MASTER'S THESIS

GREENHOUSE PRODUCTION OF FRESH MARKET BASIL

Submitted by
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WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY C. ELIZABETH SUCCOP ENTITLED GREENHOUSE PRODUCTION OF FRESH MARKET BASIL BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

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ABSTRACT OF THESIS
GREENHOUSE PRODUCTION OF FRESH MARKET BASIL

Common green sweet basil, *Ocimum basilicum* L., is a viable crop for fresh market greenhouse production due to its high value and increasing demand. Organically and hydroponically grown products conserve natural resources while providing a marketing edge and sales advantage for producers. Greenhouse growing methods fulfill a need for locally grown organic produce during the off-season. Data on greenhouse production of fresh market basil is needed by Colorado growers for efficient and profitable production.

Growing/irrigation systems had an effect on the greenhouse production of fresh market basil. Comparison of bag mix, perlite, and rockwool growing systems were made within organic and salt-based fertilizer treatments. Differences were found among growing systems for total harvest per plant, final plant dry weight and final plant height depending on the fertilizer treatment and the summer/fall 1996 or spring/summer 1997 growing season.

Comparisons were also made between fertilizer treatments within growing media. Basil yield in the organic fertilizer compared to the conventional, salt-based fertilizer depended on the growing system, the week of harvest, the *Fusarium* infection in 1997, and the growing season. Variables of interest were weekly harvested fresh weights, weekly harvested dry weights, and weekly chlorophyll readings with a SPAD meter. Nitrate nitrogen measurements and a complete plant leaf tissue analysis were taken at the termination of each study. Additionally, organoleptic taste test panel members performed a triangle difference test between the organically fertilized plants and the salt-based fertilized plants for the perlite, bag mix and rockwool growing systems. Panel members also performed a preference test between organically fertilized and conventionally fertilized plants.

This research determined that basil can be successfully grown hydroponically and organically in a Colorado greenhouse. The physical appearance and health of the plants declined after four months of

weekly harvesting in the 1996 and 1997 studies. During the last month of production of the 1996 study, the fresh weight and dry weight yields decreased for all growing systems reflective of the decreasing light intensities. The 1997 study shows an upward trend in fresh weight and dry weight yields for all growing systems reflective of increasing photoperiod reactions

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CHAPTER I

INTRODUCTION

Common green sweet basil, *Ocimum basilicum* L., is a choice crop for greenhouse production due to its high dollar value, popularity, and demand. The United States Agricultural Statistics reveal that between 1964 and 1984 basil imports into the United States increased from 19,000 kg to 1,437,000 kg per year (DeBaggio and Belsinger, 1996). Data on greenhouse production of fresh market basil is needed by Colorado growers for efficient and profitable production to meet the public demand for basil. Only a few greenhouses in Colorado are growing basil hydroponically or organically, but none are doing both. Organically and hydroponically grown products provide a marketing edge and sales advantage for producers (Marter, 1996). Many soil-borne diseases cause continual problems and concerns for greenhouse producers of organic basil. Hydroponic culture has the potential to reduce or eliminate disease and pest problems. Greenhouse hydroponic organic growing methods fulfill a need for locally grown organic produce during the off-season (Schoenstein, 1996).

The overall goals of this research were to determine if and in what manner basil can be successfully grown in a Colorado greenhouse, and whether basil can be organically grown in a greenhouse. In order to achieve the overall objectives, the following objectives were formulated:

1. Establish the length of time that basil plants are productive in the greenhouse under selected growing conditions.
2. Compare hydroponic greenhouse production of fresh market basil produced with different growing/irrigation systems.
3. Determine if the organic fertilizer produces an equal or better crop compared to a conventional, salt-based fertilizer.
4. Determine if a taste preference can be detected between organically grown basil and traditionally grown basil.

CHAPTER II

GENERAL LITERATURE REVIEW

Hydroponic Plant Production

Hydroponics is the science of growing plants in a soil-less medium. The roots feed on a nutrient rich solution that contains all the essential elements necessary for the normal plant growth and development. Plants grown hydroponically are not physiologically different from plants grown in soil. Both inorganic and organic components need to be decomposed into inorganic elements in order to become available for plant uptake (Carpenter, 1994). However, the plant processes involved in obtaining minerals from a soil solution compared to a hydroponic solution are different. Mineral nutrients become available for plant uptake when soil colloids release minerals into the soil solution through solubilization of soil minerals and organic matter (Resh, 1995). In hydroponic culture, dissolved nutrients are delivered to the plant in a solution rather than a soil solution. Therefore, hydroponics allows a grower to maintain the plant in an ideal nutrient condition. However, the margin of error is great due to the lack of buffering capacity, which can result in plant starvation or nutritional stress.

Hydroponics is an efficient, profitable, and sanitary technology for growing plants when done properly. Hydroponics is a valuable means of growing plants in regions with little arable land or regions with large, dense populations (Schoenstein, 1996). Hydroponic culture allows for increases in density spacing and yields due to minimal competition among roots. For example, hydroponic organic basil producers in California spaced their plants at 12.7 cm centers (Schoenstein, 1996) as compared to a conventional spacing of 30 to 46 cm (Debaggio and Belsinger, 1996). Herbs have the potential to grow up to 25 percent faster in a hydroponic solution compared to soil (Skagg, 1996). Plants grown hydroponically have a threefold increase in vitamins and minerals compared to plants grown in soil. (Skagg, 1996). By the year 2000, Dutch growers will more than likely be totally free of soil (Carpenter, 1994).

Organic Plant Production Versus Salt-based Fertilizer Plant Production

Colorado Department of Agriculture established an organic certification program in 1993. The Organic Certification Act Title 35 Article 11.5 outlines guidelines for producing and certifying organic food products. The act ensures uniform quality of organic products to protect the consumer and producer by standardizing production, labeling, and marketing (Organic Certification Act, 1996). In order for an agricultural product to be certified organic in Colorado, it must be grown or produced without the use of artificial irradiation, synthetic pesticides, synthetically compounded fertilizers, or synthetic plant and soil amendments; pesticide and chemical residues cannot be greater than 5 percent of the tolerance levels determined by the United States Food and Drug Administration or the Environmental Protection Agency; and the product must be documented as organic through the certification program of the Commissioner of Agriculture of Colorado (Organic Certification Act, 1996). In the United States, there are 26 organic certifying groups and over 5,000 certified organic producers (Schoenstein, 1996).

A grower must consider the advantages and disadvantages of organic or salt-based fertilizers when selecting a production system. The advantages of using salt-based fertilizers include a high nutrient analysis per unit weight, an immediate availability of nutrients to the plant, fertilizer uniformity, and the precision of the nutrient analysis. Research comparing organic and mineral nitrogen sources on yield concluded that mineral nitrogen was as productive as a three-fold greater organic nitrogen source (Maga, 1976). The high nutrient analysis per unit weight is seen in the comparison of cow manure at 2 percent nitrogen per weight basis with a common chemical fertilizer at 30 to 40 percent nitrogen per weight basis. This difference requires an application of 15 to 20 times more cow manure than chemical fertilizer for the same crop response (Cox, 1992).

The claim that salt-based fertilizers produce higher yielding crops than organic fertilizers remains questionable. Plants absorb nitrogen in the soluble forms of ammonium (NH_4^+) or nitrate (NO_3^-). Research has found that sweet basil plants fertilized with nitrate have a higher linalool and eugenol oil content than plants fertilized with ammonium (Cox, 1992). Additionally, research comparing nitrate or ammonium forms of nitrogen on basil concluded that ammonium decreased plant height, stem plus petiole dry weight, and essential oil content due to decreased yield, but nitrogen form did not effect leaf blade dry weight

(Adler, 1989). However, research on subirrigation of basil concluded no difference between nitric and ammoniacal forms of nitrogen on fresh weight of plants, but ammonium sulfate increased plant height and calcium nitrate increased nitrate content in leaves (Tesi, 1995). The availability of nitrogen in the fertilizer type is responsible for yield response in a *Lycopersicum* (tomato) study. Montagu (1990) found that application of a blood and bone organic N fertilizer had the same positive yield response as applications of either KNO_3 fertilizer or $(NH_4)_2SO_4$ inorganic N fertilizer due to similar instantaneous release behavior of N. As reviewed by Montagu (1990), researchers (Haworth 1961; Nilsson 1979; Svec et al. 1976) found that yields were not different for a range of vegetables produced with organic N fertilizers compared to inorganic N fertilizers. Research on *Allium Ampeloprasum* (leek) and *Daucus carota* (carrot) pot trials, leeks followed by *Brassica Rapa* (turnips) in container trials, and leek and *Brassica oleracea* (kale) field trials found no difference in yields between organic or conventional methods (Lairon, 1986). However, research on *Apium graveolens var. rapaceum* (celeriac) found a decrease in weight of organic celeriac compared to conventional celeriac.

The disadvantages to salt-based fertilizers address the concerns of living in a world of diminishing resources. The concerns of using salt-based fertilizers are the excessive energy requirements for manufacturing, the pollution caused by mining and processing, and the potential depletion of phosphorous, potassium, and other finite resources (Fischer and Richter, 1986). The main disadvantage, from an organic perspective, to salt-based fertilizers is that they are synthetically manufactured, which means the composition or formulation of a substance is chemically or genetically altered by combining, extracting, or refining through human activity.

The advantages of using organic fertilizers are that they are obtained from animal or plant residues, they utilize and recycle waste materials, they provide the grower with a marketing edge and higher sale price, the produce has a higher nutrient concentration, and the nutrients are held in organic molecules (Cox, 1992). According to the United States Department of Agriculture and industry calculations, organic produce has an average of 15 to 20 percent higher sale price than conventional produce (Marter, 1996). The nutritional value of organic foods compared to traditional commercial foods is twice the elemental concentration on a fresh weight basis (Smith, 1993).

However, research demonstrates that the word organic is not consistently synonymous with superior nutritional quality. When field research controlled for heredity, climate, available moisture, and available nitrogen, the results found no difference in crude protein content, moisture, and ash of organically and conventionally grown *Triticum* (wheat) (Shier, 1984). Claims have been made for higher nutritional quality of organic *Lycopersicum* (tomatoes), but research found no effects of nitrogen fertilizer form on vitamin C content of tomatoes (Montagu, 1990). Experiments show that potatoes grown with farmyard manure or compost compared to mineral fertilizer had higher food quality and vitamin C, and research found potatoes from organic farms had less nitrate and more vitamin C than *Solanum tuberosum* (potatoes) from conventional farms (Fischer and Richter, 1986). Research on *Daucus carota* (carrots) and *Apium graveolens var. rapaceum* (celeriac) found organic fertilizer compared to mineral fertilizer increased *B*-carotene and vitamin B1 content in carrots, increased vitamin C and dry matter in celeriac, and decreased nitrates in celeriac (Leclerc, 1991). As reviewed by Leclerc (1991), studies have shown that organically grown carrots were higher in phosphous (Nilsson 1979; Schuphan 1974; Termine 1984) and in calcium (Nilsson, 1979), whereas no difference occurred for potassium (Nilsson 1979; Termine 1984), magnesium (Schuphan 1974; Nilsson 1979) or vitamin C (Guerillot-Vinet et al. 1961; Nilsson 1979). Previous research on *B*-carotene found organically grown carrots to have the same, lower, or higher content than conventionally grown depending on the study (Leclerc, 1991).

Nutrients are slowly released during microbial decomposition from organic molecules resulting in long- term effects of the fertilizer, the creation a residual pool of organic nitrogen, and the prevention of nutrient leaching especially nitrate nitrogen (Smith and Hadley, 1989). However, it may be disadvantageous for nutrients not to be immediately available due to the necessary microorganism decomposition process required for nutrient availability. Additional disadvantages of organic fertilizers are a low nutrient analysis per unit weight, variability among batches, and a sometimes-unpleasant odor.

Research on plant quality of herbs grown with organic compared to chemical fertilizer have mixed results according to the variable of interest and the herb. The effects of manure composted fertilizer compared to chemical fertilizer on eight common herbs *Origanum majorana* (marjoram), *Hyssopus officinalis* (hyssop), *Origanum* spp.(oregano), *Agastache foeniculum* (anishyssop), *Mentha x piperita* (peppermint), *Carum carvi* (caraway), *Ocimum basilicum* (sweet basil), and *Dracocephalum* (dragonhead) revealed that a higher percentage of essential oil was present in all the herbs fertilized with composted manure, except peppermint, which had a higher percentage of essential oil with the chemical fertilizer (Aflatuni, 1993). Greater dry matter yields on marjoram, oregano, and peppermint were observed with composted manure, but higher yields on the remaining herbs were observed with the chemical fertilizer. Herbs treated with the composted manure had a greater percentage dry matter, except anishyssop, which was higher with the chemical fertilizer. Heights for the all the herbs were not different, except basil, which was taller with the chemical fertilizer. There were no differences between fertilizers in plant development and vigor for all the herbs (Aflatuni, 1993).

The Organic Market

Organic sales reflect the consumer's belief that environmentally friendly and chemical free produce are important for a healthy body and a responsible planet. Between 1991 and 1994, the U.S. Department of Agriculture statistics showed a doubling in acreage of organic farmland (Blank, 1996). Organic commodity sales in the United States are approximately $3 billion per year and have increased 22 percent per year (Marter, 1996). Another source shows sales of organic products at $178 million in 1980 and exceeding $4 billion in 1998, as well as sales of the undefined "natural" products exceeding $12 billion in 1998 (Gwynne, 1998). The Food Marketing Institute in 1995 reported that 42 percent of mainstream stores regularly stocked organic produce with an average of 12 organic items. Additionally, a quarter of the shoppers surveyed purchased organic foods at least once per week (Marter, 1996). Membership in Community Supported Agriculture (CSAs), small local farms that grow and deliver organic produce to shareholders, increased 160 percent between 1994 and 1996 (Blank, 1996).

Examples of the success of the organic production industry and consumer demand for organic products follow. Fresh Fields, a supermarket chain that sells organic produce, began as one store in Maryland and grew over a five year period to 22 stores in eight states with sales of $250 million per year (Marter, 1996). The growth of this company is indicative of the demand for organic produce. Customers benefit from the success of the supermarkets with lowered food prices from bulk orders. In 1997, Whole

Foods Market bought the Fresh Fields chain making Whole Foods one of two national natural-foods chains (Gwynne, 1998). Wild Oats, another national chain, grew 75% in 1997 when it bought the Alfalfa's supermarket chain. Whole Foods began in 1980 as a single store in Austin, Texas, and experienced a 900% growth in the 1990s for a total of 78 stores in 17 states. Their success was due to the public's demand for organic food, the 2,787 square meters size of the store, which allows for some mainstream shopping items and conveniences, and the employee work satisfaction as reflected by Fortune magazine as one of the top 100 places to work (Gwynne, 1998).

Mainstream supermarkets have benefited from the demand for organic produce. The introduction of organic foods to a supermarket in Boulder, Colorado created a logistic problem however; all the organic *Citrus sinensis* (oranges) and *Cucumis sativus* (cucumbers) had to be taped to distinguish them from non-organic; and the pricing and labeling required constant updating. Cashiers had difficulty distinguishing the organic from the non-organic produce. Therefore, to reduce confusion the store began charging the same price for organic foods as non-organic. This supermarket continues to struggle to supply the high demand for inexpensive organic food, which has taken on the role of a loss leader in the store (Glenn, 1994). Supermarket chains such as Albertson's and Safeway have increased their organic selection as well (Gwynne, 1998).

Organoleptic Taste Tests

Organic produce has acquired a general consumer perception of superior taste, freshness, and quality compared to conventional produce. Food quality assessment involves outer appearance, technological properties and nutritional quality (Plochberger, 1989). The primary criterion for consumer perception is typically the appearance of fruits and vegetables. Additionally, consumers tend to choose their tomatoes based on the origin and production method, whereas consumers tend to choose their apples based on the variety (Alvensleben and Meir, 1990). Perception distortion occurs when a consumer demonstrates a selective perception for the properties of a positive image product, which causes the positive image to become inaccurately stabilized as a halo-effect. A halo-effect attaches a preconceived atmosphere or quality about a product in a positive or negative direction. The perception distortion theory was confirmed by the halo-effect results from a taste test comparing identical tomatoes with different origin labels (Alvensleben and Meir, 1990). Results found a positive direction distortion of organic and/or field grown *Lycopersicum* (tomatoes), whereas the results found a negative halo-effect of glasshouse tomatoes. Results from taste tests with *Malus* (apples) found a positive direction distortion of familiar varieties (Alvensleben and Meir, 1990). In a taste test for wild *Euterpe edulis* (hearts of palm), wild *Euterpe oleracea* (hearts of palm), and cultivated *Gactris gasispaes* (hearts of palm), panelists who were familiar with hearts of palm reacted positively and were accepting of the product compared to the mixed likes and dislikes reaction of those panelists unfamiliar with the product (Lawless, 1993). A health survey showed purchasers of organic foods believe that organic food is more nutritious, fresher, and better tasting (Sloan, 1994).

The key question to answer is whether the cultivation method effects the quality of agricultural products. Hens fed with the organically produced food were heavier after 32 weeks, had greater weight gain after illness, and had heavier eggs and yolks then hens fed with the conventional food (Plochberger, 1989). Hens fed with conventional feed had eggs containing greater egg albumen. In an immediately succeeding preference test, hens from both groups distinguished between the two feeds and preferred the organically produced food compared to the conventional food (Plochberger, 1989). In other research with mice, litter size at birth, the weaning ability of the mother, and the time interval between successive litters was not different between animals receiving *Triticum* (wheat) grown with organic, chemical or a mixed organic/chemical feed (McSheehy, 1977). The offspring from parents receiving wheat grown with the mixed fertilizer were heavier compared to animals receiving the organic or chemical feed (McSheehy, 1977).

Taste tests comparing quality of organically and conventionally grown food have given inconsistent preference results. The results from a taste test of fruits and vegetables were mixed. There was no difference between the organic and conventional produce type in hedonic ratings and scores for *Citrus x paradisi* (grapefruit), *Vitis* (grapes), *Daucus carota* (carrots), *Spinacia oleracea* (spinach), *Zea mays* var. *saccharata* (sweet corn), and *Lycopersicum* (tomatoes) (Basker, 1992). However, the conventional type was preferred for *Mangifera indica* (mangoes) and *Citrus sinensis* (orange) juice, whereas the organic type was preferred for *Musa* (bananas) (Basker, 1992). The results of a taste test series over three years for tomato fruits were inconsistent. The research compared the taste of organic and conventional type *Saturn* (tomatoes) located on different positions of the plant as indicated by their cluster number. In 1980, the organic cluster No. 3 and No. 5 tomatoes were preferred; in 1981, the organic cluster No. 3 was preferred, but there was little difference in preference for clusters No. 1 and No. 6; and in 1982, the organic cluster No. 3 was preferred, but there was no difference in preference for clusters No. 1,2, and 4-8 (Yoshida, 1984).

Growing Media

Rockwool culture originated in Denmark in 1969 and is the principle form of hydroponics in the world (Resh, 1995). Rockwool is a fibrous material consisting of a molten mass of basalt, limestone, volcanic rock, and coke converted to mineral wool at high temperatures of 1500C to 2000C (Resh, 1995). Dry, pressed rockwool is 95 percent pore space and 5 percent solid by volume. Wet rockwool is 80 percent water, 15 percent air, and 5 percent solid (Barker, 1995). The ideal medium for plant growth consists of 25 percent water space, 25 percent air space, 45 percent mineral matter, and 5 percent organic matter (Carpenter, 1994). Irrigation should exceed 10 to 20 percent of plant requirements in order to alleviate salt accumulation (Barker, 1995). Fertilizer should be applied one to eight times each day with irrigation (Carpenter, 1994). The benefits of the medium are that it is sterile, uniform, lightweight, inert, and odorless. Rockwool has a pH of 7 to 8 and no cation exchange capacity. Rockwool is a recommended, suitable hydroponic growing medium for herbs when using a non-recirculating system (Barker, 1995). Problems associated with using rockwool are that it is not biologically degradable, disposal of the material may be difficult, and it is relatively expensive. Additionally, the lack of buffering capacity makes the margin of error large and potentially costly. Rockwool produced lower yields of greenhouse *Cucumis sativus* (cucumbers) than peat/sand and peat/sand/vermiculite media during one season, and lower yields than peat/sand, peat/sand/vermiculite, the peat moss alone, and peat/vermiculite media during the second season (Abou-Hadid, 1995).

Perlite culture is an alternative growing system to rockwool culture. Perlite has a volcanic origin and is mined from lava flows. Crude ore is crushed, screened, and heated to 750C to create perlite (Carpenter, 1994). The heating process expands the ground volcanic glass into white fluffy silicaceous masses with a typical particle size of 2 to 3mm. Perlite is a suitable hydroponic medium due to its ease of use, reliability, high water holding capacity of approximately 50 percent by volume, and its superior capillary rise of water enabling uniform distribution (Barker, 1995). The medium does not absorb water. However, perlite has a large surface area to which water adheres, and the medium holds three times its weight in water. Perlite has high air porosity allowing for easy drainage. The benefits of the medium are that it is sterile, uniform, lightweight, inert, and odorless. Perlite has a pH of 6.0 to 8.1, has no cation exchange capacity, and has few or no mineral nutrients (Carpenter, 1994). The cost of perlite is moderately high compared to other soil-less media and concerns with perlite include inhalation risks of dry new perlite dust, which is a health hazard. The material is inorganic, the disposal of the material may be difficult, and the particle size deteriorates as a result of over mixing while moist. Additionally, the lack of buffering capacity makes the margin of error large and potentially costly.

Peat is the prevailing ingredient in most conventional greenhouse crop culture soil-less mixtures. Peat is the residue of aquatic, marsh, bog, or swamp vegetation. Lignin is the main substance remaining after the decomposition of peat removes proteins, sugars, starches, and cellulose (Barker, 1995). Organic matter is a beneficial addition to a medium because it has high water holding capacity, aeration, and cation exchange capacity. A growing system with a peat-based medium is typically open and noncirculating (Barker, 1995). Sphagnum peat holds 12 to 20 times its weight in water and has 92 to 97 percent pore space. Sphagnum peat is clean and lightweight, has low soluble salts, and does not add significant amounts of nutrients to the media (Carpenter, 1994). Sphagnum peat is the most common organic constituent for greenhouse media due to its beneficial characteristics, wide availability, and relatively low cost. However, it is becoming increasingly unavailable, expensive, and variable. The main structural problem with peat is the low aeration of the material relative to other media.

Botanical Classification of Basil

Common green sweet basil, *Ocimum basilicum* L. has been cultivated for more than 2,000 years. The genus name, *Ocimum*, was derived from the Greek word Okimum, which means smell. Theophrastus used the name *Ocimum* for basil around 300 BC (Bown, 1995). The species name, *basilicum*, of common sweet basil is the Latin translation of the Greek word basilikon, which means king (DeBaggio and Belsinger, 1996). Basils are classified as part of the Lamiaceae family with square stems, opposite leaf orientation, and flowering characteristics.

Botanical identity of basil is somewhat controversial. Because *Ocimum basilicum* is such a variable species, many of the variants available in the horticultural trade have not been identified by botanists and are nearly impossible to obtain outside the country of origin (Bown, 1995). *Ocimum basilicum* 'Anise' originated from Iran, *O. basilicum* 'Cinnamon' is a Mexican cultivar, *O. basilicum* var. *citriodorum* originated from northwestern India, *O. basilicum* 'Genovese' is an Italian cultivar, *O. basilicum* 'Cuban' originated in Cuba, *O. basilicum* 'True Thai' grows wild in Thailand, and *O. basilicum* 'Mexican Spice' originated in Mexico (Bown, 1995; DeBaggio and Belsinger, 1996). Depending upon the author, there are 30 to 150 basil species (DeBaggio and Belsinger, 1996) and there are a minimum of 60 cultivars of *Ocimum basilicum* (Simon et al., 1984). Much of the discrepancy can be allied to its physical variability resulting from cross-pollination and ease of interspecific hybridization. This polymorphic tendency is exemplified in the leaf size, which ranges from as small as 1 cm to as large as 15 cm, and in the height range from 15 cm to 1.5 m.

The diverse gene pool of this genus is responsible for the magical list of basil aromas, which include lemon, camphor, cinnamon, clove, mint, licorice, rose and anise. Once specific cultivars are identified, testing procedures for chemical typing of basils can be done to label varieties according to essential oil content as well as appearance (DeBaggio and Belsinger, 1996). Chemical analysis of sweet basil has identified linalool, methyl chavicol, and eugenol as the three main constituents of the essential oil content of basil, and thus aroma. Linalool evokes a floral aroma, methyl chavicol provides an anise aroma, and eugenol gives a clove aroma. The determination of the percentages of these three chemicals in a basil plant is one method of identifying a sweet basil variety (Bown, 1995).

The Origin of Basil

The origin of basil is uncertain. Basil may have originated in India, spread through Asia Minor to Greece and Rome, across to northern Europe, and finally North America (Bonar, 1985). Darrah (1980) suggested that *Ocimum basilicum* was brought to Greece by Alexander the Great (356-323 BC) from a trip to Asia. The cultivation of basil spread throughout the world from Greece (Darrah, 1980). Basil was then introduced by explorers and conquerors to Europe around 2000 years ago (DeBaggio and Belsinger, 1996). In the sixteenth century, Gerard's herbal describes four basil species (Gerard, 1975). In the eighteenth century, basil seeds and plants were collected from around the world, which lead to the naming of sixty basil varieties by European horticulturists (DeBaggio and Belsinger, 1996). The Swedish botanist Linnaeus described eight basil species in 1762, and the English botanist Bentham classified 29 basil species and nine varieties of *Ocimum basilicum* by 1836 (DeBaggio and Belsinger, 1996). In the 1930s, John Briquet classified 47 basil species. Basil was brought to the New World by European colonists around 1621 (DeBaggio and Belsinger, 1996).

Today, basil is cultivated in France, Egypt, Hungary, Indonesia, Morocco, the United States (California and Hawaii), and Greece (Simon et al., 1984). Basil is now considered to be native to Africa, Asia, India, the Middle East, the Caribbean, and South America.

The Wild Parentage and Wild Species of Basil

Although basil species do grow wild in certain regions of the world, the wild parentage of basil has not been identified. One theory postulates that popular culinary herbs such as *Ocimum basilicum* have no record of wild ancestory due to their long history of use and cultivation (Bown, 1995). Bown concluded that the wild ancestors became extinct as a result of overcollection. Possible wild species may be *Ocimum micranthum* Willdenow, *Ocimum basilicum* 'Minimum', and *Ocimum americanum*. *Ocimum micranthum* has the common name wild basil and it is described as a common weed of dry waste places (Morton, 1981). *Ocimum micranthum* is native to South America, the Caribbean, and Florida, and is commonly gathered from the wild (Darrah, 1980). Despite the common name wild basil, the literature does not support *Ocimum micranthum* as the wild parent. *Ocimum basilicum* 'Minimum' is the hardiest cultivar in poor growing conditions (Bremness, 1988) and is a weedy species surviving without intervention and care. However, the literature does not identify *Ocimum basilicum* 'Minimum' as a wild ancestor. Stewart (1972) identified *Ocimum americanum* as a possible wild form of *Ocimum basilicum* in west Pakistan and Kashmir. *Ocimum americanum* is a small, wild shrub, which is smaller in all its parts than *Ocimum basilicum* and is perennial (Stewart, 1972). One of the changes associated with the domestication of plants is the change from a perennial life cycle to annual. This tendency supports the theory that *Ocimum americanum* may be a possible wild form of *Ocimum basilicum*. The majority of basils are annuals, while the minority of basils are perennial in their native tropical habitats.

Extensive breeding of basil has been conducted. *Ocimum* 'Dark Opal' is a cross between *O. basilicum* and *O. forskolei* from seeds gathered from wild populations in Turkey by U.S. Department of Agriculture plant explorers (DeBaggio and Belsinger, 1996). *Ocimum* 'Dark Opal' was the first herb to receive recognition as an All-America Selection in 1962 (DeBaggio and Belsinger, 1996). Seeds from Thailand of *Ocimum* 'Lemon' (*O. basilicum* x *O. americanum*) were brought into the U.S. by the U.S. Agriculture Department in 1940 (DeBaggio and Belsinger, 1996). *Ocimum* 'Lesbos', *Ocimum* 'Aussie Sweetie', and *Ocimum* 'Greek Column' are thought to share the same Greek gene pool. All three basils share a similar columnar growth habit, phenotypic characteristics and aroma (DeBaggio and Belsinger, 1996). The three basils do not flower during the summer like most basils, but bloom rarely and set seed in the fall and winter (DeBaggio and Belsinger, 1996). A theory speculates that Greek immigrants to Australia may have carried 'Aussie Sweetie' with them to the south.

In 1986, an herb breeder crossed *Ocimum* 'Miniature' and *Ocimum* 'Puerto Rican' to create the cultivar *Ocimum basilicum* 'Miniature Puerto Rican' (DeBaggio and Belsinger, 1996). In 1987, an enormous basil breeding program was established in the former East Germany. The program collected over 300 basils from around the world and in a 1996 seed catalog, *Ocimum* 'Osmin' became the first product available in the U.S. from the breeding program (DeBaggio and Belsinger, 1996).

Uses of Basil

Basil has been associated with a variety of myths, folklore, and superstitions across cultures and time. Around the year 310, Constantine's mother had a divine revelation, which guided her to a basil patch growing in the remains of Christ's crucifixion cross (DeBaggio and Belsinger, 1996). Christian legend has since regarded basil as a ritual plant symbolizing grief, redemption, and magic. Italian traditions believe that basil symbolizes chastity or love. Women placed pots of basil on their windowsills when they desired a lover's company (DeBaggio and Belsinger, 1996). The Greeks celebrate the powers of basil by taking basil to be blessed on St. Basil's Day, the first day of the new year (DeBaggio and Belsinger, 1996). In India, basil is grown near temples and homes to protect against danger and to ensure salvation (Macleod, 1968). Basil is also revered as sacred in India because it is believed to disinfect a house contaminated with malaria (Bonar, 1985). In the Middle Ages, herbs were hung over doors to ward off evil and misfortune (Macleod, 1968). However, some cultures have given basil a negative reputation. Dioscorides in the year 64 believed that eating basil weakened one's vision, provoked urine, and dried up women's milk (Gerard, 1975). Ancient Greece and Roman superstitions believed basil would grow where there was abuse, and basil symbolized poverty, hate, and misfortune. In Crete, basil is thought to be under the control of the devil (Macleod, 1968).

Basil is used medicinally to cure coughs and fevers in West Africa. The roots of basil are chewed to alleviate stomachaches and colds in eastern Africa. Basil is a treatment for gonorrhea in India and a basil paste is used as a skin disease remedy in the Sudan (DeBaggio and Belsinger, 1996). Basil extract is reported to have antioxidant activity (Simon et al., 1984). Basil was a traditional treatment for mild nervous diseases and taken as snuff in a dry powder form (Macleod, 1968). Basil leaf tea alleviates nausea, gas pains, and fevers, while basil juice has been used to treat warts, worms, snake bites, and insect stings (Buchanan, 1995).

Today, basil's multifunctional uses include culinary, ornamental, commercial, religious and medicinal. Throughout the world, essential oils from basil foliage and flowers are extracted for insecticides, medicines, and food flavoring. Commercially in the U.S., the essential oil of basil is a component of mouthwash, medicine, soaps, shampoos, perfume (Brut), and liqueur (Chartreuse)

(DeBaggio and Belsinger, 1996; Simon et al., 1984). Basil is found in baked goods, candy, gelatins, and ice cream. Basil leaves are used fresh or dried to add flavor to soups, tomato dishes, fish, poultry, vinegar, vegetables, and salads. A survey of 87 southern California "outstanding" restaurants responded that basil was the top ranking herb listed among the three most commonly used herbs, basil was the most commonly used herb for each restaurant type studied, and basil was the herb that restaurateurs had the second most difficulty obtaining, next to *Anthriscus cerefolium* (chervil) (Brown, 1991).

The lack of an abundance of information about the origin, evolution, and cultivation of basil is discouraging to plant breeders and growers. However, it is clear that basil's polymorphic nature and ability to hybridize across species lines has made basil a unique and challenging genus to study. The wildly free-spirited personality of this herb has only enhanced its intoxicating, mysterious qualities, which have seduced admirers for thousands of years.

Nutritional Status Methods

Chlorophyll Analysis

A chlorophyll meter allows for a quick, inexpensive, non-destructive, non-intrusive method of analyzing plant tissue chlorophyll content in the field. Chlorophyll meters eliminate the inconveniences of plant sample collection, testing preparations, processing, and tissue analysis of traditional leaf nitrogen measurement. A grower can acquire information about the nitrogen status of a crop from the positive relationship between leaf chlorophyll content and leaf nitrogen concentration (Kalra, 1998). Work on corn established a positive correlation between the chlorophyll reading and nitrogen levels in tissue. A plant experiences luxury consumption of nitrogen, therefore it continues to consume nitrogen despite no further proportional plant growth. However, leaf chlorophyll content plateaus according to the amount of chlorophyll the plant needs independent of the amount of nitrogen in the plant. These two features allow for the estimation of crop nitrogen status (Peterson, 1993). Growers often over fertilize with nitrogen because fertilizer nitrogen is relatively inexpensive and crop yield reductions from nitrogen deficiency make the risk of nitrogen deficiency high. The use of a chlorophyll meter increases the efficiency of fertilizer nitrogen application by assuring growers about the plant nitrogen status before a deficiency occurs.

Most research uses a Minolta SPAD-502 chlorophyll meter, which is currently the only commercial portable meter (Kalra, 1998). A chlorophyll reading is taken by clamping the forcep sensors around a leaf blade. The clamped forceps block out external light to enable detection of radiation transmitted through the leaf not absorbed during photosynthesis. The meter takes a measurement of the 650-nm wavelength (red light), the primary wavelength sensitive to leaf chlorophyll activity (Kalra, 1998). The inverse relationship between radiation absorbed at 650-nm wavelength and radiation transmitted through the leaf is the principle behind the meter function (Kalra, 1998).

Due to the need for reliable sampling and due to the relatively small sensor area of 2 x 3 mm, consistent sampling is necessary. It is recommended to take 30 readings for a crop because variation in individual readings is about 15 percent (Peterson, 1993). The meter forceps are positioned on the first fully expanded leaf blade at a location halfway between the leaf tip and base, and halfway between the leaf edge and the leaf midrib (Kalra, 1998; Peterson, 1993). Corn was used as the test crop for establishing proper data collection techniques.

Nitrate Nitrogen Analysis

Basil, as well as other herbs, requires nitrogen, phosphorus, and potassium elements in the largest quantities. Because nitrogen has the important functions of building amino acids, proteins, nucleotides, nucleic acids, chlorophylls, and coenzymes, nitrogen application has the greatest growth and yield response in herbs (Raven, 1992). Specific ion meters are very affordable for on-site nutrient status and can be used to measure nitrate nitrogen of plant tissues. These compact, lightweight meters measure minute samples yielding instant results. The most common procedure for collecting nitrate data is to gather a representative sample of leaf tissue, squeeze the leaf tissue with a sap press or garlic press to extract liquid from the plant tissue, place a couple drops of the sap onto the meter sensor, and read the nitrate nitrogen concentration. To determine sufficiency range for the concentration of the sample, meter readings are compared with a reference source that relates nitrate-nitrogen content to nitrogen plant status (Kalra, 1998).

Investigations of nitrate levels of organically and conventionally feed crops reveal that organic agriculture can reduce the nitrate contents of vegetables. Research shows that the ingestion of nitrates from vegetable sources can be reduced by half with the use of farmyard or brushwood compost compared to conventional N-P-K fertilization (Lairon, 1986).

CHAPTER III

MATERIALS AND METHODS

1996 Study

Growing Environment

This research was conducted at The W.D. Holley Plant Environmental Research Center greenhouses (Colorado State University, Fort Collins, Colo.). Basil seeds (Ball Seed Company, West Chicago, Ill.) were sown June 11, 1996 in rockwool multiblocks (AgroDynamics, East Brunswick, N.J.) which were 3.5cm x 3.5cm x 3.8cm with a 1cm x 1cm hole and placed under mist. The maximum day temperature was 40C and the minimum night temperature was 23C in the propagation house. The seeds emerged on June 17, 1996. After 20 days, the grow cubes were placed into rockwool grow blocks (AgroDynamics), which were 10cm x 10cm x 6.4cm with a 4.3cm x 3.8cm hole. On July 22,1996 the plants in grow blocks were transferred to a fiberglass reinforced plastic covered greenhouse and placed on to rockwool slabs, bag-mix media, and perlite media. The maximum day temperature was 34 to 37C, the minimum night temperature was 20 to 26 C, and the noonday temperature was 26 to 32 C. Data were collected from August 7, 1996 through November 18, 1996.

Root Zone Treatments

The study compared three root zone treatments, which were hydroponic rockwool slab culture, hydroponic perlite raised bed culture, and hydroponic peat/perlite/compost bag culture. The bag mix culture contained sphagnum peat, perlite, and compost consisting of wood waste and chicken manure (Eko Grower's Mix, Organix Supply, Platteville, Colo.) (Table 3.1). The dimensions of the 37.7 liter lay flat bag were 48cm (width) x 15.2cm (depth) x 76cm (length). The dimensions of the rockwool grow slabs were 15.2cm (width) x 7.6cm (depth) x 91.4cm (length). The dimensions of the perlite raised bed frame were 91.4cm x 16.5cm x 132cm. The rockwool slab culture and perlite bed culture were chosen due to their common use in hydroponic food production. The bag mix culture was chosen to compare the two traditional hydroponic media with an alternative medium.

Fertilizer Treatments

The study compared two types of liquid fertilizer, which were an organic hydroponic fertilizer and an inorganic nutrient solution. The ideal nutrient formula for basil was adapted from a hydroponic herb culture fertilizer formula recommended by AgroDynamics (Anonymous, 1988).

The organic fertilizer (Natural Source, United Environmental Technologies Inc., Sterling Colo.) consisted of organic fermented poultry compost, hydrolyzed fish emulsion, soluble kelp, and soft rock phosphate. A nutrient analysis was determined for the organic fertilizer sources by the Colorado State University Plant and Soil Testing Lab (Table 3.2). Based on the nutrient needs of basil and the nutritional contents of each fertilizer source, the organic fertilizer for the study consisted primarily of the base source with supplements of the calcium source, magnesium source, and iron source. Manipulations of the values and various dilution rate combinations produced dilution rates for the four fertilizer sources in order to create a final product mix with an analysis matched as closely as possible to Agrodynamics' ideal nutrient formula (Table 3.3). The most challenging elements to match were calcium and nitrogen because the base source had low calcium content and high nitrogen content. It was necessary to add the calcium source in order to obtain a higher calcium content in the final formula. However, the calcium source contained more nitrogen than calcium, so the addition of the calcium source subsequently increased the nitrogen content. Therefore, the final nitrogen content was higher than the ideal, and the final calcium content was lower than ideal.

The salt-based hydroponic fertilizer solution formula was designed to match as closely as possible to the final organic solution formula. Manipulations of various combinations of chemical compounds and their analysis produced a custom fertilizer analysis (Table 3.4). Since the nitrogen form may alter the composition and productivity of basil (Cox 1992; Alder 1989), it was important for the fertilizer formula used in this research to have more than one-half of the nitrogen in the nitrate form. A comparison of the ideal nutrient analysis with the final organic fertilizer analysis and the final salt-based fertilizer analysis is shown in Table 3.5.

Irrigation System

A microprocessor irrigation controller (Touch Control model 2400 LXII, Hardie Irrigation, El Paso, Texas) managed the irrigation system. A set of dual fertilizer injectors (Dosatron DI 16, Dosatron International Inc., Clearwater, Fla.) proportioned the traditional chemical feed concentrations and a second identical set of dual injectors dispensed the organic fertilizer concentrations from stock tanks into their respective irrigation lines. Fertilizer solutions were distributed to each plant in the bag mix and the rockwool by basket stake emitters with a 45.7cm leader length (Netafim, Agrodynamics, East Brunswick, N.J.). The emitters were inserted into the grow blocks. A 1.38 bar pressure regulator was installed at the head of each 0.635 cm black flexible polyethylene irrigation line. Due to the high aeration and thus high drainage property of perlite as well as the large surface area of the raised bed, Gates 180 degree perimeter emitters applied the nutrient solution to the plants to allow for even, steady coverage. The irrigation line for the raised bed was secured on the top edge of the bed and had Gates emitters positioned in the center of each side. The irrigation systems automatically fertigated all plants four times daily for a two-minute duration with 130 ml of solution each time.

Plot Design

The experiment was organized as a split-plot design where the two fertilizer treatments were whole plots and the three medium treatments were subplots. Blocks were assigned to every two benches to account for any temperature and environmental gradient due to the cooling pad and fan locations. The basil plants were grown on six wooden benches measuring 97.8cm x 424.2cm each. The experimental unit was an area of a bench measuring 83.8 cm x 127cm and each bench had three experimental units. Each medium/fertilizer combination was replicated three times for a total of 18 experimental units. Basil plants were spaced at 22.8 cm centers. All experimental units had a sample of 12 plants for a total of 216 plants.

Pest Management

Pest management strategies attempted to comply with the organic certification guidelines and greenhouse edible food crop guidelines. Pesticides used were listed in the manual of approved products for organic certification as well as labeled for edible greenhouse crops. Calcium hydroxide, also known as quicklime or hydrated lime, was placed under benches for fungus gnat control. Azadirachtin (Azatin, AgriDyne Technologies Inc., Salt Lake City, Utah) was applied as a drench for fungus gnat control. Insecticidal soap (M-pede, Mycogen Corp., San Diego, Calif.) was sprayed using a backpack sprayer for whitefly and spider mite control. On September 4, 1996 three basil plants were rogue due to an infection of impatiens necrotic spot virus determined by tissue testing (Plant Diagnostic Clinic, Colorado State University Cooperative Extension, Jefferson County, Colo.). At that point, it was necessary to treat the house for western flower thrips, the vector of the virus. Acephate (Orthene, Whitmire Research Laboratories Inc., St. Louis, Mo.) and resmethrin (Resmethrine, Whitmire Research Laboratories Inc., St. Louis, Mo.) were applied to control the thrips and to prevent the spread of the virus. This chemical pesticide application in the pest management program violated the guidelines for growing edible, organic crops.

A 10% bleach solution was run through the irrigation lines every three weeks to prevent clogging of the lines from the organic fertilizer. The ends of the irrigation lines had stoppers, which were removed at the time of cleansing to prevent any bleach contamination of the plants.

Plant Tissue Analysis

Chlorophyll Analysis with a SPAD Meter. A hand held chlorophyll SPAD meter (Minolta SPAD-502 Chlorophyll Meter, Spectrum Technologies Inc., Plainfield, Ill.) was used to take weekly readings on two leaves of each basil plant. Therefore, a total of 24 measurements were taken on each experimental unit. Because each experimental unit was replicated three times, an average of the 72 readings from each medium/fertilizer treatment combination was used to make conclusions on the chlorophyll data.

Nitrate Nitrogen Analysis. The procedure for collecting the nitrate data was to harvest a random sample of leaf tissue, squeeze the leaf tissue with a sap press to extract plant tissue liquid, place three drops of the sap onto the meter sensor, and record the nitrate nitrogen reading in ppm. A compact ion meter (The Horiba Cardy Ion Meter, Spectrum Technologies Inc., Plainfield, Ill.) was used to measure nitrate nitrogen content. Measurements were made during the final week of each study. In the 1996 study, ten random plants were sampled for each fertilizer treatment from the bag mix. Due to time constraints, five plants were sampled for each fertilizer treatment from the perlite, and five plants were sampled for each fertilizer treatment from the rockwool. For the 1997 study, five plants were sampled for each fertilizer treatment from each growing system.

Plant Leaf Analysis. At the termination of the study, samples of freshly harvested leaves from a random representation of plants were collected for a complete plant leaf analysis at the Colorado State University Plant and Soil Testing Lab, Fort Collins, Colo.

Harvesting

Five to 10 cm of the new growth were harvested weekly from the growing points of the plants. The first harvest initiating breaks occurred when four sets of true leaves remained after cutting and prior to bloom (Davis, 1991). Harvested foliage with flowers has reduced flavor, quality, and therefore price. For small-scale production, once or twice a week harvesting of the terminal five to eight cm long whorls of leaves is ideal for a high quality basil product with little stem tissue (Davis, 1991). For large scale dried production, harvesting with a sickle bar type mower is common (Davis, 1991). Research on postharvest shelf life of sweet basil utilized shoots harvested with six to eight leaves just below the second fully expanded node from the growing point after six weeks of growth from seed (Lange, 1994).

Final Plant Dry Weights and Heights

At the termination of the study, final dry weights and heights of the plants were taken. Final plant heights were measured from the rockwool block surface to the tallest growing point on the plant. Dry weights were taken of every individual plant. The stems of the plants were cut at the rockwool block surface for dry weight data collection.

Statistical Analyses

Fresh weights on the weekly harvest, dry weights on the weekly harvest, and weekly chlorophyll SPAD readings were analyzed by analysis of variance with a pairwise t-test on the least square means and repeated measures model. Differences were determined by doubling the standard error of the means. Total harvest per plant, final plant dry weight, and final plant height were analyzed with a pre-planned comparison using least square means. Means were separated using Fisher's least significant difference (LSD) between treatments with a probability level of 0.05.

1997 Study

Changes in the 1997 Study from 1996

Minor adjustments were made in the 1997 study from 1996 in order to improve the plant growing environment and to expand our understanding about growing basil. The adjustments to the study were made in the growing process, the irrigation system, and pest management. The materials and methods for the root zone treatments, the fertilizer treatments, the plot design, the plant tissue analysis, harvesting, and statistical analysis are described in the 1996 study.

Growing Process

The research was again conducted at The W.D. Holley Plant Environmental Research Center greenhouses (Colorado State University, Fort Collins, Colo.). Due to boiler failure problems, the process of growing the basil plants began by transplanting rooted basil cuttings donated from Welby Gardens, Denver, Colorado. On March 10, 1997 the basil starters growing in a soil-less peat medium were transplanted from their 5.5cm (width) x 7.5cm (depth) x 5.5cm (length) cell packs into rockwool grow blocks and placed block to block in the greenhouse. On March 12, the plants were spaced on the rockwool slab, bag-mix, and perlite media. The maximum day temperature was 27 to 32 C, and the minimum night temperature was 14 to 18 C. Data was collected for the second run from March 18, 1997 through July 28, 1997.

Irrigation System

Changes in the irrigation system were needed to reduce the overwatering of the perlite raised beds. The Gates emitters located on the two short sides of the raised beds were removed in order to alleviate the overwatering and excessive leaching. Additionally, transparent plastic splash shields with dimensions of 89 cm x 53 cm were erected to eliminate the spraying from the Gates emitters onto adjacent experimental units.

Pest Management

Pest management strategies attempted to comply with the organic certification guidelines and greenhouse edible food crop guidelines. Insecticidal soap (M-pede, Mycogen Corp., San Diego, Calif.) was used for whitefly and aphid control. Parasitic wasps (*Encarsia formosa*, International Technology Services, Boulder, Colo.) were released weekly for whitefly control. Volunteer ladybird beetles (*Hippodamia convergens)* eliminated the aphid population. The biofungicide *Streptomyces griseoviridis* Strain K61(Mycostop, Kemira Agro Oy, Helsinki, Finland), Thiophanate-methyl (Cleary's 3336, W.A. Cleary Chemical Corp., Somerset, N.J.) and Metalaxyl (Subdue, Ciba-Geigy Corp., Greensboro, N.C.) were applied as drenches after transplanting the basil to control *Fusarium oxysporum*. Tissue testing of plant samples determined that the crop had an infestation of *Fusarium oxysporum* (Plant Diagnostic Clinic, Colorado State University Cooperative Extension, Jefferson County, Colo.). The application of Thiophanate-methyl and Metalaxyl violated the organic guidelines.

A 10% bleach solution was run through the irrigation lines every three weeks to prevent clogging of the lines from the organic fertilizer. The ends of the irrigation lines had stoppers, which were removed at the time of cleansing to prevent any bleach contamination of the plants.

Organoleptic Sensory Test

Two taste tests were conducted to evaluate the taste differences and taste preferences of the organically and conventionally grown plants. All samples were harvested the day prior to testing and stored over night in a cooler at 15C. A study showed shelf life or visual quality of sweet basil was longest with seven days or more at 15C compared to 0, 5, 10, 20, and 25C. Chilling injury became severe at 5C storage temperature, while chilling injury was moderate at 7.5 and 10C (Lange, 1994). Immediately before presenting the samples to the tasters, the plants were ground with a kitchen blender. This process eliminated any size or visual differences between the samples. Thirty milliliters of the samples were placed into white plastic cups labeled with a random three-digit number. The cups were brought to the panel members on a tray. Evaluations were based on the taste, aroma, and/or texture of the samples.

Triangle Difference Taste Test

A triangle difference test was performed on May 22, 1997 to determine whether there was a difference in taste between the organically grown basil and the conventionally grown basil. The triangle difference test method simultaneously presents three unknown samples per set to a panel member (Kramer and Twigg, 1962). Each panel member was given three samples: two of the samples were the same, and one of the samples was different. The panel members checked on a sheet of paper the sample identification number that corresponded to the sample they believed to be different. The panel members were employees of the Food Science Department, Colorado State University, who have served as panel members for various projects such as this research. Twelve panel members evaluated the difference between the organically treated plants and the conventionally treated plants grown in the bag mix. Seven panel members evaluated the difference between the organically treated plants and the conventionally treated plants grown in rockwool. Seven panel members evaluated the difference between the organically treated plants and the conventionally treated plants grown in perlite.

Preference Taste Test

After the panel members detected a difference between basil samples, a ranked preference test was performed on June 6, 1997. The ranking test was conducted to determine whether a difference exists between samples with regard to degree of acceptability or general quality. A ranking test is an effective method of screening inferior samples in product development (Amerine, 1965). Twenty-nine panel members were given four samples to rank in order of preference. The four samples were plants grown in the bag mix with the salt-based feed, plants grown in the bag mix with the organic feed, plants grown in the rockwool with the salt-based feed, and plants grown in rockwool with the organic feed. At the time of the taste test, the plants grown in perlite were not producing enough mass to make samples. The panel members were instructed to use any of their senses in order to determine a preference. On a sheet of paper, the panel members ranked from one to four the sample identification numbers, which corresponded to an order of preference. The panel members were as previously described.

Table 3.1. Nutrient analysis report of Organix Supply Company's Eko Grower's Bag Mix (Colorado Analytical Laboratory, Brighton, Colo.)

Element	PPM in Extract	MMOLES per Sample	UMOLES per Sample	General Acceptable PPM Range
Calcium	342.5 H	8.56		40-200
Magnesium	56.1 A	2.31		20-100
Potassium	149.4 A	3.83		50-175
Nitrate-Nitrogen	35.9 L			70-180
Nitrate	159.04 L	2.56		310-797
Nitrite-Nitrogen	<.01			
Sulfate-Sulfur	11			
Sulfate	33	0.34		
Phosphorus as P	84.2 H	2.7		5.-25
Iron	0.272 L		4.866	0.3-3
Copper	0.038 A		0.598	0.01-0.5
Manganese	2.557 H		46.55	0.01-0.5
Molybdenum	0.04 A		0.417	0.01-0.2
Zinc	0.373 A		5.706	0.3-3
Ammonia	4.1 A	0.241		1.-20
Boron	0.12 A			0.1-10
pH (Sat. Paste)	6.38 A			5.5-6.5
Salts (MMHOS/CM)	2.32 A			0.5-3.5
Organic Matter (%)	40.5			

L=low, A=acceptable, H=high

Table 3.2. Nutrient analyses of the seven liquid organic fertilizer sources available from United Environmental Technologies, Inc.'s product line. Nutrient analyses are in % units, 1% = 10,000 ppm.

		Nutrient Analyses of Organic Fertilizer Sources (%)					
Element	Ideal (ppm)	Base Source	Calcium Source	Magnesium Source	Iron Source	Boron Source	Manganese Source
N	210	**4.49000**	8.543900	0.084000	0.62920	0.488020	0.298300
P	80	**1.44000**	0.001000	0.003000	0.10500	0.000000	0.003000
K	275	**5.11000**	0.000000	0.085000	0.08300	0.020000	0.013000
Ca	180	**0.16000**	6.870000	0.013000	0.02200	0.100000	0.051000
Mg	80	**0.04600**	0.002000	1.450000	0.00600	0.010000	0.266000
Mn	0.25	**0.01450**	0.000000	0.000000	0.03200	0.000000	1.950000
Fe	3.7	**0.03000**	0.005000	0.003000	3.56000	0.050000	0.013000
Cu	0.26	**0.01450**	0.000000	0.000000	0.00031	0.000000	0.001710
B	1	**0.00475**	0.000000	0.000000	0.00915	9.850000	0.000692
Zn	0.25	**0.01400**	0.000212	0.000231	3.56000	0.000545	0.012200
Mo	0.06	**0.00000**	0.000000	0.000000	0.00000	0.000000	0.000065
S	200	**1.36000**	0.004000	16.200000	15.00000	0.100000	12.200000
Na		**0.50000**	0.328000	0.278000	0.16900	0.090000	0.500000
pH	6.0	**5.70**	6.10	5.1	2.1	7.4	4.9
EC(dS/m)	2.5-3.5	**112.1**	63.9	39.3	46.9	5.4	31.6

Table 3.3. Hydroponic organic fertilizer sources used for the research with their dilution rate analyses, and final organic fertilizer formula created by summing the analyses of the four sources. Nutrient analyses are in ppm units; 1% = 10,000 ppm.

	Nutrient Analyses of Diluted Organic Fertilizer Sources (ppm)					
Element	**Ideal Formula**	Base Source Diluted 185X	Calcium Source Diluted 700X	Magnesium Source Diluted 220X	Iron Source Diluted 18,786X	**Final Formula Sum of Sources**
N	**210**	242.70	122.06	3.82	0.33	**368.91**
P	**80**	77.84	0.01	0.14	0.06	**78.04**
K	**275**	276.22	0.00	3.86	0.04	**280.12**
Ca	**180**	8.65	98.14	0.59	0.01	**107.39**
Mg	**80**	2.49	0.03	65.91	0.00	**68.43**
Mn	**0.25**	0.78	0.00	0.00	0.02	**0.80**
Fe	**3.75**	1.62	0.07	0.14	1.90	**3.72**
Cu	**0.26**	0.78	0.00	0.00	0.00	**0.78**
B	**0.6**	0.26	0.00	0.00	0.00	**0.26**
Zn	**0.25**	0.76	0.00	0.01	1.90	**2.67**
Mo	**0.06**	0.00	0.00	0.00	0.00	**0.00**
S	**200**	73.51	0.06	736.36	7.98	**817.92**
Na		27.03	4.69	12.64	0.09	**44.44**

Table 3.4. Salt-based fertilizer analysis

	Chemical Formula	Chemical Name	grams/liter
Stock A	$Ca(NO_3)_2$	Calcium nitrate	62.37
	FeEDTA	Iron chelate	3.75
Stock B	KNO_3	Potassium nitrate	39.58
	KH_2PO_4	Monopotassium phosphate	34.30
	$MgSO_4$	Magnesium sulfate	81.56
	$MnSO_4$	Manganese sulfate	0.32
	$CuSO_4$	Copper sulfate	0.31
	ZnEDTA	Zinc chelate	1.90
	H_3BO_3	Boric acid	0.15
	$(NH_4)_6Mo_7O_{24}$	Ammonium molybdate	0.01
	$(NH_4)_2SO_4$	Ammonium sulfate	107.71
	Na_2SO_4	Sodium sulfate	13.91
	K_2SO_4	Potassium sulfate	13.91

Table 3.5. Ideal nutrient analysis, organic fertilizer analysis and salt-based fertilizer analysis.

Element	Analyses in ppm		
	Ideal	Organic	Salt-based
N	210.00	368.91	363.67
P	80.00	78.04	78.00
K	275.00	280.12	307.60
Ca	180.00	107.39	118.60
Mg	80.00	68.43	81.00
Mn	0.25	0.80	0.80
Fe	3.75	3.72	3.75
Cu	0.26	0.78	0.78
B	0.60	0.26	0.26
Zn	0.25	2.67	2.66
Mo	0.06	0.00	0.06
S	200.00	817.92	425.98
Na	NA	44.44	44.00

CHAPTER IV

RESULTS AND DISCUSSION

Organoleptic Sensory Tests

Results and Discussion of Triangle Difference Taste Test

Panel members determined that the organically fertilized plants were different from the traditionally fertilized plants for all three growing systems. Five of seven panel members correctly identified the sample that corresponded to the different perlite sample. Eight of twelve panel members correctly identified the sample that corresponded to the different bag mix sample. Five of seven tasters correctly identified the sample that corresponded to the different rockwool sample. The ratio of the number of correctly identified samples to the total number of panelists makes the differences significant ($\alpha = 0.05$) (Jellinek, 1985).

Results and Discussion of Preference Taste Test

The pooled results from the group of twenty-nine panel members revealed that no differences existed between organically fertilized and traditionally fertilized plants with regard to preference. The results were determined with a chart that lists the rank totals required for significance when $\alpha = 0.05$ (Jellinek, 1985). The results show that there is no taste preference for plants grown with any of the four production methods tested, even though differences are distinguishable.

1996 and 1997 Results and Discussion of pH and Electrical Conductivity

Just as a grower should, pH and electrical conductivity of the media leachates and the emitter solutions were monitored (Table 4.1). Producers need to monitor pH and electrical conductivity of the nutrient solution in a hydroponic system in order to ensure adequate mineral nutrient availability for the plant (Barker, 1995). In a categorization of sensitivity of herbs to soil acid, basil falls in the less sensitive category, which means that basil will not tolerate and cannot grow in a soil with a pH below four (Barker, 1989). The pH recommendation for basil in a hydroponic organic system is in the range five to seven (Schoenstein, 1996). The monitored pH (Portable Hach One pH Meter Model 43800, Hach Company, Loveland, Colo.) throughout both 1996 and 1997 studies were within the tolerable range for basil for all treatments (Tables 4.1.A and 4.1.B).

The electrical conductivity (Conductivity/TDS Meter Model 44600, Hach Company, Loveland, Colo.) readings were variable among treatments (Tables 4.1.C and 4.1.D). The EC readings for the perlite system were within the tolerable range of less than four. This was due to the high drainage characteristic of perlite, which prevents the accumulation of salts in the medium. The doubling of the EC values for the organic bag mix during both the 1996 and 1997 studies may have been a factor in decreased productivity of the plants. The bag mix medium had no or minimal leaching throughout the day which would account for the high EC levels. Plant health deteriorates when the osmotic gradients are disturbed by the rise in solution ion concentrations (Jones, 1991). Crop growth is reduced with large concentrations of inorganic nitrogen due to an increase in osmotic stress (Smith and Hadley, 1988). The EC values for the rockwool systems were fairly consistent throughout both studies.

1996 and 1997 Results and Discussion of Chlorophyll Data

Weekly SPAD readings for chlorophyll leaf analysis were taken from September 17 to November 18 in the 1996 study and from April 23 to July 8 in the 1997 study. In the last month of the 1996 study, there was a downward trend in chlorophyll content for all growing systems (Fig. 4.1). During the second half of the 1997 study, there was a general increase in plant chlorophyll content for all growing systems (Fig. 4.2). The trends can be attributed to the difference in growing seasons and light intensities. Triggered by light, protoplastids will develop into chloroplasts containing chlorophyll, which are the receptors of light energy in photosynthesis (Taiz, 1991). The plants in the 1996 study experienced decreasing light intensities and a reduction in photoperiod activity as well as chlorophyll content. The plants in the 1997 study experienced increasing light intensities and a rise in photoperiod activity as well as chlorophyll content.

Differences between fertilizer treatments were determined by doubling the standard error difference. In the 1996 study, no differences occurred between fertilizer treatments in the bag mix system, however there were differences between fertilizer treatments in the perlite and rockwool growing systems (Figure 4.1.A, 4.1.B, and 4.1.C). In the 1996 perlite growing system, the organic fertilizer had higher SPAD readings on September 17 and 24, and on October 15 and 29, while the salt-based fertilizer had a higher reading on November 11. There was no difference in SPAD readings between the organic and salt-based fertilizers on the remaining dates (Figure 4.1.B). The data shows that the salt-based perlite growing system provided poor growing conditions for plant production of chlorophyll. The chlorophyll readings indicate that the plants grown in the salt-based perlite had more difficulty uptaking or utilizing nutrients, especially nitrogen. In the 1996 rockwool growing system, the organic fertilizer had higher SPAD readings on September 30. There was no difference in SPAD readings between the organic and salt-based fertilizers on the remaining dates (Figure, 4.1.C). Except on September 30, there was no difference between fertilizer treatment in the rockwool plants' chlorophyll content.

The chlorophyll data from the 1997 study is inconsistent. In the 1997 bag mix, the salt-based fertilizer had a higher SPAD reading on April 23, while the organic fertilizer had higher SPAD readings on May 20, June 3, and July 8 (Fig. 4.2.A). The organic and salt-based fertilizers did not have different SPAD readings on the remaining dates. In the 1997 perlite growing system, the organic fertilizer had higher SPAD readings on April 23 and May 5, while the salt-based fertilizer had higher readings for the remainder of the study (Fig. 4.2.B). In the 1997 rockwool growing system, the organic fertilizer had a higher SPAD reading on April 23, whereas the salt-based fertilizer had higher readings on June 3 and 25. The organic and salt-based fertilizers did not have different SPAD readings on the remaining dates (Fig. 4.2.C).

1996 and 1997 Results and Discussion of Nitrate Nitrogen Data

Nitrate nitrogen data was collected during the last weeks of both the 1996 and 1997 studies. An analysis of variance for combined 1996 and 1997 data found the organic fertilized plants had greater nitrate nitrogen content than the conventional plants. The organic fertilizer was a better source of nutrients for mineralization of nitrate due to the microbial biomass in the organic fertilizer.

A non-linear relationship was determined between the chlorophyll analysis and the nitrate nitrogen analysis taken on the same leaves. A non-linear relationship occurs when the fertilizer has a surplus of nitrogen and when a crop's chlorophyll content plateaus, while nitrogen uptake continues resulting in luxury consumption (Kalra, 1998).

1996 and 1997 Results and Discussion of Plant Leaf Analysis

The results from the plant leaf analysis show inconsistencies in some of the element concentrations between organically and conventionally fed plants (Table 4.2). In the 1996 and 1997 studies, the N:S ratio was 18:1 for the plants with the conventional feed, and 15:1 for the plants with the organic feed. An N:S ratio of 20:1 would cause deficiencies in many crops (Jones, 1991). In the 1997 study, the organic leaves had higher Ca and higher nitrate nitrogen than the conventional leaves. The greater nitrate nitrogen content was due to the organic fertilizer being a better nutrient source for mineralization of nitrate by microbial biomass. This is consistent with the results from the nitrate nitrogen analysis from the Cardy meter. However, the conventional leaves had more S, more Mn, more Cu, and more B than the organic leaves. Manganese has better oxidation with good aeration, which allows for greater availability to the plant. Phosphorus and magnesium contents of vegetables tended to be higher with organic production than conventional (Lairon, 1986). Because of the dilution effect, the nutrient content of the elements was higher in the August 7 to November 18, 1996 study compared to the March 31 to July 28, 1997 study, except Na and S were the same. The dilution effect of element concentrations occurs with greater light exposure due to the greater production of carbohydrates, which causes a reduction in most nutrients (Jones, 1991). All the nutrient levels in both studies were equivalent to or in excess of the recommended sufficiency range for plants (Table 4.2) (Jones, 1991).

1996 Study

Yield

Plants were harvested weekly to simulate activity in a working production greenhouse. Yield is often the top priority in agricultural production (Plochberger, 1989). Fresh weights on the weekly harvests were taken August 7 through November 18, 1996. The fresh weight data was an average of the 12 plants in each experimental unit. Dry weights on the weekly harvests were calculated from September 17 to November 18, 1996. The dry weight data was a sum of the 12 plants in each experimental unit. For all three growing systems, plant productivity, visual health, and plant structure declined after four months of weekly harvesting. The graphs show a general downward trend in fresh weight and dry weight data for all growing systems during the last month of productivity (Figs. 4.3 and 4.4). The plants in the 1996 study experienced decreasing light intensities and a reduction in photoperiod activity, which may have been responsible for the decline in plant productivity.

Comparisons of weekly harvests were made by doubling the standard error bars. For the bag mix growing system, there was no difference in weekly fresh weights or weekly dry weights between fertilizer treatments throughout the duration of the study, except on the final harvest date (Fig. 4.3.A and 4.4.A). On November 18, the salt-based plants were more productive than the organic plants. The organic irrigation lines had some clogging during the last month of the study, which reduced the amount of fertigation delivered to the plants on those lines. The organic plants received 5-30 ml less nutrient solution than the other plants during the last month of the study due to slight clogging of the organic lines. At the end of the study, the salt-based bag mix leachate had a high EC reading of 11.02, and the organic bag mix leachate had a higher EC reading of 14.64 (Table 4.1.C). The high EC reading of the organic bag mix may have been caused by the absence of leaching of the medium at each watering and may have attributed to lower fresh weights at the end of the study. The clogging coupled with the absence of leaching may be the cause of the high EC levels in the organic plants, which may have attributed to lower productivity.

In the perlite growing system, there was no difference in weekly fresh weights between fertilizer treatments throughout the duration of the study, except on the final harvest date. On November 18, the organic plants were more productive than the salt-based plants (Fig. 4.3.B). There was no difference in weekly dry weights between fertilizer treatments throughout the duration of the study, except on September 24 when the organic plants had greater dry weights (Fig. 4.4.B). Due to the high aeration of the perlite medium, oxygen was available to enable the decomposition process of organic material. 'Natural Source' undergoes a fermentation extraction process during manufacturing, which allows a portion of the total percent of nitrogen to be immediately available in the nitrate nitrogen and ammonium nitrate forms. However, the remainder of the total percent nitrogen is in an organic form that becomes available over time. Organic nitrogen is converted to the mineral form in a process called mineralization with the aid of heterotrophic organisms such as bacteria, fungi, and actinomycetes (Foth and Ellis, 1988). The process involved in converting organic matter into available nitrogen is ammonification followed by nitrification. Bacteria, primarily from the genus *Nitrosomonas*, oxidize the ammonia formed by mineralization into nitrite. Immediately, bacteria from the genus *Nitrobacter* oxidize the nitrite into nitrate, which is the main form of nitrogen absorbed by the roots (Foth and Ellis, 1988). The nitrifiers are most active with a pH of 6.6 to 8.0 or higher and with a water content at 50 to 67 percent of the water-holding capacity for an ideal oxygen supply (Foth and Ellis, 1988). Over time, the organic fertilizer improved the medium structure and enhanced rhizosphere microbial activity (Smith and Hadley, 1988). Therefore, perlite's well-aerated and high drainage capacity characteristics allow for the microbial decomposition process and subsequent increase in plant productivity over time. Additionally, the high drainage in the perlite causes leaching of salt-based nitrate nitrogen component, which could be responsible for reduced efficiency of the growing system. The delay in release of available N in the organic fertilizer may be responsible for the better establishment of the plants and better utilization of the applied available N (Smith and Hadley, 1989). During the crop establishment period, transplants may successfully absorb greater quantities of available nitrogen from organic materials compared to inorganic sources, which experience N loss during leaching (Smith and Hadely, 1989).

In the rockwool growing system, there was no difference in weekly fresh weights between fertilizer treatments throughout the duration of the study, except on the second to last week of harvest (Fig. 4.3.C). On November 11, the salt-based plants were more productive than the organic plants. There was no difference in weekly dry weights between fertilizer treatments throughout the duration of the study, except on November 4 and 11 when the salt-based plants had greater dry weights (Fig. 4.4.C). As described in the previous paragraph about the bag mix results, the organic irrigation lines had some clogging during the last month of the study, which reduced the volume of solution distribution delivered to the plants on those lines. Rockwool has a design compatibility with salt-based fertilizers. Rockwool's low aeration and high water holding capacity make it unsuitable for oxygen driven microorganism activity to occur with the organic fertilizer. The inconsistent distribution of water to the organic plants coupled with rockwool's compatibility with salt-based fertilizers may explain the lower productivity of the organic plants.

Results for the total harvest per plant for the entire duration of the study are shown in Table 4.3. For the plants treated with the salt-based fertilizer, there was no difference in total harvest among growing systems. The salt-based fertilizer is compatible with all three growing systems. For the plants treated with the organic fertilizer, there was a difference in total harvest among growing systems. The plants grown in the bag mix system were not different in productivity compared to the plants grown in the perlite or rockwool systems. However, the plants grown in the perlite system were more productive than the plants grown in the rockwool system. The differences can be attributed to the microbial decomposition process occurring in the perlite that is responsible for increased plant growth as well as the characteristics of rockwool that make it less compatible with organic fertilizers.

Final Dry Weight and Height Data

For the conventional plants as well as the organic plants, the bag mix system had significantly greater final plant dry weights than the perlite and rockwool growing systems (Table 4.4). During the first few weeks of growth in the greenhouse, the plants in the bag mix system established themselves in the medium more quickly than the plants in the rockwool or perlite systems. The roots interfaced better in the bag mix medium than in the rockwool and perlite media due to the texture, physical properties, and nutrient content of the bag mix medium. The plants in the bag mix system were stronger, more vigorous, and more robust during the establishment time period and thereafter during the entire study.

The plants treated with the salt-based fertilizer had significantly taller final plant heights in the bag mix system compared to the perlite and rockwool growing systems (Table 4.5). Plant heights are a general indication of plant health and a plant's ability to root in a medium. Because the bag mix compared to the rockwool or perlite was conducive to rapid plant establishment, the plants were healthier and had longer internode lengths initially and then subsequently throughout the study. The plants treated with the organic fertilizer did not have different final plant heights among growing systems. During the crop establishment period, transplants may successfully absorb greater quantities of available nitrogen from organic materials compared to inorganic sources, which experience N loss during leaching (Smith and Hadley, 1989). This information explains why the organic fertilizer did not affect final plant height while the salt-based fertilizer did effect plant height among growing systems.

1997 Study

Yield

Fresh weights and dry weights on the weekly harvests were weighed from March 31 through July 28, 1997(Figs. 4.5 and 4.6). The dry weight data was a sum of the 12 plants in each experimental unit. The fresh weight data was an average of the 12 plants in each experimental unit. For all three growing systems, visual health and plant structure declined after four months of weekly harvesting. The graphs show a general upward trend in fresh weight and dry weight quantities for all growing systems. The plants in the 1997 study experienced increasing light intensities and a rise in photoperiod activity responsible for increased plant productivity. Comparisons of weekly harvests were made by doubling the standard error bars.

For the bag mix growing system, there were no differences in weekly fresh weights between fertilizer treatments, except on May 20, July 1 and July 16 when the salt-based plants were more productive (Fig. 4.5.A). The dry weight data show no difference in dry weight quantities between fertilizer treatments for the duration of the study (Fig. 4.6.A). As with the 1996 study, the organic irrigation lines in the 1997 study had some clogging during the last month of production, which reduced the amount of nutrient solution delivered to the plants on those lines. At the end of the study, the organic bag mix leachate had a high EC reading of 7.7 compared to the 4.96 EC reading of the conventional plants. The high EC reading of the organic bag mix may have been caused by the absence of leaching of the medium at each watering and may have attributed to lower fresh weights (Table 4.1D).

In the perlite growing system, the fresh weights of the organic plants were greater than the salt-based plants for the majority of the study (Figs.4.5.B). There were no differences in weekly fresh weights between fertilizer treatments for the first three weeks, on June 10, on July 8, and on July 16. There were no differences in weekly dry weights between fertilizer treatments except on April 30, May 13, and July 21 when the organic plants had greater dry weights. Salt-based plants grown in the perlite suffered from *Fusarium oxysporum* infection. The salt-based perlite plants were visually weak and short. Results from research comparing plant performance of *Fusarium oxysporum* inoculated and unoculated *Ocimum basilicum* included a 43 percent reduction in fresh weight for plants inoculated with *Fusarium oxysporum* (Keinath, 1994). When the plants were checked weekly to determine interface rooting success from the rockwool cubes into the media, the plants rooted quickly and easily into the bag mix and rockwool, but the plants rooted slowly into the perlite. The inability of the perlite plants to establish as quickly into the medium made the plants weak and vulnerable to *Fusarium oxysporum.* The beneficial micro-organisms in the organic fertilizer provide a living system in the perlite conducive to rhizosphere development, root growth, and plant establishment. Transplants in perlite are more successful at absorbing greater quantities of available nitrogen from organic materials during the crop establishment period compared to inorganic sources which experience N loss during leaching due to the high drainage characteristic of perlite. During the crop establishment period, transplants may successfully absorb greater quantities of available nitrogen from organic materials compared to inorganic sources that experience N loss during leaching (Smith and Hadley, 1989).

In the rockwool growing system, there were no differences in weekly fresh weights between fertilizer treatments for the first two months, however the salt-based treated plants were more productive for the remainder of the study (Figs. 4.5.C). There were no differences in weekly dry weights between fertilizer treatments except on July 1 and July 8 when the salt-based plants had greater dry weights. The greater weekly productivity of the salt-based plants could be attributed to rockwool's design compatibility with salt-based fertilizers. Rockwool's low aeration and high water holding capacity make it unsuitable for oxygen driven microorganism activity to occur with the organic fertilizer over time.

Results for the total harvest per plant for the entire duration of the study are shown in Table 4.3. For the plants treated with the salt-based fertilizer, the perlite growing system was less productive in total harvest compared to the bag mix system and rockwool system. As discussed with the weekly harvested fresh weight, the salt-based perlite plants were vulnerable to and infected by *Fusarium*, which had deleterious effects on total harvest. For the plants treated with the organic fertilizer, there was no significant difference in total harvest among growing systems. Compared to the 1996 results, which found perlite to have a greater total harvest per plant compared to the rockwool system, the plants grown in the 1997 perlite system may have been deleteriously effected by *Fusarium*. The 1997 study found the organic fertilizer to be compatible with all three growing systems under the conditions of the study.

Final Dry Weight and Height Data

For the conventionally grown plants, the final plant dry weight results were consistent with total harvest per plant results. The perlite system had a lower final plant dry weight than the bag mix and rockwool growing systems (Table 4.4). The salt-based perlite plants were observed to be small, weak, and insubstantial due to vulnerability to *Fusarium*. Results from research comparing plant performance of *Fusarium oxysporum* inoculated and unoculated *Ocimum basilicum* included a 40 percent reduction in leaf area (Keinath, 1994). For the organic plants, the bag mix system had greater final dry weight than the rockwool or perlite systems. During the first few weeks of growth in the greenhouse, the organic plants in the bag mix system established themselves in the medium quicker than the plants in the rockwool or perlite systems. The roots interfaced better in the bag mix medium than in the rockwool and perlite media due to the texture, physical properties, and nutrient contents of the bag mix medium. The plants in the bag mix system were stronger, more vigorous, and more robust during the establishment time period and thereafter during the entire study.

The plants treated with the salt-based fertilizer had taller final plant heights in the bag mix system compared to the perlite and rockwool systems, and the plants in the rockwool were taller than the plants in the perlite (Table 4.5). Results from research comparing plant performance of *Fusarium oxysporum* inoculated and unoculated *Ocimum basilicum* included a 30 percent reduction in height (Keinath, 1994). The plants treated with the organic fertilizer had taller final plant heights in the bag mix system compared to the perlite and rockwool systems growing systems. Plant heights are a general indication of plant health and a plant's ability to root in a medium. Because the bag mix compared to the rockwool or perlite was conducive to rapid plant establishment, the plants were healthier and had longer internode lengths initially and then subsequently throughout the study.

Table 4.1. pH and electrical conductivity (EC) of media leacheate and emitter solution.

4.1.A. pH 1996

	Sept. 16		Oct. 28		Nov. 25	
	Salt-based	Organic	Salt-based	Organic	Salt-based	Organic
Perlite leachate	5.60	6.64	5.73	6.88	4.43	6.79
Bag-mix leachate	5.60	6.10	4.94	7.10	4.30	5.78
Rockwool leachate	5.00	5.26	4.34	5.19	4.08	5.04
Emitter	6.10	7.00	—	—	6.42	7.69

4.1.B. pH 1997

	Apr. 30		Jul. 2	
	Salt-based	Organic	Salt-based	Organic
Perlite leachate	5.50	6.88	5.42	6.52
Bag-mix leachate	5.81	7.20	4.86	6.40
Rockwool leachate	3.98	7.16	4.9	4.35
Emitter	—	—	6.09	6.35

4.1.C. 1996 EC (dS/m)

	Sept. 16		Oct. 28		Nov. 25	
	Salt-based	Organic	Salt-based	Organic	Salt-based	Organic
Perlite leachate	3.89	2.32	2.25	1.57	3.00	1.95
Bag-mix leachate	8.40	6.98	10.9	10.95	11.02	14.64
Rockwool leachate	11.38	6.02	4.21	5.63	7.76	6.18
Emitter	—	—	—	—	3.20	2.09

4.1.D 1997 EC (dS/m)

	Apr. 30		Jul. 2	
	Salt-based	Organic	Salt-based	Organic
Perlite leachate	3.25	2.21	3.74	2.14
Bag-mix leachate	4.83	2.81	4.96	7.7
Rockwool leachate	5.64	1.77	6.16	4.47
Emitter	—	—	3.77	1.86

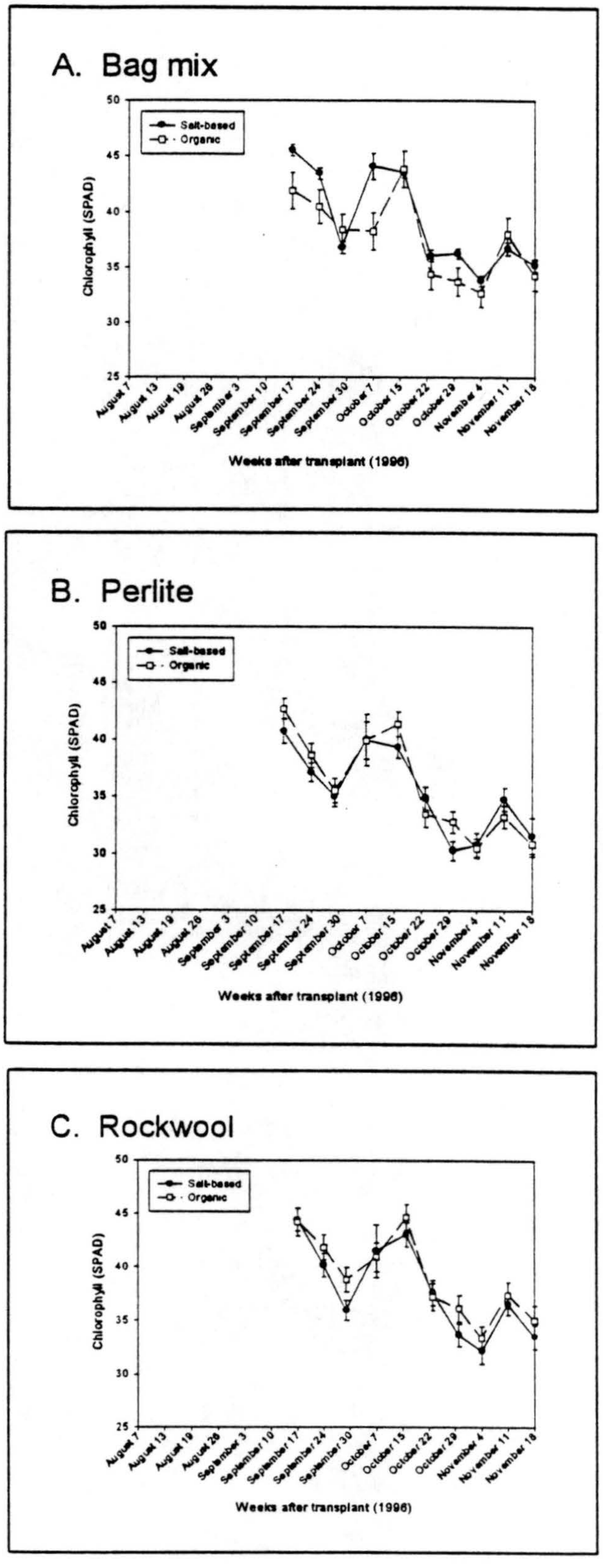

Fig.4.1. 1996 weekly SPAD readings for chlorophyll leaf analysis. Plants grown from August 7 to November 18, 1996. SPAD readings began September 17.

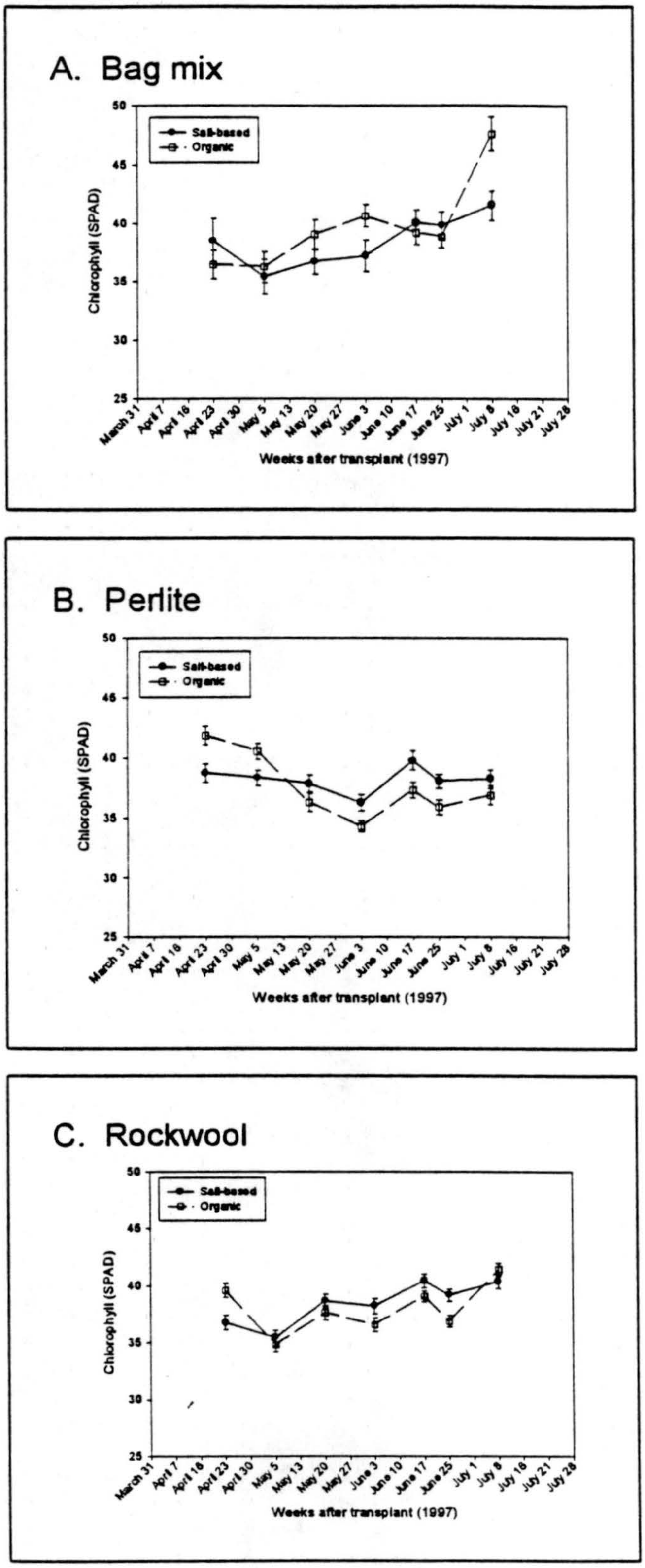

Fig.4.2. 1997 weekly SPAD readings for chlorophyll leaf analysis. Plants grown from March 31 to July 28, 1997. SPAD readings began April 23.

Table 4.2. Plant leaf analysis at completion of 1996 and 1997 studies, and mineral nutrient sufficiency values.

	Element %							Element ppm				
	1996 Study: leaves cut on December 3.											
Sample	N	P	K	Ca	Mg	Na	S	Zn	Fe	Mn	Cu	B
Organic Bag	6.31	1.21	3.95	1.69	0.617	0.019	0.36	133.0	190.0	120.0	28.4	25.7
Organic Perlite	6.83	1.42	3.89	1.23	0.430	0.005	0.34	94.4	145.0	161.0	19.1	21.4
Organic Rockwool	7.25	1.41	3.35	1.43	0.624	0.014	0.42	114.0	198.0	141.0	30.2	36.2
Salt-based Bag	7.31	1.53	2.50	0.933	0.461	0.010	0.52	140.0	220.0	215.0	26.3	31.1
Salt-based Perlite	7.50	1.88	3.75	0.915	0.443	0.030	0.47	131.0	166.0	236.0	27.9	31.2
Salt-based Rockwool	7.24	1.81	3.68	0.623	0.362	0.011	0.47	155.0	196.0	185.0	36.0	36.8
	1997 Study: leaves cut on August 8.											
Sample	N	P	K	Ca	Mg	Na	S	Zn	Fe	Mn	Cu	B
Organic Bag	5.87	0.78	2.14	1.25	0.56	0.06	0.351	84.1	136.0	50.4	13.1	10.7
Organic Perlite	5.90	1.26	2.39	0.91	0.35	0.07	0.375	106.0	121.0	74.6	8.56	25.3
Organic Rockwool	5.52	1.04	3.38	0.82	0.37	0.04	0.389	69.9	155.0	27.7	5.47	10.6
Salt-based Bag	6.10	1.18	2.85	0.48	0.27	0.090	0.529	124.0	110.0	169.0	25.2	20.8
Salt-based Perlite	5.84	1.23	2.02	0.71	0.32	0.140	0.408	109.0	109.0	183.0	29.3	34.6
Salt-based Rockwool	5.77	1.34	2.07	0.55	0.34	0.14	0.563	154.0	167.0	169.0	34.3	37.6
	Sufficiency values.											
	N	P	K	Ca	Mg	Na	S	Zn	Fe	Mn	Cu	B
	2.5-3.5	0.2-0.4	1.5-3.0	0.3-1.0	0.25	----	0.15-0.5	15-50	100	50	3.0-7.0	20-70

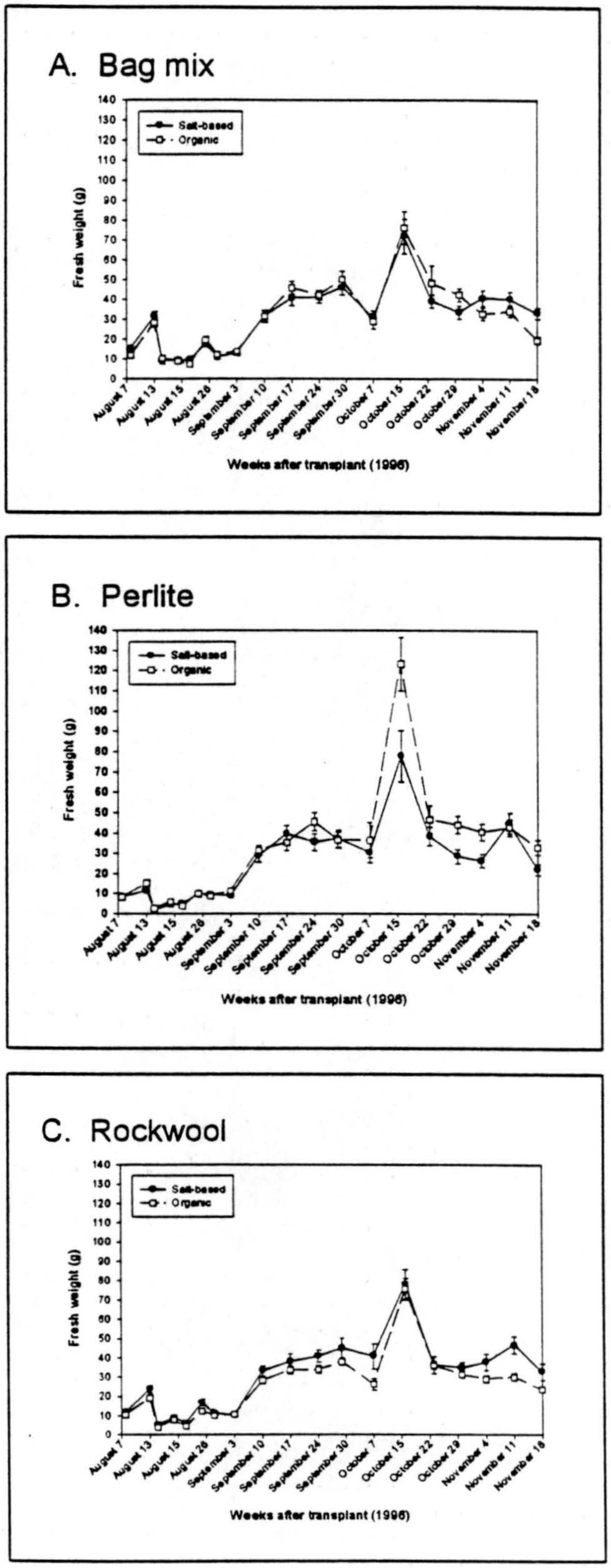

Fig.4.3. 1996 weekly harvest fresh weight means. Plants grown from August 7 to November 18, 1996.

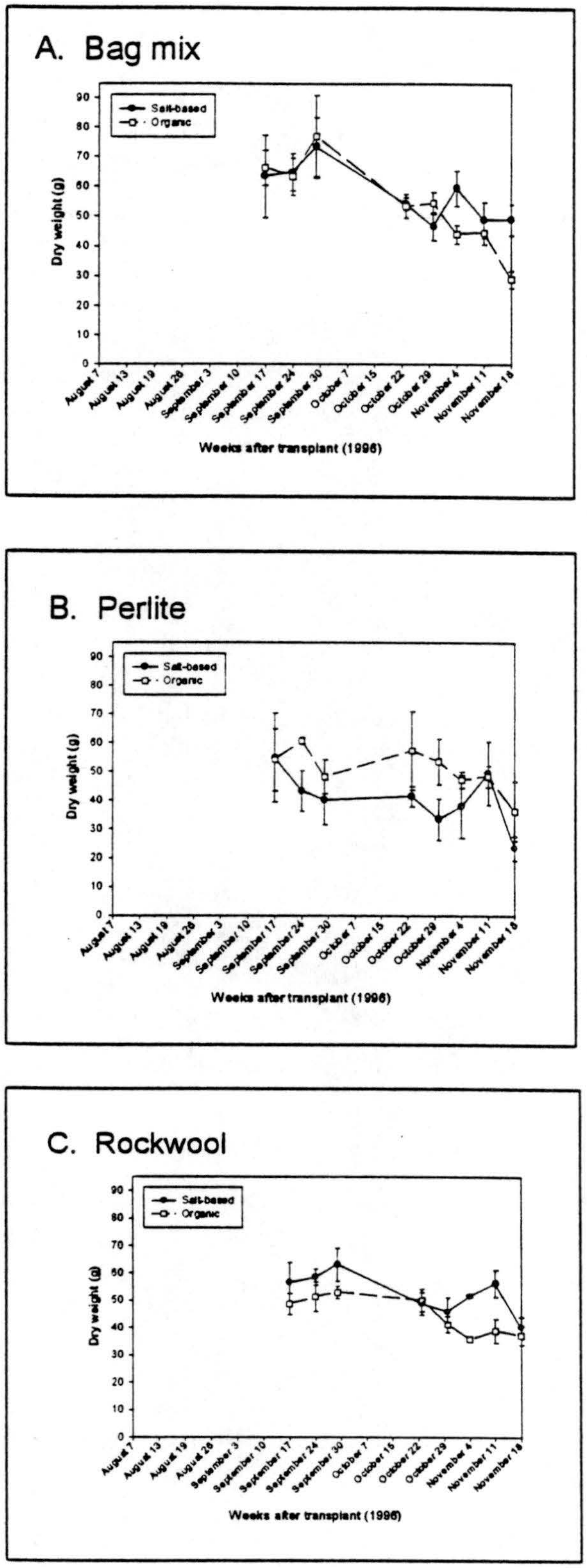

Fig.4.4. 1996 weekly harvest dry weight means. Plants grown from August 7 to November 18, 1996.

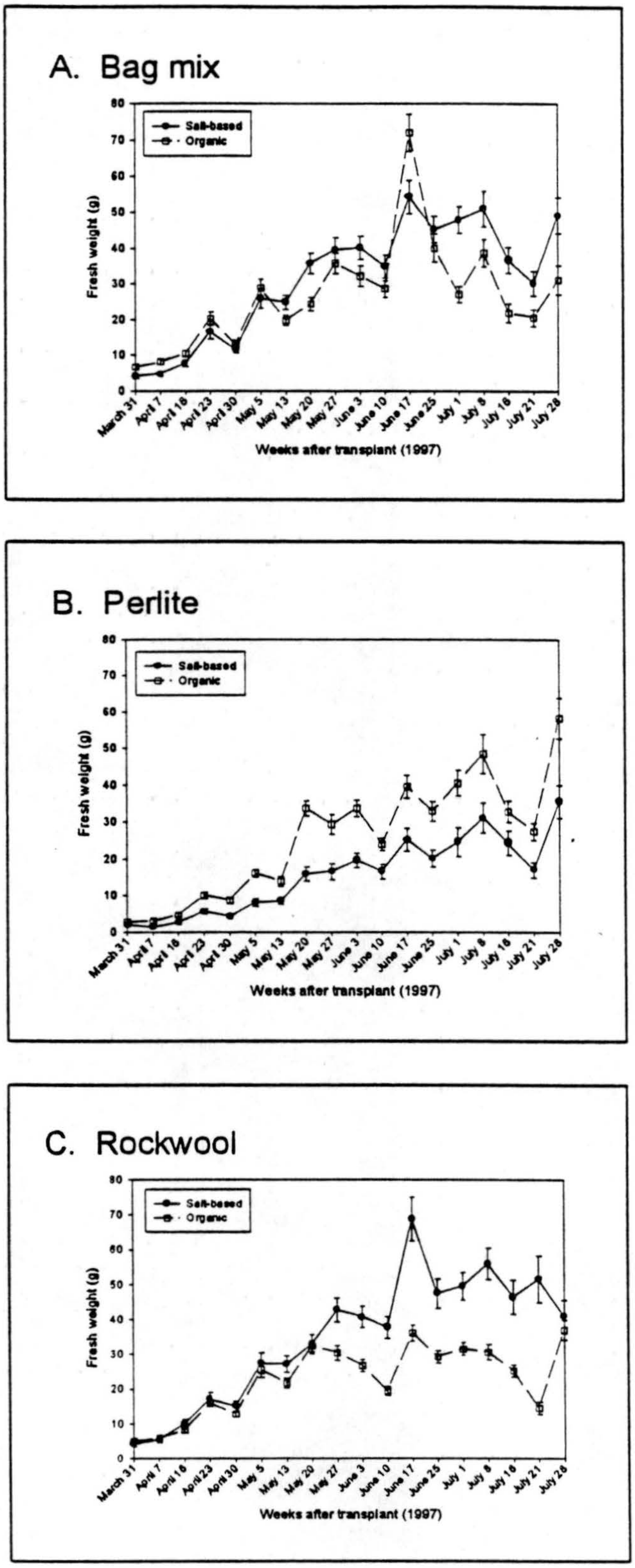

Fig.4.5. 1997 weekly harvest fresh weight means. Plants grown from March 31 to July 28, 1997.

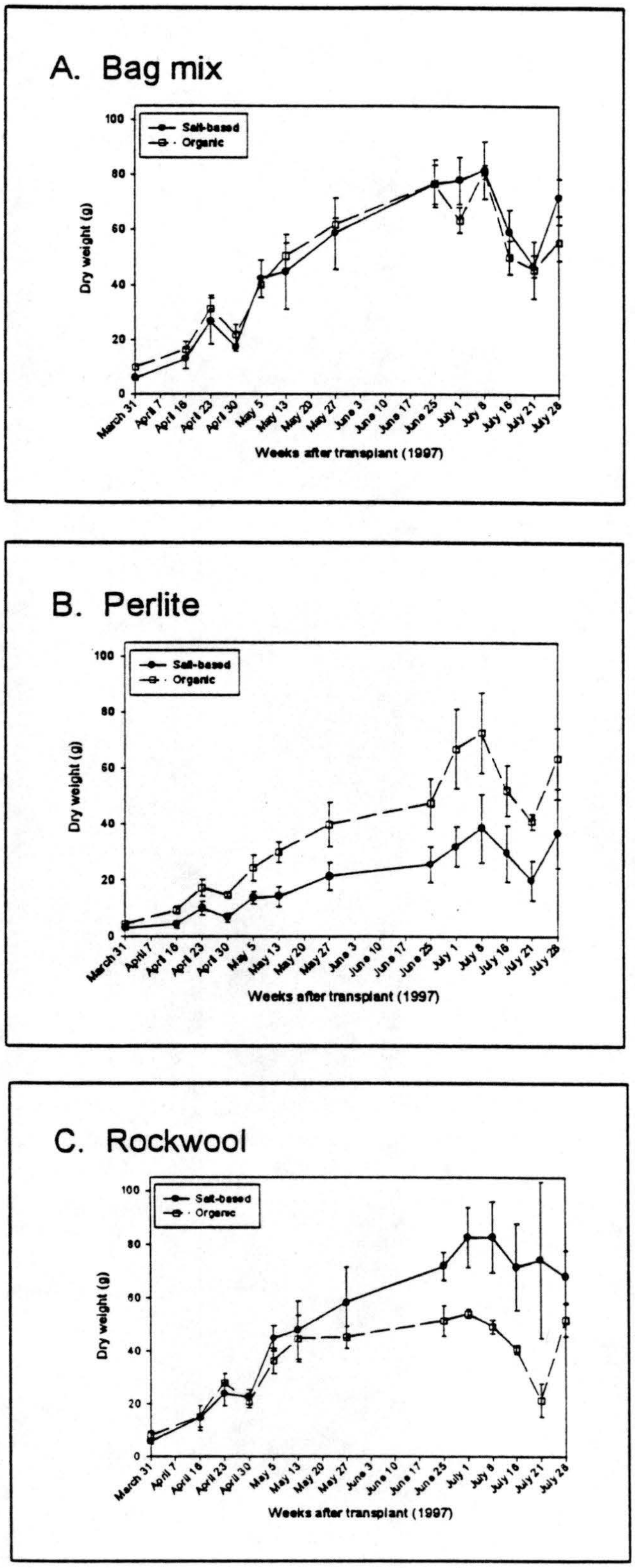

Fig.4.6. 1997 weekly harvest dry weight means. Plants grown from March 31 to July 28, 1997.

Table 4.3. 1996 and 1997 total harvest per plant (g)

	1996		1997	
Growing System	Salt-based	Organic	Salt-based	Organic
Perlite	458 a	557 a	229 b	459 a
Bag mix	555 a	505 ab	555 a	478 a
Rockwool	544 a	446 b	585 a	399 a

Table 4.4. 1996 and 1997 final plant dry weight (g)

	1996		1997	
Growing System	Salt-based	Organic	Salt-based	Organic
Perlite	35.6 b	60.5 b	36.2 b	69.7 b
Bag mix	69.7 a	82.4 a	77.8 a	93.8 a
Rockwool	49.3 b	56.7 b	64.8 a	55.7 b

Table 4.5. 1996 and 1997 final plant height (cm)

	1996		1997	
Growing System	Salt-based	Organic	Salt-based	Organic
Perlite	57.5 b	69.5 a	41.2 c	55.5 b
Bag mix	71.0 a	73.0 a	53.4 a	65.7 a
Rockwool	57.7 b	72.0 a	45.3 b	56.3 b

CHAPTER VI

SUMMARY AND CONCLUSION

This research determined that *Ocimum basilicum* (sweet basil) can be successfully grown in a Colorado greenhouse and can be grown hydroponically and organically in a greenhouse. The physical appearance and health of the plants declined after four months of weekly harvesting in the 1996 and 1997 studies, and the yield declined after four months in the 1996 study. The 1996 study shows a general downward trend during the last month of harvesting in fresh weight and dry weight yields for all growing systems reflective of the decreasing light intensities and a reduction in photoperiod activity. The 1997 study shows an upward trend in fresh weight and dry weight quantities for all growing systems reflective of increasing light intensities and a rise in photoperiod activity.

Differences between fertilizer treatments and among growing systems existed in the research. The growing/irrigation systems within fertilizer treatments had an effect on the hydroponic greenhouse production of fresh market basil. Differences in total harvest per plant, final plant dry weight, and final plant height were seen among growing systems within fertilizer treatments depending on growing season and *Fusarium oxysporum* infection. Differences in basil yield between the organic fertilizer and the salt-based fertilizer occurred depending on the growing system, the week of harvest, *Fusarium oxysporum* infection in 1997, and the growing season.

The research for both studies concludes that the most favorable growing system for fresh market basil in a Colorado greenhouse irrespective of fertilizer treatment is the bag mix system. The most productive growing system for the organic fertilizer, according to the 1996 study, is the bag mix or perlite. However, the most productive growing system for the organic fertilizer, according to the 1997 study, is any of the three systems. The most productive growing system for the salt-based fertilizer, according to the 1996 study, is any of the three systems. However, the most productive growing system for the salt-based fertilizer, according to the 1997 study, is either the bag mix or rockwool system. The research shows weekly productivity for any of the three growing systems, according to the 1996 study, is not effected by fertilizer treatment. However, according to the 1997 study, weekly productivity in the bag mix was occasionally greater with the salt-based fertilizer, weekly productivity in the rockwool was greater during the final half of the season with the salt-based fertilizer, but weekly productivity in the perlite was greater for the majority of the season with the organic fertilizer.

Organoleptic taste test panel members determined with a triangle difference test that the organically fertilized plants were different from the salt-based fertilized plants for all three growing systems. Panel members also determined that no differences existed between organically fertilized and conventionally fertilized plants with regard to preference. The results reveal that there is no taste preference for plants grown with any of the four production methods tested, even though differences are distinguishable.

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