EVALUATION OF OPTIMAL SUBSTRATES AND FERTILIZERS FOR ORGANIC

VEGETABLE TRANSPLANT PRODUCTION IN ALABAMA

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# EVALUATION OF OPTIMAL SUBSTRATES AND FERTILIZERS FOR ORGANIC VEGETABLE TRANSPLANT PRODUCTION IN ALABAMA

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A Thesis

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EVALUATION OF OPTIMAL SUBSTRATES AND FERTILIZERS FOR ORGANIC VEGETABLE TRANSPLANT PRODUCTION IN ALABAMA

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# VITA

CJ McGrath was born in January 1978 in a small town located in Kansas. She is the daughter of Chuck and Candy McGrath, sister to Jonie, sister-in-law to Gavin, and aunt/Godmother to Chase and Molly. She has a little girl named Daisy whom resembles Dorothy's Toto from the 'Wizard of Oz.' CJ graduated from Virginia Tech with a Bachelor of Arts degree in English with minors in Horticulture and History in May 2002. After receiving her BA, CJ moved to Orlando, Fla. to work for Walt Disney World as an Epcot Plant Scientist for a year long advanced college internship. Upon completion, she traveled around the U.S. in pursuit of work for five weeks in her 1995 Saturn. Finding work as a greenhouse grower in central Florida, she grew nearly four acres of tropical foliage plants for a year before deciding to go back to school. CJ found her next home in Auburn, Ala. and entered graduate school at Auburn University in January 2006, pursuing a Master of Science degree under the guidance and direction of Dr. Joe Kemble. While at Auburn, CJ was employed as a graduate research assistant and later as a graduate teaching assistant. She received her Master of Science Degree on 10 May 2008 and began her doctorate studies in January 2008 at Auburn University.

THESIS ABSTRACT

EVALUATION OF OPTIMAL SUBSTRATES AND FERTILIZERS FOR ORGANIC VEGETABLE TRANSPLANT PRODUCTION IN ALABAMA

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Successful organic vegetable production requires a healthy transplant. Presently, there are several certified organic plug substrate blends available; however, the suitability and cost of these substrates are a concern to growers who often report inconsistent or poor results. There is a need to evaluate available certified organic mixes to develop recommendations for organic transplant production that will provide consistent results. In Alabama, four economically important crops for organic growers are tomato (*Lycopersicon esculentum* Mill.), cucumber (*Cucumis sativus* L.), lettuce (*Lactua sativa* L.) and collards (*Brassica oleracea* (Acephala Group) L.).

Untreated seed of 'Celebrity' tomato and organically produced seed of 'General Lee' cucumber were sown July 2006. Organic seed of 'Red Sails' lettuce and untreated seed of 'Georgia Southern' collard were sown Oct. 2006. The design was a RCBD

utilizing four substrates for a total of four treatments in four replicates. Each crop was grown in one of the following substrates in 72-cell plastic market trays: Fafard Organic Formula #10 (FO), Fafard 1P (FC), Sunshine Professional Organic Blend (SO), and Sunshine LC1 (SC). Upon emergence of the true leaves, seedlings grown in FO and SO were fertilized twice weekly with 50 ppm N with a 2N-1.7P-0.83K Neptune's Harvest Fish Hydrolysate for a total of 100 ppm N per week (Gloucester, Mass.). Seedlings grown in FC and SC were fertilized twice weekly with 50 ppm N from a standard TotalGro 20N-4.4P-16.6K water-soluble fertilizer for a total of 100 pmm N per week (SDT Industries, Winnsboro, LA).

Five plants were randomly selected per plot and harvested weekly over a three to five week period depending on the crop. Data of a number of growth parameters were collected: plant canopy height, stem diameter, total leaf area, and total fresh and dry weights of each plant's leaves, shoots, and roots to compare relative growth under each treatment. By last harvest of tomato and cucumber, growth in FO was statistically similar to that in FC; for lettuce and collard, growth in SO was statistically similar to FC. Results suggest growers can produce organic transplants comparable to that of conventional system but that the selection of substrates may be crop dependent.

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# CHAPTER I

# INTRODUCTION AND LITERATURE REVIEW

## Organic Agriculture Production: Past, Present and Future

Prior to the Industrial Revolution, agriculture was by definition primarily organic because agricultural chemicals were not yet available (Jordan, 2004). With the advent of the revolution, industrial farming did make agriculture easier, yet it also created environmental problems which led to the uprising against agricultural practices that had the potential to harm not only nature but also human health, creating modern organic farming (Jordan, 2004).

Local, state, and federal agencies are forcing growers to come face to face with environmental issues such as surface and ground water contamination, pesticide usage, and energy consumption (Bailey, 1998; Weiler et al., 1999). One option growers have to reduce or prevent the discharge of pollutants into the environment is by growing crops organically, a method of growing that made its way into the U.S. from England and Germany in 1938 as the topsoil blew off of the High Plains during the Dust Bowl (Worster, 1979; Fromartz, 2006). By 1941, J.I. Rodale made "organic" a household name through his magazine *Organic Farming and Gardening*. Rodale envisioned reducing the use of chemical inputs in farming and restoring soil fertility (Dimitri and Oberholtzer, 2005). Farming, however, lost sight of the organic philosophy upon the

discovery of synthetic fertilizers and pesticides following World War II (Carson, 1962; Fromartz, 2006; Jordan, 2004; Worster, 1979). Farmers found they could generate quality produce and plants more efficiently, not realizing that this efficiency had hidden costs which negatively affected land, water, and air (Carson, 1962; Jordan, 2004; Worster, 1979). Nearly 20 years after the chemical revolution, there was an environmental re-awakening with the release of Rachel Carson's *Silent Spring* (1962) which suggested that short term gain was at the expense of long-term tragedy.

Federal, state, and local legislators are requiring the Green Industry to adopt measures which decrease the leaching of chemicals into the environment and improve water quality (Drinkwater et al., 1995; Fromartz, 2006; Weiler et al., 1999). In support, various agencies are providing funds to assist farmers in converting their operations to more environmentally friendly operations (OECD, 2003; USDA, 2005). Numerous U.S. companies are adopting organic production to conserve nonrenewable resources, decrease input costs, secure the high value markets, and increase farm income (USDA, 2006).

In 1990, the United States Department of Agriculture (USDA) was mandated through the Organic Foods Production Act (OFPA) to develop standards for U.S. organic products (Dimitri and Oberholtzer, 2005). On 21 Oct. 2002, USDA's National Organic Program (NOP) went into effect defining organic agriculture as "a production system that is managed in accordance with the Organic Foods Production Act (OFPA) and regulations to respond to site-specific conditions by integrating cultural, biological, and mechanical practices that foster cycling of resources, promote ecological balance, and conserve biodiversity" (USDA, 2002). The International Federation of Organic Agriculture Movements (IFOAM), a grassroots organization based in Bonn, Germany

whose goal is the worldwide adoption of systems based on organic agriculture principles, similarly defines organic agriculture as "dramatically reducing external outputs by refraining from the use of chemo-synthetic fertilizers, pesticides and pharmaceuticals…it allows the powerful laws of nature to increase both agricultural yields and disease resistance" (Willer and Yussefi, 2006). The regulations set forth by the USDA require certification of producers by approved agencies in order for organic products to have the approved USDA "organic" label and stamp. In terms of labeling, the USDA defines the term "organic" as "a labeling term that refers to an agricultural product produced in accordance with the Act and the regulations in this part" (USDA, 2002). Although the methods and materials growers use might vary, every aspect of production and handling must comply with the provisions of the OFPA, given a particular certified organic farm (Dimitri and Greene, 2002; USDA, 2002).

Organic farming has become one of the fastest growing segments of U.S. agriculture since the implementation of the National Organic Standards (NOP) in the 1990s (Sok and Glaser, 2001; USDA, 2005). Currently with 31 million hectares in production worldwide, organic agriculture is increasing annually by approximately 5 million hectares as farmers endeavor to supply the increasing demand for organic food products (Dimitri and Greene, 2002; Willer and Yussefi, 2006). Organic sales have grown approximately twenty percent (20%) per year since 1990, due mainly in part to consumers viewing organic foods as a means to aligning, not only their nutrition and health, but also their environmental and social well-being (Fromartz, 2006; Jordan, 2004).

The benefits of organic production systems are becoming evident as products continue to develop throughout the world, especially in countries outside of North America and Europe. The principal growth in demand for organic products is in Europe and North America with the market value reaching nearly $28 billion in 2004 (Willer and Yussefi, 2006).

As of 2003, tomatoes (*Lycopersicon esculentum* Mill.), lettuce (*Lactuca sativa* L.) and carrots (*Daucus carota* L.) accounted for 30% of the 31,928 hectares (ha) of certified organic vegetables grown in the U.S. (USDA, 2003). In the U.S., the top states for organic vegetable production are California (19,606 ha), Washington (3,867 ha), Oregon (1,126 ha), North Carolina (677 ha), and Colorado (655 ha) (USDA, 2003). Alabama has 130 acres (53 ha) of certified vegetable acreage (USDA, 2003). The top organic seller is fresh produce, which, out of the $10 billion in organic food sales in 2003, accounted for 42% of total sales (Dimitri and Greene, 2002). *The National Business Journal* proposed that the sale of organic produce in the U.S. would attain nearly $18 billion by 2007 (Dimitri and Oberholzer, 2005).

**Transplants for Organic Vegetable Production**

Transplant production qualifies as one of the most intensive cropping systems since growers face rising water and fertilizer costs, declining water quality, and governmental intervention protecting surface and ground water (Granberry and Boyhan, 2003; Weiler et al., 1999). The use of transplants is often a key practice for conventional as well as organic vegetable producers. Increasing numbers of growers are purchasing transplants, discerning that the production of high-quality transplants will support the success of final crop production in both open fields and greenhouses (Kubota and

Kroggel, 2006). Growers prefer transplants rather than direct seeding because the transplants develop a distinctive root system rather than just a strong tap root (Leskovar and Stoffella, 1995), and the benefits of using transplants are many: growers have a consistent supply of quality seedlings, improved uniform stand establishment, and earlier crop production (Dufault, 1998; Greer, 2005; Jeong, 1998; Schrader, 2000).

High quality transplants are essential for successful vegetable production since the condition of the plant during transplanting influences stand establishment, yield, and fruit size (Schrader, 2000; Weston and Zandstra, 1989). Often, each vegetable species requires specific cultural conditions in order to produce a quality transplant (Kelley and Boyhan, 2003). The production of a quality transplant depends on factors such as air temperature, substrate, container size, fertilizer and irrigation timing/rates, transplant age, hardening off, and airflow within a greenhouse (Brigard et al., 2006; Brown et al., 2002; He et al., 2003; Schrader, 2000; Vavrina, 2002). Consumer specifications generally define a quality transplant as being green, stocky, disease and pest free with a well developed root system (Brigard et al., 2006; Vavrina, 2002).

Vegetable transplants are commonly produced in plug trays which utilize greenhouse space more efficiently lowering production costs (Marr and Jirak, 1990; Schrader, 2000). Based on research, disposable vacuum-molded cell packs, plastic trays, and Styrofoam trays are now the standard for the transplant industry (Kelley and Boyhan, 2003; Schrader, 2000; Vavrina, 1999). Often, transplants are not only grown in these containers but can also be shipped in them as well (Vavrina, 2002).

These plug trays contain “cells” in which each cell produces one transplant. These multi-cell plug trays vary in number of cells per tray but commonly range from 72

to 250 cells per tray. Growers are often drawn to smaller cell sizes to produce transplants to utilize greenhouse space and maximize production, yet the balance between root and shoot can be disrupted when the root system is restricted; resulting in negative short term, and possible long term, effects on plant growth (NeSmith and Duval, 1998). Although, plants have a higher chance of being over/under watered when grown in smaller cells (Bailey et al., 1998), proper watering is essential and more critical with larger cell sizes (72-cell) than smaller ones (250-cell) because over watering can be a problem in the early stages of transplant production which could result in higher incidences of root disease (Kelley and Boyhan, 2003). Larger cell sizes hold a higher volume of substrate which enables them to retain more water and nutrients; thus reducing the likelihood of water or nutrient stress (Kelley and Boyhan, 2003). Transplants with larger root systems commonly experience less post-plant shock and come into production earlier than transplants with smaller root systems (NeSmith and Duval, 1998; Weston and Zandstra, 1986). In general, water management becomes progressively more critical as transplant size increases per unit volume of substrate (Peirce, 1987). Studies in England in the 1990s showed that organically grown transplants benefited from larger cell sizes even though researchers have yet to prove whether or not container size affects crop yield (Greer, 2005; NeSmith and Duval, 1998).

Seventy-two-cell trays are recommended for crops with longer growing cycles, such as tomato (*L. esculentum*) and pepper (*Capsicum annum* L.), since they benefit from a larger cell size and have a higher rate of survival and produce earlier and larger crop yields than transplants produced in smaller cell sizes (Vavrina, 1999; Vavrina, 2005). Kemble and others (1994) found that larger container sizes result in an increase in the

amount of dry matter present in tomato stems and that as rooting volume increased, the time from sowing to anthesis was shortened for tomato. Overall, the specific cell size depends on species, cultivar, and desired age of transplant (Greer, 2005; NeSmith and Duval, 1998; Orzolek, 2005).

As early as the 1920s, researchers have been studying the importance of vegetable transplant age (Loomis, 1925; Vavrina, 1998). The age of transplants is crop dependent and critical to the performance of post-transplanting. Tomato transplants which are younger than five- to six-weeks-old are not as resistant to damage from wind, low temperatures, and soil moisture deficits (Orzolek, 2005). Vavrina (1998) stated that younger transplants of three to four weeks may reduce production costs, but the transplants may be injured when pulled from the container, resulting in an extended period in the field to achieve optimum yield. Additionally, younger tomato transplants must be grown longer in the field to reach optimum yield (Vavrina, 1998). Often, growers prefer young, actively growing transplants and questions will be raised about possible growth and yield potential if the transplant is thought to be too old (Vavrina, 1998).

Vegetables can be transplanted at an early age with little effect on growth, yet with increasing age, the situation changes (Vavrina and Orzolek, 1993; Vavrina, 1998). The rate of root replacement declines with increasing transplant age (Weaver and Bruner, 1927) and older transplants have a shorter readjustment period of vegetative growth before the reproductive phase (Peirce, 1987; Schrader, 2000). Although older transplants (seven to nine weeks) may produce earlier yields, pest and disease problems may arrive in the greenhouse affecting quality (Vavrina, 1998). Nonetheless, studies state that if

there is significant mortality in the field post-transplanting, the use of older transplants to reset fields should not reduce yield, fruit size, or earliness.

One of the more limiting factors for growers getting into organic vegetable production is the lack of organic seed or non-treated seed which are required by the OFPA. Organic production, especially to be certified organic, requires the utilization of organically-grown seed. If growers are unable to find organically grown seed, commercially available untreated seed can be used in accordance with the National Organic Program (NOP) requirements (Dodson et al., 2002). As demand increases, the seed industry is making significant strides in offering a wider selection of organically produced seed and non-treated seed for use (Adam, 2005).

For decades, growers have utilized greenhouse grown vegetable transplants (Dufault, 1998; Langston, 2003) but currently, there is a less than adequate supply of organic vegetable transplants. In part, this is due to limited research aimed at developing guidelines for their production. Current information available to organic farmers is based on observation or extrapolated from research executed for conventional transplant production. Presently, organic farmers are requesting unbiased analysis of substrates, amendments, fertilizers, and compost products that are currently available for certified organic production (Delate and Lawson, 2001).

**Organic Substrates, Fertilizers, and Amendments**

In greenhouse transplant production, growers need to integrate a substrate into their production system that not only addresses sufficient aeration and water retention, but also fertilizer requirements for plant nutrition (Bailey et al., 1998).

Transplants are generally grown in soilless substrates which can be used in any cell size and provide optimal growing conditions (sufficient aeration, root growth, and plant support) (Bailey et al., 1998; Fonteno et al., 1995; Kuepper and Everett, 2004; Schrader, 2000). According to the requirements set forth by the USDA in the National Organic Program (NOP), organic substrate mixes must not contain synthetic wetting agents or conventional fertilizers; substrates must consist of materials approved by the USDA or OMRI (Kuepper and Everett, 2004; Organic Materials Research Institute, Eugene, Ore.; USDA, 2002). These materials are listed on the National List of Approved Substances (Kuepper and Everett, 2004; USDA, 2002).

In conventional vegetable transplant production, field soils are not recommended for growing vegetable transplants for they are often contaminated with weed seed, pests, and diseases and also do not drain properly (Kelley and Boyhan, 2003). Transplant production requires substrate mixes that are soilless and consist of pine bark, peat, vermiculite, and perlite along with or without a starter fertilizer charge and wetting agents (Bailey et al., 1998; Kelley and Boyhan, 2003). Without these components, substrates would not be able to provide the nutrients needed and have the water-holding capacity to produce quality transplants (Kelley and Boyhan, 2003). Organic transplant substrate may contain any one of the above items, yet must substitute organically allowable fertilizers for the conventional starter fertilizer and wetting agents (Dodson et al., 2002; Greer, 2005).

Transplant substrates should be sterile, light-weight, friable, and have adequate water-holding capacity (Bailey et al., 1998; Kelley and Boyhan, 2003; Peirce, 1987). To obtain the correct proportions of the various elements that each vegetable crop species

requires to grow is a complex process. Growers could mix their own soilless substrate mixes, yet it would require additional time, labor, and management, and the actual cost savings would likely be minimal (Kelley and Boyhan, 2003; Greer, 2005). Therefore, growers are encouraged to use pre-blended, commercial mixes to ease the process (Kelley and Boyhan, 2003; Greer, 2005; Vavrina, 2002). Most commercial soilless substrate mixes, however, contain synthetic wetting agents and fertilizers (Greer, 2005). As a result, organic growers did not have a ready made option to utilize and needed to blend their own substrate mixes until recently. This prospect was problematic because of limited research focused on finding a consistent and affordable substrate blend for organic transplant production. There are now several certified organic plug mixes available; however, the suitability and cost of these substrates are of concern to growers who often report inconsistent or poor results: Thus, the efficacy of organic plug substrates needs clarification (Russo, 2005).

Proper nutrient rates for transplants directly impact field performance (Dufault, 1998; Vavrina, 2002). In conventional transplant production, most nutrient sources are water-soluble due to the ease of application and cost (Kelley and Boyhan, 2003; Jordan, 2004; Miles, 2000). Typically, soluble fertilizers are added to soilless substrate mixes on a weekly basis to maintain transplant health until they are ready to be transplanted in the field because the substrate mixes contain little or no available nutrient content after the seedlings are established. Slow-release fertilizers are not recommended since plant height is difficult to control with a constant nitrogen (N) supply (Kelley and Boyhan, 2003; Vavrina, 2002). Excess N often causes transplants to become "leggy," resulting in poor quality (Dufault, 1998; Vavrina, 2002). Taller transplants tend to easily break

because they are more succulent (Brigard et al., 2006). In the southern U.S., low N-P-K levels are recommended (Dufault, 1998). Moderate nutritional regimes can prevent excessive transplant height (Brigard et al., 2006; Dufault, 1998) and produce quality transplants (Vavrina, 2002). A major obstacle in developing fertilizer regimes for organic transplant production is meeting NOP certification requirements (Miles and Peet, 2002).

There is a selection of organic fertilizers (also known as soil amendments) for use in organic vegetable transplant production. Some of the more common materials are animal manure, blood meal, bone meal, feather meal, greensand, kelp meal, and dolomitic lime ($CaCO_3$) which is used to adjust soil pH (Greer, 2005; Kuepper and Everett, 2004). A major drawback of these specific organic fertilizers is that they are slowly available to the plant. Because of the rapid growth of transplants, these organic fertilizers may not be good candidates for transplant production (Kuepper and Everett, 2004) because of the short time frame they are in the greenhouse. The best results can be obtained for plant growth rates when organic fertilizers are formulated to approximate the N-P-K levels of conventional fertilizers (Miles and Peet, 2002). On average, soluble organic fertilizers (i.e. fish emulsion or fish hydrolysate) are added to soilless mixes on a weekly basis to maintain transplant health until they are ready to be transplanted in the field because these mixes do not contain sufficient nutrients to sustain development. According to Aung et al. (1983), fish and its byproducts have been recognized as a fertilizer suitable for plants because of favorable crop responses. Nielsen and Thorup-Kristensen (2004) suggested that an ideal organic substrate blend should supply most of the nutrients needed for plant growth and limit the need for additional soluble nutrients.

Economically viable and locally produced organic substrates are lacking in not only in Alabama, but many other states as well. Available commercial mixes are expensive and not always locally available. Currently, organic fertilizers are shipped long distances to growers, substantially increasing production costs (Kuepper and Everett, 2004). With ever increasing costs for substrates, water, fertilizer, and transportation, growers are looking for local supplies of these items (Kuepper and Everett, 2004).

**Objectives**

As organic production continues to grow worldwide, the need for organically grown transplants will increase, especially for vegetable crops. The first objective of this study was to understand what makes an acceptable organic substrate in terms of its physical properties in order to develop an affordable substrate that growers in Alabama can utilize for organic transplant production of economically critical crops, such as tomatoes (*L. esculentum*), cucumbers (*Cucumis sativus* L.), lettuce (*L. sativa*), and collards (*Brassica oleracea* L.). The second objective of this study was to examine the effect of currently available commercial plug mixes and their components on selected growth parameters of these economically important crops. The third objective of this study was to characterize the early growth and development of transplants in terms of changes in relative growth rate, net assimilation rate, and leaf area ratio.

By way of these objectives, growers interested in producing organic transplants will be offered a scientifically valid and detailed procedure for developing quality transplants.

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# CHAPTER II

# CUCUMBER AND TOMATO SEEDLING GROWTH IN ORGANIC PLUG SUBSTRATES


## Abstract

Transplant production qualifies as one of the most intensive cropping systems and there is a sector of the greenhouse market that would like to obtain certified organic vegetable transplants. Currently, there is a less than adequate supply of organic vegetable transplants due to limited research aimed at developing recommendations for their production. Successful transplant production requires a suitable substrate and the suitability of organic materials as an alternative to conventional materials needs clarification. There are several certified organic plug mixes available; however, the efficacy and cost of these substrates are of concern to growers who often report inconsistent or poor results. Two experiments were conducted to study the effect of two currently available certified organic plug substrate mixes on the growth of cucumber (*Cucumis sativus* L. 'General Lee') and tomato (*Lycopersicon esculentum* Mill. 'Celebrity') transplants and compared to conventional (non-organic) versions of these same mixes. Upon emergence of first true leaves, 50 ppm N of water soluble organic or conventional fertilizers were applied twice a week to respective substrates. Data of a number of growth parameters were collected: plant canopy height, stem diameter, total

leaf area, and total plant fresh and dry weights of each plant's leaves, shoots, and roots to compare relative growth under each treatment. By last harvest of both tomato and cucumber experiments and according to all growth parameters, overall growth in commercial organic (FO) substrate was statistically similar to that in the commercial conventional (FC) substrate.

**Introduction**

Organic farming has become one of the fastest growing segments of U.S. agriculture since the implementation of the National Organic Standards (NOP) in the 1990s (Sok and Glaser, 2001; USDA, 2005). U.S. farmers are joining forces by substantially expanding their organic acreage, lowering their input costs, capturing the high-value markets, boosting farm income, and conserving nonrenewable resources (Greene, 2001). Currently, with 31 million hectares in production worldwide, organic agriculture is increasing annually by approximately 5 million hectares as farmers endeavor to supply this increasing demand for organic food products (Dimitri and Greene, 2002; Greene, 2001; Willer and Yussefi, 2006). Although organic agriculture has established itself as being economically important with a sales growth of approximately twenty percent (20%) per year since 1990, there is a significant lack of scientific research to support this segment of agricultural production, especially for organic vegetable transplant production (Dimitri and Oberholtzer, 2005; Fromartz, 2006). Current information available to organic farmers concerning transplant production is limited and based on observation or extrapolated from research executed for conventional transplant production.

Conventionally, transplant substrate blends are soilless consisting of pine bark, peat, vermiculite, and perlite along with a starter fertilizer charge and wetting agents (Bailey et al., 1998; Kelley and Boyhan, 2003). Organic transplant mixes may contain any one of the above items, yet must substitute organically allowable fertilizers for the conventional starter fertilizer and wetting agents (Dodson et al., 2002; Greer, 2005). Transplants are generally grown in soilless substrates which can be used in any cell size and provide optimal growing conditions (sufficient aeration, root growth, and plant support) (Fonteno et al., 1995; Kuepper and Everett, 2004; Schrader, 2000). On average, soluble organic fertilizers (i.e. fish emulsion or fish hydrolysate) are added to soilless mixes on a weekly basis to maintain transplant health until they are ready to be transplanted in the field because these mixes do not contain sufficient nutrients to sustain development. According to Aung and others (1983), fish and its byproducts have been recognized as a fertilizer suitable for plants because of favorable crop responses. Nielsen and Thorup-Kristensen (2004) suggested that an ideal organic substrate should supply most of the nutrients needed for plant growth and limit the need for additional soluble nutrients.

Organic production, especially to be certified organic, requires the utilization of organically-grown seed. If organically grown seed were not available for desired varieties, commercially available untreated seed were used in accordance with the USDA National Organic Program (NOP) requirements (Dodson et al., 2002).

One objective of this study was to understand what makes an acceptable organic substrate in terms of its physical properties in order to develop an affordable substrate that growers in Alabama can utilize for organic transplant production of tomato (*L.*

*esculentum* ‘Celebrity’) and cucumber (*C. sativus* ‘General Lee’) crops. The second objective of this study was to examine the effect of currently available commercial organic and conventional (non-organic) plug mixes and their components on selected growth parameters. The third objective of this study was to characterize the early growth and development of transplants in terms of changes in relative growth rate, net assimilation rate, and leaf area ratio.

**Methods and Materials**

Components of substrate treatments are further described in Table 1. The Soil Testing Laboratory at Auburn University determined the elemental components of these substrate blends which are further described in Table 2. Physical properties including air space, water holding capacity, total porosity, and bulk density were determined for each substrate utilizing the North Carolina State University Porometer (Table 3) (Fonteno and Harden, 2003).

An experiment was conducted using ‘Celebrity’ tomato and ‘General Lee’ cucumber. This experiment was repeated as described below and in each run the same materials and methods were used. These cultivars were selected based on their performance and recommended use in Alabama in the 2006 Vegetable Crop Handbook for the Southeastern U.S. Untreated ‘Celebrity’ tomato seed and organic ‘General Lee’ cucumber seed were obtained from Harris Seeds (Rochester, N.Y.). All research was conducted in a glass greenhouse with computer controlled evaporative cooling pads and fans with sunshade screens in Auburn, Ala. at 32.6°N latitude. Temperature set-points were 25.5°C day and 22.7°C night with ambient light.

The experimental design was a randomized complete block design with four replicates. Each replicate contained four treatments: two conventional substrates, Fafard 1-P (FC) and Sun-Gro LC1 (SC), and two organic substrates, Fafard Organic Formula #10 (FO) and Sun-Gro Professional Organic Blend (SO) (Fafard, Inc., Anderson, S.C.; Sun-Gro Horticulture, Bellevue, Wash.).

The first run of this experiment was conducted from 23 Mar. – 24 May 2007. The second run of this experiment was conducted from 17 Apr. – 7 July 2007.

**Seeding, Plant Care, and Data Collection**

Each replicate contained six 72-cell plastic market trays (cell dimensions: 3.8 cm x 3.8 cm x 6.0 cm) which included each of the four substrates: Conventional Fafard substrate (hereafter referred to as FC), organic Fafard substrate (hereafter referred to as FO), conventional Sun-Gro substrate (hereafter referred to as SC), and organic Sun-Gro substrate (hereafter referred to as SO) which were placed into plastic flats (26.7 cm x 53.7 cm) for stability (Dillen Products, Middlefield, Ohio). Each replicate contained one and a half (1.5) flats of each substrate treatment for a total of six flats per replicate and twenty-four flats total for the experiment. Flats were seeded 0.6 cm deep, one per cell, for a total of 1728 'General Lee' cucumber seed and additional substrate of the same treatment was used to cover the seed. All substrates were watered to runoff upon completion of seeding. The 72-cell flats were divided into halves (i.e. into 36-cell sections, which is why each replicate contained 1.5 flats of each substrate) to represent a randomly assigned harvest interval from one to three. Hence, only one 36-cell section of each treatment within each replicate was destructively harvested each week (half flat (0.5) per treatment (4) per replicate (4) per harvest for a total of eight flats/week; 0.5 x 4

= 2 x 4 = 8), for a total of three weeks (Table 4a and 4b). Trays were subsequently hand watered as needed.

Upon emergence of the true leaves, 50 ppm N from a 2N-1.7P-0.83K Neptune's Harvest Fish Hydrolysate (organic, nutritional protein fertilizer, made utilizing naturally occurring enzymes present in North Atlantic fish; N derived from the fish protein in the form of amino acids) were applied twice a week (for a total of 100 ppm/week) to seedlings grown in organic substrates FO and SO (Gloucester, Mass.). Seedlings grown in conventional substrates FC and SC were fertilized with 50 ppm N twice a week (for a total of 100 ppm/week) from a standard TotalGro 20N-4.4P-16.6K water-soluble fertilizer (SDT Industries, Winnsboro, LA). Data were collected from 7 Apr. – 20 Apr. 2007.

On 6 Apr. 2007, the same methods, materials, and treatments described above were repeated with the exception of planting date, number of flats and seed, species, and harvest intervals. Each replicate contained ten 72-cell flats which included each of the four substrates. Each replicated contained two and half (2.5) flats of each substrate treatment for a total of ten flats per replicate and forty flats total for the experiment. 2880 'Celebrity' tomato seed were used and were seeded one per cell. All substrates were watered to runoff upon completion of seeding. The 72-cell flats were divided into halves (i.e. into 36-cell sections, which is why each replicate contained 2.5 flats of each substrate) to represent a randomly assigned harvest interval from one to five. Hence, only one 36-cell section of each treatment within each replicate was destructively harvested each week (half flat per treatment per replicate per harvest for a total of eight

flats/week), for a total of five weeks (Table 4a and 4b). Trays were subsequently hand watered as needed. Growth data were collected from 26 Apr. – 24 May 2007.

Procedures for the second run of each crop were the same as described above with the exception of planting date. Trays were filled and seeded on 17 Apr. 2007 for 'General Lee' cucumber and 18 May 2007 for 'Celebrity' tomato. Data were collected from 9 – 23 May 2007 and 5 June – 5 July 2007, respectively.

**Growth Analysis**

'General Lee' cucumber seedlings were harvested weekly over a period of three weeks, whereas 'Celebrity' tomato seedlings were harvested weekly over a period of five weeks based on recommendations from Vavrina (1998). Five plants were randomly selected from the center of one half (36-cell section) flat per treatment per rep and harvested weekly (80 plants total per harvest date). Measurements of plant height (taken from soil line to top of plant canopy), leaf area, stem diameter (2.5 cm above the soil line), and fresh and dry weights of leaves, shoots, and roots (after drying for 72 h at 78°C in a forced-air oven) were recorded. Roots were rinsed with tap water to remove substrate prior to data collection. Plant roots were separated from the top portion of plant by cutting at the soil line. Leaf area was measured using a LI-COR 3000 (Lincoln, Nebr.).

Growth parameters were calculated based upon weekly changes in plants using equations described by Hunt (1982) and Kemble (1993). Relative growth rate (RGR) was calculated as:

$$RGR = [(\ln W_2 - \ln W_1)/ (T_2 - T_1)],$$

where 'ln' is the natural log and $W_2$ and $W_1$ represent plant dry weight (shoots + leaves + roots) at time two ($T_2$) and time one ($T_1$), respectively. Net assimilation rate (NAR) was calculated as:

$$NAR = [(W_2 - W_1)/(T_2 - T_1)] \times [(\ln LA_2 - \ln LA_1)/(LA_2 - LA_1)],$$

where $LA_2$ and $LA_1$ represent plant leaf area at $T_2$ and $T_1$, respectively. Leaf area ratio (LAR) was calculated as:

$$LAR = [(LA_1/ W_1) + (LA_2 /W_2)]/2$$

Data were analyzed as a randomized complete block design using PROC ANOVA in SAS 9.1 (SAS Institute Inc., Cary, N.C.). Means were separated by Fisher's Protected Least Significant Difference (LSD) test at $\alpha = 0.05$ (5%). Unless otherwise stated, all data were analyzed at the 5% level. Each crop was analyzed separately. When necessary, data for a dependent variable were log transformed if plots of residual and predicted values displayed heterogeneity of variances; therefore, data were generated using transformed values. All data presented within text is non-transformed. Data were initially analyzed to detect significant differences between runs. If there were no significant differences between runs, data were pooled for runs (i.e. Run 1 and Run 2). If data indicated significant differences, data were not pooled and runs were analyzed separately and then analyzed for interactions between runs and harvests. If data indicated no significant interactions, harvests were pooled with runs. If data indicated significant interactions, harvests were analyzed individually within runs.

## Results

*Cucumber Growth Parameters*

Statistical analysis indicated that each run needed to be analyzed separately due to significant interactions between runs and harvests. Thus, each harvest was analyzed separately from one another for both experiments with the exception of shoot fresh weight for Run 2. These data were pooled for analysis because there were no significant interactions between harvests and treatments. Mean shoot fresh weight ranged from 1.33 g to 3.73 g. In Run 2, shoot fresh weight did not differ from each other statistically when plants were grown in conventional treatments, Sun-Gro LC1 (SC) and Fafard 1-P (FC), with growth in Sun-Gro Professional Organic Blend (SO) being significantly lower.

*Harvest 1*

In Run 1, average transplant canopy heights (average 10.92 cm) and shoot dry weights (0.03 g) did not differ statistically when grown in SC and FC and were higher than other treatments. Transplant stem diameters (3.68 mm in SC vs. 3.25 mm in FC), total plant fresh weights (3.33 g in SC vs. 2.78 g in FC), shoot fresh weights (0.92 g in SC vs. 0.72 g in FC), and leaf fresh weights (1.37 g in SC vs. 1.06 g in FC) were statistically higher when plants were grown in SC and were lower when plants were grown in FC. Average root fresh weights and total plant dry weights did not differ statistically when plants were grown in SC and FC (average 1.02 g and 0.20 g, respectively). Cucumber transplants grown in SO and FO had statistically similar but lower root fresh weights and total plant dry weights than when plants were grown in SC and FC (average 0.56 g and 0.14 g, respectively). Total leaf areas were statistically higher when transplants were grown in SC (49.00 $cm^2$). When transplants were grown in

FC (39.63 $cm^2$) and FO (35.12 $cm^2$), leaf areas were statistically similar but lower than when grown in SC. Plants grown in SC and FC had statistically similar root dry weights (average 0.05 g) and leaf dry weights (0.12 g).

In Run 2, average transplant canopy height did not differ when plants were grown in both conventional treatments (average 7.80 cm in FC and SC). Canopy heights of transplants grown in FC and FO were similar but lower than when grown in FC and SC (7.17 cm in FO and 7.63 cm). There were no significant differences between any of the four plug substrates for total leaf area ($p \leq 0.3781$). Among these four substrates, leaf area ranged from 34.3 $cm^2$ to 42.4 $cm^2$. Stem diameters (average 3.31 mm), leaf fresh weights (0.64 g), shoot dry weights (0.04 g), and leaf dry weights (0.02 g) were statistically similar when transplants were grown in FC and SC and growth in SO was significantly lower (2.85 mm, 0.36 g, 0.02 g, and 0.01 g, respectively). Transplants grown in FC and SC had similar and higher total plant fresh weights (average 3.06 g), total plant dry weights (0.17 g), and root fresh weights (1.28 g) than when grown in the organic treatments (2.26 g, 0.13 g, and 0.99 g, respectively). Root dry weights did not differ from each other statistically when transplants were grown in both conventional treatments and were higher than organic treatments (0.11 g).

*Harvest 2*

In Run 1, average transplant canopy heights, stem diameters, total plant fresh weights, root fresh weights, leaf fresh weights, and leaf dry weights were higher when transplants were grown in SC and were significantly lower in SO. Canopy heights were 14.8 cm in SC vs. 7.80 cm in SO; stem diameters were 3.97 mm in SC vs. 3.09 mm in SO; total plant fresh weights were 6.52 g in SC vs. 2.44 g in SO; root fresh weights were

2.43 g in SC and 0.98 g in SO; leaf fresh weights were 1.30 g in SC vs. 0.44 g in SO; and leaf dry weights were 0.07 g in SC vs. 0.02 g in SO. Total leaf areas (84.71 $cm^2$ in SC, 61.79 $cm^2$ in FC, and 55.87 $cm^2$ in FO) and total plant dry weights (0.40 g in SC, 0.32 g in FC and FO) of transplants grown in SC were statistically higher than when grown in FC and FO. Transplants grown in SC (11.01 g) had higher shoot fresh weights and were lower but similar when grown in FO and FC (2.16 g for both). Average shoot dry weights did not differ from each other statistically when plants were grown in SC (0.12 g) and FO (0.11 g).

In Run 2, there were no significant differences between any of the four plug substrates for root fresh weight and root dry weight ($p \leq 0.2341$ and 0.0553 respectively). Among these four substrates, root fresh weights ranged from 1.77 g to 2.05 g and root dry weights ranged from 0.21 g to 0.23 g. Average canopy heights were higher when plants were grown in SC (16.18 cm) and had reduced growth in FO and FC (15.00 cm and 14.59 cm, respectively). Transplant stem diameters were higher when plants were grown in FC (4.42 mm) and growth was reduced yet comparable when grown in FO and SC (4.14 mm and 4.11 mm, respectively). Total plant fresh weights and leaf fresh weights of plants grown in SC, FC, and FO did not differ from each other statistically and were higher than treatment SO with weight in SO was significantly reduced (3.70 g in SO for fresh weight and 0.82 g for leaf fresh weight). Total plant fresh weights ranged from 5.56 g to 5.70 g in SC and leaf fresh weights ranged from 1.50 g to 1.63 g. Transplants grown in FO and SC did not differ from each other statistically, were higher than other treatments, and had the highest total leaf areas (86.11 $cm^2$). Growth in FC (0.39 g), SC (0.37 g), and FO (0.37 g) did not differ from each other statistically and had higher total dry weights.

*Harvest 3*

In Run 1, average canopy heights (17.42 cm in SC vs. 8.91 cm in SO), leaf fresh weights (1.77 g in SC vs. 0.55 g in SO), and leaf dry weights (0.12 g in SC vs. 0.03 g in SO) were higher when plants were grown in SC with growth being significantly reduced in SO (Fig. 1a, Fig. 1f, and Fig. 2e). Transplant stem diameters (4.16 mm in SC vs. 3.80 mm in FC and FO), total plant fresh weights (8.11 g in SC vs. 5.49 g in FC and FO), total plant dry weights (0.56 g in SC vs. 0.38 g in FC and FO), root fresh weights (3.19 g in SC vs. 2.35 g in FC and FO), root dry weights (0.44 g in SC vs. 0.28 g in FC and FO), total leaf areas (110.1 $cm^2$ in SC vs. 81.89 $cm^2$ in FC and FO), and shoot dry weights (0.12 g in SC vs. 0.10 g in FC and FO) were statistically higher when plants were grown in SC and growth was lower but similar when grown in FC and FO (Fig. 1b, Fig. 1c, Fig. 2b, Fig. 1d, Fig. 2c, Fig. 2a, and Fig. 2d, respectively). Shoot fresh weights were statistically higher when plants were grown in SC and were lower but similar when grown in FO, FC and SO (3.02 g in SC vs. 2.12 g in FO, FC, and SO) (Fig. 1e).

In Run 2, average canopy heights (20.06 cm), total plant fresh weights (9.23 g), and leaf fresh weights (2.12 g) were higher when plants were grown in SC and FO with growth being significantly lower in SO (12.29 mm, 5.43 g, and 0.96 g, respectively). Transplant stem diameters (4.36 mm), shoot dry weights (0.15 g), and leaf dry weights (0.14 g) were higher and similar when plants were grown in SC, FO, and FC. For the first time, total plant dry weights (0.61 g), root fresh weights (3.44 g), root dry weights (0.45 g), and total leaf areas (143.2 $cm^2$) were higher when plants were grown in FO and reduced when grown in SO (0.37 g, 2.08 g, 0.28 g, and 82.11 $cm^2$, respectively).

In summary, across both runs and according to all growth parameters, transplants grown in SC consistently had higher overall growth than when grown in SO, which had lower overall growth. By final harvest (Harvest 3) in Run 1, the average total plant fresh and dry weights of cucumber transplants grown in FC did not differ statistically to those grown in FO (fresh weight ranged from 5.40 g to 5.58 g; dry weight ranged from 0.36 g to 0.40 g for FC and FO, respectively) (Fig. 1c and Fig. 2b). By the final harvest for Run 2, the average fresh weights of transplants grown in FO did not differ statistically to those grown in SC (9.24 g vs. 9.21 g). The average dry weights of cucumber transplants grown in FO was statistically higher than all other treatments (FO weight: 0.61 g; SC weight: 0.53 g; FC weight: 0.50 g; SO weight: 0.37 g).

*Tomato Growth Parameters*

Pooled data from both runs of this experiment showed significant interaction between runs and harvests. As a result, data from each run were analyzed separately. Similarly, harvest week interacted with treatment, so data for each week were analyzed separately.

*Harvest 1*

In Run 1, tomato transplants grown in SC had average canopy heights (5.12 cm) and root fresh weights (0.78 g) that were significantly higher than all other treatments; growth in FO was significantly lower for both (3.52 mm and 0.43 g). Stem diameters (2.35 mm) and leaf fresh weights (0.73 g) of plants grown in FC and SC were similar to each other while growth in FO and SO were statistically similar and less than that of FC and SC (1.90 mm for stem diameter and 0.46 g for leaf fresh weight, respectively). Plants grown in SC had average total plant fresh weights (1.76 g), total plant dry weights

(0.16 g), and root dry weights (0.05 g) significantly higher than that of FO and SO. Total plant fresh and dry weights and root dry weights of FO and SO did not differ statistically (1.02 g; 0.09 g; and 0.03 g, respectively). Average shoot fresh weights did not differ statistically when plants were grown in SC and FC (0.19 g). The total leaf areas of plants grown in SC (30.64 $cm^2$) were significantly higher than the leaf areas of plants grown in FC and FO (23.40 $cm^2$). The leaf area of plants grown in FC and FO did not differ statistically. Plants grown in SC had higher shoot dry weights (0.02 g) while plants grown in FC and SO (0.01 g) had similar shoot dry weights that were significantly lower than that of plants grown in SC. Leaf dry weights of tomato transplants did not differ statistically when grown in SC and FC (0.09 g) while leaf dry weights in FO and SO were statistically similar and lower than that of SC and FC (data not shown).

In Run 2, tomato plants grown in FC had average canopy heights significantly higher than that of all other treatments (10.53 cm) and heights were significantly lower when plants were grown in FO (5.30 cm). The stem diameters (3.28 mm), total plant fresh weights (2.45 g), leaf fresh weights (1.21 g), leaf areas (61.69 $cm^2$), and shoot dry weights (0.04 g) of tomato plants grown in FC were significantly higher than that of all other treatments. Average shoot fresh weights (0.75 g), total plant dry weighs (0.18 g), and leaf dry weights (0.11 g) of plants grown in FC were significantly higher than that of the two organic mixes, FO and SO, which did not differ statistically (data not shown). Root dry weights of tomato plants grown in SC and FC were statistically similar and higher than that of the organic treatments (0.04 g).

*Harvest 2*

In Run 1, plants grown in SC had higher average canopy heights among the four substrates (7.37 cm). Stem diameters, total plant fresh weights, leaf fresh weights, and total leaf areas were higher when tomato plants were grown in SC as compared to SO (3.39 mm vs. 2.44 mm; 3.41 g vs. 1.43 g; 1.73 g vs. 0.67 g; 59.96 $cm^2$ vs. 23.54 $cm^2$, respectively). Plants grown in SC had significantly higher root (1.13 g) and shoot fresh weights (0.54 g), total plant dry weights (0.36 g), and root (0.07 g) and leaf dry weights (0.24 g) compared to FC and FO. FC and FO did not differ statistically (data not shown).

In Run 2, average canopy heights, stem diameters, and shoot fresh weights of tomato transplants did not differ when they were grown in conventional treatments, SC and FC, versus lower heights and diameters when grown in organic treatments, FO and SO (canopy height: 17.82 cm vs. 13.13 cm in FO and 10.96 in SO; stem diameter: 3.80 mm vs. 3.50 mm in FO and 3.09 mm in SO; shoot fresh weight: 1.75 g vs. 1.11 g in FO and 0.76 g in SO, respectively). Total plant fresh weights (5.23 g), root fresh weights (1.43 g), leaf fresh weights (2.05 g), and leaf areas (95.80 $cm^2$) were higher and did not differ when grown in SC and FC as compared to that of FO and SO. Total plant fresh weights (3.40 g), root fresh weights (1.05 g), leaf fresh weights (1.43 g), and leaf areas (64.65 $cm^2$) did not differ and were lower than when grown in SC and FC. Total plant dry weights (0.59 g), root dry weights (0.11 g), shoot dry weights (0.16 g), and leaf dry weights (0.32 g) were higher when tomato plants were grown in FC and SC as compared to that of FO and SO, which did not differ statistically (data not shown).

*Harvest 3*

In Run 1, average canopy heights (10.92 cm), total plant fresh weights (6.01 g), total plant dry weights (0.65 g), shoot fresh (1.32 g) and dry weights (0.11 g), leaf fresh (2.53 g) and dry weights (0.39 g), and root dry weights (0.14 g) were statistically higher when tomato plants were grown in SC as compared to all other substrates with the same growth parameters. Stem diameters did not differ statistically when tomato plants were grown in SC and FO (3.71 mm and 3.53 mm, respectively). Plants grown in SC had higher average root fresh weights (2.20 g) and leaf areas (84.83 $cm^2$) as compared to all other treatments.

In Run 2, average plant canopy heights (23.39 cm) and total plant dry weights (1.02 g) were higher when tomato plants were grown in FC as compared to FO and SC. Plants grown in FO and SC did not differ statistically (data not shown). Transplant stem diameters were higher when plants were grown in FO and were significantly lower when plants were grown in SO (4.12 mm vs. 3.23 mm). Tomato plants grown in FC had higher average total plant fresh weights and shoot fresh weights than when grown in SO (8.25 g vs. 4.32 g; 2.90 g vs. 1.11 g, respectively). Root fresh weights did not differ statistically when grown in SC and FC and were significantly lower when grown in SO (2.37 g in SC and FC vs. 1.47 g in SO). Tomato plants grown in FC and FO had statistically similar leaf fresh weights than that of the other treatments (2.85 g). Total leaf areas were higher when plants were grown in FC, SC and FO (average 99.76 $cm^2$) which were all statistically similar and higher than that of plants grown in SO (62.14 $cm^2$). Plants grown in FC and SC had higher and similar average root dry weights (0.20 g) while leaf dry weights were higher and statistically similar in FC and FO (0.45 g). Shoot dry weights

were higher when plants were grown in FC and weights were statistically lower when grown in SO (0.34 g vs. 0.12 g).

*Harvest 4*

In Run 1, average canopy heights (14.74 cm), total plant fresh weights (6.99 g), total plant dry weights (1.01 g), shoot fresh (1.80 g) and dry weights (0.30 g), leaf fresh (3.01 g) and dry weights (0.59 g), and root dry weights (0.20 g) were higher when plants were grown in SC while measurements and volumes for these same parameters for FC and FO were statistically similar and lower than all other treatments (data not shown). Plants grown in SC had higher stem diameters (3.92 mm) and total leaf areas (101.6 $cm^2$) and had significantly reduced growth when grown in SO (2.76 mm and 40.46 $cm^2$, respectively). Root fresh weights were higher when tomato plants were grown in SC (2.13 g) with growth in FO, FC and SO all being statistically similar and lower to that of SC (1.95 g).

In Run 2, canopy heights, total plant fresh weights, total plant dry weights, shoot fresh and dry weights, and total leaf areas were significantly higher when plants were grown in SC and significantly lower when plants were grown in SO (26.30 cm vs. 16.19 cm; 9.53 g vs. 4.72 g; 1.25 g vs. 0.51 g; 3.29 g vs. 1.23 g; 0.50 g vs. 0.15 g; 129.44 $cm^2$ vs. 68.82 $cm^2$, respectively). Plants grown in SC and FO had comparable stem diameters while stem diameters in FC and SO were statistically similar and lower than those of SC and FO (average 3.96 mm vs. 3.57 mm). Plants grown in SC had higher root fresh weights (2.99 g), leaf fresh weights (3.29 g), and leaf dry weights (0.54 g). Tomato plants grown in FC and FO had statistically similar root fresh weights (average of 2.36 g), leaf fresh weights (2.50 g), and leaf dry weights (0.41 g) but were lower than those of

plants grown in SC. Root dry weights did not differ statistically when plants were grown in SC and FC and weights were significantly lower when plants were grown in SO (0.20 g vs. 0.11 g).

*Harvest 5*

In Run 1, tomato plants grown in SC had higher total plant fresh weights (7.82 g), total plant dry weights (0.97 g), shoot fresh (1.63 g) and dry weights (0.23 g), leaf fresh (2.79 g) and dry weights (0.50 g), and root dry weights (0.23 g) while plants grown in FC and FO shared similarities and were lower (data not shown) (Fig. 3c, Fig. 4b, Fig. 3e, and Fig. 4d, respectively). The stem diameters of plants were higher when grown in FC and FO (3.64 mm and 3.61 mm, respectively) as compared to other treatments (Fig. 3b). Average canopy heights were statistically similar when plants were grown in SC and FO (13.59 cm in SC and 13.17 cm in FO) (Fig. 3a). Plants grown in SC had higher root fresh weights (3.47 g) while all other treatments were statistically similar and lower (Fig. 3d). The total leaf areas of tomato plants did not differ statistically when plants were grown in SC and FO as compared to the other substrates (77.13 $cm^2$) (Fig. 4a).

In Run 2, tomato plants grown in both SC and FO had statistically similar and higher leaf fresh weights (average of 3.01 g), leaf dry weights (0.52 g), total plant dry weights (1.23 g), root dry weights (0.23 g), and leaf areas (115.39 $cm^2$) as compared to the other treatments. Average canopy heights were higher when plants were grown in SC but were reduced and comparable for plants grown in FO and FC (25.46 cm vs. 22.74 cm). Stem diameters were statistically higher when tomato plants were grown in FO as compared to all other treatments (4.26 mm). Plants grown in SC had higher total fresh weights as compared to all other treatments (9.82 g). Root fresh weights were higher

when plants were grown in SC and weights were statistically similar but lower when plants were grown in FO and FC (3.38 g vs. 2.11 g). Shoot fresh weights and shoot dry weights were statistically similar and higher when plants were grown in SC and FO than in the other treatments (averages of 3.01 g and 0.49 g, respectively).

In summary, across both runs and based on all growth parameters, tomato transplants grown in SC consistently had higher overall growth than when grown in SO. By the last harvest (Harvest 5) in Run 1, the average canopy height (13.38 cm), stem diameter (3.63 mm), and leaf area (77.13 $cm^2$) of tomato transplants grown in FO did not differ statistically from those grown in FC (Fig. 3a, Fig. 3b, and Fig. 4a, respectively). Transplant canopy heights ranged from 12.8 cm to 13.2 mm; stem diameters ranged from 3.61 mm to 3.64 mm; and leaf areas ranged from 63.8 $cm^2$ to 73.3 $cm^2$, for FO and FC substrates, respectively. By the final harvest in Run 2, the average dry weight of transplants grown in FO did not differ statistically from those grown in FC (0.68 g and 0.72 g for FO and FC, respectively).

*Elemental analysis of substrates*

Elemental analysis indicated variability in all major nutrients among the four substrates (Table 2). SC (pH 5.82) performed well in terms of the highest recorded growth data in both experiments, having the lowest amount of phosphorous (16 parts per million (ppm)) and the highest amounts of potassium, calcium, and nitrate-nitrogen (161, 238, 108 ppm, respectively). SO did not perform as well having the highest pH of 6.33 and lowest nutrient levels (364, 16, 13, 13, 0.12, and <0.1 ppm of soluble salts, potassium, magnesium, calcium, iron, and manganese respectively). FO had the lowest pH (4.96) and nitrate-nitrogen level (4 ppm) and the highest amounts of soluble salts,

magnesium, manganese, aluminum, and sodium (1820, 32, 0.7, 0.3, and 68 ppm, respectively). FC (pH 5.78) had the highest amount of iron and zinc (0.88 and 0.6 ppm).

*Growth analysis*

In plant growth analysis, relative growth rate integrates the efficiency of various growth processes into one value (Hunt, 1982). Relative growth rate of a plant depends on the ability of a plant to produce leaf area and on the ability of its leaves to assimilate dry-matter (Beadle, 1982; Hunt, 1982). Therefore, differences in relative growth rate over time can be due to changes in the assimilation rate of carbon (net assimilation rate) and/or to changes in the leaf area per unit of plant dry weight (leaf area ratio) (Beadle, 1982). Relative growth rate is generally higher in young determinate and indeterminate tomatoes and declines as the plants age (Kemble, 1993).

Net assimilation rate is a measure of the ability of leaves to fix carbon and is calculated as the increase of plant dry weight per unit leaf area per unit time (Hunt, 1982; Mengel et al., 2001). Bruggink and Heuvelink (1987) reported that indeterminate tomatoes generally exhibited their higher net assimilation rate when young and that this rate declined steadily as the plants aged. Leaf area ratio represents the ratio of photosynthesizing material (plant leaf area) to plant dry weight (Hunt, 1982). Smeets and Garretsen (1986) reported that young tomato plants had high leaf area ratios that decreased as they aged.

*Cucumber*

Relative Growth Rate (RGR) and Net Assimilation Rate (NAR) data were pooled for both runs because there were no significant interactions between runs and harvests ($p \leq 0.0936$ and 0.7274, respectively). RGR did not differ statistically when cucumbers

were grown in FO and SC (average 0.56 $g \cdot g^{-1} \cdot week^{-1}$) and RGR were statistically similar, but lower, when plants were grown in FC and SO (average 0.47 $g \cdot g^{-1} \cdot week^{-1}$). NAR did not differ statistically when plants were grown in FO, SC, and FC (average 0.0024 $g \cdot m^{-2} \cdot week^{-1}$). NAR of plants grown in SO were statistically similar to SC and FC but not FO (0.0020 $g \cdot m^{-2} \cdot week^{-1}$) (Fig. 5a).

Leaf Area Ratio (LAR) data were analyzed separately by run due to a significant interaction between runs and harvest ($p \leq 0.0015$). Further, in Run 1, there were significant interactions between harvests and treatments, thus LAR data were analyzed separately by harvests ($p \leq 0.0344$). Run 1 illustrated that the higher LAR between Harvest 2 and Harvest 1 was when cucumber transplants were grown in SC with statistically similar, but lower, LAR in FO and FC (229.1 $m^2 \cdot g^{-1}$ in SC vs. FO and FC average of 209.4 $m^2 \cdot g^{-1}$). Between Harvest 3 and Harvest 2, LAR did not differ statistically when transplants were grown in FO and SC and LAR were statistically similar but lower when grown in SO and FC (averages of 216.9 $m^2 \cdot g^{-1}$ vs. 200.1 $m^2 \cdot g^{-1}$, respectively) (Fig. 6a).

In Run 2, LAR data were pooled because there were no significant interactions between harvests and treatments ($p \leq 0.6429$). LAR was higher when cucumber plants were grown in FO and statistically similar but lower when grown in SC and SO (257.7 $m^2 \cdot g^{-1}$ vs. SC and SO average of 237.2 $m^2 \cdot g^{-1}$) (Fig. 6b).

*Tomato*

Relative Growth Rate (RGR) and Net Assimilation Rate (NAR) data were pooled because there were no significant interactions between runs and harvests ($p \leq 0.4940$ and 0.8151, respectively). Thus, there was no difference across time. RGR were statistically

similar when tomato transplants were grown in FO and SC and statistically lower when grown in FC (FO and SC average of 0.52 $g \cdot g^{-1} \cdot week^{-1}$ vs. 0.38 $g \cdot g^{-1} \cdot week^{-1}$). NAR did not differ statistically between treatments (average of 0.003 $g \cdot m^{-2} \cdot week^{-1}$) (Fig. 5b).

Leaf Area Ratio (LAR) data were analyzed separately by run due to a significant interaction between runs and harvests. Further, there were significant interactions found between harvests and treatments, so LAR data were analyzed separately by harvests within runs. According to the differences between harvests in Run 1, LAR was higher when tomato plants were grown in FO (248.7 $m^2 \cdot g^{-1}$; 196.1 $m^2 \cdot g^{-1}$; 141.3 $m^2 \cdot g^{-1}$; and 114.6 $m^2 \cdot g^{-1}$, between Harvest 2 and 1; 3 and 2; 4 and 3; and 5 and 4, respectively). The difference between Harvest 2 and Harvest 1, LAR was statistically similar when plants were grown in SC, SO, and FC (average of 175.0 $m^2 \cdot g^{-1}$); which also applies between Harvest 4 and Harvest 3 (average of 112.1 $m^2 \cdot g^{-1}$). The difference between Harvest 3 and Harvest 2, LAR was statistically similar when plants were grown in SC and SO (average of 142.6 $m^2 \cdot g^{-1}$), which also applies between Harvest 5 and Harvest 4 (average of 101.9 $m^2 \cdot g^{-1}$) (Fig. 7a).

In Run 2, between Harvest 2 and Harvest 1, LAR was higher when tomato plants were grown in FO and had similar but lower LAR when plants were grown in SO, SC, and FC (300.9 $m^2 \cdot g^{-1}$ vs. average of 264.2 $m^2 \cdot g^{-1}$). Between Harvest 3 and Harvest 2, LAR did not differ statistically when tomato plants were grown in FO, SO, and SC and LAR was lower when grown in FC (average of 170.1 $m^2 \cdot g^{-1}$ vs. 126.6 $m^2 \cdot g^{-1}$). Between Harvest 4 and Harvest 3, LAR was higher when plants were grown in SO and similar but lower when grown in FO, SC, and FC (141.9 $m^2 \cdot g^{-1}$ vs. average of 115.4 $m^2 \cdot g^{-1}$). Between Harvest 5 and Harvest 4, LAR was again higher when plants were grown in SO

and similar but lower when grown in SC, FO, and FC (121.7 $m^2 \cdot g^{-1}$ vs. average of 105.1 $m^2 \cdot g^{-1}$) (Fig. 7b).

**Discussion**

Transplant growth was variable between runs. One source of variation between runs may have been due to the time of year and day length (early spring versus late spring/early summer). Toida and others (2005) found that tomatoes had better growth when the light period was extended.

Initial growth was variable within treatments between runs. Cucumber growth was consistently higher when grown in SC through all harvest weeks. By final harvest (Harvest 3) in Run 1, the total plant fresh and dry weights of cucumber transplants grown in FC did not differ statistically from those grown in FO. By the final harvest for Run 2, the fresh weights of transplants grown in FO did not differ statistically from those grown in SC. The dry weights of cucumber transplants grown in FO were statistically higher than all other treatments.

In Run 1, tomato growth was consistently higher when grown in SC through all harvest weeks. In Run 2, tomato growth was higher in FC until Harvest 3 where growth began performing better in SC through the final harvest (Harvest 5). By the final harvest in Run 1, the canopy height, stem diameter, and leaf area of tomato transplants grown in FO did not differ statistically from those grown in FC. By the final harvest in Run 2, the dry weight of transplants grown in FO did not differ statistically from those grown in FC.

Cucumber and tomato transplant growth was stunted when grown in SO. SO had the higher pH (6.33) and the lowest nutrient levels out of all other treatments. Even the weekly addition of the soluble organic fertilizer did not significantly improve growth.

Miles and Peet (2002) found that plant vigor was excessive when receiving one organic fertilizer treatment versus the other.

Although both crops exhibited higher growth indices when the transplants were grown in SC, it does not mean that bigger is better. In fact, it may be the most undesirable (Granberry and Boyhan, 2003). Many growers transplant in the field when the first or second set of true leaves form, usually two to three weeks after sowing seed, preferring to begin when the plants are quite small (Motes and Roberts, 2002). Vavrina (1998) recommended that cucumbers should be field set with a maximum of two true leaves and before the plant grows much larger than a silver dollar, stating that the rigors of the natural environment can take their toll on "leggy" plants. The industry may reject large transplants due to the difficulty in transplanting with mechanical transplanting equipment and to a greater incidence of transplant shock in the field (Brown et al., 2002; Dufault, 1998). The recommended height for the least transplant shock and for faster re-growth is approximately ten centimeters (four inches) as opposed to twenty-five or thirty centimeters (ten to twelve inches) tall for vegetable transplants (Relf, 1997). The ideal transplant is young, has compact growth, a deep green shoot, a short production time period, and a well developed root system (Brown et al, 2002; Motes and Roberts, 2002; Nelson et al., 2000).

The Fafard blends (FC and FO) were the better performers for both crops according to what is considered the "ideal" transplant. Both Fafard blends had incorporated starter charges: FC contained a synthetic starter charge while FO contained Nature Safe, an organic slow release fertilizer that consists of meat meal, hydrolyzed

feather meal, bone meal, blood meal, and sulfate of potash, which is in compliance with USDA and OMRI guidelines.

Generally, substrates with a low pH (i.e. FO) reduce the availability of calcium (Ca) and potassium (K) (Mengel et al., 2001; Miles and Peet, 2002) but it appears FO counteracts that effect, containing nearly the highest concentrations of Ca (133 ppm) and K (128 ppm), likely due to its incorporated starter charge. Crops, such as tomatoes, are quite sensitive to ratios between N and K, which regulate whether or not growth will occur in vegetative tissue (i.e. shoot and leaves) or in the fruit (Miles and Peet, 2002).

Delate and Lawson (2001), whose goal was to obtain equivalent N rates in organic and conventional systems, discovered that canopy height was not significantly different in plants that were fertilized with an organic (poultry-based) compost. Additionally, Delate and Lawson (2001) found that the total fresh weights of peppers (*Capsicum annuum*) over a five week harvest period were not significantly different among treatments. Russo (2005) found that bell pepper seedlings that were treated with four times the recommended rate of an organic fertilizer would produce transplants equivalent in height and dry weight to those produced conventionally.

Additionally, in accordance with the findings of Bruggink and Heuvelink (1987), Kemble (1993), and Smeets and Garretsen (1986), the RGR, NAR, and LAR of both tomato and cucumber crops exhibited their highest rates when they were young and declined as they aged.

In summary, based upon the findings of this research, farmers now have guidelines to help them discover what commercially available substrates may work to achieve similar results utilizing organic production methods to that of conventional ones.

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**Table 1.** List of treatments and their contents; abbreviations for treatments.

| Substrate type | Substrate name | Substrate contents | Abbreviations |
|---|---|---|---|
| Commercial conventional | Fafard 1-P | Sphagnum moss, horticultural perlite, wetting agent, starter nutrients | FC |
| | Sun-Gro LC1 | Canadian sphagnum peat moss, coarse grade perlite, gypsum, dolomitic lime, wetting agent | SC |
| Commercial organic | Fafard Organic Formula #10 | Canadian sphagnum peat moss (80%), perlite, gypsum, dolomitic lime, Nature Safe Fertilizer 10-2-8 and 8-3-5 | FO |
| | Sun-Gro Professional Organic Blend | Canadian sphagnum peat moss, coarse grade perlite, gypsum, dolomitic lime, Yucca extract (organic wetting agent) | SO |

**Table 2**. Elemental results of substrate treatments. Units are parts per million with exception of pH and specific conductance.

| Treatment | Sun-Gro LC1 (SC) | Fafard 1-P (FC) | Fafard Organic Formula #10 (FO) | Sun-Gro Prof. Organic (SO) |
|---|---|---|---|---|
| pH | 5.82 | 5.78 | 4.96 | 6.33 |
| Specific Conductance (mmhos/cm) | 2.5 | 1.6 | 2.6 | 0.52 |
| Soluble Salts | 1750 | 1120 | 1820 | 364 |
| Phosphorus | 16 | 36 | 35 | 20 |
| Potassium | 161 | 118 | 128 | 16 |
| Magnesium | 31 | 31 | 32 | 13 |
| Calcium | 238 | 98 | 133 | 13 |
| Copper | 0.2 | 0.2 | 0.3 | 0.3 |
| Iron | 0.5 | 0.88 | 0.37 | 0.12 |
| Manganese | 0.2 | 0.5 | 0.7 | <0.1 |
| Zinc | 0.3 | 0.6 | <0.1 | <0.1 |
| Boron | <0.1 | <0.1 | <0.1 | <0.1 |
| Aluminum | 0.2 | 0.1 | 0.3 | 0.1 |
| Sodium | 36 | 40 | 68 | 36 |
| Nitrate-Nitrogen | 108 | 104 | 4 | 8 |

**Table 3.** Substrate treatment Porometer analysis.

| **Treatment** | **Total Porosity** % vol | **Container Capacity** % vol | **Air Space** % vol | **Bulk Density** G/cc |
|---|---|---|---|---|
| Sun-Gro LC1 (SC) | 77.2 | 59.6 | 17.6 | 0.08 |
| Fafard 1-P (FC) | 80.9 | 64.6 | 16.3 | 0.08 |
| Fafard Organic Formula #10 (FO) | 84.7 | 73.9 | 10.8 | 0.11 |
| Sun-Gro Prof. Organic (SO) | 71.7 | 56.8 | 14.9 | 0.08 |
| Recommended values | 50-85 | 45-65 | 10-30 | 0.11 - 0.20 |

**Table 4a.** 'General Lee' cucumber and 'Celebrity' tomato seeding dates, number of materials used, weekly harvests, replicates, treatments, growth parameters measured, and data collection dates.

| Crop | Planting dates | Total seed used | Total trays used | Number of weekly harvests | Number of replicates | Treatments | Growth parameters measured | Dates of data collection |
|---|---|---|---|---|---|---|---|---|
| 'General Lee' cucumber | Run 1 = 23 Mar. 2007<br>Run 2 = 17 Apr. 2007 | 1728 | 24 | 3 | 4 | 4 | Plant canopy height, leaf area, stem diameter, fresh and dry weights of leaves, shoots, and roots | Run 1 = 7 - 20 Apr. 2007<br>Run 2 = 9 - 23 May 2007 |
| 'Celebrity' tomato | Run 1 = 6 Apr. 2007<br>Run 2 = 18 May 2007 | 2880 | 40 | 5 | 4 | 4 | | Run 1 = 26 Apr. - 24 May 2007<br>Run 2 = 5 June - 5 July 2007 |

**Table 4b.** Example schematic of one replication in experimental design for a crop with three weekly harvests.

| | |
|---|---|
| FC H3 | FC H2 |
| FO H1 | SO H3 |
| FO H2 | FO H3 |

| | |
|---|---|
| SC H3 | SC H1 |
| SO H1 | SO H2 |
| SC H2 | FC H1 |

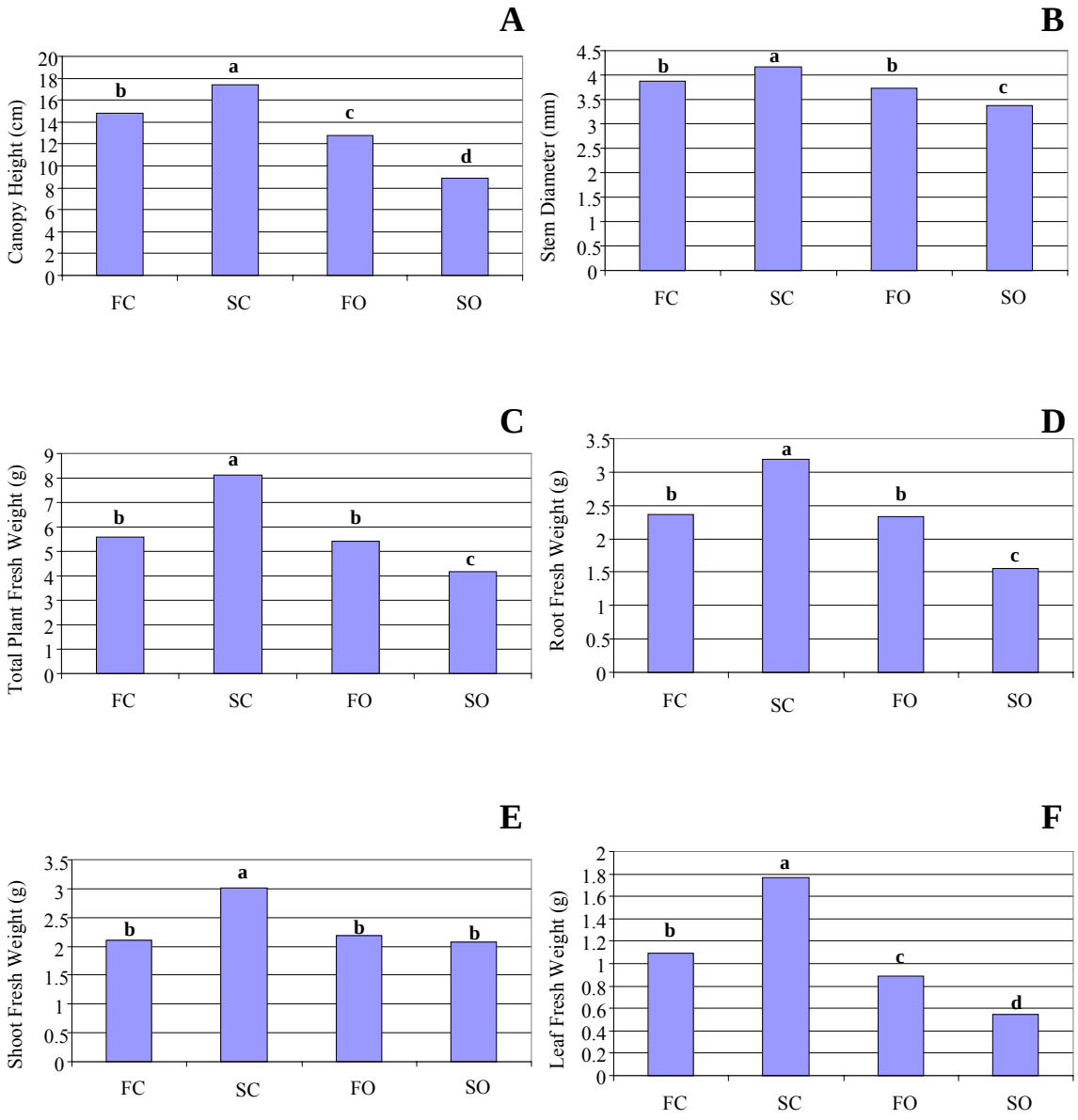


**Figure 1.** Effect of substrate treatments on 'General Lee' cucumber in Run 1 for final harvest (Harvest 3). Treatments included two conventional substrates: Fafard 1-P (FC) and Sun-Gro LC1 (SL); and two organic substrates: Fafard Organic Formula (FO) and Sun-Gro Prof. Organic Blend (SO). Transplants were seeded 23 Mar. 2007 and harvested on 20 Apr. 2007. Growth parameters include: Canopy height **(A)**; stem diameter **(B)**; total plant fresh weight **(C)**; root fresh weight **(D)**; shoot fresh weight **(E)**; and leaf fresh weight **(F)**. Different letters within columns indicate statistical significant difference among treatments according to ANOVA and Fisher's Protected LSD test ($p \leq 0.05$).

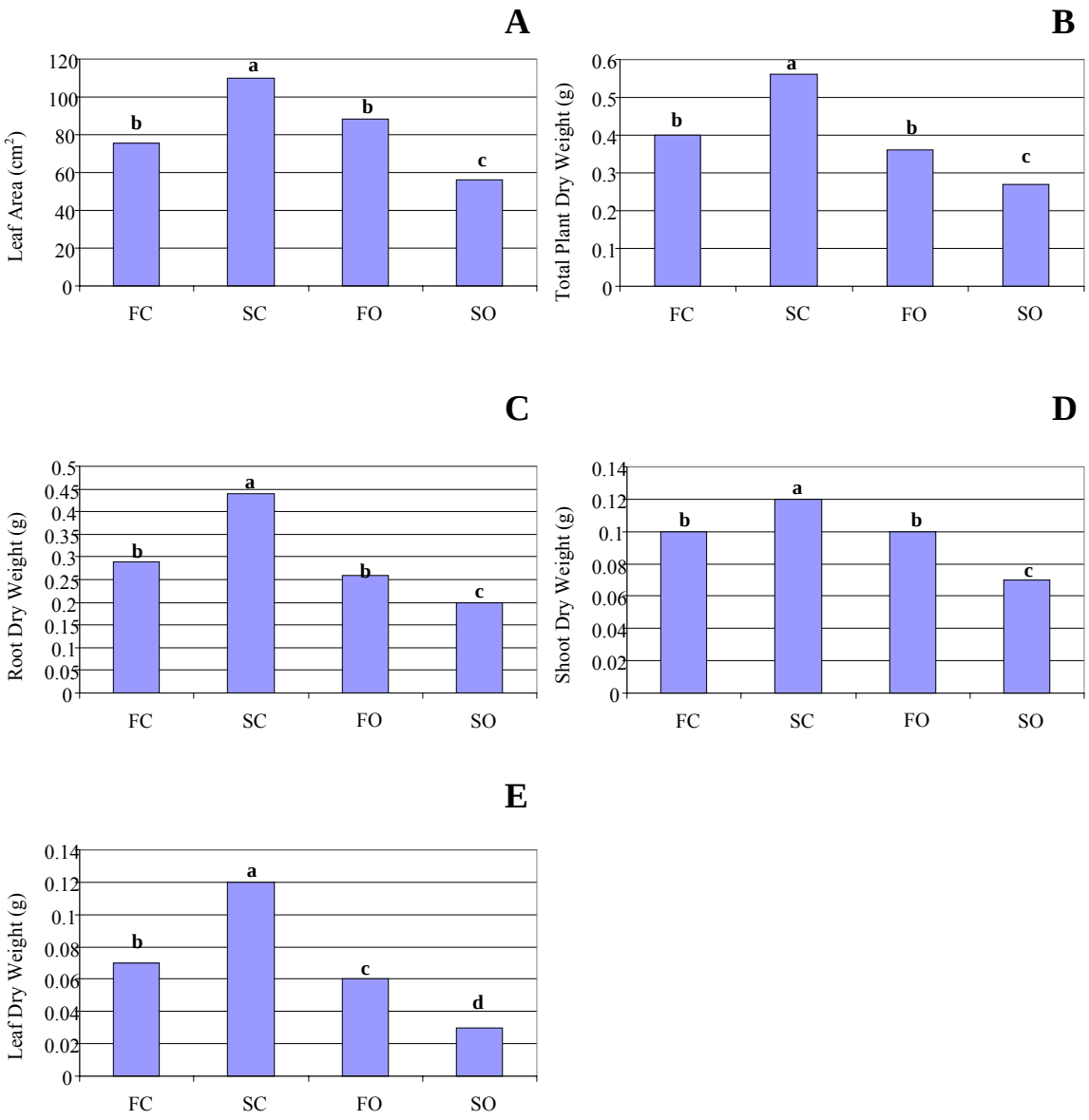


**Figure 2.** Effect of substrate treatments on 'General Lee' cucumber in Run 1 for final harvest (Harvest 3). Treatments included two conventional substrates: Fafard 1-P (FC) and Sun-Gro LC1 (SL); and two organic substrates: Fafard Organic Formula (FO) and Sun-Gro Prof. Organic Blend (SO). Transplants were seeded 23 Mar. 2007 and harvested on 20 Apr. 2007. Growth parameters include: Leaf area **(A)**; total plant dry weight **(B)**; root dry weight **(C)**; shoot dry weight **(D)**; and leaf dry weight **(E)**. Different letters within columns indicate statistical significant difference among treatments according to ANOVA and Fisher's Protected LSD test ($p \leq 0.05$).

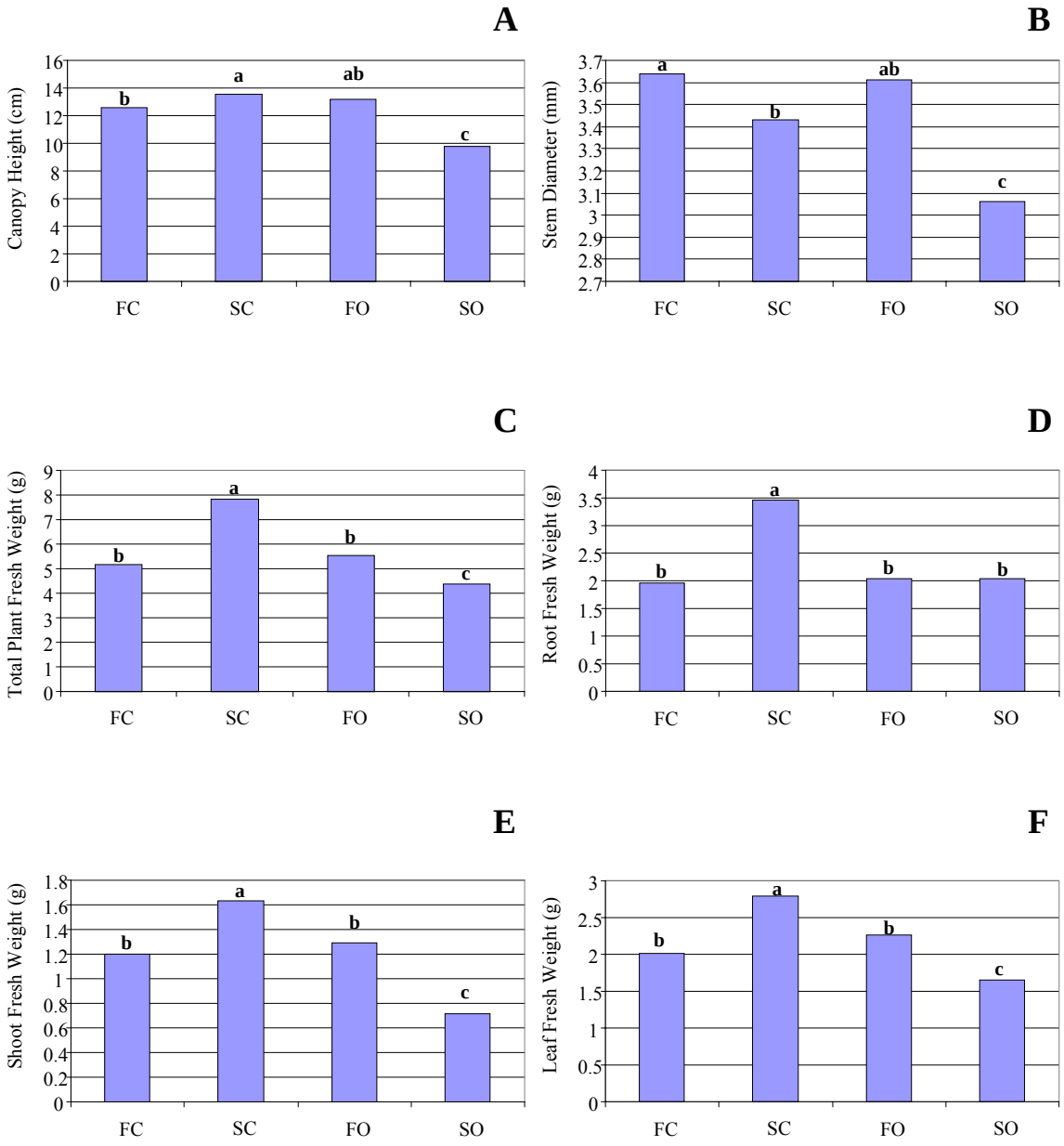


**Figure 3.** Effect of substrate treatments on 'Celebrity' tomato in Run 1 for final harvest (Harvest 5). Treatments included two conventional substrates: Fafard 1-P (FC) and Sun-Gro LC1 (SL); and two organic substrates: Fafard Organic Formula (FO) and Sun-Gro Prof. Organic Blend (SO). Transplants were seeded 6 Apr. 2007 and harvested on 24 May 2007. Growth parameters include: Canopy height **(A)**; stem diameter **(B)**; total plant fresh weight **(C)**; root fresh weight **(D)**; shoot fresh weight **(E)**; and leaf fresh weight **(F)**. Different letters within columns indicate statistical significant difference among treatments according to ANOVA and Fisher's Protected LSD test ($p \leq 0.05$).

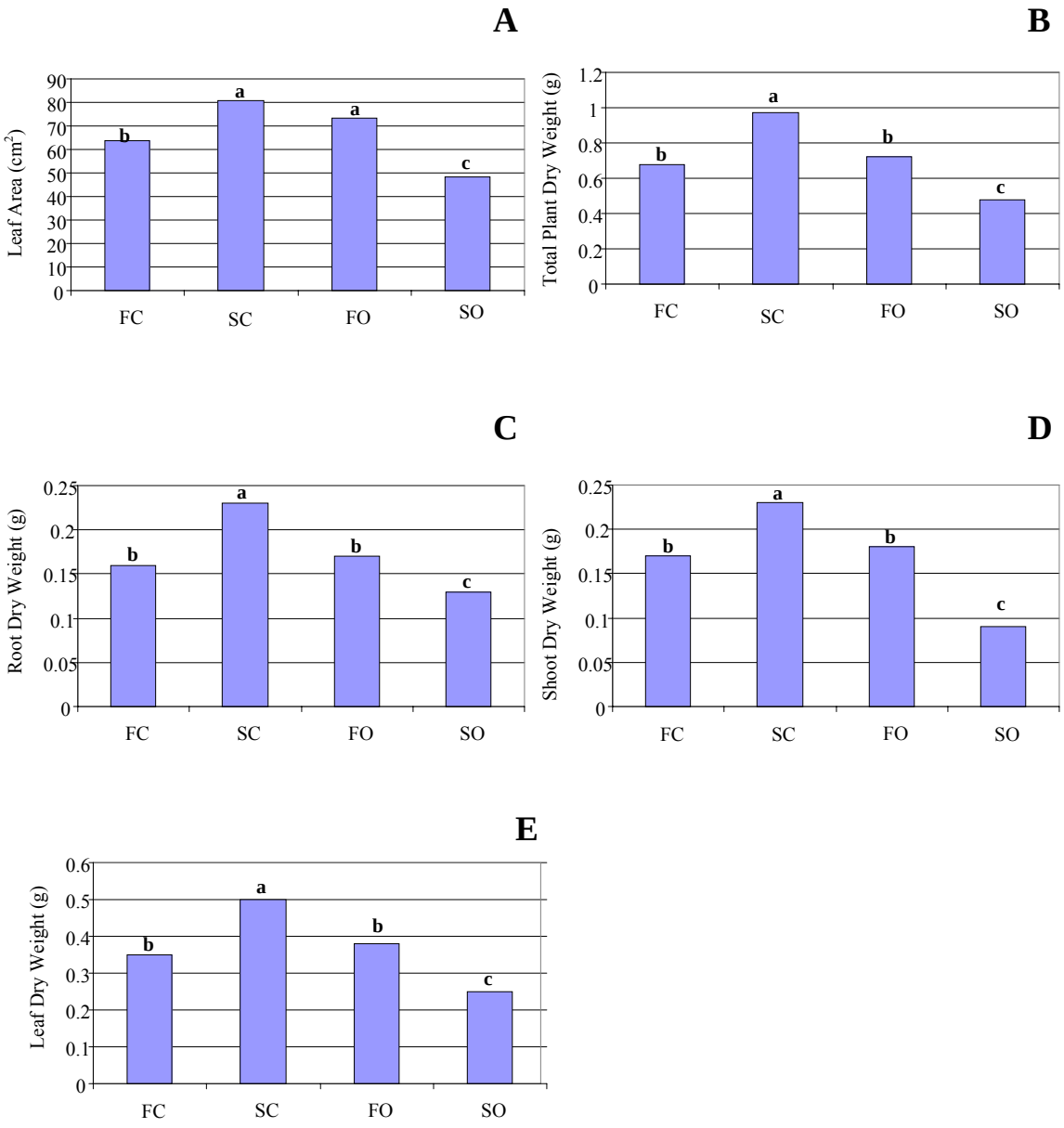


**Figure 4.** Effect of substrate treatments on 'Celebrity' tomato in Run 1 for final harvest (Harvest 5). Treatments included two conventional substrates: Fafard 1-P (FC) and Sun-Gro LC1 (SL); and two organic substrates: Fafard Organic Formula (FO) and Sun-Gro Prof. Organic Blend (SO). Transplants were seeded 6 Apr. 2007 and harvested on 24 May 2007. Growth parameters include: Leaf area **(A)**; total plant dry weight **(B)**; root dry weight **(C)**; shoot dry weight **(D)**; and leaf dry weight **(E)**. Different letters within columns indicate statistical significant difference among treatments according to ANOVA and Fisher's Protected LSD test ($p \leq 0.05$).

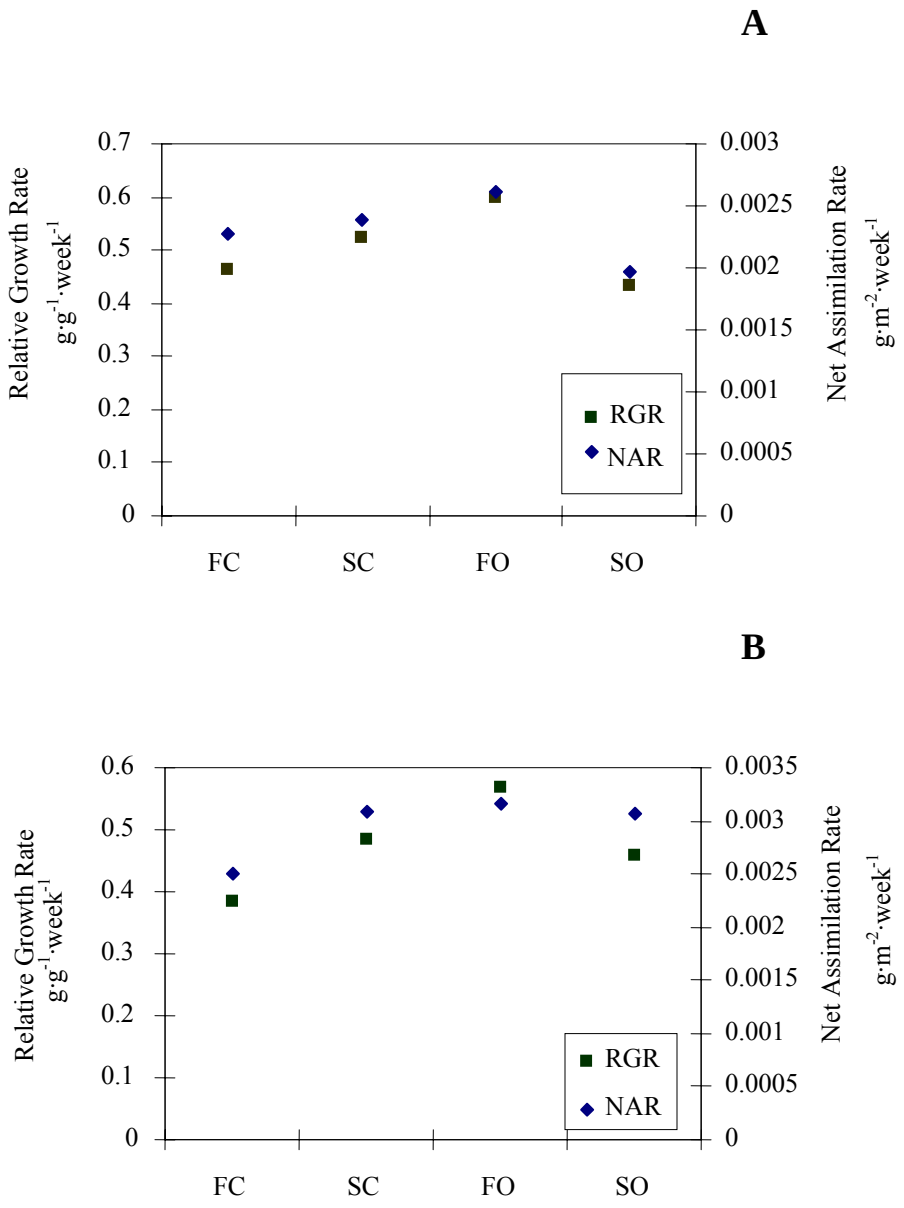


**Figure 5.** Effect of substrate treatments on 'General Lee' cucumber **(A)** and 'Celebrity' tomato **(B)** for RGR and NAR. Due to no significant difference between runs and harvests, data were pooled for Run 1 and Run 2.

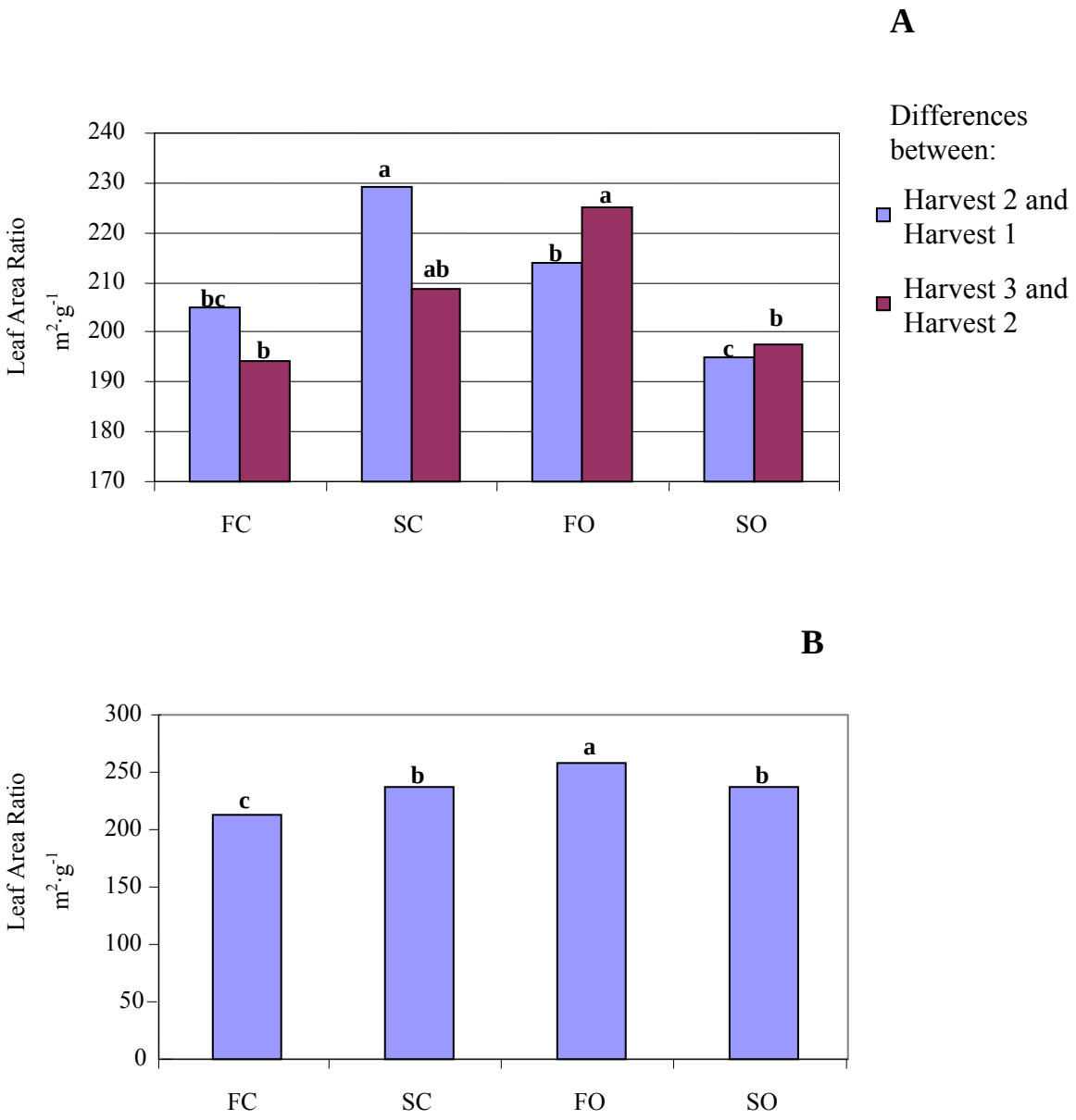


**Figure 6.** Substrate treatment effects on LAR development for 'General Lee' cucumber transplants in Run 1 **(A)**. Due to no significant difference between harvests and treatments, LAR 'General Lee' cucumber data were pooled for Run 2 **(B)**. Different letters within columns indicate statistical significant difference among treatments according to ANOVA and Fisher's Protected LSD test ($p \leq 0.05$).

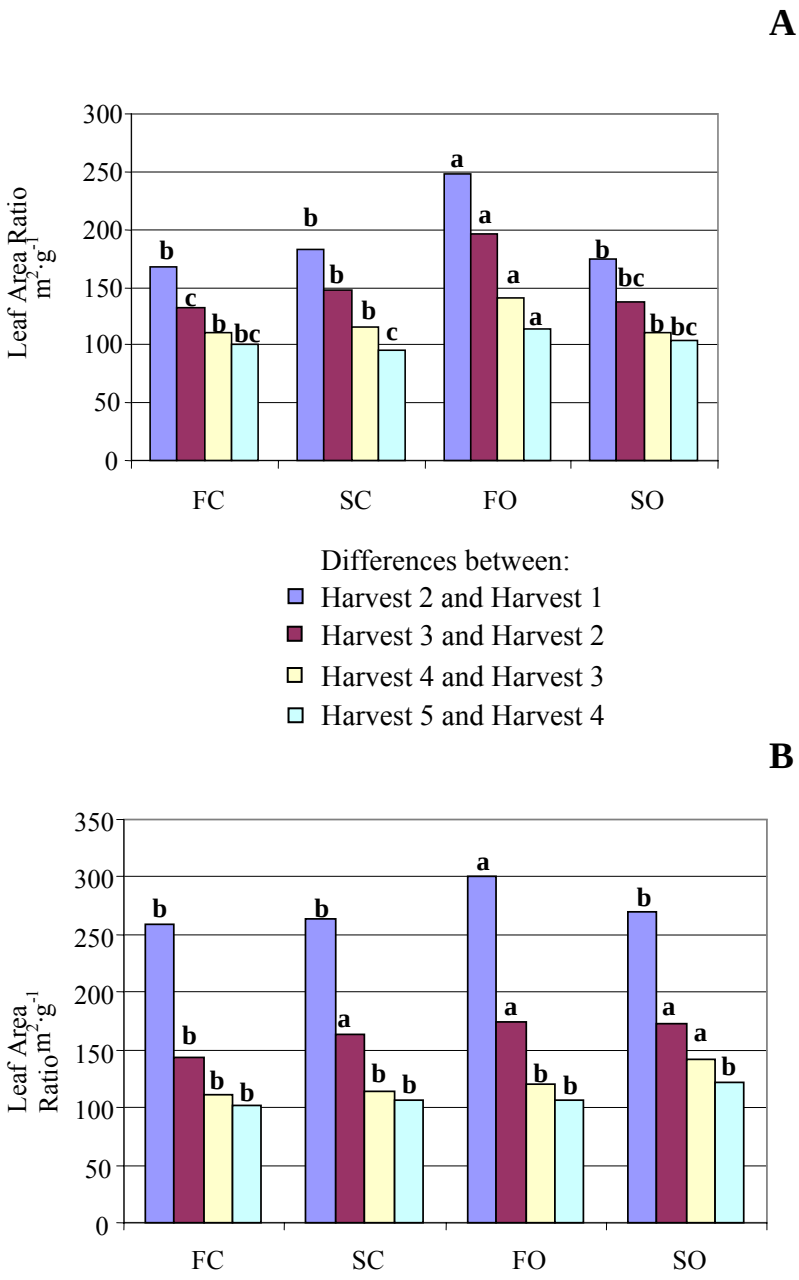


**Figure 7.** Substrate treatment effects on LAR development for 'Celebrity' tomato transplants in Run 1 **(A)** and for Run 2 **(B)**. Different letters within columns indicate statistical significant difference among treatments according to ANOVA and Fisher's Protected LSD test ($p \leq 0.05$).

# CHAPTER III

# LETTUCE AND COLLARD SEEDLING GROWTH IN ORGANIC PLUG SUBSTRATE


## Abstract

Transplant production qualifies as one of the most intensive cropping systems and there is a sector of the greenhouse market that would like to obtain certified organic vegetable transplants. Currently, there is a less than adequate supply of organic vegetable transplants due to limited research aimed at developing recommendations for their production. Successful transplant production requires a suitable substrate and the suitability of organic materials as an alternative to conventional materials needs clarification. There are several certified organic plug mixes available; however, the suitability and cost of these substrates are of concern to growers who often report inconsistent or poor results. Two experiments were conducted to study the effect of two currently available certified organic plug mixes on the growth of lettuce (*Lactuca sativa* L. 'Red Sails') and collard (*Brassica oleracea* L. (Acephala Group) 'Georgia Southern') transplants and compared to conventional (non-organic) versions of these same mixes. Upon emergence of first true leaves, 50 ppm N of soluble organic or conventional fertilizers were applied twice a week to respective substrates. Data of a number of growth parameters were collected: plant canopy height, total leaf area, and total fresh and

dry weights of each plant's leaves, shoots, and roots to compare relative growth under each treatment. Conventional Sun-Gro mix (SC) was statistically higher across the board for both runs according to all growth parameters. By the final harvest of lettuce (Harvest 3), all growth parameters indicated that growth in commercial Fafard organic (FO) was statistically similar to that in conventional Fafard mix (FC). By the final harvest of collards (Harvest 5), many growth parameters indicated that growth in organic Sun-Gro mix (SO) was similar to that in conventional Fafard (FC); the other commercially available organic mix (FO) was statistically lower in both runs.

**Introduction**

Organic farming has become one of the fastest growing segments of U.S. agriculture since the implementation of the National Organic Standards (NOP) in the 1990s (Sok and Glaser, 2001; USDA, 2005). U.S. farmers are joining forces by substantially expanding their organic acreage, lowering their input costs, capturing the high-value markets, boosting farm income, and conserving nonrenewable resources (Greene, 2001). Currently, with 31 million hectares in production worldwide, organic agriculture is increasing annually by approximately 5 million hectares as farmers endeavor to supply this increasing demand for organic food products (Dimitri and Greene, 2002; Greene, 2001; Willer and Yussefi, 2006). Although organic agriculture has established itself as being economically important with a sales growth of approximately twenty percent (20%) per year since 1990, there is a significant lack of scientific research to support this segment of agricultural production, especially for organic vegetable transplant production (Dimitri and Oberholtzer, 2005; Fromartz, 2006). Current information available to organic farmers concerning transplant production is

limited and based on observation or extrapolated from research executed for conventional transplant production.

Conventionally, transplant substrate blends are soilless consisting of pine bark, peat, vermiculite, and perlite along with a starter fertilizer charge and wetting agents (Bailey et al., 1998; Kelley and Boyhan, 2003). Organic transplant mixes may contain any one of the above items, yet must substitute organically allowable fertilizers for the conventional starter fertilizer and wetting agents (Dodson et al., 2002; Greer, 2005). Transplants are generally grown in soilless substrate blends which can be used in any cell size and provide optimal growing conditions (sufficient aeration, root growth, and plant support) (Fonteno et al., 1995; Kuepper and Everett, 2004; Schrader, 2000). On average, soluble organic fertilizers (i.e. fish emulsion or fish hydrolysate) are added to soilless mixes on a weekly basis to maintain transplant health until they are ready to be transplanted in the field because these mixes do not contain sufficient nutrients to sustain development. According to Aung and others (1983), fish and its byproducts have been recognized as a fertilizer suitable for plants because of favorable crop responses. Nielsen and Thorup-Kristensen (2004) suggested that an ideal organic substrate should supply most of the nutrients needed for plant growth and limit the need for additional soluble nutrients.

Organic production, especially to be certified organic, requires the utilization of organically-grown seed. If organically grown seed were not available for desired varieties, commercially available untreated seed were used in accordance with the USDA National Organic Program (NOP) requirements (Dodson et al., 2002).

One objective of this study was to understand what makes an acceptable organic substrate in terms of its physical properties in order to develop an affordable substrate that growers in Alabama can utilize for organic transplant production of lettuce (*L. sativa* 'Red Sails') and collard (*B. oleracea* (Acephala Group) 'Georiga Southern') crops. The second objective of this study was to examine the effect of currently available commercial organic and conventional (non-organic) plug mixes and their components on selected growth parameters. The third objective of this study was to characterize the early growth and development of transplants in terms of changes in relative growth rate, net assimilation rate, and leaf area ratio.

**Methods and Materials**

Components of the substrate treatments are further described in Table 5. The Soil Testing Laboratory at Auburn University determined the elemental components of these substrate blends which are further described in Table 6. Physical properties including air space, water holding capacity, total porosity, and bulk density were determined for substrates utilizing the North Carolina State University Porometer (Table 7) (Fonteno and Harden, 2003).

An experiment was conducted using 'Red Sails' lettuce and 'Georgia Southern' collard. This experiment was repeated as described below and in each run the same materials and methods were used. These cultivars were selected based on their performance and recommended use in Alabama in the 2006 Vegetable Crop Handbook for the Southeastern U.S. Organic 'Red Sails' lettuce seed were obtained from Harris Seeds (Rochester, N.Y.) and untreated 'Georgia Southern' collard seed were obtained from Heirloom Seeds (West Elizabeth, Pa.). All research was conducted in a glass

greenhouse with computer controlled evaporative cooling pads and fans with sunshade screens in Auburn, Ala. at 32.6°N latitude. Temperature set-points were 23.8°C day and 22.2°C night with ambient light.

The experimental design was a randomized complete block design with four replicates. Each replicate contained four treatments: two conventional substrates, Fafard 1-P (FC) and Sun-Gro LC1 (SC), and two organic substrates, Fafard Organic Formula #10 (FO) and Sun-Gro Professional Organic Blend (SO) (Fafard, Inc., Anderson, S.C.; Sun-Gro Horticulture, Bellevue, Wash.).

The first run of this experiment was conducted from 11 Oct. – 29 Nov. 2006. The second run of this experiment was conducted from 17 Jan. – 2 Mar. 2007.

**Seeding, Plant Care, and Data Collection**

Each replicate contained six 72-cell plastic market trays (cell dimensions: 3.8 cm x 3.8 cm x 6.0 cm) which included each of the four substrates: Conventional Fafard substrate (hereafter referred to as FC), organic Fafard substrate (hereafter referred to as FO), conventional Sun-Gro substrate (hereafter referred to as SC), and organic Sun-Gro substrate (hereafter referred to as SO) which were placed into plastic flats (26.7 cm x 53.7 cm) for stability (Dillen Products, Middlefield, Ohio). Each replicate contained one and a half (1.5) flats of each substrate treatment for a total of six flats per replicate and twenty-four flats total for the experiment.

On 11 Oct. 2006, flats were seeded 0.6 cm deep, one per cell, for a total of 1728 'Red Sails' lettuce seed and additional substrate of the same treatment was used to cover the seed. All substrates were watered to runoff upon completion of seeding. The 72-cell flats were divided into halves (i.e. into 36-cell sections, which is why each replicate

contained 1.5 flats of each substrate) to represent a randomly assigned harvest interval from one to three. Hence, only one 36-cell section of each treatment within each replicate was destructively harvested each week (half flat (0.5) per treatment (4) per replicate (4) per harvest for a total of eight flats/week; 0.5 x 4 = 2 x 4 = 8), for a total of three weeks (Table 8a and 8b). Trays were subsequently hand watered as needed.

Upon emergence of the true leaves, 50 ppm N from a 2N-1.7P-0.83K Neptune's Harvest Fish Hydrolysate (organic, nutritional protein fertilizer, made utilizing naturally occurring enzymes present in North Atlantic fish; N derived from the fish protein in the form of amino acids) were applied twice a week (for a total of 100 ppm/week) to seedlings grown in organic substrates FO and SO (Gloucester, Mass.). Seedlings grown in conventional substrates FC and SC were fertilized with 50 ppm N twice a week (for a total of 100 ppm/week) from a standard TotalGro 20N-4.4P-16.6K water-soluble fertilizer (SDT Industries, Winnsboro, LA). Data were collected from 30 Oct. – 13 Nov. 2006.

On 15 Oct. 2006, the same methods, materials, and treatments described above were repeated with the exception of planting date, number of flats and seed, species, and harvest intervals. Each replicate contained ten 72-cell flats which included each of the four substrates. Each replicated contained two and half (2.5) flats of each substrate treatment for a total of ten flats per replicate and forty flats total for the experiment. 2880 'Georgia Southern' collard seed were used and were seeded one per cell. All substrates were watered to runoff upon completion of seeding. The 72-cell flats were divided into halves (i.e. into 36-cell sections, which is why each replicate contained 2.5 flats of each substrate) to represent a randomly assigned harvest interval from one to five. Hence,

only one 36-cell section of each treatment within each replicate was destructively harvested each week (half flat per treatment per replicate per harvest for a total of eight flats/week), for a total of five weeks (Table 8a and 8b). Trays were subsequently hand watered as needed. Growth data were collected from 1 Nov. – 29 Nov. 2006.

Procedures for the second run of this experiment were the same as described above with the exception of planting date. Trays were filled and seeded on 22 Jan. 2007 for 'Red Sails' lettuce and 17 Jan. 2007 for 'Georgia Southern' collard. Data were collected from 6 – 20 Feb. 2007 and 2 Feb. – 2 Mar. 2007, respectively.

**Growth Analysis**

'Red Sails' lettuce seedlings were harvested weekly over a period of three weeks whereas 'Georgia Southern' collard seedlings were harvested once weekly over a period of five weeks based on recommendations from Vavrina (1998). Five plants were randomly selected from the center of one half (36-cell section) flat per treatment per rep and harvested weekly (80 plants total per harvest date). Measurements of plant height (taken from soil line to top of plant canopy), leaf area, and fresh and dry weights of leaves, shoots, and roots (after drying for 72 h at 78°C in a forced-air oven) were recorded. Roots were rinsed with tap water to remove substrate prior to data collection. Plant roots were separated from the top portion of plant by cutting at the soil line. Leaf area was measured using a LI-COR 3000 (Lincoln, Nebr.).

Growth parameters were calculated based upon weekly changes in plants using equations described by Hunt (1982) and Kemble (1993). Relative growth rate (RGR) was calculated as:

$$RGR = [(\ln W_2 - \ln W_1)/ (T_2 - T_1)],$$

where 'ln' is the natural log and $W_2$ and $W_1$ represent plant dry weight (shoots + leaves + roots) at time two ($T_2$) and time one ($T_1$), respectively. Net assimilation rate (NAR) was calculated as:

$$NAR = [(W_2 - W_1)/(T_2 - T_1)] \times [(\ln LA_2 - \ln LA_1)/(LA_2 - LA_1)],$$

where $LA_2$ and $LA_1$ represent plant leaf area at $T_2$ and $T_1$, respectively. Leaf area ratio (LAR) was calculated as:

$$LAR = [(LA_1/ W_1) + (LA_2 /W_2)]/2$$

Data were analyzed as a randomized complete block design using PROC ANOVA in SAS 9.1 (SAS Institute Inc., Cary, N.C.). Means were separated by Fisher's Protected Least Significant Difference (LSD) test at $\alpha = 0.05$ (5%). Unless otherwise stated, all data were analyzed at the 5% level. Each crop was analyzed separately. When necessary, data for a dependent variable were log transformed if plots of residual and predicted values displayed heterogeneity of variances; therefore, data were generated using transformed values. All data presented within text is non-transformed. Data were initially analyzed to detect significant differences between runs. If there were no significant differences between runs, data were pooled for runs (i.e. Run 1 and Run 2). If data indicated significant differences, data were not pooled and runs were analyzed separately and then analyzed for interactions between runs and harvests. If data indicated no significant interactions, harvests were pooled with runs. If data indicated significant interactions, harvests were analyzed individually within runs.

## Results

*Lettuce Growth Parameters*

Statistical analysis indicated that each run had to be analyzed separately due to significant interactions between runs and harvests with the exception of root dry weight because there were no significant interactions between runs and harvests ($p \leq 0.5963$). Regardless of run, root dry weight responded similarly among the four substrates (0.04 g), i.e. root dry weight for FO in Run 1 was similar to that in Run 2.

All other growth parameters were analyzed separately by harvest within runs, with the exception of total plant dry weight and leaf dry weight for Run 1 and only total plant dry weight for Run 2. In Run 1, total plant dry weights (0.21 g) and leaf dry weights (0.15 g) were higher when plants were grown in SC and weights were similar but reduced when grown in FO and SO (Fig. 8f and Fig. 8g). In Run 2, total plant dry weights (0.17 g) of plants grown in SC and FC were similar and higher than all other treatments.

*Harvest 1*

In Run 1, average canopy heights did not differ statistically when lettuce plants were grown in FC and SO (9.04 cm) and heights were similar but reduced when grown in SC and FO (7.97 cm). Lettuce plants grown in SC and FC did not differ statistically for total plant fresh weights, root fresh weights, leaf fresh weights, and total leaf areas (2.18 g; 0.34 g; 3.66 g; 71.32 $cm^2$, respectively). Total plant fresh weights, root fresh weights, leaf fresh weights, and total leaf areas were similar but reduced when plants were grown in SO and FO (1.52 g; 0.24 g; 1.15 g; 50.42 $cm^2$, respectively).

In Run 2, average canopy heights and leaf dry weights did not differ statistically when plants were grown in FC and SC and were reduced but similar when grown in SC and SO (6.63 cm in FC and SC vs. 5.87 cm in SO and FO; 0.05 g in SC and FC vs. 0.03 in SO and FO, respectively). Plants grown in SC had higher total plant fresh weights and weights were reduced when grown in FO (0.93 g in SC vs. 0.45 g in FO). Plants grown in SC had higher leaf fresh weights and total leaf areas and had similar but reduced weights and leaf areas when grown in SO and FO (0.80 g in SC vs. 0.43 g in SO and FO; 31.58 $cm^2$ in SC vs. 17.87 $cm^2$ in SO and FO, respectively). Root fresh weights were higher when plants were grown in SC and had similar but reduced when grown in FC and SO (0.12 g in SC vs. 0.08 g in FC and in SO).

*Harvest 2*

In Run 1, analysis indicated that root fresh weights did not differ statistically among the four substrates ($p \leq 0.8936$ with weights ranging from 0.85 g to 0.91 g). Average canopy heights were higher when plants were grown in SC and heights were similar but reduced when grown in SO and FO (12.00 cm vs. 10.78 cm in FO and SO). Total plant fresh weights of lettuce plants grown in SC were statistically higher than all other treatments (4.85 g) and weights were similar but reduced when grown in FC and FO (4.15 g in FC and FO). Lettuce plants grown in SC had higher leaf fresh weights and had similar but reduced weights when grown in FC and FO (3.95 g in SC vs. 3.25 g in FC and FO). Total leaf areas of plants grown in SC were statistically higher and were similar but reduced when grown in FC and FO (147.4 $cm^2$ in SC vs. 122.2 $cm^2$ in FC and FO).

In Run 2, average canopy heights did not differ statistically when lettuce plants were grown in FC and SC and had reduced heights when grown in FO (10.01 cm in FC

and SC vs. 8.07 cm in FO). Total plant fresh weights, leaf fresh weights, leaf dry weights, and total leaf areas did not differ statistically when plants were grown in FC and SC (2.99 g; 2.56 g; .13 g; and 93.46 $cm^2$, respectively). Root fresh weights were similar when plants were grown in FC and SC and had significantly reduced weights when grown in FO (0.45 g in FC and SC vs. 0.18 g in FO).

*Harvest 3*

In Run 1, average canopy heights, total plant fresh weights, leaf fresh weights, and total leaf areas were statistically higher when lettuce plants were grown in SC and were significantly reduced in SO (13.98 cm in SC vs. 11.58 cm in SO; 7.70 g in SC vs. 4.86 g in SO; 6.32 in SC vs. 3.80 g in SO; 244.9 $cm^2$ in SC vs. 149.2 $cm^2$ in SO, respectively) (Fig. 8a, Fig. 8b, Fig. 8d, and Fig 8e, respectively). Plants grown in SC had higher root fresh weights and weights were significantly reduced when grown in FO (1.37 g in SC vs. 0.90 g in FO) (Fig. 8c). Root fresh weights did not differ when plants were grown in FC and SO (1.09 g) but were lower than when grown in SC.

In Run 2, analysis indicated that leaf dry weights did not differ statistically among the four substrates ($p \leq 0.1239$ with weights ranging from 0.15 g to 0.23 g). Average total plant fresh weights and leaf dry weights did not differ statistically when plants were grown in FC and SC and had similar but reduced weights when grown in SO and FO (4.85 g in SC and FC vs. 3.20 g in FO and SO; 0.23 g in FC and SC vs. 0.17 g in FO and SO, respectively). Plants grown in FC had higher canopy heights and similar but reduced heights when grown in FO and SO (11.50 cm in FC vs. 9.07 cm in FO and SO). Leaf fresh weights and total leaf areas did not differ statistically when plants were grown in FC and SC and were significantly reduced when grown in SO (3.91 g in FC and SC vs.

2.38 g in SO; 144 $cm^2$ in FC and SC vs. 85.78 $cm^2$ in SO, respectively). Root fresh weights did not differ statistically when plants were grown in FC and SC and were significantly reduced when grown in FO (0.99 g in SC and FC vs. 0.56 g in FO).

In summary, lettuce growth was consistently higher when grown in SC through all harvest weeks in both runs. By final harvest (Harvest 3) in Run 1, the average total plant fresh and dry weights of transplants grown in FC did not differ statistically to those grown in FO. By the final harvest in Run 2, the average total plant fresh weights and leaf dry weights did not differ statistically when plants were grown in FC and SC and had similar but reduced weights when grown in SO and FO.

*Collard Growth Parameters*

Statistical analysis indicated that there were no significant interactions between runs and harvests for total plant fresh weights (1.32 g to 3.59 g), leaf fresh weights (1.05 g to 1.96 g), leaf dry weights (0.11 g to 0.23 g), and total leaf areas (29.7 $cm^2$ to 59.5 $cm^2$) ($p \leq 0.4436$, 0.0519, 0.5568, and 0.0913 respectively). Plants grown in SC had higher total plant fresh weights, leaf fresh weights, and total leaf areas with weights and leaf areas being reduced when grown in FO (Fig. 9b, Fig. 9d, and Fig. 9e). Leaf dry weights were higher when plants were grown in SC and weights were reduced when grown in either FC or SO (Fig. 9h).

Further analysis indicated that for all other growth parameters, runs were analyzed separately and then due to significant interactions between harvests and treatments, data were analyzed separately by harvest week.

*Harvest 1*

In Run 1, average canopy heights did not differ when plants were grown in FC, SC, and SO (7.53 cm). Collard plants grown in FC had significantly higher root fresh weights (0.16 g) and significantly reduced weights when grown in FO (0.04 g). Total plant dry weights did not differ and were higher when plants were grown in FC and SC (0.06 g) and similar but reduced weights when grown in FC and SO (0.03 g). Plants grown in FC and SC had higher root dry weights and weights were reduced when grown in FO (0.01 g vs. 0.002 g in FO).

In Run 2, average canopy heights and root dry weights did not differ when plants were grown in SC, FC and SO (7.18 cm and 0.01 g, respectively). Root fresh weights did not differ when collards were grown in SC and FC (0.05 g) and weights were reduced when grown in FO (0.02 g). Collard transplants grown in SC had higher total plant dry weights (0.05 g) and weights were similar but reduced when grown in FC and SO (0.04 g).

*Harvest 2*

In Run 1, average canopy heights were higher when plants were grown in SC (11.12 cm) and heights were reduced but similar when grown in SO and FC (10.04 cm). Root dry weights did not differ when plants were grown in SC and FC (0.03 g). Root fresh weights were higher when plants were grown in FC and SC (0.35 g) and weights were reduced when grown in FO (0.07 g). Plants grown in SC and FC had higher total plant dry weights (0.12 g) and weights were reduced when grown in FO (0.04 g).

In Run 2, average canopy heights were higher when plants were grown in SC (10.34 cm) and heights were reduced but similar when grown in FC and SO (9.38 cm).

Root dry weights did not differ when plants were grown in SC and SO (0.04 g) and were reduced when grown in FO (0.01 g). Plants grown in SC had higher root fresh weights (0.51 g) and reduced but similar weights when grown in SO and FC (0.40 g). Collard transplants had higher total plant dry weights when plants were grown in SC and had similar but reduced weights when grown in FC and SO (0.17 g vs. 0.11 g).

*Harvest 3*

In Run 1, average canopy heights were higher when plants were grown in SC (14.57 cm) and heights were similar but reduced when grown in SO and FC (12.83 cm). Root fresh weights were higher when plants were grown in FC (0.73 g) and were reduced but similar when grown in SC and SO (0.59 g). Root dry weights did not differ when plants were grown in SC and FC (0.07 g) and were significantly lower when grown in FO (0.02 g). Total plant dry weights were higher when plants were grown in FC and SC (0.22 g) and weights were reduced when grown in FO (0.09 g).

In Run 2, average canopy heights did not differ when plants were grown in FC and SC (11.05 cm) and had reduced heights when grown in FO (7.11 cm). Total plant dry weights were higher when collard transplants were grown in SC (0.32 g) and had reduced but similar weights when grown in FC and SO (0.24 g). Root fresh weights and root dry weights did not differ when plants were grown in FC, SC and SO (0.75 g and 0.06 g, respectively).

*Harvest 4*

In Run 1, average canopy heights were higher when plants were grown in SC (15 cm) and heights were similar but reduced when grown in SO and FC (13.26 cm). Total plant dry weights were higher when plants were grown in SC and weights were similar

but reduced when grown in FC and SO (0.44 g in SC vs. 0.29 g in FC and SO). Root fresh and dry weights were higher when collard transplants were grown in SC (0.81 g and 0.08 g, respectively) and were significantly lower when grown in FO (0.30 g and 0.02, respectively).

In Run 2, average canopy heights did not differ when plants were grown in SC, FC, and SO (11.64 cm). Root dry weights were higher when plants were grown in SC and had similar but reduced weights when grown in FC and SO (0.09 g in SC vs. 0.07 g in FC and SO). Root fresh weights were higher when plants were grown in SC and had similar but reduced weights when grown in SO, FC and FO (1.61 g vs. 1.09 g). Total plant dry weights did not differ when plants were grown in SC and FC with growth being significantly reduced when grown in FO (0.36 g vs. 0.27 g).

*Harvest 5*

In Run 1, average canopy heights did not differ when plants were grown in SC and FC (15.4 cm) and had similar but reduced heights when grown in FC and SO (14.75 cm) (Fig. 9a). Root dry weights were higher when plants were grown in SC (0.11 g) and weights were reduced when grown in FO (0.05 g) (Fig. 9g). Root fresh weights did not differ when plants were grown in SC and FC (1.16 g) and weights were similar but reduced when grown in FO (0.60 g) (Fig. 9c).

In Run 2, average canopy heights did not differ when plants were grown in SC and FC and had reduced heights when grown in FO (13.22 cm vs. 9.29 cm in FO). Root fresh weights did not differ when plants were grown in SC and FC and had similar but reduced weights when grown in SO and FO (1.92 g vs. 1.30 g). Root dry weights did not differ when plants were grown in SC and FC and had reduced weights when grown in FO

(0.15 g vs. 0.10 g). Total plant dry weights were higher when plants were grown in SC with growth being significantly reduced when grown in FO (0.61 g vs. 0.35 g). Total plant dry weights were reduced yet similar when plants were grown in FC and SO (0.47 g).

In summary, the commercial conventional mix (SC) was consistently higher between both runs among all growth parameters. By the final harvest of collards (Harvest 5), many growth parameters indicated that growth in organic Sun-Gro mix (SO) was similar to that in conventional Fafard (FC); the other commercially available organic mix (FO) was statistically lower in both runs.

*Elemental analysis of substrates*

Elemental analysis indicated variability in all major nutrients among the four substrates (Table 6). Cole crops perform best when the soil pH is between 6.0 and 6.8 which both Sun-Gro mixes provided (SC pH 5.82 and SO pH 6.33) and in which crops exhibited higher growth patterns (Kahn et al., 2007). SC performed well through both runs, having the lowest amount of phosphorous (16 parts per million (ppm)) and the highest amounts of potassium, calcium, and nitrate-nitrogen with (161, 238, 108 ppm respectively). Lettuce and collards had similar growth in SO, which has the higher pH of 6.33 and lowest nutrient levels (364, 16, 13, 13, 0.12, and <0.1 ppm of soluble salts, potassium, magnesium, calcium, iron, and manganese respectively). FC had the higher amount of iron and zinc (0.88 and 0.6 ppm). FO performed poorly having the lowest pH of 4.96 and nitrate-nitrogen level of 4 ppm and the highest amounts of soluble salts, magnesium, manganese, aluminum, and sodium (1820, 32, 0.7, 0.3, and 68 ppm respectively).

*Growth analysis*

In plant growth analysis, relative growth rate integrates the efficiency of various growth processes into one value (Hunt, 1982). Relative growth rate of a plant depends on the ability of a plant to produce leaf area and on the ability of its leaves to assimilate dry-matter (Beadle, 1982; Hunt, 1982). Therefore, differences in relative growth rate over time can be due to changes in the assimilation rate of carbon (net assimilation rate) and/or changes in the leaf area per unit of plant dry weight (leaf area ratio) (Beadle, 1982). Relative growth rate is generally higher in young determinate and indeterminate tomatoes and declines as the plants age (Kemble, 1993).

Net assimilation rate is a measure of the ability of leaves to fix carbon and is calculated as the increase of plant dry weight per unit leaf area per unit time (Hunt, 1982; Mengel et al., 2001). Bruggink and Heuvelink (1987) reported that indeterminate tomatoes generally exhibited their higher net assimilation rate when young and that this rate declined steadily as the plants aged. Leaf area ratio represents the ratio of photosynthesizing material (plant leaf area) to plant dry weight (Hunt, 1982). Smeets and Garretsen (1986) reported that young tomato plants had high leaf area ratios that decreased as they aged.

*Lettuce*

Relative Growth Rate (RGR), Net Assimilation Rate (NAR), and Leaf Area Ratio (LAR) data were pooled for there were no significant interactions between runs and harvests ($p \leq 0.0934$, 0.3772, and 0.6128, respectively). Thus, there were no differences across time. Lettuce RGR did not differ statistically among the four substrates (RGR ranged from 0.66 $g \cdot g^{-1} \cdot week^{-1}$ to 0.72 $g \cdot g^{-1} \cdot week^{-1}$) (Fig. 10a). NAR did not differ among

the four substrates (ranged from 0.004 $g \cdot m^{-2} \cdot week^{-1}$ to 0.001 $g \cdot m^{-2} \cdot week^{-1}$) (Fig. 10a). Transplants had similar LAR when grown in FO, SC, and FC (587.9 $m^2 \cdot g^{-1}$ to 605.7 $m^2 \cdot g^{-1}$) (Fig. 11a).

*Collard*

RGR and NAR data were kept pooled for there were no significant interactions between runs and harvests ($p \leq 0.9526$ and 0.7761, respectively). Thus, there were no differences across time. Collard had the highest RGR when grown in FO and similar but reduced RGR when grown in SC, SO, and FC (0.76 $g \cdot g^{-1} \cdot week^{-1}$ vs. 0.58 $g \cdot g^{-1} \cdot week^{-1}$ in SC, 0.57 $g \cdot g^{-1} \cdot week^{-1}$) (Fig. 10b). NAR was highest when plants were grown in FO and similar but reduced NAR when grown in SC, SO, and FC (0.003 $g \cdot m^{-2} \cdot week^{-1}$ vs. 0.002 $g \cdot m^{-2} \cdot week^{-1}$) (Fig. 10b).

Collard LAR data were analyzed separately by runs because there were significant interactions between runs and harvests. Further, there were significant interactions found between harvests and treatments within Run 1, so LAR data were analyzed separately by harvests within Run 1. There were no significant interactions found between harvests and treatments within Run 2, so LAR data were kept pooled for analysis.

In Run 1, there were significant interactions found between harvests and treatments; thus the data for LAR were analyzed separately by the difference between harvest weeks (Fig. 11b). Between Harvest 2 and Harvest 1, there were no significant differences found among treatments ($p \leq 0.1059$), with the highest LAR found when collard plants were grown in SO and had similar LAR when grown in SC and FO (374.9 $m^2 \cdot g^{-1}$ to 422.5 $m^2 \cdot g^{-1}$). Between Harvest 3 and Harvest 2, LAR was higher and

comparable when plants were grown in FO and SO and had similar but reduced LAR when grown in SC and FC (429.1 $m^2 \cdot g^{-1}$ vs. 338.9 $m^2 \cdot g^{-1}$). Between Harvest 4 and Harvest 3, LAR was higher when plants were grown in FO and had similar but reduced LAR when grown in SO and SC (388.1 $m^2 \cdot g^{-1}$ in FO vs. 273.8 $m^2 \cdot g^{-1}$). Between Harvest 5 and Harvest 4, LAR was highest when plants were grown in FO (262.8 $m^2 \cdot g^{-1}$). Similar, but reduced, LAR was found when plants were grown in FC, SC, and SO (184.7 $m^2 \cdot g^{-1}$ to 198.1 $m^2 \cdot g^{-1}$) (Fig. 11b).

In Run 2, there were no significant interactions found between harvests and treatments; thus the data for LAR were kept pooled. LAR did not differ when collard plants were grown in FO and FC (244 $m^2 \cdot g^{-1}$). LAR was reduced when collards were grown in SC (225.0 $m^2 \cdot g^{-1}$) (Fig. 11c).

**Discussion**

In summary, lettuce growth was consistently higher when grown in conventional Sun-Gro substrate (SC) through all harvest weeks in both runs. By the final lettuce harvest (Harvest 3) in Run 1, the average total plant fresh and dry weights of transplants grown in FC did not differ statistically to those grown in FO. By the final harvest in Run 2, the average total plant fresh weights and leaf dry weights did not differ statistically when plants were grown in FC and SC and had similar but reduced weights when grown in SO and FO.

By the final harvest of collards (Harvest 5), many growth parameters indicated that growth in organic Sun-Gro mix (SO) was similar to that in conventional Fafard (FC); the other commercially available organic mix (FO) was statistically lower in both runs.

Cole crops are successfully grown in both fall and early spring, preferring pH ranges of 5.5-6.5 and considering the time of year they grow well in, Cole crops do not require a whole lot of nutrition; especially for the first half of the season (Kahn et al., 2007; Vavrina, 2002). Contemplating this explains why the collards did not perform as well in organic treatment FO. This treatment contains an incorporated starter charge, Nature Safe: An organic slow release fertilizer which consists of meat meal, hydrolyzed feather meal, bone meal, blood meal, and sulfate of potash. Additionally, FO has the lowest pH, higher phosphorous and manganese levels, and the most sodium. Miles and Peet (2002) reported that a problem with organic fertilizers was high pH and salt levels. Collard transplant growth was significantly reduced when grown in FO, which has the highest soluble salt concentration with 1820 ppm. As reported by Vavrina (2002), if a substrate contains high salt levels, it could cause complications in germination and early growth. Collard growth in SO was comparable to both conventional treatments across both runs and through all harvests. SO has the highest pH of 6.33 and the lowest nutrient levels; with the added fish hydrolysate, it appears that this provided adequate nutrition for transplant growth. Miles and Peet (2002) found that plant vigor was excessive when receiving one organic fertilizer versus the other.

Although both crops exhibited higher growth indices when the transplants were grown in SC, it does not mean that bigger is better. In fact, it may be the most undesirable (Granberry and Boyhan, 2003). The industry may reject large transplants due to the difficulty in transplanting with mechanical transplanting equipment and to a greater incidence of transplant shock in the field (Brown et al., 2002; Dufault, 1998). The ideal transplant is young, has compact growth, a short production time period, and a well

developed root system (Brown et al., 2002; Motes and Roberts, 2002; Nelson et al., 2000).

Lettuce and collard canopy heights did not differ and were similar when transplants were grown in either conventional substrate or organic blends (FO for lettuce and SO for collard). Delate and Lawson (2001), whose goal was to obtain equivalent N rates in organic and conventional systems, discovered that canopy height was not significantly different in plants that were fertilized with an organic (poultry-based) compost. Lettuce total fresh weights did not differ between FC and FO and Delate and Lawson (2001) found that the total pepper fresh weights over a five-week harvest period were not significantly different among both conventional and organic treatments. Russo (2005) found that bell pepper seedlings that were treated with four times the recommended rate of an organic fertilizer would produce transplants equivalent in height and dry weight to those produced conventionally.

Collard growth parameters indicated that transplant growth was quite variable when grown in FO, ranging from small to average size and weight. However, growth analysis (i.e. RGR, etc.) indicated that growth was higher in FO even though statistical analysis for the individual growth parameters indicated that growth excelled when Cole crops were grown in both Sun-Gro mixes (SC and SO).

However, when lettuce and collard were grown in FO, they had the highest RGR, NAR, and LAR across the board. In individual growth parameter analysis, growth in FO and FC resulted in poor collard growth parameters yet as far as RGR, NAR, and LAR were concerned, the FO treatment performed well. Additionally, in accordance with the findings of Kemble (1993), Bruggink and Heuvelink (1987), and Smeets and Garretsen

(1986), the RGR, NAR, and LAR of Cole crops, like tomatoes, exhibited their higher rates when they were young and declined as they aged.

In summary, based upon the findings of this research, farmers now have guidelines to help them discover what commercially available substrates may work to achieve similar results utilizing organic production methods to that of conventional ones.

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**Table 5.** List of treatments and their contents; abbreviations for treatments.

| Substrate type | Substrate name | Substrate contents | Abbreviations |
|---|---|---|---|
| Commercial conventional | Fafard 1-P | Sphagnum moss, horticultural perlite, wetting agent, starter nutrients | FC |
| | Sun-Gro LC1 | Canadian sphagnum peat moss, coarse grade perlite, gypsum, dolomitic lime, wetting agent | SC |
| Commercial organic | Fafard Organic Formula #10 | Canadian sphagnum peat moss (80%), perlite, gypsum, dolomitic lime, Nature Safe Fertilizer 10-2-8 and 8-3-5 | FO |
| | Sun-Gro Professional Organic Blend | Canadian sphagnum peat moss, coarse grade perlite, gypsum, dolomitic lime, Yucca extract (organic wetting agent) | SO |

**Table 6**. Elemental results of substrate treatments. Units are parts per million with exception of pH and specific conductance.

| Treatment | Sun-Gro LC1 (SC) | Fafard 1-P (FC) | Fafard Organic Formula #10 (FO) | Sun-Gro Prof. Organic (SO) |
|---|---|---|---|---|
| pH | 5.82 | 5.78 | 4.96 | 6.33 |
| Specific Conductance (mmhos/cm) | 2.5 | 1.6 | 2.6 | 0.52 |
| Soluble Salts | 1750 | 1120 | 1820 | 364 |
| Phosphorus | 16 | 36 | 35 | 20 |
| Potassium | 161 | 118 | 128 | 16 |
| Magnesium | 31 | 31 | 32 | 13 |
| Calcium | 238 | 98 | 133 | 13 |
| Copper | 0.2 | 0.2 | 0.3 | 0.3 |
| Iron | 0.5 | 0.88 | 0.37 | 0.12 |
| Manganese | 0.2 | 0.5 | 0.7 | <0.1 |
| Zinc | 0.3 | 0.6 | <0.1 | <0.1 |
| Boron | <0.1 | <0.1 | <0.1 | <0.1 |
| Aluminum | 0.2 | 0.1 | 0.3 | 0.1 |
| Sodium | 36 | 40 | 68 | 36 |
| Nitrate-Nitrogen | 108 | 104 | 4 | 8 |

**Table 7.** Substrate treatment Porometer analysis.

| **Treatment** | **Total Porosity** % vol | **Container Capacity** % vol | **Air Space** % vol | **Bulk Density** G/cc |
|---|---|---|---|---|
| Sun-Gro LC1 (SC) | 77.2 | 59.6 | 17.6 | 0.08 |
| Fafard 1-P (FC) | 80.9 | 64.6 | 16.3 | 0.08 |
| Fafard Organic Formula #10 (FO) | 84.7 | 73.9 | 10.8 | 0.11 |
| Sun-Gro Prof. Organic (SO) | 71.7 | 56.8 | 14.9 | 0.08 |
| Recommended values | 50-85 | 45-65 | 10-30 | 0.11 - 0.20 |

**Table 8a.** 'Red Sails' lettuce and 'Georgia Southern' collard seeding dates, number of materials used, weekly harvests, replicates, treatments, growth parameters measured, and data collection dates.

| Crop | Planting dates | Total seed used | Total trays used | Number of weekly harvests | Number of replicates | Treatments | Growth parameters measured | Dates of data collection |
|---|---|---|---|---|---|---|---|---|
| 'Red Sails' lettuce | Run 1 = 11 Oct. 2006<br>Run 2 = 22 Jan. 2007 | 1728 | 24 | 3 | 4 | 4 | Plant canopy height, leaf area, fresh and dry weights of leaves, shoots, and roots | Run 1 = 30 Oct. – 13 Nov. 2006<br>Run 2 = 6 – 20 Feb. 2007 |
| 'Georgia Southern' collard | Run 1 = 15 Oct. 2006<br>Run 2 = 17 Jan. 2007 | 2880 | 40 | 5 | 4 | 4 | | Run 1 = 1 – 29 Nov. 2006<br>Run 2 = 2 Feb. – 2 Mar. 2007 |

**Table 8b.** Example schematic of one replication in experimental design for a crop with three weekly harvests.

| | | | |
|---|---|---|---|
| FC H3 | FC H2 | SC H3 | SC H1 |
| FO H1 | SO H3 | SO H1 | SO H2 |
| FO H2 | FO H3 | SC H2 | FC H1 |

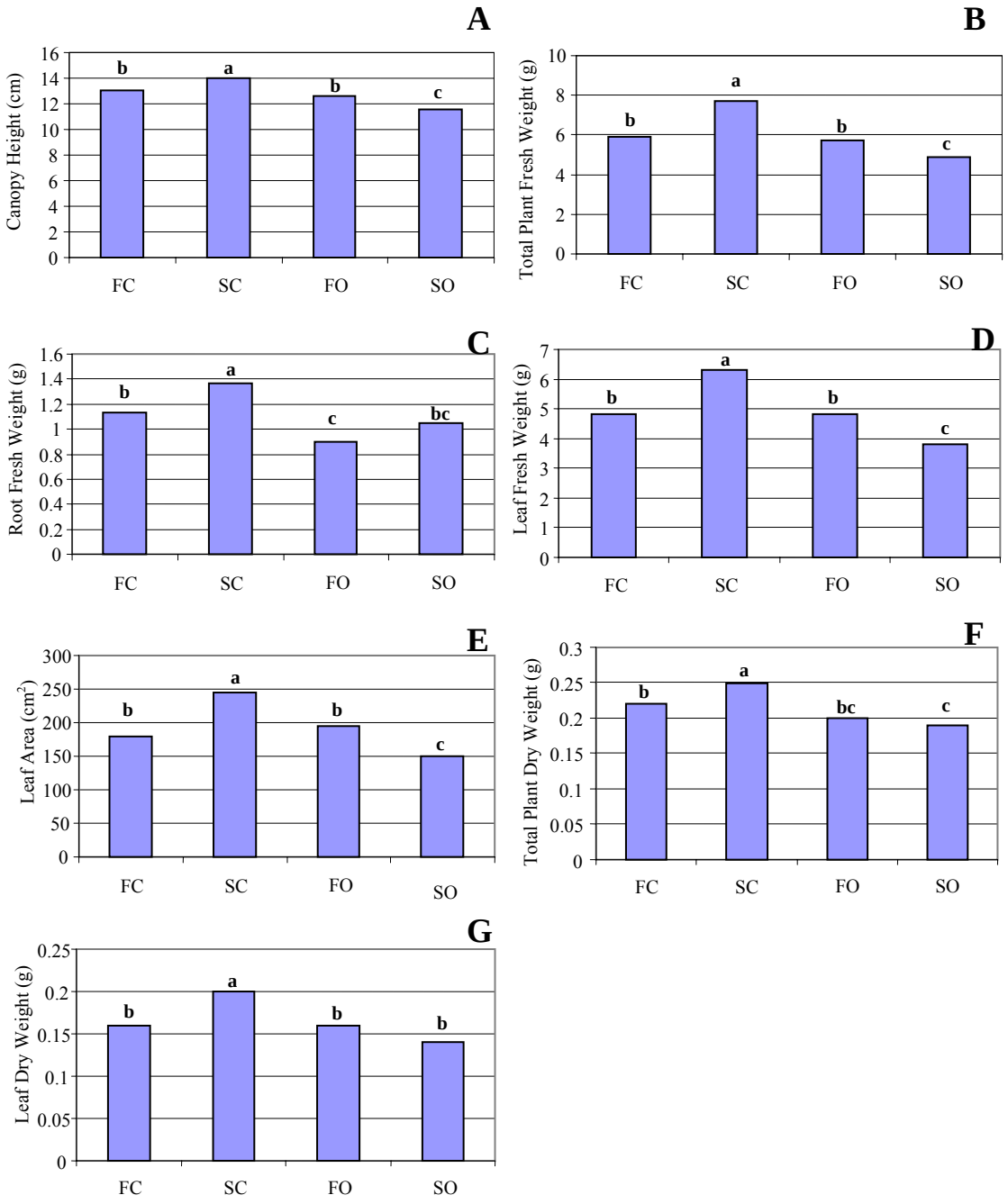


**Figure 8.** Effect of substrate treatments on 'Red Sails' lettuce in Run 1 for (Harvest 3). Treatments included two conventional substrates: Fafard 1-P (FC) and Sun-Gro LC1 (SL); and two organic substrates: Fafard Organic Formula (FO) and Sun-Gro Prof. Organic Blend (SO). Transplants were seeded 11 Oct. 2006 and harvested on 13 Nov. 2006. Growth parameters include: Canopy height **(A)**; total plant fresh weight **(B)**; root fresh weight **(C)**; leaf fresh weight **(D)**; and leaf area **(E)**. Substrate treatment effects were pooled within Run 1 for all harvests for total plant dry weight **(F)** and leaf dry weight **(G)**. Different letters within columns indicater statistical significant difference among treatments according to ANOVA and Fisher's Protected LSD test ($p \leq 0.05$).

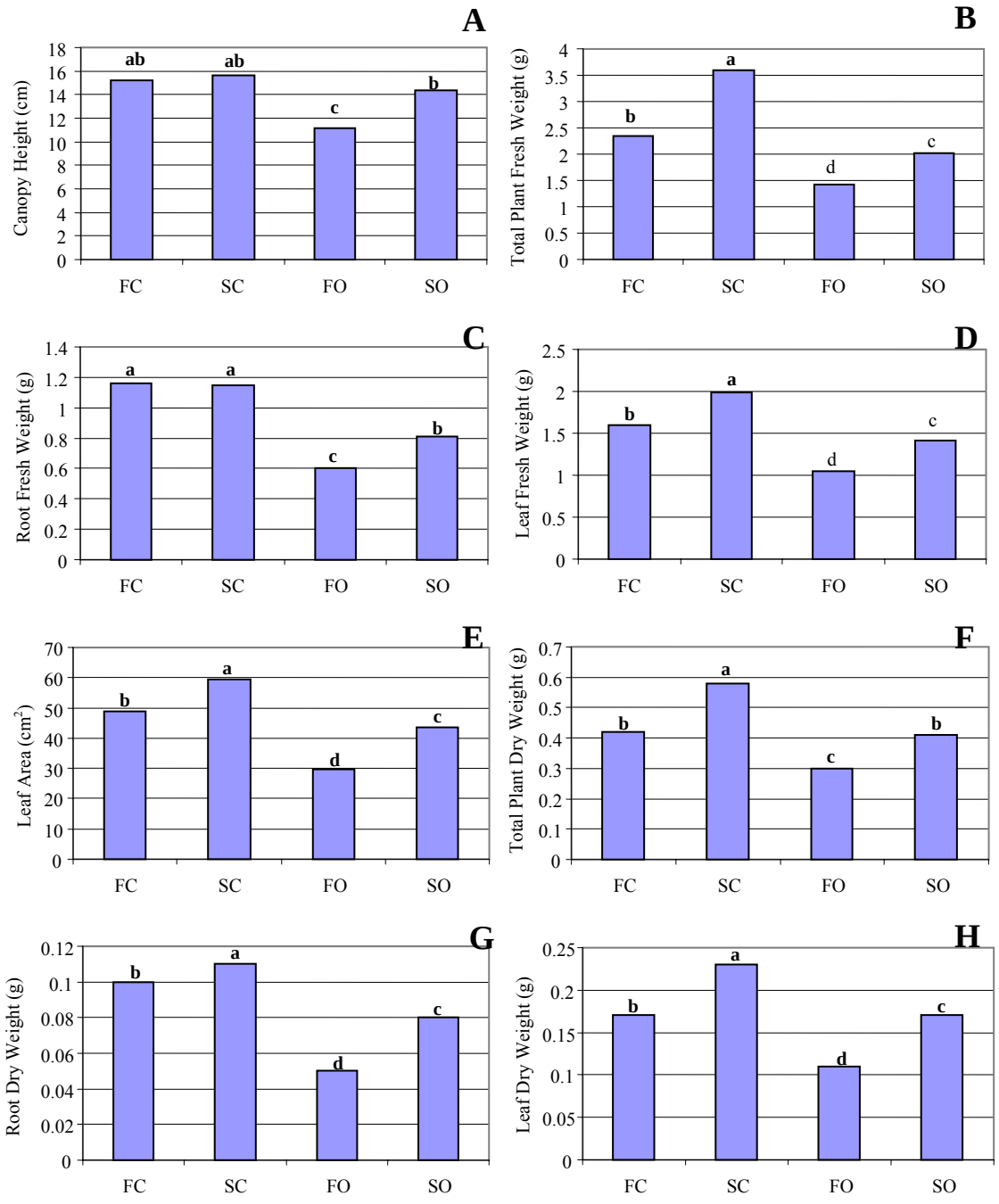


**Figure 9.** Effect of substrate treatments on 'Georgia Southern' collard in Run 1 for final harvest (Harvest 5). Treatments included two conventional substrates: Fafard 1-P (FC) and Sun-Gro LC1 (SL); and two organic substrates: Fafard Organic Formula (FO) and Sun-Gro Prof. Organic Blend (SO). Transplants were seeded 15 Oct. 2006 and harvested on 29 Nov. 2006. Growth parameters include: Canopy height **(A)**; root fresh weight **(C)**; total plant dry weight **(F)**; and root dry weight **(G)**. Growth parameter data were pooled within Run 1 for all harvests for total plant fresh weight **(B)**; leaf fresh weight **(D)**; leaf area **(E)**; and leaf dry weight **(H)**. Different letters within columns indicate statistical significance among treatments according to ANOVA and Fisher's Protected LSD test ($p \leq 0.05$).

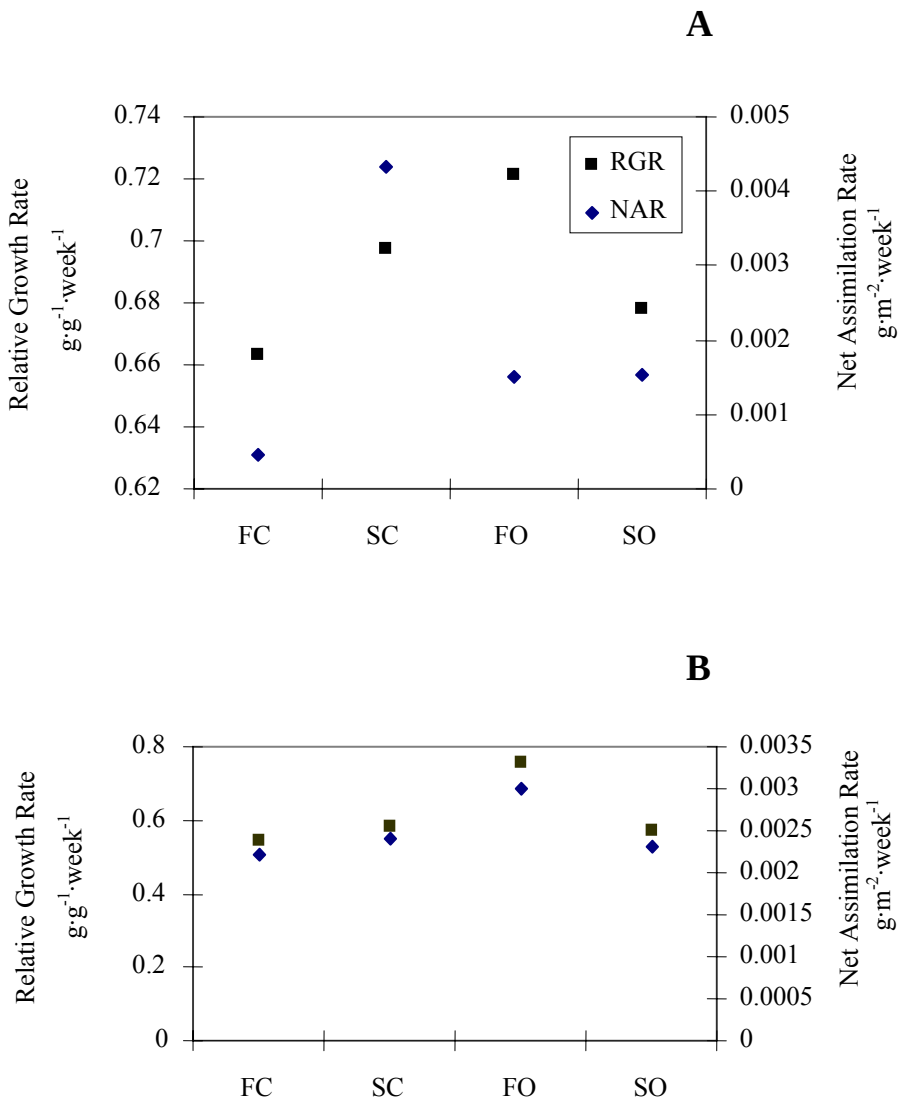


**Figure 10.** Effect of substrate treatments on 'Red Sails' lettuce **(A)** and 'Georgia Southern' collard **(B)** for RGR and NAR. Due to no significant difference between runs and harvests, data were pooled for Run 1 and Run 2.

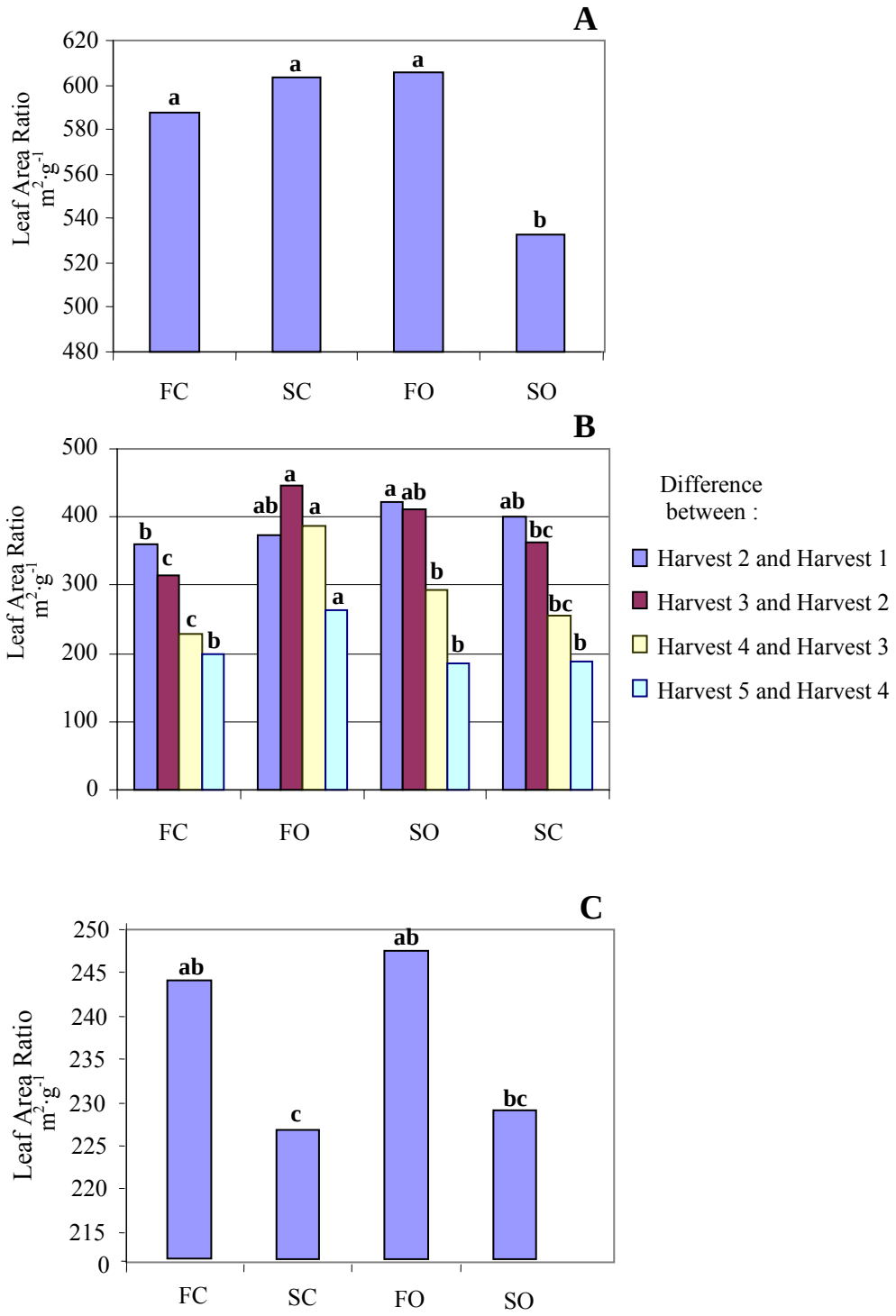


**Figure 11.** Substrate treatment effects on LAR for 'Red Sails' lettuce **(A)** where data were pooled due to no significant difference between runs and harvests. Substrate treatment effects on LAR development for 'Georgia Southern' collard over Run 1 **(B)** and the differences between harvests were pooled in Run 2 due to no significant difference between runs and harvests **(C)**. Different letters within columns indicate statistical significant difference among treatments according to ANOVA and Fisher's Protected LSD test ($p \leq 0.05$).

# CHAPTER IV

# FINAL DISCUSSION

Transplant production qualifies as one of the most intensive cropping systems since growers face rising water and fertilizer costs, declining water quality, and governmental intervention protecting surface and ground water (Weiler et al., 1999). For decades, growers have utilized greenhouse grown vegetable transplants (Dufault, 1998; Langston, 2003) and currently, there is a less than adequate supply of organic vegetable transplants due to limited research aimed at developing recommendations for their production. Successful transplant production requires a suitable substrate and the suitability of organic materials as an alternative to conventional materials needs clarification (Russo, 2005). There are several certified organic plug mixes available; however, the efficacy and cost of these substrates are of concern to growers who often report inconsistent or poor results. One objective of this study was to understand what makes an acceptable organic substrate in terms of its physical properties in order to develop an affordable substrate that growers in Alabama can utilize for organic transplant production of economically critical crops, such as tomatoes (*Lycopersicon esculentum* Mill.), cucumbers (*Cucumis sativus* L.), lettuce (*Lactuca sativa* L.), and collards (*Brassica oleracea* (Acephala Group) L.). The second objective of this study was to

examine the effect of currently available commercial plug mixes and their components on selected growth parameters of these economically important crops. The third objective of this study was to characterize the early growth and development of transplants in terms of changes in relative growth rate, net assimilation rate, and leaf area ratio.

*Cucumber and Tomato*

Crop growth was variable among both runs. According to recorded growth parameters, overall growth was consistently higher in the conventional Sun-Gro LC1 (SC) blend yet similar growth patterns were achieved when transplants were grown in the conventional Fafard 1-P (FC) and organic Fafard Formula #10 (FO) blends.

The determined physical properties of the substrates all fell in line with recommendations from Fonteno and Harden (2003). Considering that both Fafard blends had incorporated starter fertilizer charges, it was surprising to note that their growth patterns lagged behind that of SC. Nonetheless, the Leaf Area Ratios (LAR) were higher for both crops when transplants were grown in FO. Miles and Peet (2002) found that plant vigor proved to be excessive in one organic fertilizer treatment versus the other: FO had an incorporated Nature Safe fertilizer in addition to the weekly addition of the Neptune's Harvest Fish Hydrolysate while the Sun-Gro Professional Organic Blend (SO) did not have an incorporated fertilizer, only the weekly addition of the fish hydrolysate. Also interesting to note is that the Fafard blends contain the highest concentrations of soluble salts and sodium, which typically cause complications in germination and early growth but seemed to have no substantial effect during this study (Mauromicale et al., 2003; Miles and Peet, 2002; Vavrina, 2002). Cucumber and tomato transplant growth in SO was stunted. SO had the highest pH (6.33) and the lowest nutrient concentrations that

all other treatments. Even the weekly addition of the fish hydrolysate did not improve growth.

In accordance with the findings of Bruggink and Heuvelink (1987), Kemble (1993), and Smeets and Garretsen (1986), the Relative Growth Rate (RGR), Net Assimilation Rate (NAR), and LAR of both crops exhibited their higher rates when they were young and declined as they aged.

*Lettuce and Collard*

Lettuce and collard growth were consistently higher when grown in SC through all harvest weeks in both runs. By the final harvest for lettuce, growth parameters indicated that growth in FC was comparable to that in FO. However, collard parameters indicated that transplant growth was quite variable when grown in FO, ranging from small to average size and weight. Collard transplant growth was similar when grown in FC and SO. Although, growth analysis (RGR, NAR, and LAR) indicated that growth was higher in FO even though statistical analysis for the individual growth parameters indicated that growth was highest when Cole crops were grown in both Sun-Gro mixes (SC and SO). Miles and Peet (2002) found that plant vigor was excessive when receiving one organic fertilizer versus the other.

The determined physical properties of the substrates all fell in line with recommendations from Fonteno and Harden (2003). In general, Cole crops prefer pH ranges of 5.5-6.5 and do not require a whole lot of nutrition (as compared to cucumbers and tomatoes); especially for the first half of the season (Kahn et al., 2007; Vavrina, 2002). Contemplating this explains why the collard transplants did not perform well in FO. These blends both contained incorporated fertilizers and the higher sodium

concentrations. As reported by Vavrina (2002), if a substrate contains high salt levels, it could cause complications in germination and early growth; which is exactly what happened to the collards when they were grown in FO. Collard growth in SO was similar to both conventional treatments (SC and FC) through all harvests across both runs. SO had the highest pH (6.33) and the lowest nutrient concentrations, thus the weekly addition of the fish hydrolysate provided adequate nutrition for transplant growth.

In accordance with the findings of Bruggink and Heuvelink (1987), Kemble (1993), and Smeets and Garretsen (1986), RGR, NAR, and LAR of Cole crops, like the cucumbers and tomatoes, exhibited their higher rates when they were young and declined as they aged.

Although all crops exhibited higher growth indices when the transplants were grown in SC, it does not mean that bigger is better. In fact, it may be the most undesirable (Granberry and Boyhan, 2003). Many growers transplant in the field when the first or second set of true leaves form, usually two to three weeks after sowing seed, preferring to begin when the plants are quite small (Motes and Roberts, 2002). Vavrina (1998) recommended that cucumbers should be field set with a maximum of two true leaves and before the plant grows much larger than a silver dollar, stating that the rigors of the natural environment can take their toll on "leggy" plants. The industry may reject large transplants due to the difficulty in transplanting with mechanical transplanting equipment and to a greater incidence of transplant shock in the field (Brown et al., 2002; Dufault, 1998). The recommended height for the least transplant shock and for faster re-growth is approximately ten centimeters (four inches) as opposed to twenty-five or thirty centimeters (ten to twelve inches) tall for vegetable transplants (Relf, 1997). The ideal

transplant is young, has compact growth, a deep green shoot, a short production time period, and a well developed root system (Brown et al, 2002; Motes and Roberts, 2002; Nelson et al., 2000).

The Fafard blends (FC and FO) were the better performers for both crops according to what is considered the "ideal" transplant. Both Fafard blends had incorporated starter charges: FC contained a synthetic starter charge while FO contained Nature Safe, an organic slow release fertilizer that consists of meat meal, hydrolyzed feather meal, bone meal, blood meal, and sulfate of potash, which is in compliance with USDA and OMRI guidelines.

In summary, further research relating to organic transplant production needs to be addressed because growers are constantly challenged to find a consistent and affordable substrate for organic vegetable transplant production (Clark and Cavigelli, 2005).

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