln-Gran fertilizer treatment, NC produced higher fruit percent TKN than YW or PL. Within NC compost treatment, Convtl and Soln-Gran produced similar fruit percent TKN that as higher than that of all other fertilizer treatments. Within YW and PL compost treatments, Convtl produced higher fruit percent TKN than all other fertilizer treatments.

Spring 2011

Fertilizer main effect significantly influenced fruit pericarp thickness, fresh weight, percent TKN and percent NUE (*P* = 0.0191, 0.0001, <0.0001 and <0.0001, respectively) (Table 2-17), generally reflecting yield and quality results. Convtl, Gran-Gran and Gran-Soln fertilizer treatments produced fruit with comparable pericarp thickness, and Convtl and Gran-Soln produced thicker pericarps than Soln-Soln. Convtl and Gran-Soln produced fruit with comparable fresh weights that were greater than that of fruit produced by the other fertilizer treatments. Convtl produced higher fruit percent TKN and percent NUE than all other fertilizer treatments, and Soln-Gran and Soln-Soln produced higher fruit percent TKN than Gran-Gran and Gran-Soln. Across all treatments, fruit pericarp thickness, fresh weight and dry weight was lower than that of fruit from Fall 2010, reflecting yield and quality results.

Fertilizer x Compost interaction effect significantly influenced fruit lobe number (*P* = 0.0227) (Figure 2-24). Within Gran-Soln and Soln-Gran fertilizer treatments, PL compost treatment produced fruit with more lobes than NC; and within Soln-Soln fertilizer treatment, both PL and YW compost treatments produced fruit with more lobes than NC. Within NC compost treatment, Convtl and Gran-Gran fertilizer treatments produced fruit with more lobes than Soln-Gran and Soln-Soln; and within YW compost treatment, Convtl and Gran-Gran fertilizer treatments produced fruit with more lobes than Soln-Gran.

Conclusions

Peat and pine bark substrate amended with poultry litter compost and fertilized with all granular or either combination of organic granular and nutrient solution sources produced the highest organic greenhouse marketable red bell pepper yields of 57-138% of the hydroponic control. Because different organic nutrient fertilizers and media/composts vary considerably in their properties and rates of nutrient availability, using multiple sources of organic nutrients and a combination of incorporated, top-dressed and fertigated fertilization systems may increase the size, biodiversity and activity of the microbial populations in the media, thereby influencing the physical, chemical and biological characteristics of the media that govern plant health as well as nitrification/mineralization activities and, therefore, yield (Chang et al., 2007, Greer and Diver, 2000; Treadwell et al., 2007; Zhai et al., 2009). In my study, organic granular fertilizer treatments consisted of four different products, and organic solution fertilizer treatments consisted of three different products, for a total of seven different organic nutrient sources applied to the Gran-Soln or Soln-Gran fertilizer treatments. Since organic fertilizers delivered hydroponically tend to clog the irrigation system, it may be best to not use them at all (Gran-Gran treatment) or delay their use for the first 30 days and then fertigate with them at low concentration (Gran-Soln treatment). Incorporating half of total season nutrients via granular organic fertilizers into the media at transplant avoids excessive EC and allows the plants to derive their nutrients from granular sources until 30 days after transplant, at which time the rest of total season nutrients can be supplied by an organic granular sidedress or a dilute organic nutrient solution delivered through the irrigation system regularly until harvest.

Poultry litter compost is more effective than yard waste compost for organic greenhouse bell pepper production because it has lower pH, higher EC, more temperature-buffering capacity, higher water-holding capacity, lower C:N ratio, higher micronutrient concentrations and possibly more active nitrifying/mineralizing microorganism populations as evidenced by the higher leachate [NO_3-N] and fruit percent NUE. As a result, the media treatment containing poultry litter compost (PL) resulted in higher yields, taller plants throughout the season and greater whole plant dry weight at harvest compared to the media treatments containing no compost or yard waste compost. However, it is important to keep water availability consistent because the high sodium, potassium and soluble salt levels in poultry litter compost can lead to higher than optimal EC and salt salinity stress under water deficiency, resulting in higher blossom end rot incidence and lower yields. Also, the phosphorus content in poultry litter compost could potentially limit Ca availability through precipitation reactions, leading to blossom end rot, so effective calcium supplementation via fertilizers must be utilized to avoid this problem. On the other hand, because the poultry litter compost increased the water-holding capacity of the media to 90%, it is important to not over-irrigate, reducing the oxygen-filled pore spaces that are necessary for nitrification reactions (Evanylo and McGuinn, 2009).

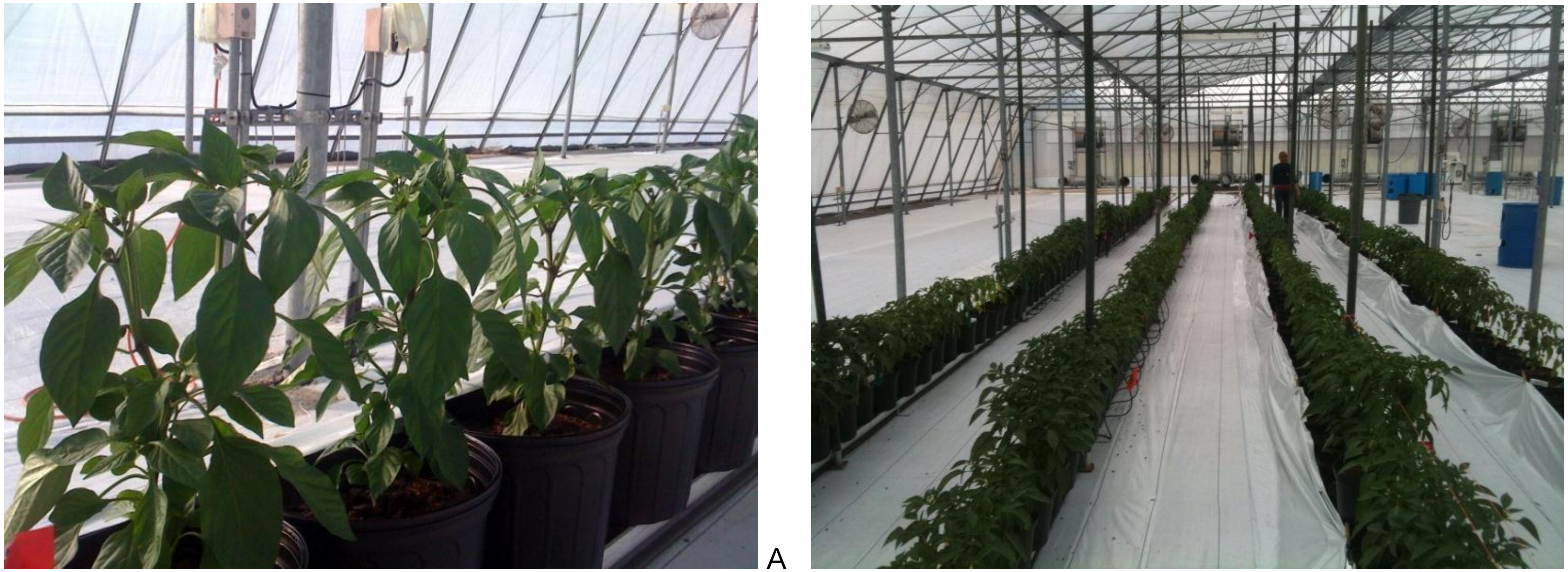
For future research, it would also be interesting to apply this experiment to an indeterminate bell pepper cultivar, which is typically used in greenhouse production systems and has a crop season of 10 months. Although the organic nutrient solution in low concentration did fairly well, there were still clogging problems, and so a future study could look at exploring a variety of different organic nutrient sources to make into fertigation solution and assess their clogging potential. Also, future research could attempt to acidify the organic nutrient solution with citric acid or other OMRI-approved acidifying agent to help solubilize the materials and decrease the pH in the media of the organic treatments. It is important to note that during the course of this study, treatments, types and amounts of nutrient inputs, irrigation management and cultural practices were fixed for the sake of scientific and statistical repetition, consistency and comparison. Future research could plan more of a system's approach in order to more closely relate results to real-world situations in which a grower would adjust all these factors throughout the season and from season to season to explore different approaches, remediate problems and maximize yield.

Figure 2-1. The experiment site: a multi-bay, passively-ventilated, saw-tooth style greenhouse located at the University of Florida's PSREU in Marion County near Citra, Florida. (Source: http://www.hos.ufl.edu/protectedag. Last accessed 1 July 2012).

A

B

Figure 2-2. The experiment site: inside the greenhouse. A) The experiment was established in one bay of the greenhouse, where PVC pipes were placed in four rows (1.2 m apart) down the north-south length of the greenhouse to serve as a drainage system. B) The fate of leachate on the north end of the greenhouse and a close-up view of the 50-mesh screen covering the side wall.



A B

Figure 2-3. Experiment set-up. A) Determinate red bell pepper seedlings were transplanted into 11.4-L polyethylene nursery pots and B) placed on the four rows of PVC pipe, representing the four blocks of the experiment, at a density of three plants/m^2.

Table 2-1. Nutrient sources used to make custom fertilizer mixes “Convtl,” “Gran” and “Soln” for the determinate red bell pepper study in a saw-tooth style greenhouse at UF’s PSREU research farm near Citra, FL in Fall 2010 and Spring 2011

Fertilizer	Manufacturer	Ingredients	Percent of element[z]
“Convtl”			
Calcium nitrate	Chemical Dynamics, FL	$Ca(NO_3)_2$	9 N, 11 Ca
DynaPhos phosphoric acid	Chemical Dynamics, FL	H_3PO_4	23 P
Potassium chloride	Chemical Dynamics, FL	KCl	51.5 K
Epsom magnesium sulfate	Giles Chemical, NC	$MgSO_4$	9.8 Mg, 12.9 S
Sequestrene chelated iron	Southern Ag, FL	FE 330	9 Fe
Copper sulfate	Southern Ag, FL	$CuSO_4$	25.2 Cu
Manganese sulfate	Southern Ag, FL	$MnSO_4$	29 Mn
Zinc sulfate	Hi-Yield, FL	$ZnSO_4$	36 Zn
Solubor boron	Southern States, FL	B	20.5 B
Sodium molibdate	Southern Ag, FL	$Na_2(MoO_4)$	39 Mo
“Gran”			
Ag-Life 2-4-2 OC	Rhizogen, TX	Composted poultry manure (granular)	2 N, 1.8 P, 1.7 K, 5 Ca, 1 Mg, 0.8 S, 0.6 Fe, 0.1 Mn, 0.1 Zn
Blending Base Fertilizer 13- 0-0	Nature Safe, KY	Hydrolyzed feather meal, meat meal and blood meal (pelleted)	13 N, 2 Ca, 1.3 S
Allganic potassium sulfate 0-0-51	SQM, GA	K_2SO_4 (granular)	42.3 K, 0.1 Ca, 0.2 Mg, 17 S
Cal-CM Plus calcium sulfate MP	Art Wilson Co, NV	Anhydrite $CaSO_4$ (granular)	23.3 Ca, 18.6 S
“Soln”			
HFPC spray dried hydrolyzed fish protein	California Spray Dry Co, CA	Fresh fish or fish frames from filleting plants (fine powder)	10.7 N,1.6 P, 1.1 K, 2.1 Ca, 0.1 Mg, 0.8 S, 0.1 Fe,
Allganic potassium sulfate 0-0-52	SQM, GA	K_2SO_4 (crystalline, water soluble)	43.2 K, 0.1 Ca, 0.2 Mg, 18 S
Cal-CM Plus calcium sulfate SG	Art Wilson Co, NV	Anhydrite $CaSO_4$ (solution grade)	23.3 Ca, 18.6 S

[z]N: nitrogen; Ca: calcium; P: phosphorus; K: potassium; Mg: magnesium; S: sulfur; Fe: iron, Cu: copper; Mn: manganese; Zn: zinc; B: boron; Mo: molibdate.

Table 2-2. Target concentrations (mg/L) of nutrients in the "Convtl" fertilizer solution delivered through the irrigation system to determinate red bell pepper plants in a saw-tooth style greenhouse at UF's PSREU research farm near Citra, FL in Fall 2010 and Spring 2011

Nutrient	Transplant to establishment	Vegetative growth	Vegetative growth to fruit set	Fruit growth to mature green	Fruit growth to mature red
Nitrogen	80	120	140	150	160
Phosphorus	50	50	50	50	50
Potassium	119	148	173	202	215
Calcium	127	135	159	171	182
Magnesium	40	48	48	48	48
Sulfur	56	66	66	66	66
Iron	2.8	2.8	2.8	2.8	2.8
Copper	0.2	0.2	0.2	0.2	0.2
Manganese	0.8	0.8	0.8	0.8	0.8
Zinc	0.3	0.3	0.3	0.3	0.3
Boron	0.7	0.7	0.7	0.7	0.7
Molibdate	0.06	0.06	0.06	0.06	0.06

Table 2-3. Explanation of organic fertilizer treatments applied to determinate red bell pepper plants in a saw-tooth style greenhouse at UF's PSREU research farm near Citra, FL in Fall 2010 and Spring 2011

Fertilizer Treatment	Fertilizer	Application	Rates[z]
Gran-Gran	"Gran"	Incorporated into pots at transplant	50% of total season N, P, K and Ca.
	"Gran"	Incorporated into pots at sidedress	50% of total season N, P, K and Ca.
Gran-Soln	"Gran"	Incorporated into pots at transplant	50% of total season N and K; 78% of total season P; 69% of total season Ca.
	"Soln"	Delivered through irrigation system at low concentration from sidedress to harvest	50% of total season N and K; 22% of total season P; 31 % of total season Ca.
Soln-Gran	"Soln"	Delivered through irrigation system at full concentration from transplant to sidedress and at low concentration from sidedress to harvest	50% of total season N and K; 22% of total season P; 31% of total season Ca.
	"Gran"	Incorporated into pots at sidedress	50% of total season N and K; 78% of total season P; 69% of total season Ca.
Soln-Soln	"Soln"	Delivered through irrigation system at full concentration from transplant to harvest	Nutrient schedule matching that of Convtl

[z]N: nitrogen; P: phosphorus; K: potassium; Ca: calcium.

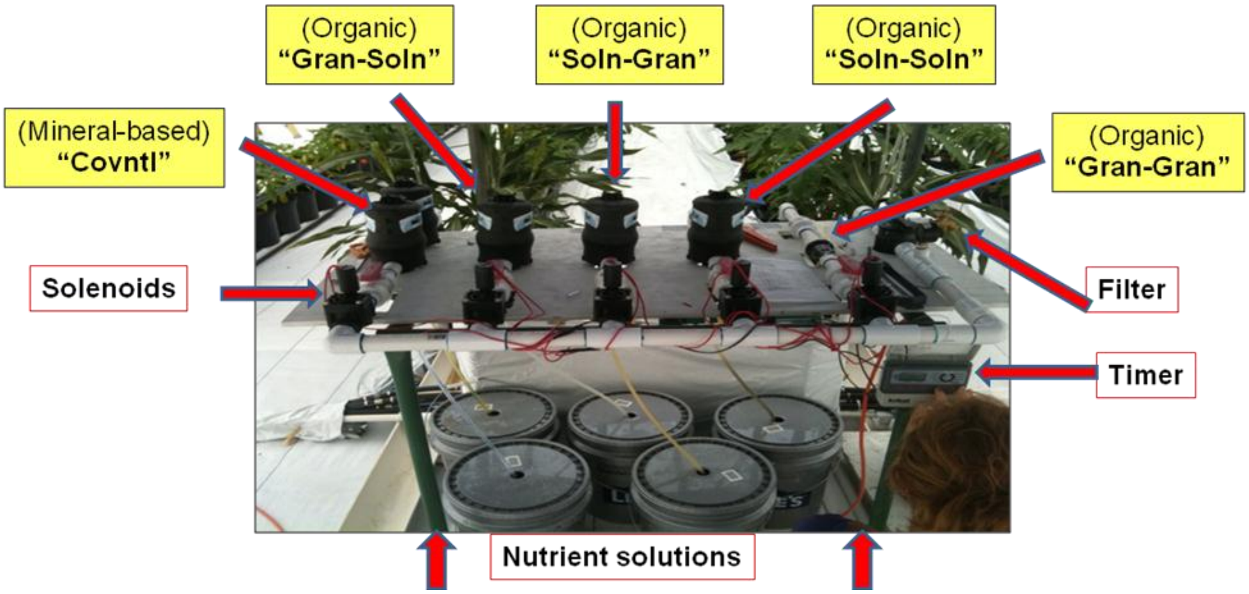


Figure 2-4. Irrigation design and equipment for delivery of water and nutrients to determinate red bell pepper plants in the saw-tooth style greenhouse at UF's PSREU research farm near Citra, FL in Fall 2010 and Spring 2011

Figure 2-5. Details of individual micro-irrigation units. Each determinate red bell pepper plant received water (and, in some treatments, nutrients) through a 7.6 L/h pressure-compensated emitter on the end of a 60-cm long spaghetti tube

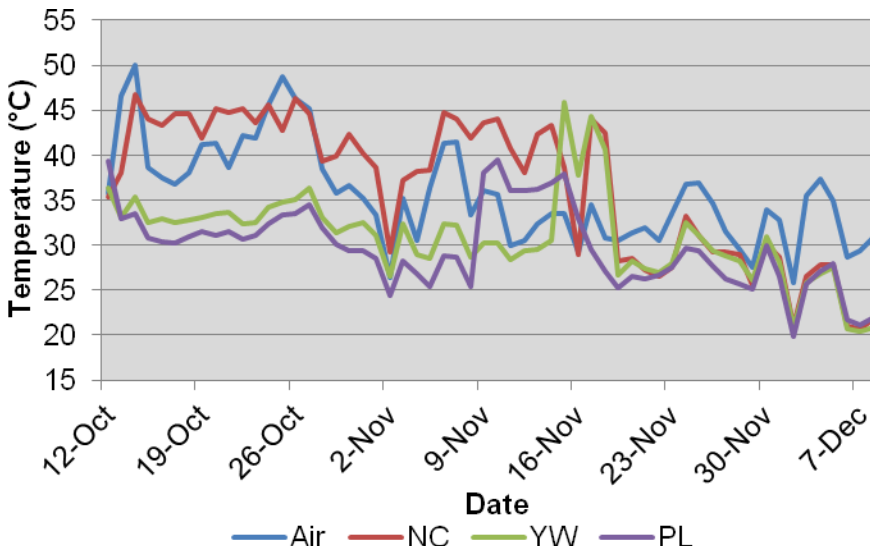
Table 2-4. Relevant physical and chemical properties of media components in the determinate red bell pepper study in the saw-tooth style greenhouse at UF's PSREU research farm near Citra, FL in Fall 2010 and Spring 2011

Property	Peat	Pine bark	Yard waste compost	Poultry litter compost
Soluble salts (mmhos/cm)	0.21	0.07	0.40	11.67
Organic matter (%)	57.72	56.70	22.88	11.63
Carbon:nitrogen ratio	64:1	121:1	25:1	7:1
pH	6.33	5.14	--	--
Total nitrogen (mg/kg)	12.61	7.35	3,200	10,000
Nitrate nitrogen (mg/kg)	6.30	2.80	100	700
Phosphorus (mg/kg)	0.79	2.03	528	9,284
Potassium (mg/kg)	7.91	12.86	1,494	11,205
Calcium (mg/kg)	16.88	3.98	29,200	18,600
Magnesium (mg/kg)	13.09	0.81	1,100	4,000
Sulfur (mg/kg)	18.36	3.29	600	3,400
Iron (mg/kg)	1.62	0.26	1,100	1,200
Copper (mg/kg)	0.05	0.05	10	300
Manganese (mg/kg)	0.04	0.02	80	300
Zinc (mg/kg)	0.05	0.03	40	400
Boron (mg/kg)	0.13	0.21	50	50
Sodium (mg/kg)	--	--	800	4,200

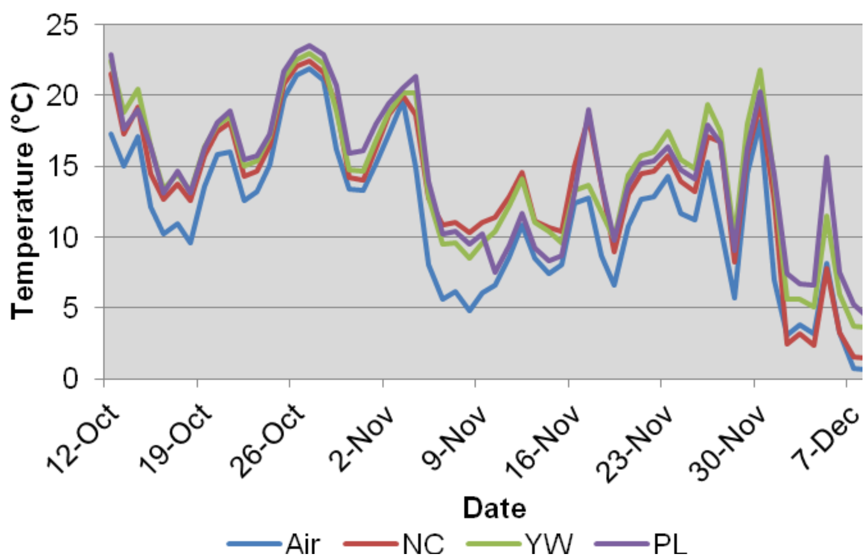
Table 2-5. Relevant physical and chemical properties of custom media mixes that represent the compost treatments in the determinate red bell pepper study in the saw-tooth style greenhouse at UF's PSREU research farm near Citra, FL in Fall 2010 and Spring 2011

Property	NC[z]	YW	PL
Soluble salts (mmhos/cm)	0.30	0.61	8.28
Cation exchange capacity (%)	55.00	38.05	31.65
Bulk density (g/cm^3)	0.19	0.37	0.33
pH	5.18	6.87	6.88
Water holding capacity (%)	56.02	70.83	91.47
Ammonia nitrogen (mg/kg)	10.50	29.32	36.40
Nitrate nitrogen (mg/kg)	6.48	7.26	270.46
Phosphorus (mg/kg)	2.24	7.48	183.95
Potassium (mg/kg)	14.85	102.58	2953.99
Calcium (mg/kg)	24.17	60.04	100.25
Magnesium (mg/kg)	17.48	17.86	159.50
Sulfur (mg/kg)	18.20	21.02	383.20
Iron (mg/kg)	0.21	0.23	0.45
Copper (mg/kg)	0.05	0.05	1.52
Manganese (mg/kg)	0.06	0.11	0.48
Zinc (mg/kg)	0.04	0.04	0.44
Boron (mg/kg)	0.49	0.12	0.80

[z]NC: no compost; YW: 30% yard waste compost by volume; PL: 30% poultry litter compost by volume. All have a media base of 1 peat : 1 pine bark (by volume).

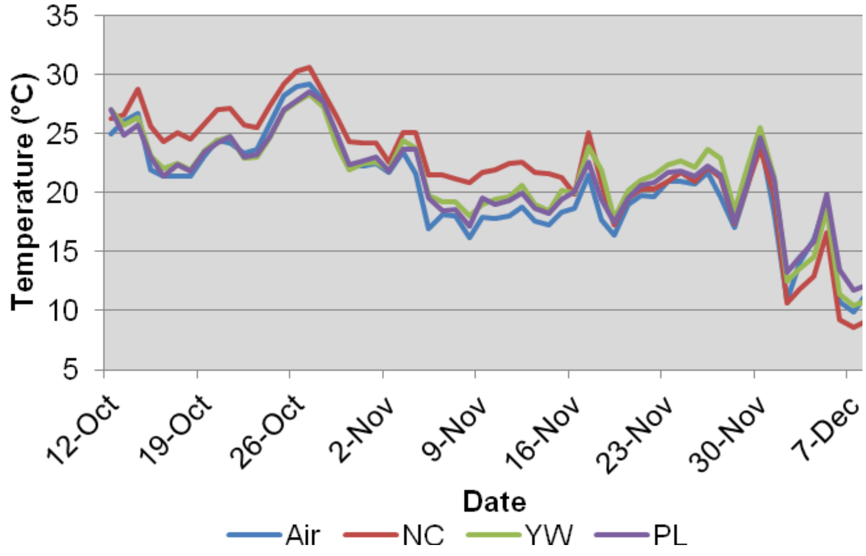


A



B

Figure 2-6. Inside the greenhouse, air temperature at a height of 1 meter and the temperature of each of the three media/compost mixes in Fall 2010. A) High temperature. B) Low temperature. C) Average temperature. NC: no compost; YW: 30% yard waste compost by volume; PL: 30% poultry litter compost by volume. All have a media base of 1 peat : 1 pine bark (by volume).



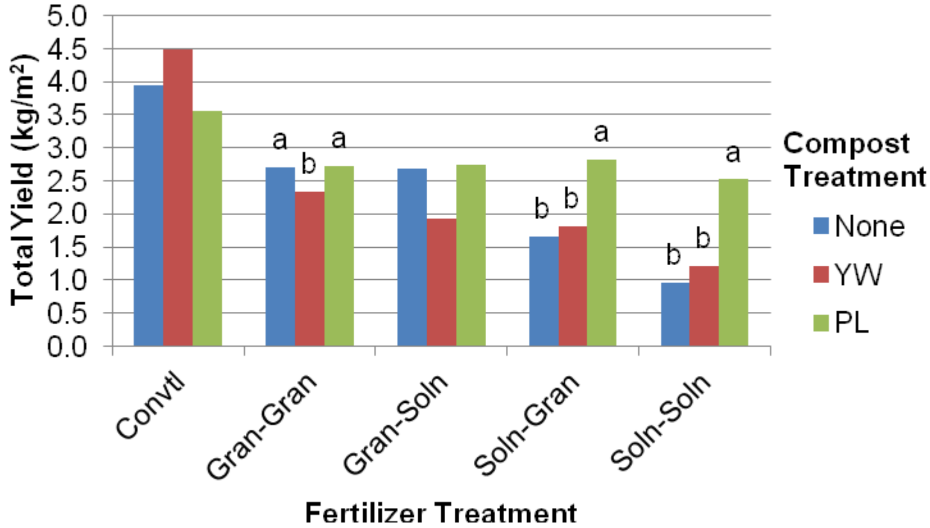
C

Figure 2-6. Continued

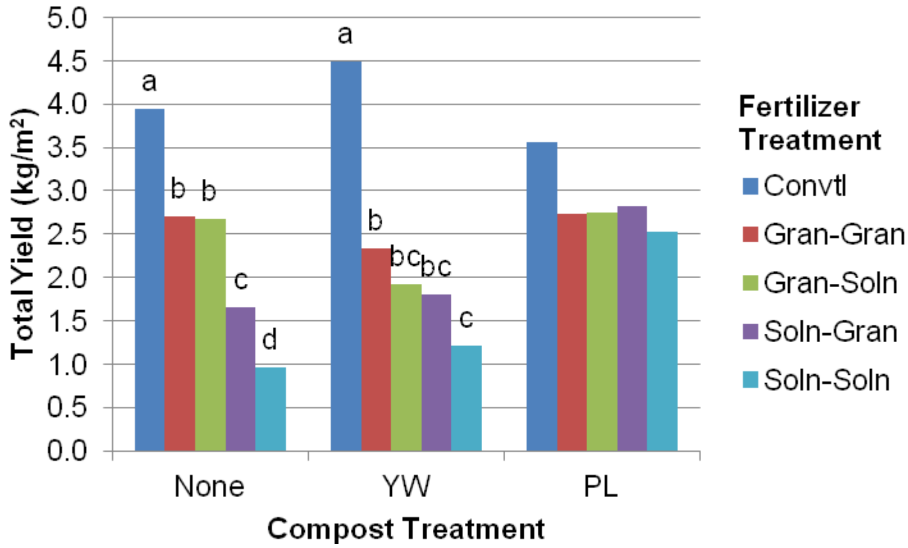
Table 2-6. The effects of conventional and organic fertilizer and compost treatments on total yields, marketable yields and fruit size distribution (kg/m^2) from determinate red bell pepper plants grown in a saw-tooth style greenhouse at UF's PSREU near Citra, FL in Fall 2010

Main effects	Total yield (kg/m^2)	Marketable yield[z] (kg/m^2)		Size distribution by class[y] (kg/m^2) XL		L	M	S	U
Fertilizer treatment (F)[x]									
Convtl	4.00	3.47	a	1.78	a	0.97	0.52	0.19	0.04
Gran-Gran	2.59	2.32	b	0.57	b	0.89	0.69	0.16	0.04
Gran-Soln	2.45	2.17	b	0.64	b	0.66	0.66	0.20	0.05
Soln-Gran	2.10	1.89	b	0.51	b	0.63	0.57	0.18	0.05
Soln-Soln	1.56	1.31	c	0.11	c	0.26	0.65	0.30	0.07
P-value[v]	<0.0001	<0.0001		<0.0001		<0.0001	0.6071	0.2000	0.5285
Compost treatment (C)[w]									
NC	2.39	2.12		0.63		0.83	0.50	0.15	0.03
YW	2.35	2.15		0.70		0.60	0.63	0.22	0.06
PL	2.87	2.42		0.83		0.62	0.72	0.25	0.06
P-value	<0.0060	0.3185		0.4198		0.0220	0.0713	0.1339	0.2922
Interaction (F*C)									
P-value	0.0014	0.0611		0.1231		0.0092	0.0433	0.1893	0.8000

[z]Marketable yield: size classes XL, L, M and S with no external defects. Plant density = 3 pl/m^2.
[y]Size classes (by diameter): U < 55 mm, S = 55 to 64.9 mm, M = 65 to 74.9 mm, L = 75 to 83.9 mm, XL ≥ 84 mm.
[x]Convtl: conventional mineral-based solution injected through irrigation system throughout the season; Gran-Gran: organic granular incorporated into media at transplanting and sidedress; Gran-Soln: organic granular incorporated into media at transplanting and organic solution injected through irrigation system beginning at sidedress; Soln-Gran: organic solution injected through irrigation system beginning at transplanting and organic granular incorporated into media at sidedress; Soln-Soln: organic solution injected through irrigation system throughout the season. Total season application of N, P, K, Ca and water were consistent across all treatments.
[w]NC: no compost; YW: 30% yard waste compost by volume; PL: 30% poultry litter compost by volume. All have a media base of 1 peat : 1 pine bark (by volume).
[v]Means separated within columns by Fisher's Least Significant Difference (LSD) test a $P \leq 0.05$. Means with the same letter are not significantly different.

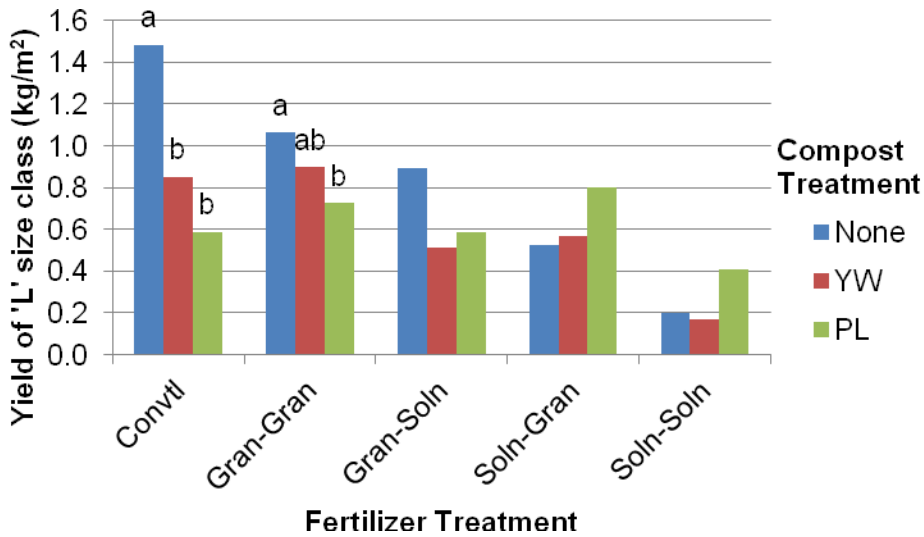


A

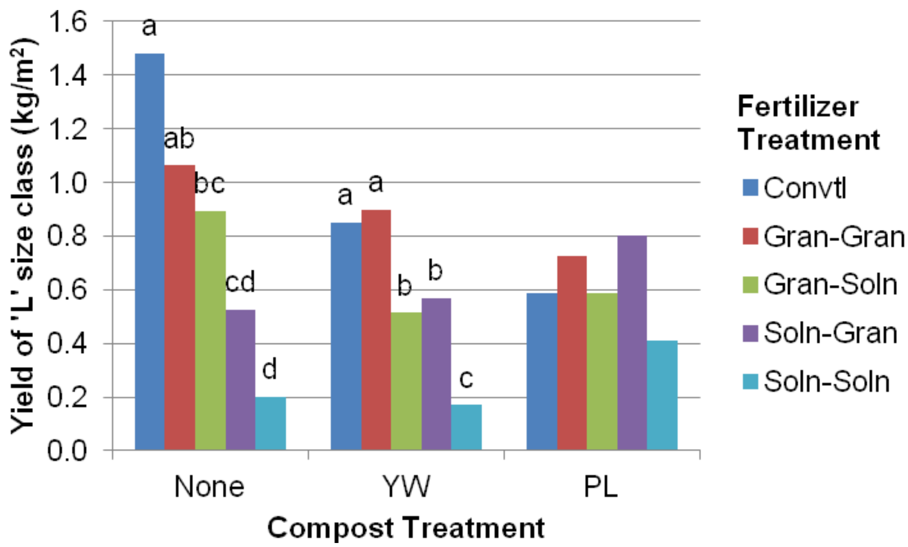


B

Figure 2-7. Total yield (kg/m^2) interaction effects in Fall 2010. Interaction means designated by different letters within each x-axis treatment are significantly different at $P \leq 0.05$. Means with no letters are not significantly different. A) Fertilizer x Compost sliced by Fertilizer. B) Fertilizer x Compost sliced by Compost.

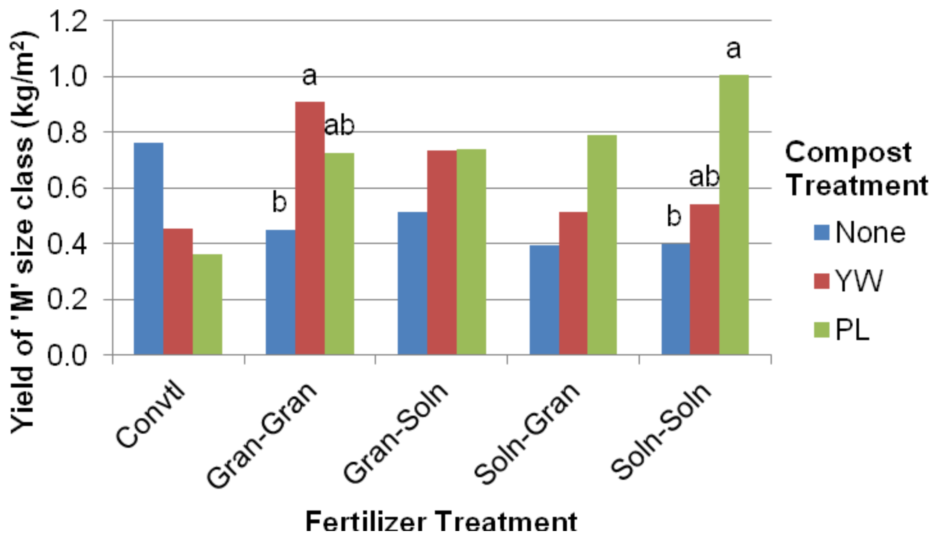


A

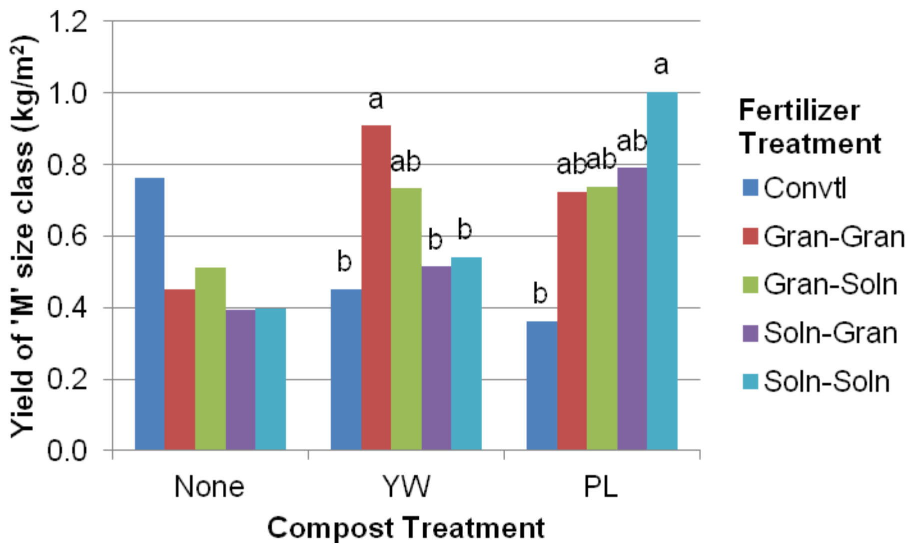


B

Figure 2-8. Yield (kg/m^2) of 'L' size class (75-83.9 mm in fruit diameter) interaction effects in Fall 2010. Interaction means designated by different letters within each x-axis treatment are significantly different at $P \leq 0.05$. Means with no letters are not significantly different. A) Fertilizer x Compost sliced by Fertilizer. B) Fertilizer x Compost sliced by Compost.



A



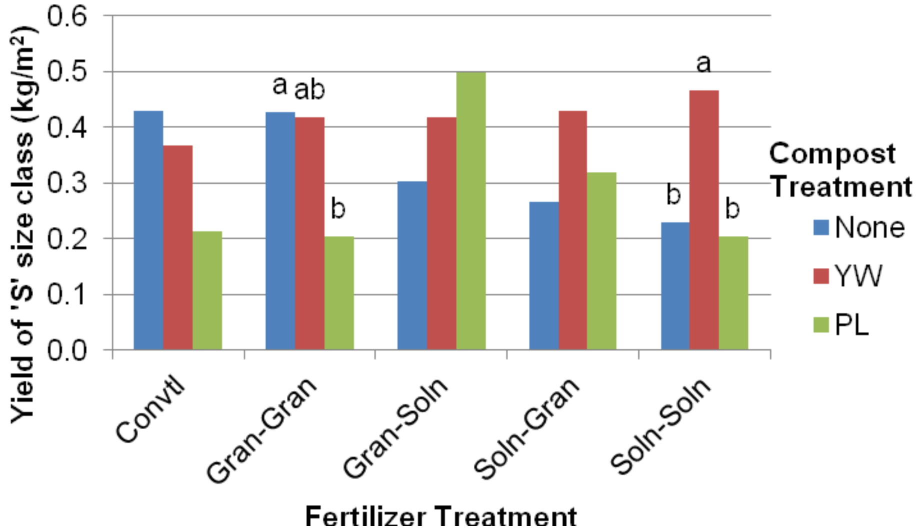
B

Figure 2-9. Yield (kg/m^2) of 'M' size class (65-74.9 mm in fruit diameter) interaction effects in Fall 2010. Interaction means designated by different letters within each x-axis treatment are significantly different at $P \leq 0.05$. Means with no letters are not significantly different. A) Fertilizer x Compost sliced by Fertilizer. B) Fertilizer x Compost sliced by Compost.

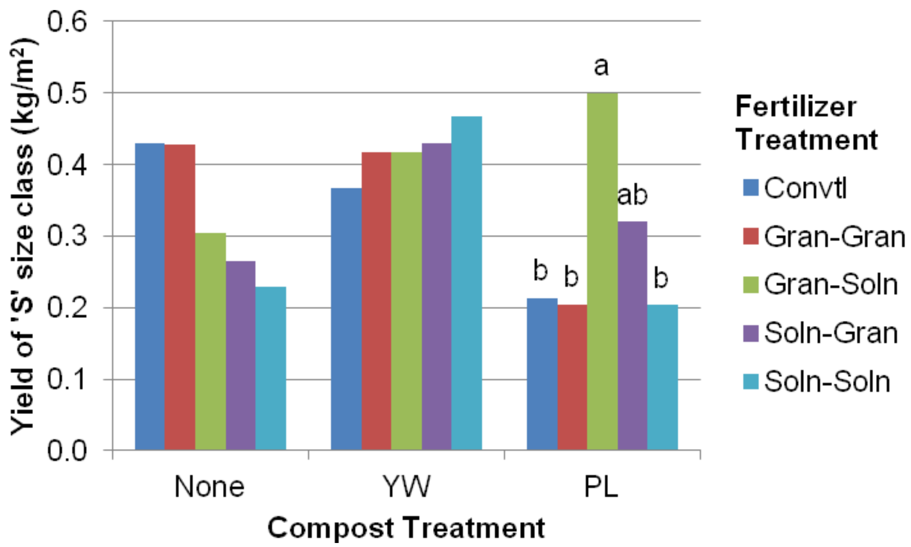
Table 2-7. The effects of conventional and organic fertilizer and compost treatments on total yields, marketable yields and fruit size distribution (kg/m^2) from determinate red bell pepper plants grown in a saw-tooth style greenhouse at UF's PSREU near Citra, FL in Spring 2011

Main effects	Total yield (kg/m^2)		Marketable yield[z] (kg/m^2)		Size distribution by class[y] (kg/m^2) XL		L		M		S	U	
Fertilizer treatment (F)[x]													
Convtl	3.55	a	2.21	a	0.64	a	0.51	a	0.72	a	0.34	0.19	ab
Gran-Gran	2.00	bc	1.40	ab	0.06	bc	0.28	ab	0.68	a	0.35	0.14	bc
Gran-Soln	2.25	b	1.92	a	0.29	ab	0.52	a	0.71	a	0.41	0.10	c
Soln-Gran	1.63	c	1.05	bc	0.03	bc	0.17	b	0.51	a	0.34	0.22	a
Soln-Soln	1.09	d	0.58	c	0.00	c	0.05	b	0.23	b	0.30	0.18	ab
P-value[v]	<0.0001		0.0003		0.0137		0.0044		0.0007		0.4592	0.0322	
Compost treatment (C)[w]													
NC	1.86		1.34		0.10		0.26		0.65	a	0.33	0.16	
YW	2.14		1.66		0.28		0.32		0.64	a	0.42	0.17	
PL	2.30		1.27		0.23		0.34		0.41	b	0.29	0.18	
P-value	0.0990		0.1767		0.7738		0.7371		0.0231		0.0151	0.7636	
Interaction (F*C)													
P-value	0.3133		0.5992		0.3354		0.9086		0.4608		0.0442	0.1042	

[z]Marketable yield: size classes XL, L, M and S with no external defects. Plant density= 3 pl/m^2.
[y]Size classes (by diameter): U < 55 mm, S = 55 to 64.9 mm, M = 65 to 74.9 mm, L = 75 to 83.9 mm, XL ≥ 84 mm.
[x]Convtl: conventional mineral-based solution injected through irrigation system throughout the season; Gran-Gran: organic granular incorporated into media at transplanting and sidedress; Gran-Soln: organic granular incorporated into media at transplanting and organic solution injected through irrigation system beginning at sidedress; Soln-Gran: organic solution injected through irrigation system beginning at transplanting and organic granular incorporated into media at sidedress; Soln-Soln: organic solution injected through irrigation system throughout the season. Total season application of N, P, K, Ca and water were consistent across all treatments.
[w]NC: no compost; YW: 30% yard waste compost by volume; PL: 30% poultry litter compost by volume. All have a media base of 1 peat : 1 pine bark (by volume).
[v]Means separated within columns by Fisher's Least Significant Difference (LSD) test a $P \leq 0.05$. Means with the same letter are not significantly different.



A



B

Figure 2-10. Yield (kg/m^2) of ‘S’ size class (55-64.9 mm in fruit diameter) interaction effects in Spring 2011. Interaction means designated by different letters within each x-axis treatment are significantly different at $P \leq 0.05$. Means with no letters are not significantly different. A) Fertilizer x Compost sliced by Fertilizer. B) Fertilizer x Compost sliced by Compost.

Table 2-8. The effects of conventional and organic fertilizer and compost treatments on yield of culled fruit (kg/m^2) from determinate red bell pepper plants grown in a saw-tooth style greenhouse at UF's PSREU near Citra, FL in Fall 2010

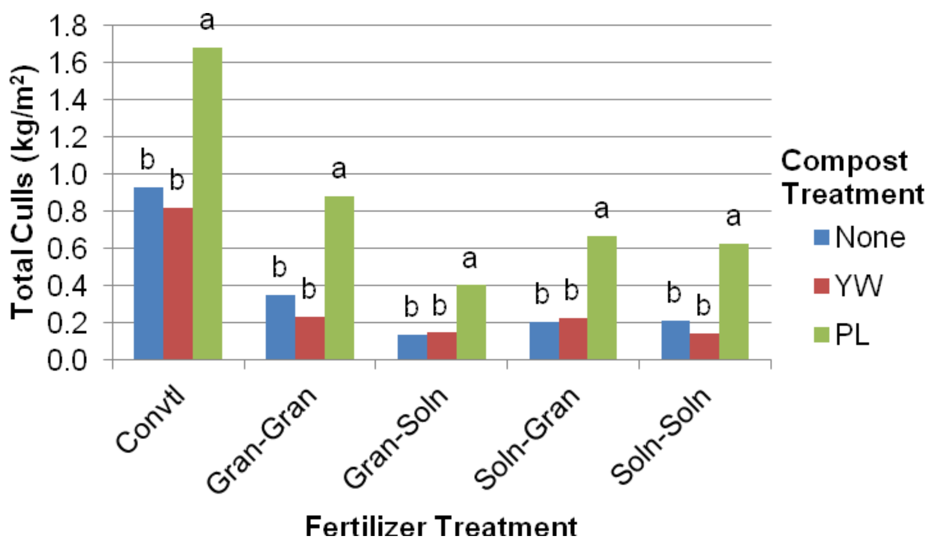
		Fruit external defects (kg/m^2)					
Main effects	Total culls[z]	Blossom end rot	Sunscald	Radial cracking	Flat shape	Mis-shapen	Russeting
Fertilizer treatment (F)[y]							
Convtl	0.49 a	0.34 a	0.03	0.01	0.07 a	0.03	0.00
Gran-Gran	0.24 b	0.12 b	0.07	0.01	0.02 b	0.01	0.01
Gran-Soln	0.24 b	0.10 b	0.07	0.02	0.01 b	0.03	0.00
Soln-Gran	0.16 b	0.05 b	0.01	0.00	0.08 a	0.02	0.00
Soln-Soln	0.18 b	0.04 b	0.06	0.02	0.01 b	0.03	0.01
P-value[w]	0.0165	0.0026	0.4479	0.2752	0.0066	0.7490	0.3882
Compost treatment (C)[x]							
NC	0.24 b	0.13 b	0.03 b	0.01	0.04	0.02	0.00
YW	0.14 b	0.06 c	0.01 b	0.02	0.03	0.03	0.01
PL	0.40 a	0.20 a	0.11 a	0.01	0.04	0.03	0.01
P-value	0.0084	0.0003	0.0029	0.6050	0.5508	0.7698	0.6355
Interaction (F*C)							
P-value	0.8940	0.6571	0.3079	0.3894	0.4568	0.4036	0.7825

[z]Total culls includes the sum of blossom end rot, sunscald, radial cracking, flat-shape, misshapen and russeting. Plant density = 3 pl/m^2.
[y]Convtl: conventional mineral-based solution injected through irrigation system throughout the season; Gran-Gran: organic granular incorporated into media at transplanting and sidedress; Gran-Soln: organic granular incorporated into media at transplanting and organic solution injected through irrigation system beginning at sidedress; Soln-Gran: organic solution injected through irrigation system beginning at transplanting and organic granular incorporated into media at sidedress; Soln-Soln: organic solution injected through irrigation system throughout the season. Total season application of N, P, K, Ca and water were consistent across all treatments.
[x]NC: no compost; YW: 30% yard waste compost by volume; PL: 30% poultry litter compost by volume. All have a media base of 1 peat : 1 pine bark (by volume).
[w]Means separated within columns by Fisher's Least Significant Difference (LSD) test a $P \leq 0.05$. Means with the same letter are not significantly different.

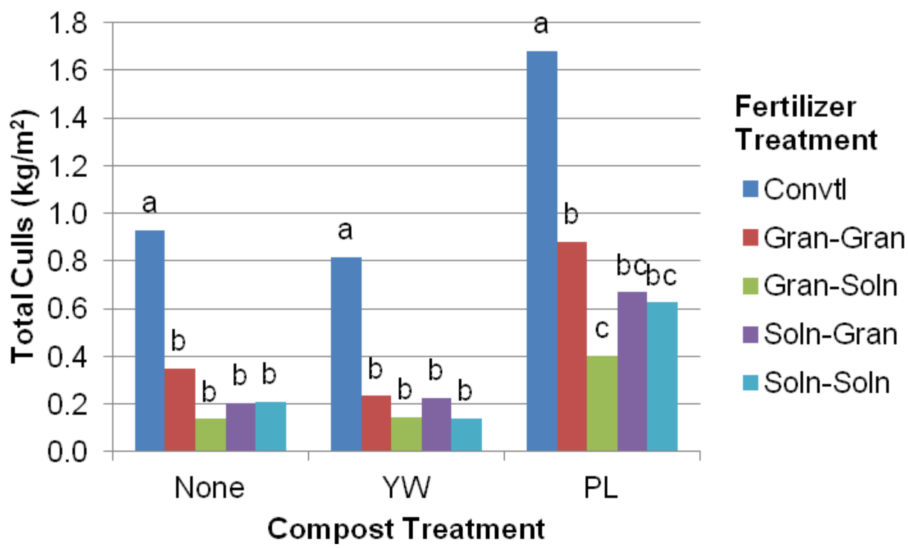
Table 2-9. The effects of conventional and organic fertilizer and compost treatments on yield of culled fruit (kg/m^2) from determinate red bell pepper plants grown in a saw-tooth style greenhouse at UF's PSREU near Citra, FL in Spring 2011

	Fruit external defects (kg/m^2)						
Main effects	Total culls[z]	Blossom end rot	Sunscald	Radial cracking	Flat shape	Mis-shapen	Russeting
Fertilizer treatment (F)[y]							
Convtl	1.14	0.87	0.13	0.00	0.13 a	0.01 b	0.00
Gran-Gran	0.49	0.27	0.11	0.00	0.10 a	0.01 b	0.00
Gran-Soln	0.23	0.04	0.13	0.00	0.03 b	0.02 ab	0.00
Soln-Gran	0.37	0.14	0.18	0.00	0.02 b	0.01 b	0.00
Soln-Soln	0.33	0.15	0.11	0.00	0.02 b	0.04 a	0.00
P-value[w]	<0.0001	<0.0001	0.3297	0.4183	<0.0001	0.0287	NS
Compost treatment (C)[x]							
NC	0.37	0.18	0.12	0.00	0.05	0.02	0.00
YW	0.31	0.12	0.12	0.00	0.05	0.02	0.00
PL	0.85	0.59	0.17	0.00	0.07	0.01	0.00
P-value	<0.0001	<0.0001	0.1545	0.3765	0.2504	0.3939	NS
Interaction (F*C)							
P-value	0.0204	0.0143	0.4128	0.4504	0.9594	0.0765	NS

[z]Total culls includes the sum of blossom end rot, sunscald, radial cracking, flat-shape, misshapen and russeting. Plant density = 3 pl/m^2.
[y]Convtl: conventional mineral-based solution injected through irrigation system throughout the season; Gran-Gran: organic granular incorporated into media at transplanting and sidedress; Gran-Soln: organic granular incorporated into media at transplanting and organic solution injected through irrigation system beginning at sidedress; Soln-Gran: organic solution injected through irrigation system beginning at transplanting and organic granular incorporated into media at sidedress; Soln-Soln: organic solution injected through irrigation system throughout the season. Total season application of N, P, K, Ca and water were consistent across all treatments.
[x]NC: no compost; YW: 30% yard waste compost by volume; PL: 30% poultry litter compost by volume. All have a media base of 1 peat : 1 pine bark (by volume).
[w]Means separated within columns by Fisher's Least Significant Difference (LSD) test a $P \leq 0.05$. Means with the same letter are not significantly different. NS: not significant because whole data set is zeroes.

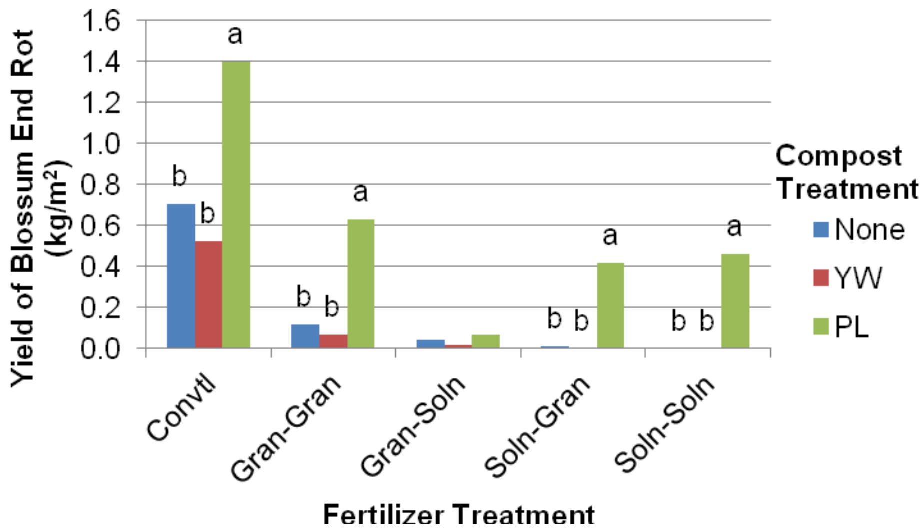


A

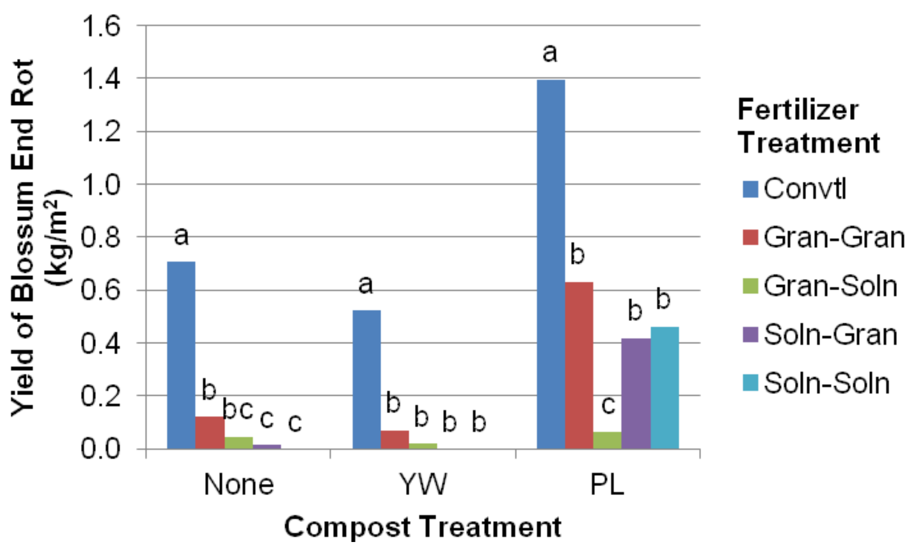


B

Figure 2-11. Yield (kg/m^2) of 'Total Culls' (sum of blossom end rot, sunscald, radial cracking, flat shape, misshapen and russeting) interaction effects in Spring 2011. Interaction means designated by different letters within each x-axis treatment are significantly different at $P \leq 0.05$. Means with no letters are not significantly different. A) Fertilizer x Compost sliced by Fertilizer. B) Fertilizer x Compost sliced by Compost.



A



B

Figure 2-12. Yield of blossom end rot (kg/m^2) interaction effects in Spring 2011. Interaction means designated by different letters within each x-axis treatment are significantly different at $P \leq 0.05$. Means with no letters are not significantly different. A) Fertilizer x Compost sliced by Fertilizer. B) Fertilizer x Compost sliced by Compost.

Table 2-10. The effects of conventional and organic fertilizer and compost treatments on total yield (number of fruit per m^2) and marketable yield, total culls and blossom end rot (number of fruit per m^2 and percent of total yield by weight) from determinate red bell pepper plants grown in a saw-tooth style greenhouse at UF's PSREU near Citra, FL in Fall 2010

	Number of fruit per square meter[z]				Percent of total yield (by weight)[w]		
Main effects	Total yield	Marketable yield[y]	Total culls[x]	Blossom end rot	Marketable yield	Total Culls[x]	Blossom end rot
Fertilizer treatment (F)[v]							
Convtl	33.2	26.0	5.8 a	3.3 a	85.8	13.2	9.3 a
Gran-Gran	22.4	18.3	3.1 b	1.3 b	88.8	9.6	4.5 ab
Gran-Soln	20.9	17.1	2.6 b	1.0 b	87.2	10.3	4.1 ab
Soln-Gran	20.2	15.3	3.1 b	1.1 b	89.0	7.5	1.8 b
Soln-Soln	17.8	13.5	2.7 b	0.8 b	83.4	10.8	2.0 b
P-value[t]	<0.0001	<0.0001	0.0167	0.0125	0.6522	0.7884	0.0195
Compost treatment (C)[u]							
NC	21.1	17.4	2.7 b	1.2 b	87.3 ab	9.9 ab	4.1 b
YW	20.2	16.7	1.8 b	0.5 c	91.3 a	5.5 b	1.5 c
PL	27.4	20.0	5.9 a	2.8 a	81.9 b	15.4 a	7.4 a
P-value	<0.0001	0.0003	<0.0001	0.0002	0.0218	0.0074	<0.0001
Interaction (F*C)							
P-value	<0.0001	<0.0001	0.0711	0.5892	0.9928	0.8369	0.5524

[z]Data log (negative binomial) transformed for analysis.
[y]Marketable yield: fruit with diameter ≥ 55 mm with no external defects. Plant density = 3 pl/m^2.
[x]Total culls includes the sum of blossom end rot, sunscald, radial cracking, flat-shape, misshapen and russeting.
[w]Data square root transformed for analysis.
[v]Convtl: conventional mineral-based solution injected through irrigation system throughout the season; Gran-Gran: organic granular incorporated into media at transplanting and sidedress; Gran-Soln: organic granular incorporated into media at transplanting and organic solution injected through irrigation system beginning at sidedress; Soln-Gran: organic solution injected through irrigation system beginning at transplanting and organic granular incorporated into media at sidedress; Soln-Soln: organic solution injected through irrigation system throughout the season. Total season application of N, P, K, Ca and water were consistent across all treatments.

[u]NC: no compost; YW: 30% yard waste compost by volume; PL: 30% poultry litter compost by volume. All have a media base of 1 peat : 1 pine bark (by volume).
[t]Means separated within columns by Fisher's Least Significant Difference (LSD) test a $P \leq 0.05$. Means with the same letter are not significantly different.

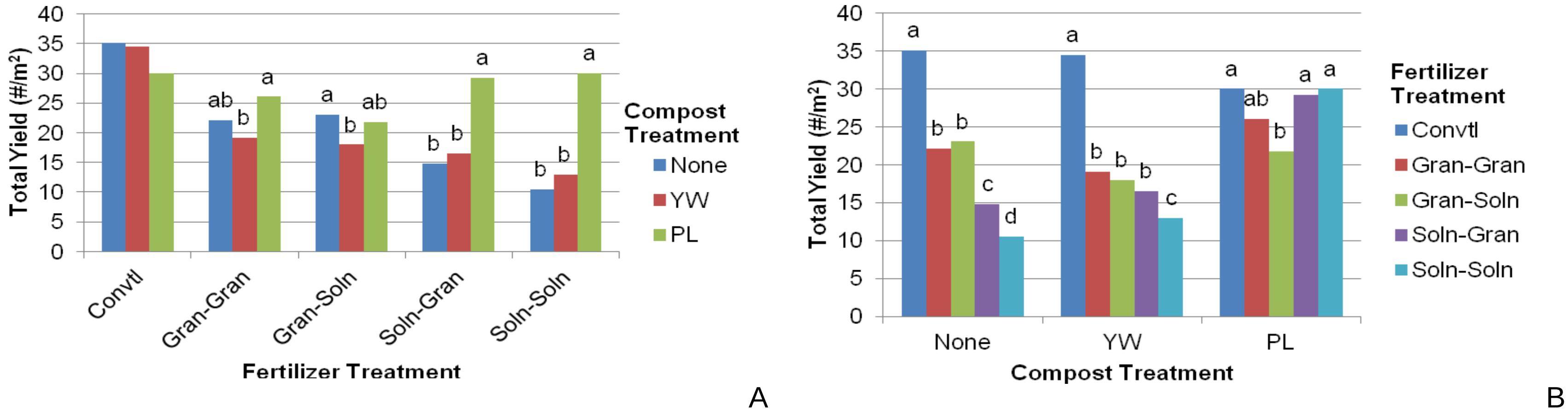


Figure 2-13. Total yield (# of fruit/m^2) interaction effects in Fall 2010. Interaction means designated by different letters within each x-axis treatment are significantly different at $P \leq 0.05$. Means with no letters are not significantly different. A) Fertilizer x Compost sliced by Fertilizer. B) Fertilizer x Compost sliced by Compost.

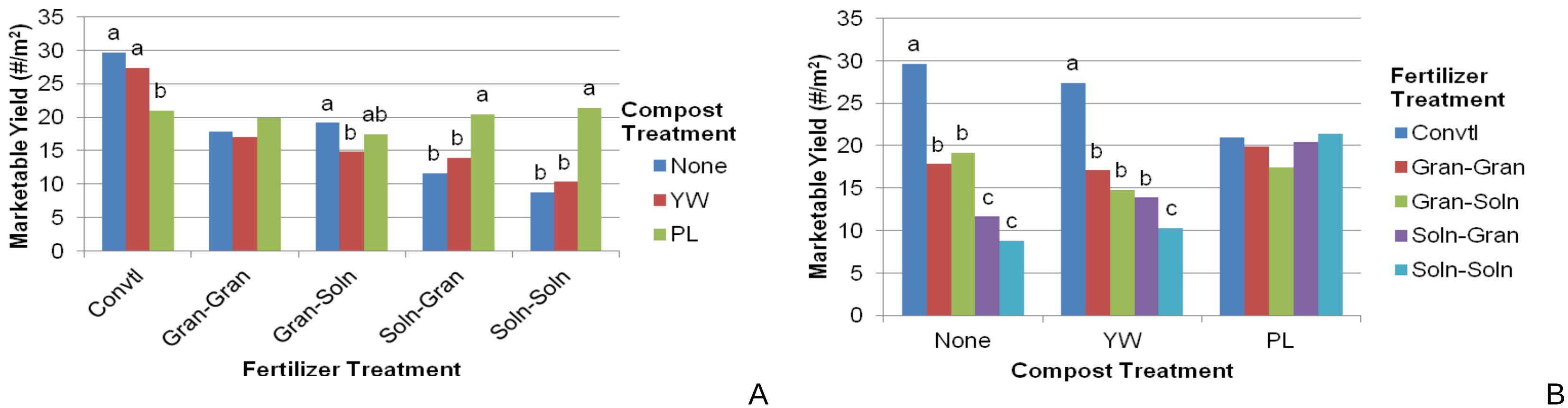


Figure 2-14. Marketable yield (# of fruit/m^2) interaction effects in Fall 2010. Interaction means designated by different letters within each x-axis treatment are significantly different at $P \leq 0.05$. Means with no letters are not significantly different. A) Fertilizer x Compost sliced by Fertilizer. B) Fertilizer x Compost sliced by Compost.

Table 2-11. The effects of conventional and organic fertilizer and compost treatments on total yield (number of fruit per m^2) and marketable yield, total culls and blossom end rot (number of fruit per m^2 and percent of total yield by weight) from determinate red bell pepper plants grown in a saw-tooth style greenhouse at UF's PSREU near Citra, FL in Spring 2011

	Number of fruit per square meter[z]				Percent of total yield (by weight)[w]		
Main effects	Total yield	Marketable yield[y]	Total culls[x]	Blossom end rot	Marketable yield	Total Culls[x]	Blossom end rot
Fertilizer treatment (F)[v]							
Convtl	70.0	25.9 a	34.1 a	27.8	52.9 bc	39.9 a	32.0
Gran-Gran	42.9	19.8 ab	17.5 b	11.7	62.8 b	29.3 b	16.9
Gran-Soln	34.4	24.3 a	4.6 d	1.1	82.0 a	11.1 c	2.3
Soln-Gran	37.9	14.4 b	10.3 c	5.9	57.0 bc	26.2 b	13.4
Soln-Soln	31.3	9.1 c	12.1 c	8.3	47.0 c	35.7 ab	14.0
P-value[t]	<0.0001	<0.0001	<0.0001	<0.0001	0.0004	<0.0001	<0.0001
Compost treatment (C)[u]							
NC	35.6	18.2 ab	9.5 b	5.4	65.9 a	23.1 b	7.6
YW	37.6	21.5 a	8.1 b	3.9	73.0 a	15.6 b	5.4
PL	56.8	16.4 b	29.5 a	23.5	42.2 b	46.7 a	34.2
P-value	<0.0001	0.0272	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Interaction (F*C)							
P-value	0.0004	0.1645	0.1027	0.0050	0.2431	0.1834	0.0038

[z]Data log (negative binary) transformed for analysis.
[y]Marketable yield: fruit with diameter ≥ 55 mm with no external defects. Plant density = 3 pl/m^2.
[x]Total culls includes the sum of blossom end rot, sunscald, radial cracking, flat-shape, misshapen and russeting.
[w]Data square root transformed for analysis.
[v]Convtl: conventional mineral-based solution injected through irrigation system throughout the season; Gran-Gran: organic granular incorporated into media at transplanting and sidedress; Gran-Soln: organic granular incorporated into media at transplanting and organic solution injected through irrigation system beginning at sidedress; Soln-Gran: organic solution injected through irrigation system beginning at transplanting and organic granular incorporated into media at sidedress; Soln-Soln: organic solution injected through irrigation system throughout the season. Total season application of N, P, K, Ca and water were consistent across all treatments.

[u]NC: no compost; YW: 30% yard waste compost by volume; PL: 30% poultry litter compost by volume. All have a media base of 1 peat : 1 pine bark (by volume).
[t]Means separated within columns by Fisher's Least Significant Difference (LSD) test a $P \le 0.05$. Means with the same letter are not significantly different.

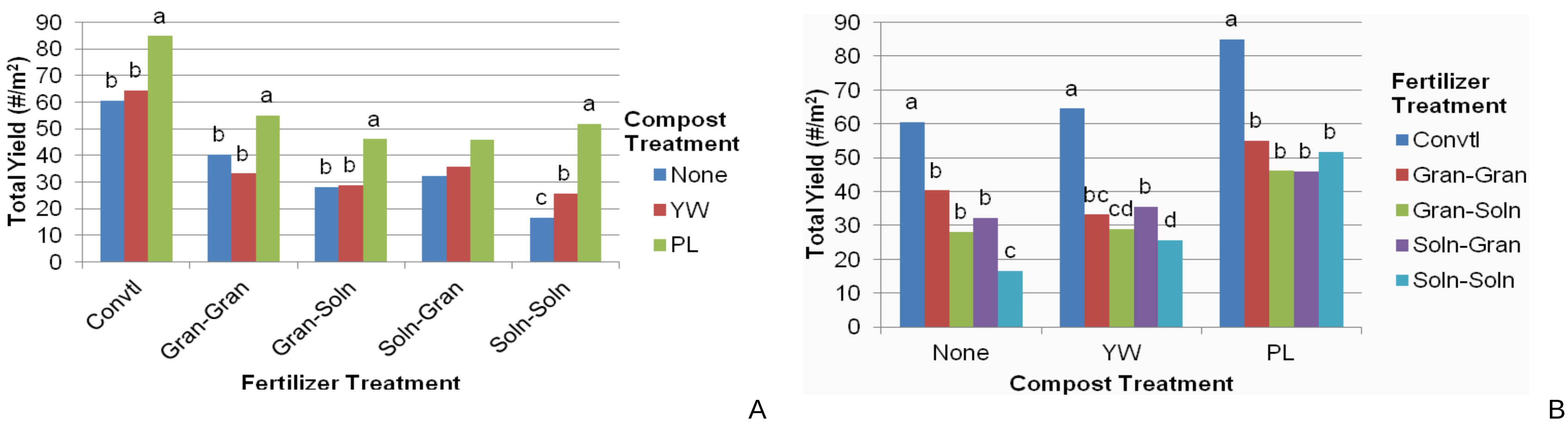
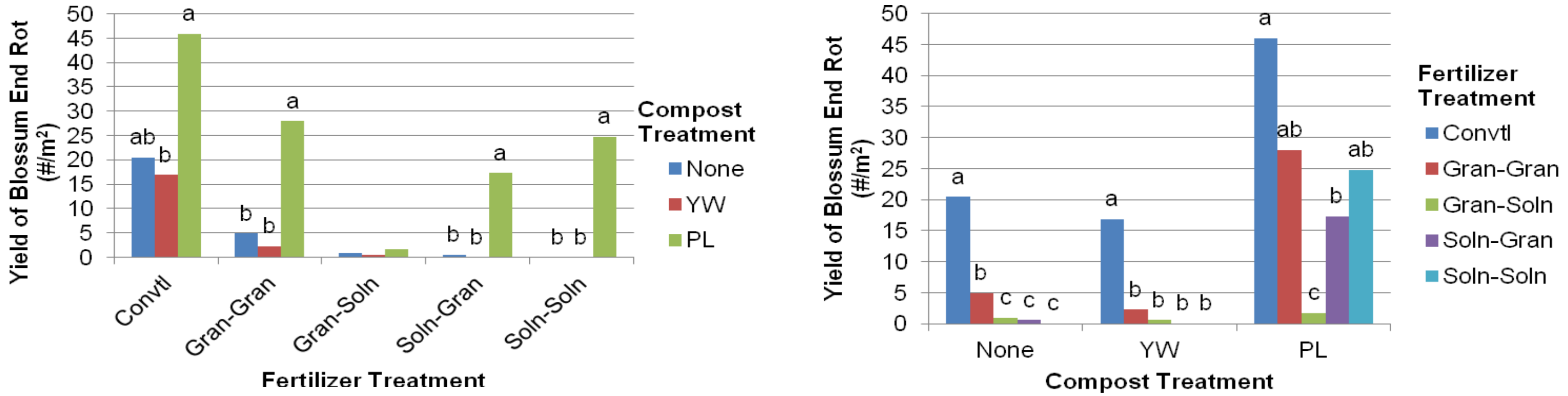
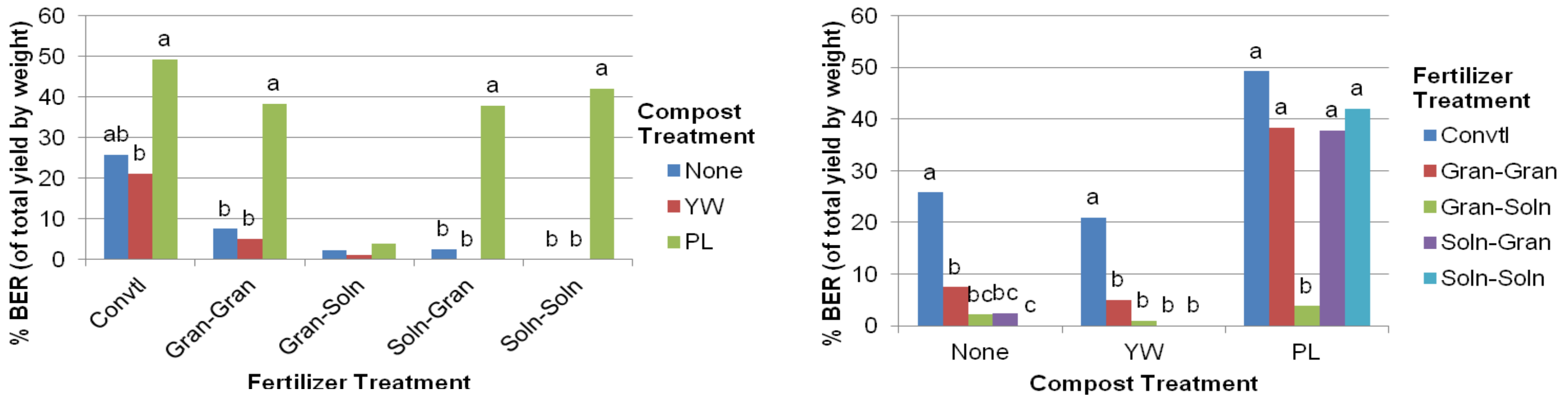


Figure 2-15. Total yield (# of fruit/m^2) interaction effects in Spring 2011. Interaction means designated by different letters within each x-axis treatment are significantly different at $P \le 0.05$. Means with no letters are not significantly different. A) Fertilizer x Compost sliced by Fertilizer. B) Fertilizer x Compost sliced by Compost.



A B

Figure 2-16. Yield of blossom end rot (# of fruit/m^2) interaction effects in Spring 2011. Interaction means designated by different letters within each x-axis treatment are significantly different at $P \leq 0.05$. Means with no letters are not significantly different. A) Fertilizer x Compost sliced by Fertilizer. B) Fertilizer x Compost sliced by Compost.



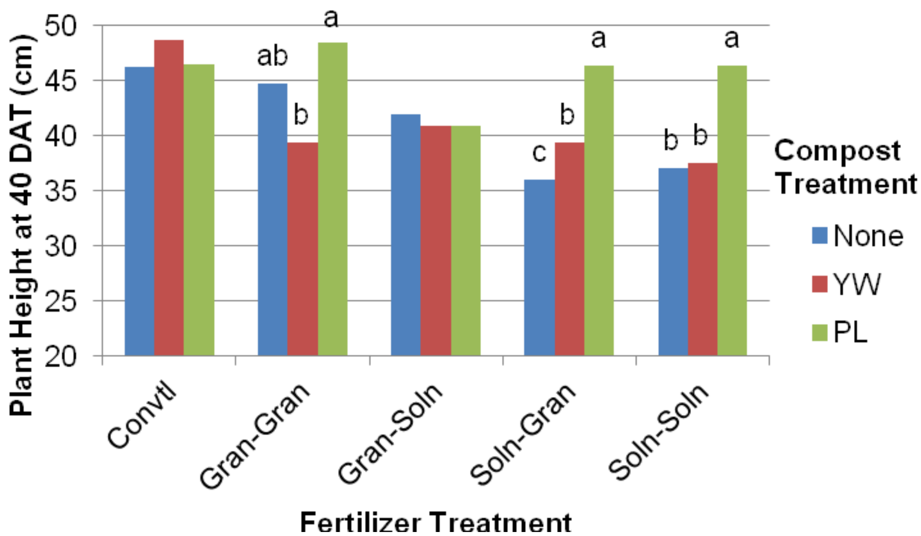
A B

Figure 2-17. Percent blossom end rot (BER) interaction effects in Spring 2011. Interaction means designated by different letters within each x-axis treatment are significantly different at $P \leq 0.05$. Means with no letters are not significantly different. A) Fertilizer x Compost sliced by Fertilizer. B) Fertilizer x Compost sliced by Compost

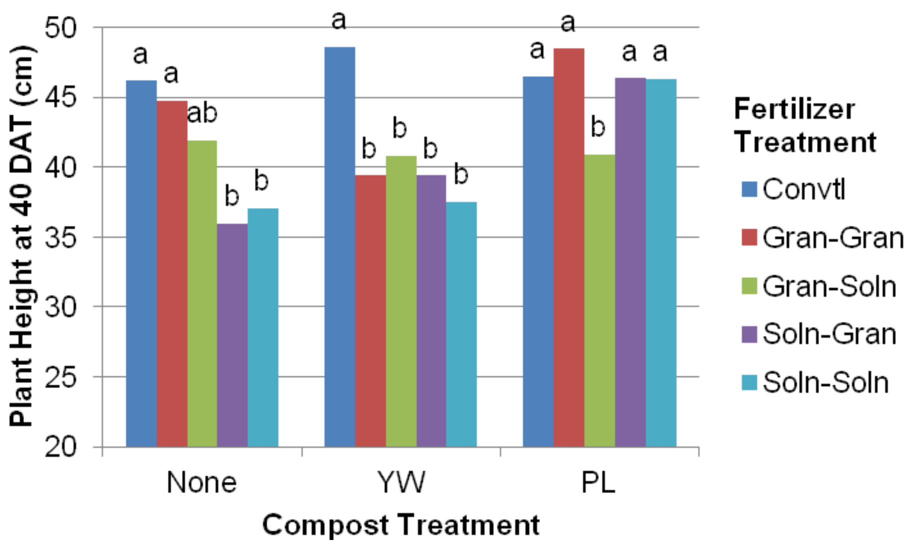
Table 2-12. The effects of conventional and organic fertilizer and compost treatments on plant height and leaf SPAD values of determinate red bell pepper plants grown in a saw-tooth style greenhouse at UF's PSREU near Citra, FL in Fall 2010

	Days after transplanting					
	Plant height (cm)[z]		Leaf SPAD values[y]			
Main effects	17	40	17	40	60	86
Fertilizer treatment (F)[x]						
Convtl	24.8	47.1	52.6 a	68.1 a	72.6 a	74.2 a
Gran-Gran	26.4	44.2	51.6 a	58.1 b	65.5 bc	64.4 bc
Gran-Soln	23.7	41.2	46.8 b	60.8 b	61.1 d	61.4 c
Soln-Gran	26.6	40.6	51.6 a	58.9 b	66.3 b	67.9 b
Soln-Soln	26.4	40.3	50.3 a	60.2 b	61.9 cd	63.3 c
P-value[v]	0.0511	<0.0001	0.0155	0.0002	<0.0001	<0.0001
Compost treatment (C)[w]						
NC	24.3 b	41.2	52.8 a	64.3 a	66.4	66.9
YW	25.2 b	41.1	48.0 b	56.4 b	63.6	65.9
PL	27.3 a	45.7	51.0 a	62.9 a	66.4	66.0
P-value	0.0041	0.0001	0.0027	<0.0001	0.0870	0.7495
Interaction (F*C)						
P-value	0.5405	0.0029	0.7912	0.2153	0.3255	0.2224

[z]Plant height was measured from the media surface to the last node of the longest stem on all four center plants in each plot.
[y]Leaf SPAD values: measured on the most recently fully expanded leaf of the four center plants in each plot; relative numbers that estimate leaf "greenness" – a representation of leaf nitrogen status.
[x]Convtl: conventional mineral-based solution injected through irrigation system throughout the season; Gran-Gran: organic granular incorporated into media at transplanting and sidedress; Gran-Soln: organic granular incorporated into media at transplanting and organic solution injected through irrigation system beginning at sidedress; Soln-Gran: organic solution injected through irrigation system beginning at transplanting and organic granular incorporated into media at sidedress; Soln-Soln: organic solution injected through irrigation system throughout the season. Total season application of N, P, K, Ca and water were consistent across all treatments.
[w]NC: no compost; YW: 30% yard waste compost by volume; PL: 30% poultry litter compost by volume. All have a media base of 1 peat : 1 pine bark (by volume).
[v]Means separated within columns by Fisher's Least Significant Difference (LSD) test a $P \le 0.05$. Means with the same letter are not significantly different.



A



B

Figure 2-18. Plant height (cm) at 40 days after transplant (DAT) interaction effects in Fall 2010. Interaction means designated by different letters within each x-axis treatment are significantly different at $P \leq 0.05$. Means with no letters are not significantly different. A) Fertilizer x Compost sliced by Fertilizer. B) Fertilizer x Compost sliced by Compost.

Table 2-13. The effects of conventional and organic fertilizer and compost treatments on plant height and leaf SPAD values of determinate red bell pepper plants grown in a saw-tooth style greenhouse at UF's PSREU near Citra, FL in Spring 2011

	Days after transplanting															
	Plant height (cm)[z]								Leaf SPAD values[y]							
Main effects	21		44		56		89		21		44		56		89	
Fertilizer treatment (F)[x]																
Convtl	26.5	a	46.1		51.8	a	63.5	a	63.9		64.1	a	66.5	a	75.1	a
Gran-Gran	23.6	b	42.2		46.8	b	52.8	bc	60.2		60.0	b	60.6	b	55.5	c
Gran-Soln	24.2	b	44.9		49.5	ab	54.2	b	57.9		58.2	b	55.2	c	55.8	c
Soln-Gran	24.6	b	36.5		42.0	c	49.3	c	53.8		59.2	b	65.2	a	67.2	b
Soln-Soln	23.9	b	36.8		40.5	c	49.0	c	56.7		58.3	b	60.0	b	72.3	a
P-value[v]	0.0059		<0.0001		<0.0001		<0.0001		<0.0001		0.0009		<0.0001		<0.0001	
Compost treatment (C)[w]																
NC	23.5	b	39.3		43.6	b	49.8	b	58.7		60.0	b	63.2	a	67.5	a
YW	24.4	b	41.6		46.7	a	54.2	a	56.4		56.7	c	60.1	b	65.8	ab
PL	25.8	a	42.9		48.1	a	57.3	a	60.4		63.2	a	61.2	ab	62.3	b
P-value	0.0015		0.0023		0.0017		0.0002		0.0023		<0.0001		0.0382		0.0241	
Interaction (F*C)																
P-value	0.2228		0.0267		0.2162		0.3899		0.0061		0.0824		0.3551		0.3655	

[z]Plant height was measured from the media surface to the last node of the longest stem on all four center plants in each plot.
[y]Leaf SPAD values: measured on the most recently fully expanded leaf of the four center plants in each plot; relative numbers that estimate leaf "greenness" – a representation of leaf nitrogen status.
[x]Convtl: conventional mineral-based solution injected through irrigation system throughout the season; Gran-Gran: organic granular incorporated into media at transplanting and sidedress; Gran-Soln: organic granular incorporated into media at transplanting and organic solution injected through irrigation system beginning at sidedress; Soln-Gran: organic solution injected through irrigation system beginning at transplanting and organic granular incorporated into media at sidedress; Soln-Soln: organic solution injected through irrigation system throughout the season. Total season application of N, P, K, Ca and water were consistent across all treatments.

[w]NC: no compost; YW: 30% yard waste compost by volume; PL: 30% poultry litter compost by volume. All have a media base of 1 peat : 1 pine bark (by volume).
[v]Means separated within columns by Fisher's Least Significant Difference (LSD) test a $P \leq 0.05$. Means with the same letter are not significantly different

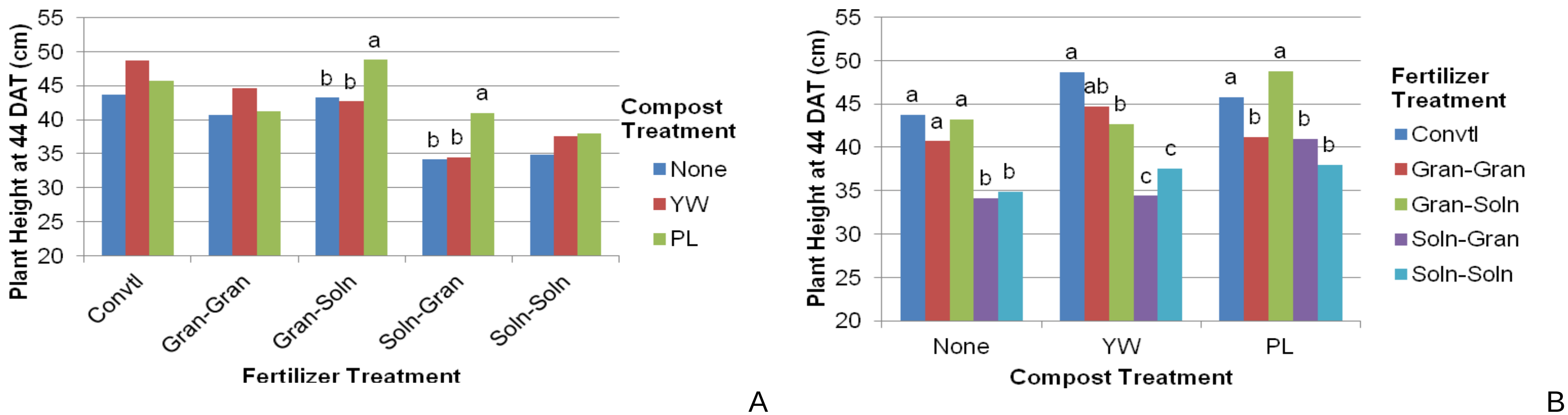


Figure 2-19. Plant height (cm) at 44 DAT interaction effects in Spring 2011. Interaction means designated by different letters within each x-axis treatment are significantly different at $P \leq 0.05$. Means with no letters are not significantly different. A) Fertilizer x Compost sliced by Fertilizer. B) Fertilizer x Compost sliced by Compost.

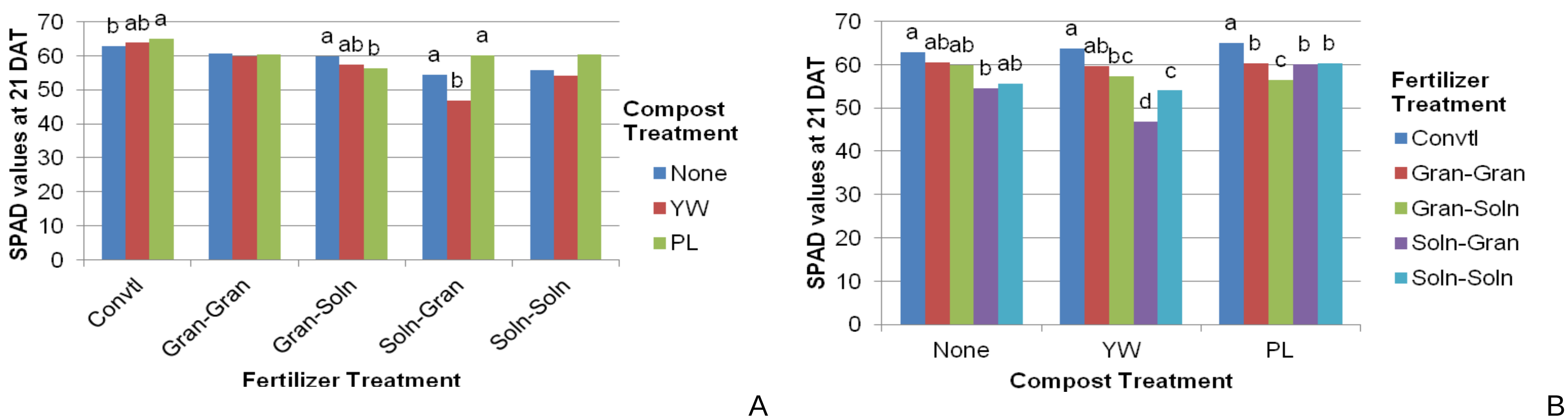


Figure 2-20. Leaf SPAD values at 21 DAT interaction effects in Spring 2011. Interaction means designated by different letters within each x-axis treatment are significantly different at $P \leq 0.05$. Means with no letters are not significantly different. A) Fertilizer x Compost sliced by Fertilizer. B) Fertilizer x Compost sliced by Compost.

Table 2-14. The effects of conventional and organic fertilizer and compost treatments on the pH, electrical conductivity (EC) and nitrate (NO_3-N) concentration of leachate over the season from determinate red bell pepper plants grown in a saw-tooth style greenhouse at UF's PSREU near Citra, FL in Fall 2010

	pH			EC (mS/cm)			NO_3-N (mg/L)[z]		
Main effects	29 DAT[y]	59 DAT	92 DAT	29 DAT	59 DAT	92 DAT	29 DAT	59 DAT	92 DAT
Fertilizer treatment (F)[x]									
Convtl	6.7	6.5 c	6.4 c	1.9 a	2.9 a	3.7 a	44.6 a	58.8 a	78.5 a
Gran-Gran	7.1	7.3 a	7.0 b	1.2 b	0.9 c	2.5 b	4.2 b	0.7 b	9.0 bc
Gran-Soln	7.2	7.2 ab	7.3 a	1.1 b	1.1 bc	0.8 c	4.1 b	1.6 b	3.1 cd
Soln-Gran	7.3	7.0 b	7.0 b	0.9 b	1.7 b	2.6 b	4.9 b	1.5 b	16.0 b
Soln-Soln	7.1	7.1 ab	7.0 b	1.0 b	1.3 bc	1.1 c	0.9 b	0.6 b	2.4 d
P-value[v]	0.0933	<0.0001	<0.0001	0.0025	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Compost treatment (C)[w]									
NC	6.5 c	6.6 b	6.5 c	0.6 c	1.0 b	1.5 b	6.6 b	7.8	15.6 b
YW	7.5 a	7.3 a	7.3 a	1.0 b	1.4 b	1.6 b	10.9 b	12.5	12.3 b
PL	7.1 b	7.1 a	7.1 b	2.1 a	2.4 a	3.4 a	17.7 a	17.6	37.5 a
P-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0163	0.2766	0.0004
Interaction (F*C)									
P-value	0.8903	0.3873	0.2198	0.2582	0.2124	0.2067	0.3047	0.0608	0.1566

[z]Data square root transformed for analysis.
[y]DAT: days after transplanting.
[x]Convtl: conventional mineral-based solution injected through irrigation system throughout the season; Gran-Gran: organic granular incorporated into media at transplanting and sidedress; Gran-Soln: organic granular incorporated into media at transplanting and organic solution injected through irrigation system beginning at sidedress; Soln-Gran: organic solution injected through irrigation system beginning at transplanting and organic granular incorporated into media at sidedress; Soln-Soln: organic solution injected through irrigation system throughout the season. Total season application of N, P, K, Ca and water were consistent across all treatments.
[w]NC: no compost; YW: 30% yard waste compost by volume; PL: 30% poultry litter compost by volume. All have a media base of 1 peat : 1 pine bark (by volume).
[v]Means separated within columns by Fisher's Least Significant Difference (LSD) test a $P \leq 0.05$. Means with the same letter are not significantly different.

Table 2-15. The effects of conventional and organic fertilizer and compost treatments on the pH, electrical conductivity (EC) and nitrate (NO_3-N) concentration of leachate over the season from determinate red bell pepper plants grown in a saw-tooth style greenhouse at UF's PSREU near Citra, FL in Spring 2011

	pH			EC (mS/cm)^z			NO_3-N (mg/L)^y		
Main effects	30 DAT^x	52 DAT	73 DAT	30 DAT	52 DAT	73 DAT	30 DAT	52 DAT	73 DAT
Fertilizer treatment (F)^w									
Convtl	6.4	6.4	6.1 b	2.0	2.2 bc	3.3 a	46.4 a	31.6 a	67.4 a
Gran-Gran	6.5	6.5	6.5 a	2.5	3.3 a	2.5 ab	22.8 b	38.7 a	11.4 b
Gran-Soln	6.7	6.6	6.6 a	1.5	1.0 d	1.1 c	11.8 b	1.7 b	1.3 c
Soln-Gran	6.6	6.4	6.6 a	1.6	2.4 ab	2.1 b	35.3 ab	24.3 a	13.5 b
Soln-Soln	6.6	6.5	6.4 a	1.8	1.7 cd	1.8 c	22.7 b	7.7 b	3.3 c
P-value^u	0.2756	0.4923	0.0065	<0.0001	<0.0001	<0.0001	0.0242	<0.0001	<0.0001
Compost treatment (C)^v									
NC	6.4 b	6.2 b	6.2 b	0.9	1.6 b	1.5 b	14.2 b	13.1 b	10.9 b
YW	6.6 a	6.6 a	6.6 a	1.3	1.5 b	1.5 b	8.5 b	14.4 b	19.6 b
PL	6.7 a	6.6 a	6.6 a	3.5	3.3 a	3.4 a	60.6 a	34.9 a	27.6 a
P-value	0.0214	0.0010	0.0004	0.1267	<0.0001	<0.0001	<0.0001	0.0003	0.0131
Interaction (F*C)									
P-value	0.1518	0.9417	0.9105	0.0017	NS	NS	0.1380	0.4651	0.1680

^{z}Data transformed to fit a censor data model for analysis.
^{y}Data square root transformed for analysis.
^{x}DAT: days after transplanting.
^{w}Convtl: conventional mineral-based solution injected through irrigation system throughout the season; Gran-Gran: organic granular incorporated into media at transplanting and sidedress; Gran-Soln: organic granular incorporated into media at transplanting and organic solution injected through irrigation system beginning at sidedress; Soln-Gran: organic solution injected through irrigation system beginning at transplanting and organic granular incorporated into media at sidedress; Soln-Soln: organic solution injected through irrigation system throughout the season. Total season application of N, P, K, Ca and water were consistent across all treatments.
^{v}NC: no compost; YW: 30% yard waste compost by volume; PL: 30% poultry litter compost by volume. All have a media base of 1 peat : 1 pine bark (by volume).

[u]Means separated within columns by Fisher's Least Significant Difference (LSD) test a $P \leq 0.05$. Means with the same letter are not significantly different.

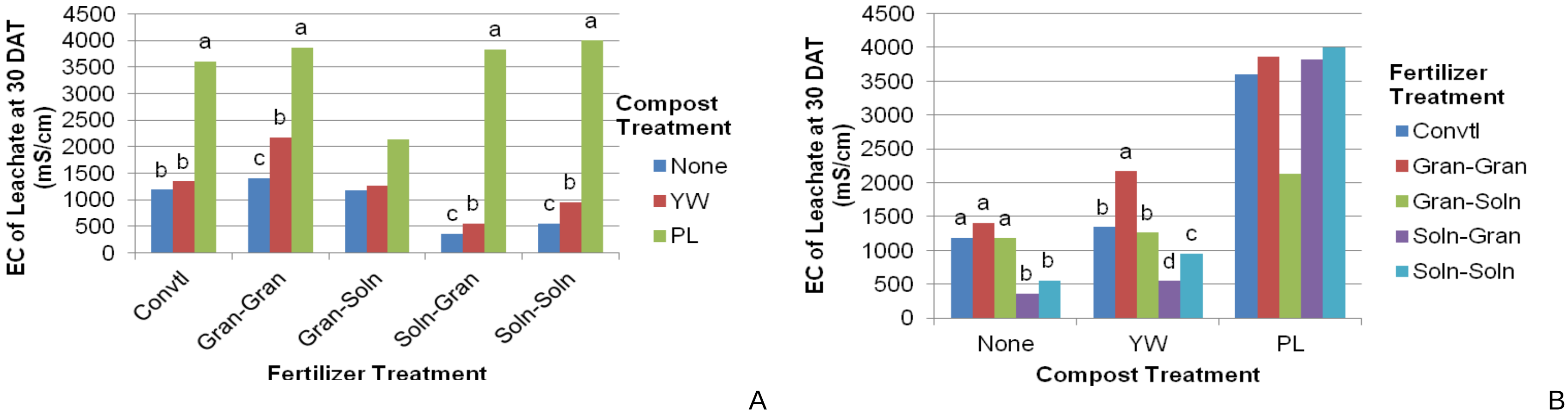


Figure 2-21. Electrical conductivity (EC) of leachate (mS/cm) at 30 DAT interaction effects in Spring 2011. Interaction means designated by different letters within each x-axis treatment are significantly different at $P \leq 0.05$. Means with no letters are not significantly different. A) Fertilizer x Compost sliced by Fertilizer. B) Fertilizer x Compost sliced by Compost.

Table 2-16. The effects of conventional and organic fertilizer and compost treatments at harvest on whole plant dry weight, leaf percent total kjeldahl nitrogen (TKN), and fruit pericarp thickness, lobe number, fresh weight, dry weight, percent TKN and percent nitrogen use efficiency (NUE) from determinate red bell pepper plants grown in a saw-tooth style greenhouse at UF's PSREU near Citra, FL in Fall 2010

Main effects	Whole plant dry weight (g)	Leaf TKN (%)	Pericarp thickness (mm)	Fruit lobe number	Fruit fresh weight (g)	Fruit dry weight (g)	Fruit TKN (%)	Fruit NUE (%)[z]
Fertilizer treatment (F)[y]								
Convtl	50.3	3.47 a	6.06 a	3.73	323 a	18.16 a	2.59	19.33 a
Gran-Gran	25.3	2.83 c	5.65 b	3.63	288 ab	18.06 a	1.88	10.04 b
Gran-Soln	23.2	2.85 c	5.41 bc	3.59	256 b	15.66 b	1.86	8.94 b
Soln-Gran	22.7	3.16 b	5.53 b	3.58	273 b	18.39 a	2.19	9.78 b
Soln-Soln	16.4	3.10 b	5.13 c	3.60	193 c	12.65 c	1.98	6.61 c
P-value[w]	<0.0001	<0.0001	<0.0001	0.3359	<0.0001	<0.0001	<0.0001	<0.0001
Compost treatment (C)[x]								
NC	24.5	3.24 a	5.58	3.55 b	253	16.18	2.09	10.45 b
YW	25.5	2.98 b	5.60	3.60 ab	273	16.31	2.09	9.76 b
PL	32.7	3.02 b	5.49	3.73 a	272	17.27	2.11	12.61 a
P-value	0.0001	0.0031	0.6562	0.0208	0.4057	0.3330	0.9505	0.0028
Interaction (F*C)								
P-value	0.0048	0.1051	0.3025	0.4091	0.3174	0.3647	0.0001	0.0736

[z]NUE: calculated using total yield values.
[y]Convtl: conventional mineral-based solution injected through irrigation system throughout the season; Gran-Gran: organic granular incorporated into media at transplanting and sidedress; Gran-Soln: organic granular incorporated into media at transplanting and organic solution injected through irrigation system beginning at sidedress; Soln-Gran: organic solution injected through irrigation system beginning at transplanting and organic granular incorporated into media at sidedress; Soln-Soln: organic solution injected through irrigation system throughout the season. Total season application of N, P, K, Ca and water were consistent across all treatments.
[x]NC: no compost; YW: 30% yard waste compost by volume; PL: 30% poultry litter compost by volume. All have a media base of 1 peat : 1 pine bark (by volume).

[w]Means separated within columns by Fisher's Least Significant Difference (LSD) test a $P \leq 0.05$. Means with the same letter are not significantly different.

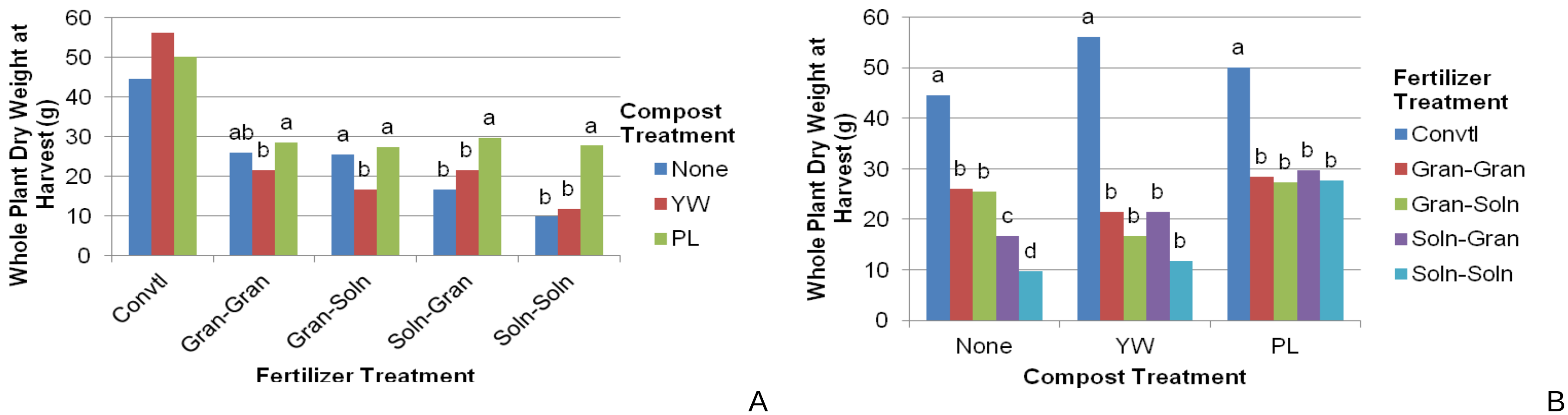


Figure 2-22. Whole plant dry weight (g) at harvest interaction effects in Fall 2010. Interaction means designated by different letters within each x-axis treatment are significantly different at $P \leq 0.05$. Means with no letters are not significantly different. A) Fertilizer x Compost sliced by Fertilizer. B) Fertilizer x Compost sliced by Compost.

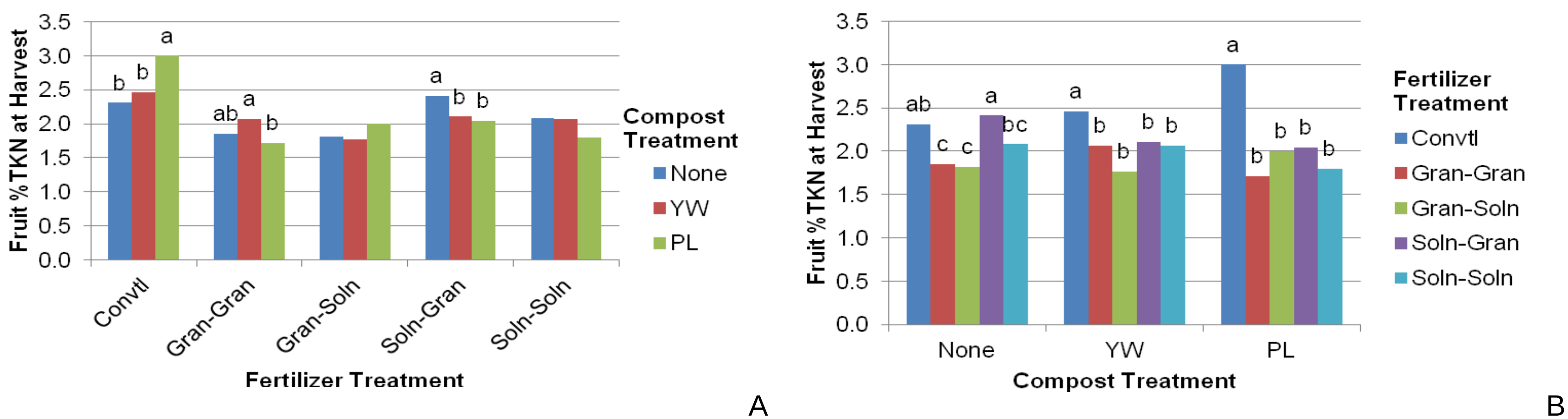


Figure 2-23. Fruit percent TKN at harvest interaction effects in Fall 2010. Interaction means designated by different letters within each x-axis treatment are significantly different at $P \leq 0.05$. Means with no letters are not significantly different. A) Fertilizer x Compost sliced by Fertilizer. B) Fertilizer x Compost sliced by Compost.

Table 2-17. The effects of conventional and organic fertilizer and compost treatments at harvest on whole plant dry weight, leaf percent total kjeldahl nitrogen (TKN), and fruit pericarp thickness, lobe number, fresh weight, dry weight, percent TKN and percent nitrogen use efficiency (NUE) from determinate red bell pepper plants grown in a saw-tooth style greenhouse at UF's PSREU near Citra, FL in Spring 2011

Main effects	Whole plant dry weight (g)	Leaf TKN (%)	Pericarp thickness (mm)	Fruit lobe number	Fruit fresh weight (g)	Fruit dry weight (g)	Fruit TKN (%)	Fruit NUE (%)[z]
Fertilizer treatment (F)[y]								
Convtl	88.7 a	5.21 a	4.57 a	3.85	220 a	13.97	3.07 a	21.91 a
Gran-Gran	45.9 b	2.87 d	4.20 a-c	3.85	175 bc	14.27	1.89 c	9.79 b
Gran-Soln	46.1 b	2.71 d	4.32 ab	3.75	194 ab	14.09	1.93 c	10.20 b
Soln-Gran	31.0 c	3.26 c	4.15 bc	3.67	159 c	13.56	2.31 b	10.20 b
Soln-Soln	31.3 c	3.73 b	3.87 c	3.62	147 c	11.41	2.44 b	6.73 b
P-value[w]	<0.0001	<0.0001	0.0191	0.0004	0.0001	0.2182	<0.0001	<0.0001
Compost treatment (C)[x]								
NC	41.0 b	3.64	4.21	3.67	170	12.85	2.40	11.01
YW	44.3 b	3.48	4.35	3.76	192	13.96	2.28	11.52
PL	60.5 a	3.55	4.10	3.81	175	13.56	2.30	12.76
P-value	<0.0001	0.4096	0.2952	0.0123	0.1379	0.5670	0.3529	0.5305
Interaction (F*C)								
P-value	0.1751	0.0783	0.2776	0.0227	0.1618	0.4493	0.2865	0.8710

[z]NUE: calculated using total yield values.
[y]Convtl: conventional mineral-based solution injected through irrigation system throughout the season; Gran-Gran: organic granular incorporated into media at transplanting and sidedress; Gran-Soln: organic granular incorporated into media at transplanting and organic solution injected through irrigation system beginning at sidedress; Soln-Gran: organic solution injected through irrigation system beginning at transplanting and organic granular incorporated into media at sidedress; Soln-Soln: organic solution injected through irrigation system throughout the season. Total season application of N, P, K, Ca and water were consistent across all treatments.
[x]NC: no compost; YW: 30% yard waste compost by volume; PL: 30% poultry litter compost by volume. All have a media base of 1 peat : 1 pine bark (by volume).

[w]Means separated within columns by Fisher's Least Significant Difference (LSD) test a $P \leq 0.05$. Means with the same letter are not significantly different.

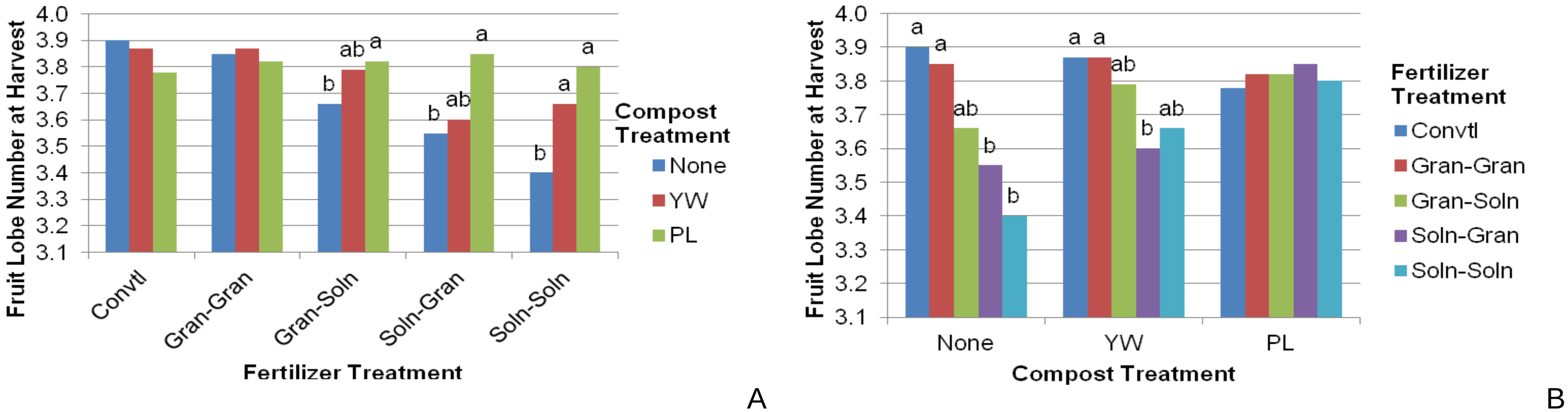


Figure 2-24. Fruit lobe number at harvest interaction effects in Spring 2011. Interaction means designated by different letters within each x-axis treatment are significantly different at $P \leq 0.05$. Means with no letters are not significantly different. A) Fertilizer x Compost sliced by Fertilizer. B) Fertilizer x Compost sliced by Compost.

.

CHAPTER 3
ECONOMIC ANALYSIS

Materials and Methods

The data used in this economic analysis were from experiments conducted at the University of Florida's (UF) Plant Science Research and Education Unit (PSREU) in Marion County, near Citra, Florida in Fall 2010 and Spring 2011.

Site Description

The experiment was conducted in Fall 2010 and Spring 2011 in a multi-bay, 2023 m^2, passively-ventilated, saw-tooth style greenhouse (Top Greenhouses Ltd., Barkan, Israel). The high-roof structure is covered with UV-absorbing polyethylene film, the ventilated side walls and roof vents are covered with 50-mesh insect screen and the floors are covered in white landscape fabric. The experiment was established in one bay of the greenhouse, where 0.15-m diameter polyvinyl chloride (PVC) pipes were placed in four rows (1.2 m apart) down the north-south length of the greenhouse to serve as a drainage system. Because the experiment contained a conventional fertilizer treatment for comparison, the greenhouse was not certified organic. Pest management was achieved using biological control methods as described below, and no prohibited pesticides were applied in the greenhouse for six months prior to and during the course of the experiment.

Experimental Design

Overview

An experiment was arranged as a randomized complete block design with treatments replicated four times to evaluate the effects of fertilizer and media source and form on the yield and quality of 'Red Knight' bell pepper (Osborne Seed Company, Mount Vernon, WA) in Fall 2010 and Spring 2011. Treatments were a factorial combination of five fertilizer treatments (one conventional hydroponic and four organic-compliant) and three compost treatments (no compost, 30% yard waste compost or 30% poultry litter compost) for a total of 15 treatments.

‘X3R Red Knight F1’ was used because it is a top-yielding and top-quality determinate variety well adapted to Florida climate (Shuler, 2003) which could potentially be grown in three crops per year (spring, summer and fall); it is resistant to Bacterial Leaf Spot (*Xanthomonas axonopodis* pv. *vesicatoria* races 1-3), Tobacco Mosaic Virus and Potato Virus Y strain which is important in an organic-compliant growing system that does not use chemicals for disease suppression; and it is an early-mid maturing variety which would allow growers to target specific market windows.

On 13 Sept. 2010 and 9 Mar. 2011, bell pepper seedlings were transplanted into 11.4-L black polyethylene nursery pots (C1200, BWI Co Inc., Apopka, FL) with two 1.5-cm diameter drainage holes drilled equidistant from each other and 3.8 cm from the bottom of the pot to create a reservoir. Pots were placed on the four rows of PVC pipe, and each row of pipe comprised one block of the experiment. Plots contained six plants (one plant per pot) arranged in a row, for a total of 60 plots and 360 plants. Plants within each row were 30 cm apart and between-row spacing was 120 cm from center to center for a plant density of three plants per m^2. The center four plants in each plot were harvested by hand on 2 and 9 Dec 2010 [80 and 87 days after transplant (DAT), respectively] and 18 May, 25 May and 7 June 2011 (70, 77 and 90 DAT, respectively).

Fertilizer treatments

The conventional hydroponic fertilizer (“Convtl”) consisted of a custom-mix of mineral-based fertilizers and was injected through the irrigation system throughout the season based on a nutrient levels and irrigation schedule formulated for hydroponic greenhouse-grown bell peppers (Jovicich et al., 2004). The organic granular fertilizer ("Gran") consisted of a custom mix of four OMRI-approved sources and was incorporated directly into the media either at transplant or at sidedress depending on the treatment. The organic fertilizer solution ("Soln") consisted of a custom-mix of three OMRI-approved sources and was injected through the irrigation system beginning either at transplant or at sidedress depending on the treatment. Sidedress fertilizers were applied on 13 October 2010 and 9 April 2011. The five fertilizer treatments were as follows:

- Convtl: mineral-based; "Convtl" beginning at transplanting and applied throughout the season
- Gran-Gran: organic; "Gran" applied at transplanting, "Gran" applied at sidedress
- Gran-Soln: organic; "Gran" applied at transplanting, "Soln" beginning at sidedress
- Soln-Gran: organic; "Soln" beginning at transplanting, "Gran" applied at sidedress
- Soln-Soln: organic; "Soln" beginning at transplanting and applied throughout the season

Total season applications of N, P, K and Ca were consistent across all treatments (i.e., 10,220, 3513, 13,365 and 11,692 mg per plant, respectively).

In conventional greenhouse hydroponic fertigation production systems, all nutrients are typically metered out via the irrigation system with each irrigation event throughout the season allowing precise control over nutrient applications, and calcium is usually injected separately from phosphorus and sulfur because they precipitate when mixed together. In field production systems that utilize fertigation, most, if not all, of the phosphorus is applied in granular form at planting because it is relatively less soluble (especially if it is derived from organic sources), and can clog the irrigation system if injected. In field systems, at least half of the nitrogen and potassium are applied in granular form at planting, but the other half is injected through the irrigation system so that the nutrient supply can be controlled and adjusted according to plant demand during the season. An advantage shared by both the greenhouse and field fertigation methods is the reduced risk of fertilizer leaching and salt toxicity in young plants because these methods supplant heavy fertilizer applications early in the season. The application timing and strategies of the organic fertilizer treatments in this study were based on these basic principles in addition to the goal of keeping total season N, P, K and Ca consistent across treatments.

Application of “Convtl” fertilizer. Two fertilizer proportional injectors (MiniDos 2.5%, Dosmatic U.S.A., Inc, Carrollton, TX) placed in series were used to pump mineral-based stock solution into the irrigation water (dilution rate 1:50; v/v) from two 18.9-L buckets according to conventional hydroponic greenhouse practices that keep calcium separate from both phosphorus and sulfur to prevent precipitation.

Application of “Gran” fertilizer. At transplanting, the “Gran” fertilizer was incorporated into the top 15 cm of the media in the pots. The depth was chosen because it is the most biologically active zone for transforming organic sources of nutrients into plant-available forms. At sidedress, the “Gran” fertilizer was incorporated into the top 8 cm to avoid damaging plant roots.

Application of “Soln” fertilizer. A fertilizer proportional injector was used to pump organic stock solution into irrigation water (dilution rate 1:50; v/v) from an 18.9-L bucket for each of the three fertilizer treatments involving “Soln”. To reduce the incidence of clogging, new organic stock solutions were made weekly, emitters were frequently checked for clogging and flushed out, the dilution ratio of 1:50 was chosen to feed a less concentrated fertilizer solution and all filters were cleaned at least twice a week (Rippy et al., 2004, Zhai et al., 2009).

Compost treatments

All pots received a media base-mix of 1 peat : 1 pine bark (by volume). The OMRI-approved peat (Sunshine Peat Moss; Sun Gro Horticulture Canada Ltd, Orlando, FL) was custom-mixed with dolomitic limestone for a target pH between pH 5.5 and pH 6.5. The OMRI-approved pine bark (Elixson Wood Products, Starke, FL) was screened to a size less than 2.5 x 2.5 cm. The three compost treatments were as follows:

- NC: no compost
- YW: 30% yard waste compost by volume
- PL: 30% poultry litter compost by volume

The OMRI-approved yard waste compost was locally-sourced (Gainesville Wood Resource and Recovery, Gainesville, FL) was screened to 0.95 cm. The poultry litter compost was sourced from a local organic farm (Hoover's Organic Farm, Live Oak, FL, certified by Quality Certification Services, Gainesville, FL) and was composed of 100% poultry manure and pine sawdust from a neighboring poultry producer. The compost was screened to 1.27 cm.

Irrigation system

Untreated well water was used for irrigation. Water was delivered through black 1.9-cm diameter polyethylene pipe (John Deere Landscapes, Gainesville, FL) with or without fertilizer depending on the treatment. Previous studies (Rippy et al., 2004; Zhai et al., 2009) have found that typical hydroponic greenhouse emitters with a flow rate of 1.9 L/h or less are readily clogged by fertilizer solutions made from organic sources; therefore, in this study, each plant received the irrigation through a 7.6 L/h pressure-compensated emitter on the end of a 60-cm long spaghetti tube. Other measures taken to avoid clogging issues included using polyethylene pipe and spaghetti tubing with diameters larger than normal for hydroponic greenhouse operations, incorporating three filters before the fertilizer proportional injectors in order to filter out particulates from the well water and drawing each stock solution up through its own filter.

Irrigation duration and frequency was automated using a timer, was consistent across all treatments and was increased over the course of the season to meet plant demand (ranging from 300 to 1500 mL/plant/day). Although the fertilizer proportional injectors were all operated on the same timer, each was connected to its own solenoid and separate program on the timer to allow them to run individually and avoid reductions in pressure.

Crop Seasonal Management

Temperature control and trellising

Throughout the season, the greenhouse polyethylene side curtains were manually lowered when air temperatures were less than 18°C or during periods of rainfall and were raised when air temperatures were greater than 25°C. Thermal tubes (Polyon, Barkai, Israel) and aluminized thermal screens were used when air temperatures were less than 10°C (Jovicich et al., 2005; Jovicich et al., 2007). In high temperatures, fans were used to improve air circulation. All plants were trellised in a modified “Spanish” system as the plants were a determinate growth structure (Jovicich et al., 2004; Saha and Cantliffe, 2009). Pairs of vertical poles and horizontal twine supported the plants on both sides of the rows, and twine was placed every vertical 20 cm as the plants grew.

Integrated pest management practices

No chemical means of pest control were used in this study. Plants were scouted on a weekly basis or more often as needed to identify disease occurrence and increasing pest thresholds. Pests were controlled using integrated pest management (IPM) practices, including biological control with banker plant systems and alternate hosts that help to sustain beneficial insect populations but do not negatively affect bell pepper crops (Jovicich et al., 2004; Osborne and Barrett, 2005; Saha and Cantliffe, 2009; Shaw and Cantliffe, 2002). Alternate host grain aphids were reared on sorghum banker plants in order to sustain the beneficial parasitic wasp colonies (*Aphidius colemani*) that control the aphid pests. Alternate host papaya whiteflies were reared on papaya banker plants in order to sustain the beneficial parasitic wasp colonies (*Encarsia formosa* and *Eretmocerus eremicus*) that control the whitefly pests. Alternate host grass mites were reared on sorghum banker plants in order to sustain the beneficial predatory mite colonies (*Amblyseius swirskii*, *Neoseiulus cucumeris* and *Neoseiulus californicus*) that control mite and thrip pests. Additionally, sticky cards were used to trap winged pests such as fungus gnats, and diligent sanitation habits were observed during the course of the season. Bumblebees (*Bombus impatiens*) were introduced for supplementary pollination to aid in fruit set; one bee hive per season serviced 650 to 1115 m^2 (Jovicich et al., 2004; Saha and Cantliffe, 2009; Shaw and Cantliffe, 2002). Beneficials (i.e., Aphipar, Enermix, Swirski-Mite, Thripex-V and Spical) and bumblebees (i.e., NATUPOL – class B) were acquired from Koppert Biological Systems in Romulus, Michigan.

The seedlings were transplanted to the depth of the cotyledonary node level and the emitter placed at the base of the seedling at transplant was gradually moved back from the base of the plant over the course of 4 weeks. These IPM measures were taken to prevent a physiological basal stem disorder known as “Elephant’s Foot” disorder which could predispose the plants to a Fusarium infection (Jovicich and Cantliffe, 2004)

Fruit Yields

Harvest

Bell pepper fruit were harvested by hand on 2 and 9 Dec 2010 (80 and 87 DAT, respectively) and 18 May, 25 May and 7 June 2011 (70, 77 and 90 DAT, respectively). Using a slide ruler, all peppers on the center four plants of each plot were graded by size according to a fresh-market diameter scale used for imported greenhouse-grown bell peppers (Jovicich et al., 2004; Saha and Cantliffe, 2009). Marketable fruit were graded as extra large (XL diameter ≥ 84 mm), large (L = 75 to 83.9 mm), medium (M = 65 to 74.9 mm) or small (S = 55 to 64.9 mm) with no serious external defects. Unmarketable fruit were less than 55 mm in diameter or had at least one of the six major bell pepper external defects: blossom end rot, sunscald, radial cracking, flat shape, misshapen or russeting. Weight of fruit in each of the five size categories and six cull categories were recorded per plant.

Statistical analysis

Combined analyses of variance (ANOVA) among years (Fall 2010 and Spring 2011) indicated significant treatment and year interactions. This may have been attributed to the seasonal variation in growing conditions and the resulting differences in irrigation scheduling as well as to the minor adjustments made when the study was repeated in Spring 2011. Therefore separate statistical analyses for each year were conducted to evaluate the effect of fertilizer treatment, compost treatment and their interaction on organic greenhouse-grown bell pepper production. In each year, the two highest yielding conventional treatments (Convtl x NC and Convtl x YW) and the two highest yielding organic treatments (Gran-Gran x PL and Gran-Soln x PL) were selected for use in the economic analysis.

Economic Analysis

A partial budget analysis can be used to examine the effects of changes in costs of certain production inputs on the change in profit of an agriculture system (Barrett et al., 2012; Cantliffe et al. 2008; Jovicich et al. 2005; Rivard et al., 2010). This technique was utilized to focus on the portion of the budget that differs between treatments of interest, rather than the entire budget. A partial budget analysis was conducted using data acquired during this hydroponic greenhouse bell pepper study to compare the potential partial net returns from conventional vs. organic production methods. The portion of the budget that differed between the conventional and organic treatments of interest was the nutrient management system, i.e. the fertilizer inputs, the media inputs and parts of the hydroponic fertigation system. All other costs for materials and labor were not included in the partial budget analysis because they were consistent across all treatments in the study and will vary considerably from grower to grower. These other production, harvest, and packing costs (e.g. site preparation, greenhouse structure, irrigation and climate control systems, electrical and drainage systems, growing containers, trellis accessories, IPM materials, pollinators, energy, packing cartons, labor, etc.) must be factored in by the grower to achieve a full net return.

Sources and prices for the nutrient management system materials of interest that were used to perform the partial budget analysis were identified (Table 3-1) for estimating the differential cost of producing hydroponic greenhouse-grown red bell pepper under the two conventional treatments (Convtl x NC and Convtl x YW) and the two organic treatments (Gran-Gran x PL and Gran-Soln x PL) (Table 3-2). The amount and cost of each material used for each of the four treatments was based on one 4-month determinate bell pepper crop and Fall 2010 price estimates from manufacturing companies for a population of 1000 plants. The MiniDos 2.5% fertilizer proportional injector used in the experiment has a 45 L/min flow rate and can service 360 plants fed by 7.6 L/h emitters; this information was used to calculate the quantity and cost of the equipment per 1000 plants based on a straight-line depreciation applied for five expected years of use. The total cost per plant and per square meter of greenhouse area (based on a plant density of 3 plants/m^2) for each of the four treatments was then calculated from the total cost of nutrient management for 1000 plants.

Sensitivity analyses were conducted to compare partial net returns for determinate red bell pepper plants grown under conventional and organic greenhouse nutrient management systems. Gross revenue was estimated by multiplying the wholesale market price ($/kg) by the marketable fruit yield (kg/m^2). The partial net returns ($/$m^2$) were calculated by subtracting the nutrient management cost from the gross revenue. The yields used in the sensitivity analyses were the mean yield per square meter ±3 standard errors to provide a 99% confidence interval of expected yields. The mean yields and standard errors for each of the four nutrient management treatments were estimated from the analyses of yield data from the Fall 2010 and Spring 2011 greenhouse trials separately.

The prices used in the sensitivity analyses are expressed in terms of 5-kg cartons because this is the typical packaging unit for greenhouse-grown bell pepper. The range of prices and the mean price for each analysis was based on historical price data collected from the U.S. Department of Agriculture, Fruit and Vegetable Market News Portal (U.S. Dept. of Agriculture, 2012a). For the sensitivity analyses of Convtl x NC and Convtl x YW treatments, prices per kg were calculated from published weekly average wholesale market prices for transactions of 5-kg cartons of imported, conventional greenhouse-grown, red bell peppers at the Atlanta terminal market during December in years 2004-2011 (for the Fall 2010 analysis) and during May in years 2004-2012 (for the Spring 2011 analysis) (U.S. Dept. of Agriculture, 2012a). For the sensitivity analyses of Gran-Gran x PL and Gran-Soln x PL, prices per kg were calculated from published weekly average wholesale market prices for transactions of 5-kg cartons of imported, organic greenhouse-grown, red bell peppers at the Atlanta, Boston, Chicago and Philadelphia terminal markets during December in years 2004-2011(for the Fall 2010 analysis) and during May in years 2005-2012 (for the Spring 2011 analysis) (U.S. Dept. of Agriculture, 2012a). Price data were gathered from the three other markets in addition to the Atlanta market because organic price data are more scarce.

Results and Discussion

Nutrient Management Cost Analysis

Sources and prices for materials used in hydroponic greenhouse production of conventional and organic red bell peppers is presented in Table 3-1. Organic inputs are often more expensive than conventional inputs. However, the results of this cost-analysis show that this is not always the case. With diligent research on the kinds and availabilities of OMRI-approved organic inputs and locally-sourcing as many of the chosen inputs as possible, it is feasible to reduce the organic input costs to those of conventional or even, as in this case, render them less expensive than conventional. In this study, the nutrient management input costs of the Convtl x NC, Convtl x YW, Gran-

Gran x PL and Gran-Soln x PL treatments were $3.58, $3.08, $2.31 and $2.94 per square meter, respectively (Table 3-2). A large proportion of this cost difference is attributed to the cost of peat moss as a media component. Although peat is a popular and effective hydroponic greenhouse soilless media, it is substantially more expensive at $86/yd^3 compared to the cost of the other media ingredients of pine bark, poultry litter compost and yard waste compost ($8.25, $10 and $15/yd^3, respectively). The Convtl x NC treatment used media made of 1 peat : 1 pine bark (by volume), whereas the other treatments incorporated 30% compost into the media mix, reducing the amount of peat in the mix from 50% to 35%, resulting in a 30% decrease in media costs. While compost is particularly beneficial in organic fertility programs like the Gran-Gran x PL and Gran-Soln x PL treatments, its use is not traditionally popular or necessary in systems that use conventional hydroponic fertility programs. However, one of the conventional treatments explored in this study was Convtl x YW, in which yard waste compost was incorporated into the media and coupled with conventional hydroponic fertilizers. The result was lower media costs (as previously discussed) and, surprisingly, higher yields when compared with the Convtl x NC control treatment. Therefore, this treatment was included in the sensitivity analyses in order to compare the best case scenario of the conventional treatments with that of the organic treatments in the greenhouse production study. One of the reasons why the two organic treatments were still less expensive than even the Convtl x YW treatment is the difference in compost prices. The poultry litter compost used in the two organic treatments is 33% less expensive than the yard waste compost used in the Convtl x YW treatment.

Total fertilizer costs per 1000 plants for the Convtl x NC, Convtl x YW, Gran-Gran x PL and Gran-Soln x PL treatments were $226.36, $226.36, $146.71 and $280.30, respectively. Many organic fertilizer sources can be cost-prohibitive, however the granular nature and local-sourcing of the Gran-Gran x PL treatment organic fertilizer inputs proved effective in terms of cost-reduction as well as yield, costing 35% less than the conventional mineral-based fertilizer inputs used in the Convtl x NC and Convtl x YW treatments. The Gran-Soln x PL treatment received half of its total season nutrients via the organic granular fertilizer inputs and the other half of its total season nutrients via dry finely-ground organic fertilizer inputs that were mixed with water to create an organic nutrient solution that was then fertigated to the plants. The HFPC spray dried hydrolyzed fish protein that made up a large proportion of this organic nutrient solution was more costly compared to the organic granular fertilizer inputs and so almost doubled the total fertilizer costs compared to Gran-Gran x PL treatment. However, the higher costs of the fertilizers in this organic treatment was not cost-prohibitive, and total nutrient management cost of this organic treatment was still lower than that of the conventional treatments, primarily due to the reduction of peat in the media and the use of less fertilizer proportional injectors. Also, liquid organic fertilizers are more expensive that dry, therefore I chose the dry, finely-ground, solution-grade fertilizer to dissolve in water to make the organic nutrient solution rather than utilizing an expensive liquid option.

In conventional greenhouse hydroponic fertility programs, calcium and iron are mixed into a separate nutrient solution from the rest of the elements in order to avoid precipitation problems. As a result two separate mineral-based nutrient solutions are made and injected into the irrigation system via two separate fertilizer proportional injectors. As a result, the Convtl x NC and Convtl x YW treatments incurred the cost of twice as many injectors as the Gran-Soln x PL treatment, while the Gran-Gran x PL treatment did not require any injectors at all. This also contributed to the lower total nutrient management costs of the two organic treatments compared to the two conventional treatments.

Sensitivity Analysis

A sensitivity analysis was used to examine how partial net returns changed under various combinations of marketable bell pepper yields and market prices, and to compare the returns under these varying situations of the two conventional and two organic greenhouse nutrient management treatments. Excluding the differences in nutrient management input costs, overall production costs would be similar across all four treatments. This study focused on organic greenhouse red bell pepper production because the higher market prices of red bell pepper compared to green, greenhouse-grown compared to field-grown peppers and organic produce compared to conventional produce highlights this as a potentially lucrative market niche for growers to expand into. Because many conventional greenhouse growers use soilless hydroponic systems, this study focused on the feasibility of these growers to use their existing hydroponic infrastructure and materials and modify it for successful organic greenhouse production. By adapting the existing greenhouse system, the costs of transitioning from conventional to organic production would be minimized.

The results of the Fall 2010 sensitivity analyses are presented in Tables 3-3 and 3-4. December wholesale market prices for conventional greenhouse-grown red bell peppers ranged from $14 to $35.50/5-kg carton, and the 99% confidence interval of expected prices for that range was used in the analyses ($15.75 to $33.75/5-kg carton). December wholesale market prices for organic greenhouse-grown red bell peppers ranged from $26 to $60/5-kg carton, and the 99% confidence interval of expected prices for that range was used in the analyses ($29.50 to $56.50/5-kg carton). Convtl x NC plants produced a mean marketable yield of 3.49 kg/m^2, and at that yield for the mean conventional greenhouse-grown red bell pepper price of $24.75/5-kg carton, the estimated partial net return was $13.68/m^2. Convtl x YW plants produced a mean marketable yield of 4.01 kg/m^2, and at that yield for the mean conventional greenhouse-grown red bell pepper price of $24.75/5-kg carton, the estimated partial net return was $16.79/m^2. Convtl x YW treatment achieved a higher partial net return than Convtl x NC because it produced greater yields and incurred lower nutrient management costs. Gran-Gran x PL plants produced a mean marketable yield of 2.34 kg/m^2, and at that yield for the mean organic greenhouse-grown red bell pepper price of $43.00/5-kg carton, the estimated partial net return was $17.79/m^2, which is $4.11/m^2 and $1.00/m^2 more than the partial net return of the Convtl x NC and Convtl x YW treatments, respectively. Gran-Soln x PL plants produced a mean marketable yield of 2.37 kg/m^2, and at that yield for the mean organic greenhouse-grown red bell pepper price of $43.00/5-kg carton, the estimated partial net return was $17.46/m^2, which is $3.78/m^2 and $0.67/m^2 more than the partial net return of the Convtl x NC and Convtl x YW treatments, respectively. Gran-Soln x PL nutrient management input cost of $2.94/m^2 was slightly higher than that of Gran-Gran x PL at $2.31/m^2, however the slightly higher yield of the Gran-Soln x PL treatment offset this extra cost and resulted in a partial net return comparable to that of Gran-Gran x PL. Although the yield achieved by the Gran-

Gran x PL treatment was lower than the yield achieved by the Convtl x NC and Convtl x YW treatments (by 33 and 42%, respectively), the lower nutrient management input cost of the organic treatment compared to the conventional treatments (by 35 and 25%, respectively) and the higher average market price (by 74%) resulted in a 30 and 6%, respectively, increase in partial net return for the organic treatment compared to the conventional treatments. Although the yield achieved by the Gran-Soln x PL treatment was lower than the yield achieved by the Convtl x NC and Convtl x YW treatments (by 32 and 41%, respectively), the lower nutrient management input cost of the organic treatment compared to the conventional treatments (by 18 and 5%, respectively) and the higher average market price (by 74%) resulted in a 28 and 4%, respectively, increase in partial net return for the organic treatment compared to the conventional treatments.

The results of the Spring 2011 sensitivity analyses are presented in Tables 3-5 and 3-6. May wholesale market prices for conventional greenhouse-grown red bell peppers ranged from \$13.50 to \$42.00/5-kg carton, and the 99% confidence interval of expected prices for that range was used in the analyses (\$15.75 to \$39.75/5-kg carton). May wholesale market prices for organic greenhouse-grown red bell peppers ranged from \$33 to \$54.50/5-kg carton, and the 99% confidence interval of expected prices for that range was used in the analyses (\$34.75 to \$52.75/5-kg carton). Convtl x NC plants produced a mean marketable yield of 1.78 kg/m^2, and at that yield for the mean conventional greenhouse-grown red bell pepper price of \$27.75/5-kg carton, the estimated partial net return was \$6.31/m^2. Convtl x YW plants produced a mean marketable yield of 2.91 kg/m^2, and at that yield for the mean conventional greenhouse-grown red bell pepper price of \$27.75/5-kg carton, the estimated partial net return was \$13.09/m^2. Convtl x YW treatment achieved a higher partial net return than Convtl x NC because it produced greater yields and incurred lower nutrient management costs. Gran-Gran x PL plants produced a mean marketable yield of 0.90 kg/m^2, and at that yield for the mean organic greenhouse-grown red bell pepper price of \$43.75/5-kg carton, the estimated partial net return was \$5.59/m^2, which is \$0.72/m^2 and \$7.50/m^2 less than the partial net return of the Convtl x NC and Convtl x YW treatments, respectively. Gran-Soln x PL plants produced a mean marketable yield of 2.45 kg/m^2, and at that yield for the mean organic greenhouse-grown red bell pepper price of \$43.75/5-kg carton, the estimated partial net return was \$18.48/m^2, which is \$12.17/m^2 and \$5.39/m^2 more than the partial net return of the Convtl x NC and Convtl x YW treatments, respectively. Gran-Soln x PL nutrient management input cost of \$2.94/m^2 was slightly higher than that of Gran-Gran x PL at \$2.31/m^2, however the significantly higher yield of the Gran-Soln x PL treatment offset this extra cost and resulted in a partial net return substantially higher than that of Gran-Gran x PL. Although the nutrient management input cost of the Gran-Gran x PL treatment was lower than that of the Convtl x NC and Convtl x YW treatments (by 35 and 25%, respectively) and the average market price was higher (by 58%), the yield achieved by the organic treatment was too low compared to the yield achieved by the conventional treatments (by 49 and 69%, respectively), resulting in a 11 and 57%, respectively, decrease in partial net return for the organic treatment compared to the conventional treatments. Although there were higher-yielding organic treatments in the Spring 2011 experiment, this one was included in the Spring 2011 sensitivity analysis to show how drastically conditions can change from season to season, and how important it is for growers to be aware of this before attempting organic greenhouse production of bell pepper. On the other hand, the yield achieved by the Gran-Soln x PL treatment was higher than the yield achieved by the Convtl x NC treatment (by 38%) and lower than the yield achieved by the Convtl x YW treatment (by 16%). However, the lower nutrient management input cost of the organic treatment compared to the conventional treatments (by 18 and 5%, respectively) and the higher average market price (by 58%) resulted in a 193 and 41%, respectively, increase in partial net return for the organic treatment compared to the conventional treatments. Because of the late transplant date (early March instead of January or early February) and the unavoidable greenhouse management problems that occurred in Spring 2011 that contributed to the overall yield decreases of both conventional and organic nutrient management treatments, Fall 2010 is probably a more representative season to base the economic analyses off of. However, delays and unforeseen problems will always occur in agriculture and the lessons to be taken away from the Spring 2011 economic analyses are no less important.

A full economic analysis was performed on indeterminate colored bell pepper conventionally grown in the same greenhouse structure used in this study by Jovicich et al. (2005). Under similar crop management practices and market prices for red conventionally-grown greenhouse bell pepper fruit, the study estimated that fruit yields should be greater than 7.8 kg/m^2 in order to generate positive returns to management. The indeterminate nature of the plants used in that study caused them to grow very tall and continually produce fruit for 6-7 months out of the 10-month long crop season (from seeding to plant-removal). The determinate nature of the plants used in my study means that they grow only to a height of about 3 feet and produce fruit for only 2-3 harvests at the end of the 5-month long crop season (from seeding to plant removal), resulting in lower season yields compared to indeterminate plants. Determinate plants were chosen for this study because they are, by nature of their size, less demanding than indeterminate plants and so may be more suitable for organic nutrient management systems in which nutrients have to be transformed before they become plant-available. Also, clogging of the hydroponic greenhouse fertigation systems by organic nutrient sources worsens with time, so using a determinate variety creates shorter crop seasons (and less liability), between which the fertigation lines can be thoroughly cleaned and reused for the next crop season. As a result, a greenhouse grower could potentially produce three determinate bell pepper crops per year, corresponding to spring, summer and fall. Based on the yields achieved in the Fall 2010 and Spring 2011 trials of my organic greenhouse study (and averaging the Fall and Spring yields for an estimate of what a summer crop yield would be), the Gran-Gran x PL nutrient management strategy would result in an average yearly marketable yield of 4.86 kg/m^2 and a maximum yearly marketable yield of 6.59 kg/m^2. The Gran-Soln x PL nutrient management strategy would result in an average yearly marketable yield of 7.23 kg/m^2 and a maximum yearly marketable yield of 10.08 kg/m^2. Other factors to consider are:

- The delayed transplanting, electrical issues and irrigation system clogging that negatively affected yield in the Spring 2011 trial highlights the fact that as the system is modified and improved over the years, yields will increase, thereby increasing gross revenue. Research has cited that it can take up to 5 years after transition to organic farming for growers to reach and maintain their top organic production level (U.S. Dept. of Agriculture, 2009b).

- Prices are significantly higher for organic greenhouse-grown red bell pepper compared to conventional which would result in higher gross revenue (U.S. Dept. of Agriculture, 2012a).
- Production costs may be less for determinate plants compared to indeterminate because they are significantly shorter (e.g. trellis accessories, labor, yearly fertilizer and water quantities, etc.).
- The lower nutrient management costs associated with these organic treatments (as demonstrated in Table 3-2) could be factored in.
- The costs of pesticides would not be included because pesticides are prohibited in organic production.
- Certain materials like pots, media, and irrigation lines would be re-used across crop seasons in the year.

With all these factors considered in how the organic nutrient management treatments used in my study would affect the full economic analysis of greenhouse-grown red bell pepper performed by Jovicich et al. (2005), it would be understandable to extrapolate and conclude that organic greenhouse-grown red bell pepper operations could be profitable. However a full economic analysis must be performed or the above changes made to the analysis performed by Jovicich et al (2005), in order to fully explore this hypothesis. Also different greenhouse operations vary considerably in their size, technology and infrastructure, all of which would significantly affect total costs and yields and the potential profitability of organic greenhouse colored bell pepper operations, therefore greenhouse growers should use this information only as a guide and calculate the budgets for their own enterprises.

Some research suggests that 50% of the applied nitrogen in organic nutrient sources is made available in a given season. As a result, organic production guidelines often suggest applying organic nitrogen at a rate two times that of conventional inorganic nitrogen. However, this was not done in this study because it was important to keep applied nutrient (especially nitrogen) levels consistent across treatments for comparison purposes (in both the production and economic analysis studies), and also because other research has shown higher disease incidence and leachate/substrate EC (and therefore lower marketable yields) from higher organic fertilizer rates (Miles and Peet, 2002; Rippy et al, 2004; Zhai et al., 2009). It was also important to keep organic nutrient management input costs down to help ensure positive partial net returns in the subsequent economic analysis.

Conclusions

As demand for and price premiums associated with colored, greenhouse-grown and organic fresh-market bell pepper increase, combining these aspects into a successful organic greenhouse-grown red bell pepper operation presents itself as a potentially lucrative market niche for growers to expand into. Although only a fraction of applied organic nitrogen becomes available during the season and organic yields tend to be lower than conventional yields, this study demonstrates that by keeping organic fertilizer rates consistent with typical conventional hydroponic fertilizer rates, locally sourcing relatively inexpensive organic nutrient/media sources and adjusting application strategies, the yield reduction could potentially be offset by lower nutrient management input costs and substantially higher market prices of organic compared to conventional greenhouse produce, resulting in potentially higher organic partial net returns. Since red bell pepper market prices tend to be highest in December and May (Cantliffe et al., 2008), it will be important for growers to time their growing season to capture these highest market prices. However, the economic viability of organic greenhouse-grown red bell pepper production will ultimately depend on types and amounts of organic nutrient/media sources available to a specific grower, the type of cultivar chosen (e.g.

determinate vs. indeterminate), and the specific greenhouse size, technology and infrastructure (which will affect both yields and production costs). Therefore, full cost-benefit analysis will be essential for individual growers to gauge the profitability and feasibility of such an enterprise. Future research could also focus on implementing greenhouse technologies that can contribute to organic production and in the long run reduce nutrient management and energy costs. For example, the technology exists for composting greenhouses, in which the heat and carbon dioxide generated from manure-based compost contained in a chamber attached to one side of the greenhouse can be used to heat the greenhouse during the winter months when needed (Greer and Diver, 2000). This would cut down on energy costs, prepare and provide poultry litter compost for incorporation into the media mixes of the next organic greenhouse crop season, and take advantage of local resources.

Table 3-1. Sources and prices for nutrient management materials used in greenhouse production of conventional and organic red bell peppers from determinate plants at UF's PSREU near Citra, FL in Fall 2010 and Spring 2011

Item	Source	Description	Unit	Price ($/unit)[z]
Fertilizers				
Calcium nitrate	Chemical Dynamics, FL	$Ca(NO_3)_2$	1 gal	5.15
DynaPhos phosphoric acid	Chemical Dynamics, FL	H_3PO_4	1 gal	13.50
Potassium chloride	Chemical Dynamics, FL	KCl	1 ton	870
Epsom magnesium sulfate	Giles Chemical, NC	$MgSO_4$	50 lb	15.50
Sequestrene chelated iron	Southern Ag, FL	FE 330	5 lb	36.35
Copper sulfate	Southern Ag, FL	$CuSO_4$	50 lb	92.50
Manganese sulfate	Southern Ag, FL	$MnSO_4$	50 lb	30
Zinc sulfate	Hi-Yield, FL	$ZnSO_4$	50 lb	38.75
Solubor boron	Southern States, FL	B	50 lb	38
Sodium molibdate	Southern Ag, FL	$Na_2(MoO_4)$	4 oz	5.60
Ag-Life 2-4-2 OC	Rhizogen, TX	Composted poultry manure (granular)	1 ton	405
Blending Base Fertilizer 13- 0-0	Nature Safe, KY	Hydrolyzed feather meal, meat meal and blood meal (pelleted)	1 ton	712
Allganic potassium sulfate 0-0-51	SQM, GA	K_2SO_4 (granular)	1 ton	740
Cal-CM Plus calcium sulfate MP	Art Wilson Co, NV	Anhydrite $CaSO_4$ (granular)	1 ton	182
HFPC spray dried hydrolyzed fish protein	California Spray Dry Co, CA	Fresh fish or fish frames from filleting plants (fine powder)	40 lb	68
Allganic potassium sulfate 0-0-52	SQM, GA	K_2SO_4 (crystalline, water soluble)	1 ton	670
Cal-CM Plus calcium sulfate SG	Art Wilson Co, NV	Anhydrite $CaSO_4$ (solution grade)	1 ton	106
Media				
Sunshine peat moss	SunGro Horticulture, FL	Peat; soilless substrate	1 cu yd	86
Pine bark	Elixson Wood Products, FL	Pine bark; soilless substrate	1 cu yd	8.25
Poultry litter compost	Hoovers Organic Farm, FL	Animal-based compost	1 cu yd	10
Yard waste compost	Gainesville Wood Resource and Recovery, FL	Plant-based compost	1 cu yd	15
Equipment				
MiniDos 2.5%[y]	Dosmatic U.S.A., TX	Fertilizer proportional injector	1	275

[z]Based on Fall 2010 prices.
[y]A straight-line depreciation was applied for five expected years of use.

Table 3-2. Nutrient management costs in greenhouse production of determinate red bell pepper plants under two conventional and two organic fertilizer and media treatments at UF's PSREU near Citra, FL in Fall 2010 and Spring 2011

	Per 1000 plants[z,y]							
	Convtl x NC		Convtl x YW		Gran-Gran x PL		Gran-Soln x PL	
Item	Amount	Cost($)	Amount	Cost($)	Amount	Cost($)	Amount	Cost($)
Fertilizers								
Calcium nitrate	78.32 L	106.55	78.32 L	106.55				
DynaPhos phosphoric acid	9.80 L	34.97	9.80 L	34.97				
Potassium chloride	25.95 kg	24.89	25.95 kg	24.89				
Epsom magnesium sulfate	34.24 kg	23.40	34.24 kg	23.40				
Sequestrene chelated iron	2.19 kg	35.03	2.19 kg	35.03				
Copper sulfate	0.06 kg	0.23	0.06 kg	0.23				
Manganese sulfate	0.19 kg	0.26	0.19 kg	0.26				
Zinc sulfate	0.06 kg	0.10	0.06 kg	0.10				
Solubor boron	0.24 kg	0.40	0.24 kg	0.40				
Sodium molibdate	0.01 kg	0.53	0.01 kg	0.53				
Ag-Life 2-4-2 OC					199.59 kg	89.11	155.81 kg	69.56
Blending Base Fertilizer 13- 0-0					47.91 kg	37.60	15.36 kg	12.06
Allganic potassium sulfate 0-0-51					23.75 kg	19.37	9.66 kg	7.88
Cal-CM Plus calcium sulfate MP					3.14 kg	0.63		
HFPC spray dried hydrolyzed fish protein							47.75 kg	178.94
Allganic potassium sulfate 0-0-52							14.32 kg	10.58
Cal-CM Plus calcium sulfate SG							10.95 kg	1.28
Media								
Sunshine peat moss	6.61 m^3	743.22	4.63 m^3	520.25	4.63 m^3	520.25	4.63 m^3	520.25
Pine bark	6.61 m^3	71.30	4.63 m^3	49.91	4.63 m^3	49.91	4.63 m^3	49.91
Poultry litter compost					3.96 m^3	51.85	3.96 m^3	51.85
Yard waste compost			3.96 m^3	77.78				
Equipment								
MiniDos 2.5%[x]	5.56	152.78	5.56	152.78			2.78	76.39
Total cost/1000 plants		1193.65		1027.07		768.72		978.70
Total cost/plant		1.19		1.03		0.77		0.98
Total cost/m^2[w]		3.58		3.08		2.31		2.94

[z]Estimates of amounts based on one 4-month determinate bell pepper crop and costs based on Fall 2010 prices for 1000 plants.

[y]Fertilizer x Compost treatment combinations. Fertilizer treatments: Convtl = conventional mineral-based solution injected through irrigation system throughout the season; Gran-Gran = organic granular incorporated into media at transplanting and sidedress; Gran-Soln = organic granular incorporated into media at transplanting and organic solution injected through irrigation system beginning at sidedress. Total season application of N, P, K, Ca and water were consistent across all treatments. Compost treatments: NC = no compost; YW = 30% yard waste compost by volume; PL = 30% poultry litter compost by volume. All have a media base of 1 peat : 1 pine bark (by volume).
[x]One MiniDos 2.5% fertilizer proportional injector has a 45 L/min flow rate and can service 360 plants fed by 7.6 L/h emitters. A straight-line depreciation was applied for five expected years of use.
[w]Based on a plant density of 3 plants/m^2.

Table 3-3. Estimated partial net return for yields of determinate red bell pepper plants grown with conventional fertilizer and two different compost treatments in a saw-tooth style greenhouse at UF's PSREU near Citra, FL in Fall 2010

		Estimated partial net return ($\$/m^2$)[y]						
Standard	Yield[z]	Red greenhouse-grown bell pepper price ($/5-kg carton)[x]						
Error	(kg/m^2)	15.75	18.75	21.75	24.75[w]	27.75	30.75	33.75
					Convtl x NC[v]			
-3	3.05	6.02	7.85	9.68	11.51	13.34	15.17	17.00
-2	3.19	6.48	8.40	10.32	12.23	14.15	16.07	17.99
-1	3.34	6.94	8.95	10.95	12.96	14.96	16.97	18.97
Mean	3.49	7.40	9.49	11.59	13.68	15.77	17.86	19.95
+1	3.63	7.86	10.04	12.22	14.40	16.58	18.76	20.94
+2	3.78	8.32	10.59	12.86	15.12	17.39	19.66	21.92
+3	3.92	8.78	11.14	13.49	15.84	18.20	20.55	22.91
					Convtl x YW[v]			
-3	3.08	6.61	8.45	10.30	12.14	13.99	15.83	17.68
-2	3.39	7.59	9.63	11.66	13.69	15.72	17.76	19.79
-1	3.70	8.58	10.80	13.02	15.24	17.46	19.68	21.90
Mean	4.01	9.56	11.97	14.38	16.79	19.20	21.61	24.02
+1	4.33	10.55	13.15	15.74	18.34	20.94	23.53	26.13
+2	4.64	11.54	14.32	17.10	19.89	22.67	25.46	28.24
+3	4.95	12.52	15.49	18.47	21.44	24.41	27.38	30.35

[z]Yields presented were the estimated mean marketable yield ± 3 standard errors; the estimated mean marketable yield was based on data from the Fall 2010 experimental greenhouse trials. Plant density = 3 plants/m^2.
[y]Matrix values represent [(yield x $/kg) – nutrient management cost]. Other production, harvest, and packing costs (e.g. site preparation, greenhouse structure, irrigation and climate control systems, electrical and drainage systems, growing containers, trellis accessories, IPM materials, pollinators, energy, packing cartons, labor, etc.) must be factored in to achieve a full net return.
[x]Prices per kg were calculated from published weekly average wholesale market prices for transactions of 5-kg cartons of imported, conventional greenhouse-grown, red bell peppers at the Atlanta terminal market during December and over the year period 2004-2011 (U.S. Department of Agriculture, Fruit and Vegetable Market News Portal).
[w]Mean for the collected price data.
[v]Fertilizer x Compost treatment combinations. Convtl fertilizer treatment = conventional mineral-based solution injected through irrigation system throughout the season (total season application of N, P, K, Ca and water were consistent across all treatments). Compost treatments have a media base of 1 peat : 1 pine bark (by volume) with NC = no compost, and YW = 30% yard waste compost by volume.

Table 3-4. Estimated partial net return for yields of determinate red bell pepper plants grown with two different organic fertilizer treatments and one compost treatment in a saw-tooth style greenhouse at UF's PSREU near Citra, FL in Fall 2010

		Estimated partial net return ($/m^2)[y]						
Standard	Yield[z]	Red greenhouse-grown bell pepper price ($/5-kg carton)[x]						
Error	(kg/m^2)	29.50	34.00	38.50	43.00[w]	47.50	52.00	56.50
				Gran-Gran x PL[v]				
-3	1.89	8.81	10.51	12.21	13.91	15.60	17.30	19.00
-2	2.04	9.70	11.54	13.37	15.20	17.03	18.87	20.70
-1	2.19	10.59	12.56	14.53	16.50	18.46	20.43	22.40
Mean	2.34	11.48	13.58	15.69	17.79	19.89	22.00	24.10
+1	2.49	12.37	14.61	16.85	19.08	21.32	23.56	25.80
+2	2.64	13.26	15.63	18.00	20.38	22.75	25.13	27.50
+3	2.79	14.14	16.65	19.16	21.67	24.18	26.69	29.20
				Gran-Soln x PL[v]				
-3	1.47	5.71	7.02	8.34	9.66	10.98	12.30	13.62
-2	1.77	7.49	9.08	10.67	12.26	13.85	15.44	17.03
-1	2.07	9.27	11.13	13.00	14.86	16.72	18.58	20.45
Mean	2.37	11.05	13.19	15.32	17.46	19.59	21.73	23.86
+1	2.67	12.84	15.24	17.65	20.05	22.46	24.87	27.27
+2	2.98	14.62	17.30	19.97	22.65	25.33	28.01	30.69
+3	3.28	16.40	19.35	22.30	25.25	28.20	31.15	34.10

[z]Yields presented were the estimated mean marketable yield ± 3 standard errors; the estimated mean marketable yield was based on data from the Fall 2010 experimental greenhouse trials. Plant density = 3 plants/m^2.
[y]Matrix values represent [(yield x $/kg) – nutrient management cost]. Other production, harvest, and packing costs (e.g. site preparation, greenhouse structure, irrigation and climate control systems, electrical and drainage systems, growing containers, trellis accessories, IPM materials, pollinators, energy, packing cartons, labor, etc.) must be factored in to achieve a full net return.
[x]Prices per kg were calculated from published weekly average wholesale market prices for transactions of 5-kg cartons of imported, organic greenhouse-grown, red bell peppers at the Atlanta, Boston, Chicago and Philadelphia terminal markets during December and over the year period 2004-2011 (U.S. Department of Agriculture, Fruit and Vegetable Market News Portal).
[w]Mean for the collected price data.
[v]Fertilizer x Compost treatment combinations. Gran-Gran fertilizer treatment = organic granular incorporated into media at transplanting and sidedress; Gran-Soln fertilizer treatment = organic granular incorporated into media at transplanting and organic solution injected through irrigation system beginning at sidedress; (total season application of N, P, K, Ca and water were consistent across all treatments). PL compost treatment = a media base of 1 peat : 1 pine bark (by volume) with 30% poultry litter compost by volume.

Table 3-5. Estimated partial net return for yields of determinate red bell pepper plants grown with conventional fertilizer and two different compost treatments in a saw-tooth style greenhouse at UF's PSREU near Citra, FL in Spring 2011

		Estimated partial net return ($\$/m^2$)[y]						
Standard	Yield[z]	Red greenhouse-grown bell pepper price (\$/5-kg carton)[x]						
Error	(kg/m^2)	15.75	19.75	23.75	27.75[w]	31.75	35.75	39.75
					Convtl x NC[v]			
-3	1.24	0.32	1.31	2.29	3.28	4.27	5.26	6.25
-2	1.42	0.89	2.02	3.16	4.29	5.43	6.56	7.70
-1	1.60	1.46	2.74	4.02	5.30	6.58	7.86	9.14
Mean	1.78	2.03	3.46	4.89	6.31	7.74	9.16	10.59
+1	1.96	2.61	4.18	5.75	7.32	8.89	10.46	12.03
+2	2.15	3.18	4.90	6.61	8.33	10.05	11.76	13.48
+3	2.33	3.75	5.61	7.48	9.34	11.20	13.06	14.92
					Convtl x YW[v]			
-3	0.71	-0.83	-0.26	0.32	0.89	1.46	2.03	2.60
-2	1.45	1.48	2.64	3.80	4.95	6.11	7.27	8.43
-1	2.18	3.79	5.53	7.28	9.02	10.76	12.51	14.25
Mean	2.91	6.10	8.43	10.76	13.09	15.42	17.75	20.08
+1	3.65	8.40	11.32	14.24	17.15	20.07	22.99	25.90
+2	4.38	10.71	14.21	17.72	21.22	24.72	28.22	31.73
+3	5.11	13.02	17.11	21.20	25.29	29.37	33.46	37.55

[z]Yields presented were the estimated mean marketable yield ± 3 standard errors; the estimated mean marketable yield was based on data from the Spring 2011 experimental greenhouse trials. Plant density = 3 plants/m^2.

[y]Matrix values represent [(yield x \$/kg) – nutrient management cost]. Other production, harvest, and packing costs (e.g. site preparation, greenhouse structure, irrigation and climate control systems, electrical and drainage systems, growing containers, trellis accessories, IPM materials, pollinators, energy, packing cartons, labor, etc.) must be factored in to achieve a full net return.

[x]Prices per kg were calculated from published weekly average wholesale market prices for transactions of 5-kg cartons of imported, conventional greenhouse-grown, red bell peppers at the Atlanta terminal market during May and over the year period 2004-2012 (U.S. Department of Agriculture, Fruit and Vegetable Market News Portal).

[w]Mean for the collected price data.

[v]Fertilizer x Compost treatment combinations. Convtl fertilizer treatment = conventional mineral-based solution injected through irrigation system throughout the season (total season application of N, P, K, Ca and water were consistent across all treatments). Compost treatments have a media base of 1 peat : 1 pine bark (by volume) with NC = no compost, and YW = 30% yard waste compost by volume.

Table 3-6. Estimated partial net return for yields of determinate red bell pepper plants grown with two different organic fertilizer treatments and one compost treatment in a saw-tooth style greenhouse at UF's PSREU near Citra, FL in Spring 2011

		Estimated partial net return ($\$/m^2$)[y]						
Standard	Yield[z]	Red greenhouse-grown bell pepper price (\$/5-kg carton)[x]						
Error	(kg/m^2)	34.75	37.75	40.75	43.75[w]	46.75	49.75	52.75
					Gran-Gran x PL[v]			
-3	0.21	-0.85	-0.72	-0.60	-0.47	-0.35	-0.22	-0.09
-2	0.44	0.76	1.02	1.29	1.55	1.81	2.08	2.34
-1	0.67	2.36	2.77	3.17	3.57	3.98	4.38	4.78
Mean	0.90	3.97	4.51	5.05	5.59	6.14	6.68	7.22
+1	1.13	5.57	6.26	6.94	7.62	8.30	8.98	9.66
+2	1.37	7.18	8.00	8.82	9.64	10.46	11.28	12.10
+3	1.60	8.79	9.75	10.70	11.66	12.62	13.58	14.54
					Gran-Soln x PL[v]			
-3	1.46	7.18	8.06	8.93	9.80	10.68	11.55	12.43
-2	1.79	9.48	10.55	11.62	12.70	13.77	14.84	15.91
-1	2.12	11.78	13.05	14.32	15.59	16.86	18.13	19.40
Mean	2.45	14.07	15.54	17.01	18.48	19.95	21.41	22.88
+1	2.78	16.37	18.03	19.70	21.37	23.03	24.70	26.37
+2	3.11	18.66	20.53	22.39	24.26	26.12	27.99	29.85
+3	3.44	20.96	23.02	25.09	27.15	29.21	31.27	33.34

[z]Yields presented were the estimated mean marketable yield ± 3 standard errors; the estimated mean marketable yield was based on data from the Spring 2011 experimental greenhouse trials. Plant density = 3 plants/m^2.
[y]Matrix values represent [(yield x \$/kg) – nutrient management cost]. Other production, harvest, and packing costs (e.g. site preparation, greenhouse structure, irrigation and climate control systems, electrical and drainage systems, growing containers, trellis accessories, IPM materials, pollinators, energy, packing cartons, labor, etc.) must be factored in to achieve a full net return.
[x]Prices per kg were calculated from published weekly average wholesale market prices for transactions of 5-kg cartons of imported, organic greenhouse-grown, red bell peppers at the Atlanta, Boston, Chicago and Philadelphia terminal markets during May and over the year period 2005-2012 (U.S. Department of Agriculture, Fruit and Vegetable Market News Portal).
[w]Mean for the collected price data.
[v]Fertilizer x Compost treatment combinations. Gran-Gran fertilizer treatment = organic granular incorporated into media at transplanting and sidedress; Gran-Soln fertilizer treatment = organic granular incorporated into media at transplanting and organic solution injected through irrigation system beginning at sidedress; (total season application of N, P, K, Ca and water were consistent across all treatments). PL compost treatment = a media base of 1 peat : 1 pine bark (by volume) with 30% poultry litter compost by volume.

CHAPTER 4
CONCLUSIONS AND SUMMARY

Peat and pine bark substrate amended with poultry litter compost and fertilized with all granular or either combination of organic granular and nutrient solution sources produced the highest organic greenhouse marketable red bell pepper yields of 57-138% of the hydroponic control. Because different organic nutrient fertilizers and media/composts vary considerably in their properties and rates of nutrient availability, using multiple sources of organic nutrients and a combination of incorporated, top-dressed and fertigated fertilization systems may increase the size, biodiversity and activity of the microbial populations in the media, thereby influencing the physical, chemical and biological characteristics of the media that govern plant health as well as nitrification/mineralization activities and, therefore, yield (Chang et al., 2007; Greer and Diver, 2000; Treadwell et al., 2007; Zhai et al., 2009). In my study, organic granular fertilizer treatments consisted of four different products, and organic solution fertilizer treatments consisted of three different products, for a total of seven different organic nutrient sources applied to the Gran-Soln or Soln-Gran fertilizer treatments. Since organic fertilizers delivered hydroponically tend to clog the irrigation system, it may be best to not use them at all (Gran-Gran treatment) or delay their use for the first 30 days and then fertigate with them at low concentration (Gran-Soln treatment). Incorporating half of total season nutrients via granular organic fertilizers into the media at transplant avoids excessive EC and allows the plants to derive their nutrients from granular sources until 30 days after transplant, at which time the rest of total season nutrients can be supplied by an organic granular sidedress or a dilute organic nutrient solution delivered through the irrigation system regularly until harvest.

Poultry litter compost is more effective than yard waste compost for organic greenhouse bell pepper production because it has lower pH, higher EC, more temperature-buffering capacity, higher water-holding capacity, lower C:N ratio, higher micronutrient concentrations and possibly more active nitrifying/mineralizing microorganism populations as evidenced by the higher leachate [NO_3-N] and fruit percent NUE. As a result, the media treatment containing poultry litter compost (PL) resulted in higher yields, taller plants throughout the season and greater whole plant dry weight at harvest compared to the media treatments containing no compost or yard waste compost. However, it is important to keep water availability consistent because the high sodium, potassium and soluble salt levels in poultry litter compost can lead to higher than optimal EC and salt salinity stress under water deficiency, resulting in higher blossom end rot incidence and lower yields. Also, the phosphorus content in poultry litter compost could potentially limit Ca availability through precipitation reactions, leading to blossom end rot, so effective calcium supplementation via fertilizers must be utilized to avoid this problem. On the other hand, because the poultry litter compost increased the water-holding capacity of the media to 90%, it is important to not over-irrigate, reducing the oxygen-filled pore spaces that are necessary for nitrification reactions (Evanylo and McGuinn, 2009).

For future research, it would also be interesting to apply this experiment to an indeterminate bell pepper cultivar, which is typically used in greenhouse production systems and has a crop season of 10 months. Although the organic nutrient solution in low concentration did fairly well, there were still clogging problems, and so a future study could look at exploring a variety of different organic nutrient sources to make into fertigation solution and assess their clogging potential. Also, future research could attempt to acidify the organic nutrient solution with citric acid or other OMRI-approved acidifying agent to help solubilize the materials and decrease the pH in the media of the organic treatments.

As demand for and price premiums associated with colored, greenhouse-grown and organic fresh-market bell pepper increase, combining these aspects into a successful organic greenhouse-grown red bell pepper operation presents itself as a potentially lucrative market niche for growers to expand into. Although only a fraction of applied organic nitrogen becomes available during the season and organic yields tend to be lower than conventional yields, this study demonstrates that by keeping organic fertilizer rates consistent with typical conventional hydroponic fertilizer rates, locally sourcing relatively inexpensive organic nutrient/media sources and adjusting application strategies, the yield reduction could potentially be offset by lower nutrient management input costs and substantially higher market prices of organic compared to conventional greenhouse produce, resulting in potentially higher organic partial net returns. Since red bell pepper market prices tend to be highest in December and May (Cantliffe et al., 2008), it will be important for growers to time their growing season to capture these highest market prices. However, the economic viability of organic greenhouse-grown red bell pepper production will ultimately depend on types and amounts of organic nutrient/media sources available to a specific grower, the type of cultivar chosen (e.g. determinate vs. indeterminate), and the specific greenhouse size, technology and infrastructure (which will affect both yields and production costs). Therefore, full cost-benefit analysis will be essential for individual growers to gauge the profitability and feasibility of such an enterprise. Future research could also focus on implementing greenhouse technologies that can contribute to organic production and in the long run reduce nutrient management and energy costs. For example, the technology exists for composting greenhouses, in which the heat and carbon dioxide generated from manure-based compost contained in a chamber attached to one side of the greenhouse can be used to heat the greenhouse during the winter months when needed (Greer and Diver, 2000). This would cut down on energy costs, prepare and provide poultry litter compost for incorporation into the media mixes of the next organic greenhouse crop season, and take advantage of local resources.

There is potential for organic greenhouse production of fresh market colored bell pepper to be successful for Florida growers, both in terms of yield and economic viability. However, the breadth of research on this topic needs to expand and new technologies, products and practices must be developed in order to improve organic yields, reduce costs of greenhouse production, and, eventually, render organic greenhouse production of colored bell pepper an economically and environmentally sustainable and well-established enterprise for U.S. growers.

LIST OF REFERENCES

Barrett, C.E., X. Zhao, and A.W. Hodges. 2012. Cost benefit analysis of using grafted transplants for root-knot nematode management in organic heirloom tomato production. HortTechnology 22(2):1-6.

Bar-Tal, A., M. Keinan, S. Fishman, B. Aloni, Y. Oserovitz, and M. Genard. 1999. Simulation of environmental effects on Ca content in pepper fruit. Acta Hort. 507:253-262.

Bulluck, III., L.R., M. Brosius, G.K. Evanylo, and J.B. Ristaino. 2002. Organic and synthetic fertility amendments influence soil microbial, physical and chemical properties on organic and conventional farms. Appl. Soil Ecol. 19:147-160.

Cantliffe, D.J., J.E. Webb, J.J. VanSickle, and N.L. Shaw. 2008. Increased net profits result from greenhouse-grown colored peppers compared to field production in Florida. Proc. Fla. State Hort. Soc. 121:194-200.

Celik, I., I. Ortas, and S. Kilic. 2004. Effect of compost, mycorrhiza, manure and fertilizer on some physical properties of Chromoxerert soil. Soil Till. Res. 78:59-67.

Chang, E.-H., R.-S. Chung, and Y.-H. Tsai. 2007. Effect of different application rates of organic fertilizer on soil enzyme activity and microbial population. Soil Sci. Plant Nutr. 53:132-140.

Cruz-Huerta, N. 2010. Temperature effects on ovary swelling in sweet pepper: Physiology and anatomy. Univ. of Florida, Gainesville,PhD Diss.

del Amor, F.M. 2007. Yield and fruit quality response of sweet pepper to organic and mineral fertilization. Renew. Agr. Food Syst. 22(3):233-238.

del Amor, F.M., A. Serrano-Martinez, I. Fortea, and E. Nunez-Delicado. 2008. Differential effect of organic cultivation on the levels of phenolics, peroxidase and capsidiol in sweet peppers. J. Sci. Food Agr. 88:770-777.

Dodson, M., J. Bachmann, and P. Williams. 2002. Organic greenhouse tomato production. National Center for Appropriate Technology (NCAT), ATTRA publication 54, 16p. 7 June 2012. <https://attra.ncat.org/attra-pub/summaries/summary.php?pub=54>

Evanylo, G. and R. McGuinn. 2009. Agricultural management practices and soil quality: measuring, assessing, and comparing laboratory and field test kit indicators of soil quality attributes. Communications and marketing, College of Agriculture and Life Sciences, Virginia Polytechnic Institute and State University. Virginia Cooperative Extension Publication 452-400, 9p.

Florida Dept. of Environmental Protection. 2010. SOP for using DEP's laboratory services: Containers and preservation.28 May 2010. <http://www.dep.state.fl.us/labs/docs/container_preserv.pdf>

Greer, L. and S. Diver. 2000. Organic greenhouse vegetable production. National Center for Appropriate Technology (NCAT), ATTRA publication 45, 19p. 7 June 2012. <https://attra.ncat.org/attra-pub/summaries/summary.php?pub=45>

Hartz, T.K., R. Smith, and M. Gaskell. 2010. Nitrogen availability from liquid organic fertilizers. HortTechnology 20(1):169-172.

Heeb, A., B. Lundegardh, G. Savage, and T. Ericsson. 2006. Impact of organic and inorganic fertilizers on yield, taste, and nutritional quality of tomatoes. J. Plant Nutr. Soil Sci. 169:535-541.

Hochmuth, G.J., D.N. Maynard, C. Vavrina, and E. Hanlon. 1991. Plant tissue analysis and interpretation for vegetable crops in Florida. Florida Cooperative Extension Service publication SS-VEC42, 12p.

Jovicich, E. and D.J. Cantliffe. 2004. Salts deposited on the lower stem of bell pepper contribute to a basal stem disorder in soilless greenhouse-grown plants. HortScience 39(1):36-39.

Jovicich, E., D.J. Cantliffe, N.L. Shaw, and S.A. Sargent. 2003. Production of greenhouse-grown peppers in Florida. Citrus and Vegetable Magazine 67:G7-12.

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. HortTechnology 14(4):507-513.

Jovicich, E., D.J. Cantliffe, P.J. Stoffella, and D.Z. Haman. 2007. Bell pepper fruit yield and quality as influenced by solar ratdiation-based irrigation and container media in a passively ventilated greenhouse. HortScience 42(3):642-652.

Jovicich, E., J.J. VanSickle, D.J. Cantliffe, and P.J. Stoffella. 2005. Greenhouse-grown colored peppers: a profitable alternative for vegetable production in Florida? HortTechnology 15(2):355-369.

Kelley, T.W. and G.E. Boyhan. 2009. Commercial pepper production handbook. The University of Georgia Cooperative Extension, Bulletin 1309, 45p. 6 July 2012 <http://www.caes.uga.edu/publications/pubdetail.cfm?pk_id=7461>

Kokalis-Burelle, N., J.W. Kloepper, R. Rodr´ıguez-K´abana, C.S. Vavrina, E.N. Rosskopf, and D.S. Kenney. 1999. Evaluation of amended transplant mixes for fruit and vegetable production. Proc Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions, p. 83.1–83.2. 18 Jan. 2000. <http://mbao.org/1999airc/83burell.pdf>

Kraus, H.T. and S.L. Warren. 2000. Performance of turkey litter compost as a slow-release fertilizer in containerized plant production. HortScience 35:19-21.

Kuepper, G. and K. Everett. 2004. Potting mixes for certified organic production. National Center for Appropriate Technology (NCAT), ATTRA publication 47, 20p. 7 June 2012. <https://attra.ncat.org/attra-pub/summaries/summary.php?pub=47>

Lee, J.J., R.D. Park, Y.W. Kim, J.H. Shim, D.H. Chae, Y.S. Rim, B.K. Sohn, T.H. Kim, and K.Y. Kim. 2004. Effect of food waste compost on microbial populations, soil enzyme activity and lettuce growth. Bioresour. Technol. 93:21-28.

Marcelis, L. and L.C. Ho. 1999. Blossom-end rot in relation to growth and calcium content in fruit of sweet pepper (*Capsicum annuum* L.). J. Expt. Bot. 50:357-363.

Marinari, S., G. Masciandaro, B. Ceccanti, and S. Grego. 2000. Influece of organic and mineral fertilisers on soil biological and physical properties. Bioresour. Technol. 72:9-17.

Martinez, V., F.M. del Amor, and L.F.M. Marcelis. 2005. Growth and physiological response of tomato plants to different periods of nitrogen starvation and recovery. J. Hort. Sci. Biotechnol. 80:147-153.

Miles, J.A. and M.M. Peet. 2002. Maintaining nutrient balances in systems utilizing soluble organic fertilizers. Horticultural Sciences Department, North Carolina State University, Organic Farming Res. Foundation Project Rpt., 23p.

Mylavarapu, R., W. d'Angelo, and N.S. Wilkinson. 2010. Comprehensive quality assurance plan. Environmental water quality laboratory QA Manual 6: Doc 6.

Mylavarapu, R.S. and E.D. Kennelley. 2002. UF/IFAS extension soil testing laboratory (ESTL) analytical procedures and training manual. Florida Cooperative Extension Service publication CIR 1248. July 2012. <http://edis.ifas.ufl.edu/SS312>

Nutrition Business Journal. 2009. U.S. organic food sales–($Mil), 1997-2010e–chart 22. New Hope Natural Media, Inc., Boulder, CO.

Olson, S.M. and B. Santos (eds.). 2013. Vegetable production handbook for Florida 2012-2013. Inst. Food Agr. Sci., Univ. of Florida, Gainesville.

Organic Materials Review Institute. 2010. OMRI products list: A directory of products for organic use, provided by OIA North America. NOP USDA Organic Certification Program. <http://www.omri.org>

Organic Trade Association. 2011. U.S. organic industry overview. Organic industry survey. 26 Jan. 2012. <http://www.ota.com/pics/documents/2011OrganicIndustrySurvey.pdf>

Ortas, I., A. Demirbas, C. Akpinar, M. Simsek, and Z. Kaya. 2009. The effects of organic material and mycorrhizal inoculation on horticultural seedling quality. UC Davis: The proceedings of the international plant nutrition colloquium XVI.

Osborne, L.S., and J.E. Barrett. 2005. You can bank on it, banker plants can be used to rear natural enemies to help control greenhouse pests. Ornamental Outlook, Sept. 2005:26-27.

Paul, E. and F.E. Clark. 1996. Soil microbiology and biochemistry. Academic Press, San Diego, CA.

Rippy, J.F.M., M.M. Peet, F.J. Louws, P.V. Nelson, D.B. Orr, and K.A. Sorensen. 2004. Plant development and harvest yields of greenhouse tomatoes in six organic growing systems. HortScience 39(2):1-7.

Rivard, C.L., O. Sydorovych, S. O'Connell, M.M. Peet, and F.J. Louws. 2010. An economic analysis of two grafted tomato transplant production systems in the United States. HortTechnology 20(4):794-803.

Russo, V.M. 2006. Biological amendment, fertilizer rate, and irrigation frequency for organic bell pepper transplant production. HortScience 41(6):1402-1407.

Saha, K.S. and D.J. Cantliffe. 2009. Utilization of chlorination and soilless media for management of *Pythium aphanidermatum* (Edson) Fitzp. in greenhouse production of *Capsicum annuum* L. in a closed soilless system. Univ. of Florida, Gainesville,PhD Diss.

Sanchez, E.S. and T.L. Richard. 2009. Using organic nutrient sources. The Pennsylvania State University, Ag Communications and Marketing publication UJ256, 15p. 13 Mar. 2009. <http://pubs.cas.psu.edu/FreePubs/pdfs/uj256.pdf>

SAS Institute. SAS/STST User's Guide, Version 9.2; SAS Inst.: Cary, NC, 2011.

Schwankl, L.J. and G. McGourty. 1992. Organic fertilizers can be injected through low-volume irrigation systems. California Agriculture, September-October:21-23.

Shaw, N. and D.J. Cantliffe. 2002. Brightly colored pepper cultivars for greenhouse production in Florida. Proc. Fla. State Hort. Soc. 115:236-241.

Shuler, K.D. 2003. Performance of bell pepper varieties over two seasons in southeast florida, 2000-2002. Proc. Fla. State Hort. Soc. 116:107-137.

Succop, C.E. and S.E. Newman. 2004. Organic fertilization of fresh market sweet basil in a greenhouse. HortTechnology 14(2):235-239.

Treadwell, D.D, G.J. Hochmuth, R.C. Hochmuth, E.H. Simonne, L.L. Davis, W.L. Laughlin, Y. Li, T. Olczyk, R.K. Sprenkel, and L.S. Osborne. 2007. Nutrient management in organic greenhouse herb production: Where are we now? HortTechnology 17(4):461-466.

U.S. Dept. of Agriculture. 2008a. Table 64: World bell and chile peppers, production, 1990-2007. Econ. Res. Serv., U.S. Dept. Agr. Economics, Statistics and Market Information System. United Nations, Food and Agriculture Organization, FAOStat. 5 Nov. 2008. <http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1659>

U.S. Dept. of Agriculture. 2008b. Tables 6 and 7: U.S. bell peppers, production and value of production by state, 1960-2007. Econ. Res. Serv., U.S. Dept. Agr. Economics, Statistics and Market Information System. Natl. Agr. Stat. Serv., vegetables annual summary. 5 Nov. 2008. <http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1659>

U.S. Dept. of Agriculture. 2008c. Table 10: Certified organic vegetables; acres of tomatoes, lettuce, carrots, mixed vegatables and unclassified vegetables by state, 1997 and 2000-08. Econ. Res. Serv., U.S. Dept. Agr. 24 Sept. 2010. <http://www.ers.usda.gov/data-products/organic-production.aspx>

U.S. Dept. of Agriculture. 2009a. Census of agriculture, quick stats. Natl. Agr. Stat. Serv., U.S. Dept. Agr.. 30 June 2010. <http://quickstats.nass.usda.gov/>

U.S. Dept. of Agriculture. 2009b. Marketing U.S. organic foods: Recent trends from farms to consumers. Econ. Res. Serv., U.S. Dept. Agr. Economic Information Bulletin Number 58 (by C. Dimitri and L. Oberholtzer), 36p. 7 April 2010. <http://www.ers.usda.gov/publications/eib-economic-information-bulletin/eib58.aspx>

U.S. Dept. of Agriculture. 2012a. Fruit and Vegetable Market News Portal. Agr. Mktg. Serv., U.S. Dept. Agr. 6 July, 2012. <http://marketnews.usda.gov/portal/fv>

U.S. Dept. of Agriculture. 2012b. Electronic code of federal regulations. Title 7, Subchapter M: Organic foods production act provisions, Sections 205.1-205.691. U.S. Dept. Agr. 24 July, 2012. <http://ecfr.gpoaccess.gov>

Van Delden, A. 2001. Yield and growth components of potato and wheat under organic nitrogen management. Agronomy Journal 93:1370-1385.

Zbeetnoff Agro-Environmental Consulting. 2006. The North American Greenhouse Vegetable Industry, Farm Credit Canada. 6 June 2010. <http://www.fcc-fac.ca>

Zhai, Z., D.L. Ehret, T. Forge, T. Helmer, W. Lin, M. Dorais, and A.P. Papadopoulos. 2009. Organic fertilizers for greenhouse tomatoes: productivity and substrate microbiology. HortScience 44(3):800-809.

Zinati, G.M. 2005. Compost in the 20th century: A tool to control plant diseases in nursery and vegetable crops. HortTechnology 15:61-66.

Zvomuya, F., C.J. Rosen, M.P. Russelle, and S.C. Gupta. 2003. Nitrate leaching and nitrogen recovery following application of poly-olefin coated urea to potato. J. Environ. Qual. 32:489-489.

BIOGRAPHICAL SKETCH

Allison Beyer was born in 1982 in Smithtown, Long Island, New York. She received her Bachelor of Arts degree in biology from Cornell University in December 2005. In October 2007, she began working for the University of Florida as a research assistant and field technician at the research farm in Hastings, FL under Dr. Chad Hutchinson. In 2008, she was promoted to senior statistician, conducting research and reporting on potato variety selection, BMP nitrogen rates, and performance of controlled release fertilizers with a variety of crops. In January 2010, she began her graduate studies in the Department of Horticultural Sciences at the University of Florida in Gainesville under advisor Dr. Danielle Treadwell and committee members Dr. Dan Cantliffe and Dr. Michael Gunderson, working on nutrient management strategies and economic analysis of organic greenhouse production of red bell pepper.