PASSIVE VENTILATED HIGH-ROOF GREENHOUSE PRODUCTION OF VEGETABLES IN A HUMID, MILD WINTER CLIMATE

Daniel J. Cantliffe[1], Nicole Shaw[1], Elio Jovicich[1], Juan C. Rodriguez[1], Itzhak Secker[2], and Zvi Karchi[3]

[1]University of Florida, Institute of Food and Agricultural Science, Horticultural Sciences Department, 1251 Fifield Hall, PO Box 110690, Gainesville, Florida 32611-0690, USA
[2]34 Burla St., Apt. 2, Tel-Aviv, ISRAEL 69364
[3]PERI, PO Box 6, Bet-Dagan, ISRAEL 50250

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Abstract:

Florida produces $1.8 billion (United States dollar) of vegetables on 160,000 ha of land. All of this production is destined for the fresh market and most of the produce is shipped to Northern United States markets. Most of this vegetable production is grown in the field out of season in the winter months, thus requiring land not prone to freezes. Unfortunately, Florida is becoming highly urbanized with the population exceeding 15.3 million in 2000. The major impact of urbanization has been a loss of Florida's warmest and most productive lands for winter vegetable production. In 1997, a Florida and Israeli Protected Agriculture Project was initiated in order to take better advantage of land distal from the urbanized coastline. An 8-m high passive-ventilated Israeli-style greenhouse was constructed in north Florida, a minimum of 85 km from either coast. Successful pepper, tomato, cucumber and muskmelon crops were grown as fall-winter and spring-summer crops. With proper shading, heat-sensitive crops could be produced throughout the summer. Moreover, a class of high-quality vegetable crops which could not be produced under typical field conditions in Florida's climate were produced. These included Galia-type muskmelon, Beit alpha cucumber, cluster tomato, and high-quality colored peppers. Yields from greenhouse crops are generally 10 times more than comparable field-produced crops.

1. Introduction

There were 150,000 ha of vegetables produced in Florida valued at $1.8 billion for the production season of 1997-98 (Witzig, 1999). The major crops of tomato, watermelon, pepper, cucumber, and strawberry accounted for 56% of the total statewide vegetable crop value. Vegetable culture in Florida is a very technological business involving several high-cost inputs including polyethylene mulch, drip irrigation, fertilizer, and pesticides. Currently, almost one-third of Florida vegetables, including all tomatoes, strawberries, peppers, eggplants, and most melons, are produced on polyethylene-mulch. Nearly 50% of the polyethylene-mulched crops are grown with drip irrigation (Hochmuth et al., 1998 and 1999).

Although Florida vegetable culture involves intensive production practices, there are major challenges in front of the vegetable industry. These challenges are 1.)

increased regulation of water, fertilizer, and pesticide inputs, 2.) loss of a major soil fumigant, methyl bromide, 3.) increased urbanization and loss of some of the more desirable (warmer) production land in southern Florida, and 4.) continued challenges from weather, including freezes, winds and rain (Cantliffe, 1999). Add to these challenges, the increasing problems associated with regional and global market competition. The added protection by plasticulture could lead to production of higher quality crops that will make Florida growers more competitive against imports from other vegetable production areas in the world. It is evident that for the vegetable industry in Florida to prosper and grow, there is a need to develop new cultural technologies.

Plasticulture systems, including greenhouses, could provide a means to deal with the challenges listed above (Waldo, et al., 1997, 1998, and 1999). Currently, there is a small greenhouse (hydroponic) vegetable industry in Florida, but these special greenhouses represent a substantial investment due to heating and cooling system costs. An alternative might be the use of greenhouse structures with passive ventilation and more effective heating techniques. Greenhouse vegetable culture can provide protection from the weather, a major production challenge faced by vegetable growers. The serious potential loss of crops due to freezes and rain or wind is a major challenge and concern for all vegetable growers in climates such as Florida. These could more easily be controlled in greenhouse culture.

Greenhouse structures can protect the crop from wind and rain, but also can protect from insects when fitted with insect exclusion screens. Therefore, plasticulture systems could reduce the use of pesticides.

Plasticulture systems could include the use of soilless culture for crop production. One example would be bag or container production using an inert media such as perlite, vermiculite, peat, or coconut fiber. Soilless culture has been used successfully for vegetable production in Florida. Soilless culture would address the current challenges of urbanization because with soilless culture in greenhouses, winter vegetable production would not depend on warm, sandy soils of southern, coastal Florida. In addition, the loss of methyl bromide would be less troublesome if a portion of the vegetables could be grown in soilless culture, either under a protective structure or in open-field soilless culture.

In summary, plasticulture with soilless cultural systems could address several of the serious challenges facing the vegetable industry in Florida and could provide a new industry to North Florida producers. Some of the plasticulture technologies currently exist, but need to be evaluated and refined for Florida use. Already, this technology is in use in several places in the world, including Israel and other Mid East countries, several Far East countries (China, Korea, Japan), Canada, and Mexico. These countries face some of the same challenges as does the Florida vegetable industry. The Plasticulture Institute at the Horticultural Sciences Department in Gainesville could provide much needed information for hands-on training and demonstrations so that North Florida producers could examine, work, and train in this exciting new agricultural business endeavor.

2. Results and Discussion

Protected vegetable production in greenhouses can afford several advantages to producers. They include the ability to moderate temperature during various seasons of the year, wind protection, insect protection, and rain protection. In the past 10+ years, greenhouse production of vegetables in countries such as Israel has soared. The use of plastic greenhouses, especially for vegetable production has, simply put, made an oasis out of the desert in many places in Israel. One such example is the proliferation of greenhouse vegetable and flower production in the Arava Desert. In examining production systems in this area, it was conceivable to assume that similar production systems would work in the more humid, semi-tropical areas and countries such as Florida. For that reason, in 1997, the Florida-Israeli Protected Agricultural Project was established in Gainesville, Florida.

Much of the greenhouse production schemes of Israel were brought to Florida to determine if we could economically produce various vegetable commodities in high-roof passive-ventilated greenhouse structures. In order to do this, we developed a network of Israeli partners wherein they would supply materials and some resources for us to develop the project as a demonstration research structure in Gainesville. A Top greenhouse was constructed in 1999 on approximately 3/10 ha of land. This structure was covered with Ginegar virus-free plastic and the sidewalls were screened against insects with Meteor 50-mesh insect screen. The set-up of the greenhouse in this fashion with a vented roof, which was also screened, allowed us to exclude most insects, potentially with the exception of thrips from coming into the greenhouse. It also offered the possibility of reducing potential damage from viruses by restricting reproduction of whiteflies within the greenhouse. By totally screening the greenhouse we were also given the opportunity to use bumble bees as pollinators for melons, peppers, and tomatoes.

During our first year of production we conducted variety trials on tomato, pepper, cucumber, and melon. We also investigated the effects of plant density and shoot pruning on yield and quality of sweet peppers produced in the summer (Jovicich, 1999 b and c). We also investigated a disorder on sweet pepper known as 'Elephant's Foot' which is seen when peppers are produced in hydroponic culture using media such as perlite (Jovicich et al., 1999a). Our variety trials consisted of germplasm from both Hazera and Zeraim Seed Companies of Israel, and several cultivars of the various commodities which were provided as checks from Dutch seed companies. Tomatoes and peppers were planted in January 1999 and melons and cucumbers were planted in February 1999, and then transplanted one month later into the production greenhouse. The production scheme for the cultivar trials were the use of bag culture and perlite as a media. Perlite bags were 1 meter in length. Plants were planted at 0.4 meters apart and in single rows for all crops except tomatoes which were planted in double rows. All plants were fertigated at each irrigation on a timed basis as related to sunlight and temperature within the house. Irrigation frequency was regulated by drainage frequency wherein drainage was generally maintained at less than 35% of water applied. All plants were permitted to grow in a vertical fashion to guide wires across the center of the greenhouse, approximately 4 meters high. Harvesting of all commodities was done either at full slip for melons, full color for tomato and peppers (red/yellow), or economic maturity for cucumbers. As previously mentioned, for all but the cucumbers bumble bees were used for pollination. Insect pests were monitored daily and for the first experiment, insects were controlled by approved pesticides. Sticky traps were used to collect and identify potential insect pests.

Total yields for cluster tomatoes are represented in Table 1. There were no significant differences for total marketable weight on fruit as well as average fruit weight among twelve cultivars tested. There were significant differences among various cultivars with regard to marketable number of fruit, wherein 'Champion' produced the most fruit and VT906 produced the least fruit.

In the melon cultivar trial no differences were observed in fruit production on average fruit weight or total yield (data not presented). However, there were differences in quality of brix observed, wherein 'Galia' had the highest brix and 'Arava' and 'Golan' had the lowest (Table 2).

Thirty-five pepper varieties were compared and data for marketable fruit, number marketable fruit, cull number, cull weight, and average fruit weight and total fruit produced were taken. Due to high temperatures in the greenhouse during the spring and summer months of 1999, most of the fruit produced were culled (data not presented). Several cultivars produced acceptable numbers of fruit on the plant for the July harvests, averaging in some cases 12-13 fruit per plant. Problems related to this trial were especially due to inadequate pruning of the plant or proper protection of the fruit from sun and high temperature. In subsequent trials it was found that by following an Israeli pruning system to pruning to two stems then allowing the plant to basically grow out during summer months completely reversed the situation of poor fruit quality.

Cucumbers were planted April 1, 1999, and harvest began one month later on May 1, and continued until early July of 1999. Some cultivars of cucumber produced over 60 fruit on 23 harvests from May 1, 1999 - July 1, 1999 (Table 3). Most of these fruit were in the fancy grade and a small percentage of them were cull fruit. There were no significant differences among cultivars for cull fruit, however, there was a wide dispersion of fruit numbers for the various cultivars tested. This, however, equated to no significant difference among marketable fruit weights among all cultivars. As such, European- and Dutch-type cucumbers such as 'Bologna' and 'Kalunga' produced about 20 fruit per plant, wherein in the Beit alpha types, such as 'Rambo' and 'Dishon' produced three to four times that number of fruit, but averaged the same fruit weight (Table 3).

In other experiments testing the plant density and pruning methods for peppers plant populations of 2, 3, and 4 plants per sq. m. and 66.5, 43.3, and 33.3 cm (in-row spacing) and shoot pruning methods of 1-, 2-, and 4-stem were examined using the pepper cultivar Robusta (Jovicich, 1999 b and c). Plants were grown in perlite and irrigated each time with a full compliment of nutrient solution. Red fruit were harvested twice, 84 and 118 days after transplanting. Marketable yield both number and weight per meter squared increased linearly with plant density and were greater on plants with 4 stems than those with 2 or 1 stem. Density had no effect on production of extra large fruit. Total marketable yield and extra large fruit yield per plant were greatest in the 4-stem plants at 2 plants/sq. m. The results of these studies indicated that 12 plants/sq m pruned to 4 stems led to increased marketable and extra large fruit yield in a short harvest period of the summer greenhouse pepper crop in Florida. Subsequent trials to this have improved yields and the quality of the crop by changing the pruning system from the Dutch-type to the Israeli-type.

The 21 Century brings more people, less water, more demand for world food production, and a sign of hope for the future. Vegetable agriculture with its importance for human nutrition has gone through many production changes in the past 100 years. Science has taught farmers how to intensify their efforts many fold, giving them at present, the luxury and curse to over-produce. Unfortunately, as world economies dramatically improve, demands for land for non-agricultural use has likewise dramatically increased. Many science-based alternatives to insure high productivity have been diminished including the dependency on methyl bromide as a plant bed sterilant. The result is a scramble for export economies to drastically change vegetable production schemes. Protected agricultural systems in warm winter climates will surpass much of the open field production of today. Alternatives for soil-based systems as well as improved pest management are current problems facing such protected agricultural production schemes. Breeding programs to maximize efficiency of such protected agricultural systems are likewise essential. Plant growing structures must conform to the needs of plant productivity, as well as production economics. Most importantly, field-production-based agricultural systems of such places in North America as California, Florida, and Mexico must be prepared to change to more intense protected agricultural systems in as little as the next 5 years. The future for efficient economic vegetable production on a year-round basis will be dependent on these science-based changes.

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Table 1. Means for total harvest[x] of greenhouse 'cluster' tomato. Gainesville, Florida. Spring/Summer 1999

	Small		Medium		Large		X-large	
Cultivar	no.	wt.[z]	no.	wt.	no.	wt.	no.	wt.
Amanda Z[y]	9.8cd[w]	0.8cd	16.5	2.1	3.4bcd	.6b-e	0.0e	0.1
Brillante H	5.6de	0.5de	13.5	1.8	5.6ab	1.0abc	0.9cde	0.3
Champion Z	27.4a	2.2a	9.5	1.2	0.5d	0.1e	0.4de	0.1
Daniela H	12.9c	1.0c	14.9	1.9	2.6cd	0.5cde	0.4de	0.1
Dynamite Z	9.9cd	.7cde	13.6	1.8	3.5bcd	0.6b-e	0.4de	0.1
Graziella Z	7.5cde	.6cde	14.4	2.0	4.0bc	0.7bcd	0.5de	0.2
Shirley Z	11.1cd	0.9cd	16.8	2.0	1.8cd	0.3de	0.0e	0.0
Taverna Z	18.4b	1.6b	12.1	4.3	1.1cd	0.2de	0.0e	0.0
FA-593 H	10.4cd	0.9cd	17.8	2.3	3.3cd	0.6b-e	0.5de	0.2
FA-852 H	8.5cde	0.8cd	15.1	1.	3.5bcd	0.6b-e	0.1e	0.03
VT-906 Z	3.1e	0.3e	9.3	1.3	7.6a	1.4a	2.4bc	0.6a
Tradiro D	7.0de	.7cde	13.9	1.9	6.0ab	1.1ab	1.3cde	0.3
Significance	.0001	.0001	ns	ns	.0001	0001	.0016	.0006

[z]All weights are in kilograms per plant.
[y]H = Hazera, Z=Zeraim, D=DeRuiter.
[x]Total harvest = 1, 4, 7, 14, 21, 25, 28, and 30 June combined.
[W]Mean separation within each column using Duncan's multiple range test, $P \leq 0.05$.

Table 2. Means of soluble solids content over 8 harvests[z] for hydroponic 'Galia' and 'Galia-type' muskmelon. Gainesville, Florida. Spring/Summer 1999.

Cultivar[y]	Brix
Galia H	10.4a[x]
Arava H	8.9b
Jalisco H	9.8ab
Gal-52 H	9.6ab
Revigal H	9.6ab
Galia Z	10.0ab
Arava Z	9.5ab
Golan Z	8.9b
Sivan Z	9.6ab
Significance	0.0365
R-square	0.22

[z]Harvests = 4, 9, 14, 17, 22, 25 June, and 2, 6 July, 1999.
[y]H=Hazera. Z=Zeraim.
[x]Means separation using Duncan's multiple range test, $P<0.05$.

Table 3. Means for greenhouse cucumber variety trial over 23 harvests[z]. Gainesville, Florida. Spring/Summer 1989.

Cultivar[y]	Avg. ft. wt. (kg)	Mkt. no.	Mkt. wt. (kg)	Fancy no.	Fancy wt. (kg)	Cull no.	Cull wt. (kg)
Cuke1404H[y]	.25cd[x]	52.2b	12.9ab	34.9ab	8.1ab	5.3a	1.2a
Dishon H	.22cd	52.2b	11.5ab	39.3b	8.2ab	3.7ab	.62b
Sarig H	.19d	66.8a	12.9ab	49.6a	8.8a	5.2a	.81ab
Suzan H	.22cd	45.2b	10.1b	34.9bc	7.4ab	3.4ab	.56b
Ilan Z	.26c	46.7b	12.3ab	32.4c	8.0ab	4.6ab	.99ab
Long-John Z	.51ab	22.6c	11.6ab	15.7de	8.1ab	2.4b	.80ab
Rambo Z	.27c	51.0b	13.8a	36.3bc	9.0a	3.7ab	.59b
Bologna R	.52a	19.5c	10.2b	12.6e	6.3b	2.9ab	1.0ab
Kalunga E	.46b	23.8c	11.1ab	18.2d	8.0ab	2.1b	.69ab
Significance	.0001	.0001	ns	.0001	ns	ns	ns
R-square	.96	.96	.46	.97	.47	.58	.53

[z]Total harvest = May 1, 4, 6, 8, 11, 13, 15, 18, 20, 23, 26, 28, 31; June 2, 4, 7, 10, 14, 17, 21, 24, 28; and July 1, 1999 combined. Weights are in kg per plant.
[y]H=Hazera, Z=Zeraim, R=Ritz Zwann, E=Enza Zaden.
[X]Means separation for each column using Duncan's multiple range test, P<0.05.