Comparative Water and Fertilizer Use Efficiencies of Two Production Systems for Cucumbers

Elio Jovicich, Daniel J. Cantliffe and
Eric H. Simonne
Horticultural Sciences Department
University of Florida, IFAS
1143 Fifield Hall
Gainesville, FL 32611-0690
USA

Peter J. Stoffella
Indian River Research and Education Center
University of Florida, IFAS
2199 South Rock Rd.
Ft. Pierce, FL 34945-3138
USA

Keywords: *Cucumis sativus*, irrigation, fertilization, greenhouse, field, nitrogen, potassium, hydroponics

Abstract

Potential future restrictions of amounts of water and fertilizer to be used by farmers lead to the need for evaluation of production systems that are highly efficient in the use of these resources. Water, nitrogen (N) and potassium (K) use efficiencies were estimated from data derived from Beit Alpha type of cucumbers produced in a greenhouse and from data reported for field-grown slicing cucumbers in central Florida. Beit Alpha fruits were produced in a high-roof passively ventilated greenhouse, with a plant density of 3 plants/m^2, 1-plant/11-L-container filled with pine bark, and plants pruned and trellised to a single vertical stem. Total yield was 270 t/ha after 27 harvests in a 105 day crop. With a drain-to-waste irrigation system in the greenhouse, a total of 8,190 m^3/ha of nutrient solution were applied to keep drainage between 20% to 30% of the daily irrigation volume. Field cucumbers were designated as being planted on polyethylene mulched beds (5.4 plants/m^2) on a sandy soil treated with methyl bromide. Field drip irrigation would deliver 1,406 m^3/ha of water, 160 kg/ha of N, and 243 kg/ha of K. Yield after 9 harvests was calculated as 31.2 t/ha. Water use in 1 ha of greenhouse was 5.8 times greater than field water use but water volume per gram of fruit was 1.5 times greater in the field than the greenhouse. Nitrogen and K used per kg of fruit was 28% less and 23% less, respectively, in the greenhouse than in the field (6.5 g N/kg fruit, and 7.8 g K/kg fruit). Greater fruit yields, fruit quality, and crop water and nutrient use efficiencies resulted with greenhouse than with field production system. With a closed irrigation system in the greenhouse, water needs per unit of produce could be further reduced, potentially 50% to 60%, as compared to field production systems under drip irrigation. When developing best management practices for greenhouse production systems, crop water and nutrient use efficiency, the capability of water and nutrient reuse, and off-farm water and nutrient discharge, should be added to consideration when determining amounts of water and fertilizers to be used per unit of area.

INTRODUCTION

Some of the current production issues of the fresh market vegetable industry in Florida are the loss of agricultural land to urbanization, the impending loss of methyl bromide, the increasing concern on water shortage for agricultural use, and off-farm nutrient discharge from applied fertilizers migrating to underground water or surface water bodies. To some growers, greenhouse production systems may be a solution to some of these production issues. The same fruit weight produced in numerous hectares of field grown vegetables can be obtained in a much smaller area with greenhouse systems and without the need of methyl bromide. Moreover, greenhouse systems can produce higher quality (due to the protected environment, use of cultivars that cannot be grown in the open field, and limited use of pesticides) during an extended period attracting higher produce prices and better market opportunities than produce from conventionally-grown field systems. Under protected structures plants grow under environmental conditions that are closer to optimal. These plants produce during an extended production season and since they are grown in containers with soilless media they require greater amounts of water and nutrients per unit of area than in the field.

Total amounts of water and fertilizers used per unit of crop area should not be the only factors considered when evaluating how are these resources used, as it is more important to know how efficiently they are used per unit of produce harvested. Similar to the current best management practices being developed for field-grown vegetables (Gilbert and Simonne, 2005; Simonne et al., 2003), they will be likewise developed for greenhouse systems.

In Florida, slicing cucumber is field-grown on 4,334 ha with a total production of 114 thousand tons of fruit in the 2003-2004 growing season (U.S. Dept. of Agriculture and National Agriculture Statistic Service, 2005). There is also a small but increasing area of greenhouse-produced fresh market cucumbers with currently 7 ha producing approximately 4,000 tons of fruit per year. Slicing cucumber is the main type of cucumber produced in the field while fruit types Beit Alpha and long-Dutch are produced in greenhouses. The term "slicing" refers to cucumbers that are sold fresh for immediate consumption as a salad item. These fruits are characterized by a thick, uniform and dark green skin. Slicing cucumbers are grown as a first crop on raised soil beds in the field or, as a second crop, generally following a Solanaceae crop. Planted as a second crop, cucumbers utilize the preexisting polyethylene mulched bed, drip tape, and part of the residual fertilizer from the previous crop.

Beit Alpha fruits, also consumed fresh, are seedless with a thin epidermis which does not need to be peeled before consumption. Fruits have improved fruit quality characteristics and attract higher market prices than slicing cucumbers. During spring 2002, market prices averaged $1.54/kg for Beit Alpha (local grower information) and $0.40/kg for slicing type of cucumbers (U.S. Dept. of Agriculture and National Agriculture Statistic Service, 2005). For maximum fruit yield and quality, Beit Alpha plants need to be pruned, vertically trellised, and grown with hydroponic systems under a protected structure (Hochmuth et al., 2004; Lamb et al., 2001; Shaw and Cantliffe, 2003).

In the present work, we estimated fruit yields, water volumes used for irrigation, and the amounts of N and K applied as fertilizer using data derived from greenhouse-grown Beit Alpha cucumbers and data estimated from literature for typical crops of slicing cucumbers in Central Florida. The objective of this study was to investigate the crop water and nutrient use efficiency of two cucumber production systems.

MATERIALS AND METHODS

Reference production practices for slicing cucumber (Olson and Simonne, 2005) grown in the field and for Beit Alpha cucumber produced in greenhouse were developed and crop water, N, and K use efficiencies were calculated for each production system from Table 1. Greenhouse crop data information was obtained from crops grown at the Horticultural Sciences Protected Agriculture Center, University of Florida (Cantliffe, 1998).

Field Crop

Field cucumbers were designated as being planted from transplants set at the mid to end of January (Table 1). Common practices for field cucumber crops grown in the sandy soils of central Florida include planting on raised soil beds, use of drip irrigation and use of polyethylene mulch (Olson and Simonne, 2005). Soil beds are treated with broad spectrum fumigants (methyl bromide and chloropicrin) to kill fungi, nematodes and weeds. A plant density of 5.4 plants/m^2 (53,820 plants/ha) resulted from a plant arrangement of 0.15 m between plants within the bed rows, two rows of plants per bed, and 1.22 m between centers of the beds. Flow rates of commonly-used drip tapes is 113 L/h/30 m and number of irrigation events per day in the crop period ranges from 2 to 4. Irrigation requirement for cucumbers which depends on stage of growth and evaporative demand was calculated following the methodology indicated in Olson and Simonne

(2005). Historical daily average values of Penman-method reference evapotranspiration corresponded to those reported for the city of Tampa in central Florida. Crop coefficients used with reference evapotranspiration were increased with plant growth stages from 0.25 to 0.75 (Olson and Simonne, 2005).

Cucumber was assumed to be planted as a first crop. A starter fertilizer mixture banded in the bed would contain all of the needed phosphorus (P) and micronutrients, 25% of the total nitrogen (N), and 30% of the total potassium (K) applied to the crop. Bands were placed 5 to 10 cm below the bed surface and to the outside of the plant row (51 kg/ha of N and 73 kg/ha of K). The remaining amounts of N and K were delivered through drip irrigation. The total amounts applied were 203 kg/ha of N and 243 kg/ha of K (293 kg/ha of K_2O). These values were higher than Univ. of Florida recommendations (Hochmuth and Cordasco, 1999; Olson and Simonne, 2005), as they were 20% higher for N and 117% higher for K, but were approximate to current amounts used by growers. Daily fertilizer amounts were injected after the last irrigation event of the day in the field and on every irrigation event in the greenhouse (Table 2). Fruits were assumed to be harvested 9 times and graded by size following U.S. Dept. of Agriculture standards (U.S. Dept. of Agriculture, 1958). Estimated marketable fruit yield in the field was the 10-year average value for central Florida for the year 2002 (32 t/ha; 505 boxes of 25 kg).

Greenhouse Crop

In a passively ventilated polyethylene-covered greenhouse (Top Greenhouses Ltd., Rosh Ha'ayin, Israel), 3-weeks old 'Sarig' (Hazera Seeds Ltd., Grover Beach, CA) Beit Alpha cucumber was planted into 11.4-L nursery pots filled with pine bark (from *Pinus elliottii*, sieved through a 25 x 25 mm screen). Each plant was fertigated on every irrigation event through a drip emitter with nutrient concentration levels that were modifications of recommendations indicated by Hochmuth and Hochmuth (2001) (Table 2). In a drain-to-waste irrigation system, frequency and volume of irrigation events were controlled with a time-based irrigation controller and managed to achieve a daily drainage volume at the bottom of the plant containers within a range of 20% to 30% of the total irrigation volume applied. For the growing period, the average number of daily irrigation events was 24 (with a range of 8 to 30 irrigation events per day) and with an average volume delivered per irrigation event of 100 mL/plant (with a range of 54 to 134 mL/plant).

Plant population density of 3 plants/m^2 (30,000 plants/ha) resulted from a plant arrangement of 0.30 m between plants within the row and 1.33 m between rows. Plants were pruned to a single stem by removing lateral shoots after their first leaf and with the main stem trellised upright to a twine. Fruits set on nodes of the main stem and lateral shoot. As practiced by commercial growers, curved or deformed fruits were removed from the plant during pruning operations and marketable fruits were harvested when diameters reached between 2.5 and 3.0 cm. Marketable yield of Beit Alpha cucumbers produced in the greenhouse in a 105-day crop period was 270 t/ha (Table 1). The average weight of Beit Alpha cucumbers was half the weight of slicing fruits; therefore, the number of greenhouse-grown cucumbers was 16 times greater than slicing cucumbers grown in the field (Table 1).

Calculation of Crop Water and Nutrient Use Efficiencies

Efficiencies related to the use of water and nutrients can be reported differently or can have different meanings (Haman et al., 2002). The crop water and nutrient efficiency estimates used in this report refer to the resource amounts used per unit of produce obtained. Therefore, a decrease in value of the estimate should be interpreted as an increase of the growing system efficiency in using the resource. The following formula was used to calculate water use efficiencies: Total water volume delivered (L/ha) ÷ Marketable fruit yield (in units of kg/ha or number/ha), and was expressed as L/kg or L/fruit. In both production systems, total water used was the total water delivered to the crops, which included the volumes that drained from the plant containers (greenhouse) and into the soil (field). For N and K, nutrient use efficiencies were estimated with the following formula: Total weight of nutrient used (g/ha) ÷ Marketable fruit yield (in units of kg/ha or, number/ha), and were expressed as g/kg or g/fruit.

RESULTS AND DISCUSSION

The total volume of water delivered to plants in the greenhouse was 8,190 m^3/ha, 4.8 times greater than the volume of water calculated for a hectare of field-grown cucumber (1,406 m^3/ha) (Table 1). The need to maintain a relatively high and constant level of moisture in the plant container medium and a longer crop period with growth of larger plants that lead to greater production can explain that more water is required per unit area with a greenhouse using a drain-to-waste irrigation system. However, because production in the greenhouse was much greater than in the field (7.7 times on a weight basis), the greenhouse system was more efficient in the use of water (Table 1). The volume of water delivered per kilogram of fruit harvested was 33% less with the greenhouse system than with the field crop (45 L/kg) (Table 1). With Beit Alpha fruits weighing about half the weight of slicing cucumbers, water used per unit of fruit was 60% less for fruits grown in the greenhouse (Table 1). Four liters of water per fruit were required to produce a 115-g fruit in the greenhouse while 10 L/fruit was needed for the production of a 230-g fruit in the field (Table 1).

Nitrogen applied per kilogram of fruit harvested in the greenhouse was 4.7 g, 28% less the amount used in the field (Table 1). The amounts of K per kilogram of fruit were also lower with Beit Alpha cucumbers in the greenhouse than with slicing cucumbers grown in the field (Table 1).

Without considering the type of cucumber produced, for the field system to produce the same yield as with the greenhouse system (270 t/ha), production in the field would require 8.7 ha of land. With this land area, volume of water used for growing slicing cucumbers would be 12,167 m^3 (8,190 m^3 in the greenhouse), N amounts would be 1,757 kg (1,260 kg in the greenhouse) and K amounts 2,103 kg (1,620 kg of K in the greenhouse).

The information in this report indicated that savings in water and nutrients could be obtained with cucumbers grown with protected agriculture and hydroponic systems in Florida. Although both, Beit Alpha and slicing cucumbers are fruits marketed for fresh consumption and compete as a salad item, they are different commodities which attract different market prices. Also, they must be produced under different growing systems.

Monetary returns will differ with each growing system and budget analyses are currently being conducted to estimate profitability of cucumber crops grown in greenhouse and field production systems. Lower yield and market price for slicing cucumbers led to an estimated crop value 33 times smaller with field ($12,479/ha) than with greenhouse production ($415,800/ha) during the spring of 2002 (Table 1).

Cucumbers and other vegetables grown in greenhouses with closed irrigation systems used 30% to 50% less water per fruit weight than those produced with drain-to-waste systems (García, 1997, cited in Marfà, 1999). Therefore, potentially, irrigating with recycled solution could lead to savings of 50% and 60% with respect to field irrigated crops. When developing best management practices for greenhouse production systems, crop water and nutrient use efficiency, the capability of water and nutrient reuse, and off-farm water and nutrient discharge, should be added to consideration when determining amounts of water and fertilizers to be used per unit of area.

ACKNOWLEDGMENTS

The management of the greenhouse cucumber crop and the collection of production and irrigation data was a partial requirement of the laboratory section of the graduate course "Greenhouse and Protected Vegetable Production" ALS 5932 Spring 2002. Course Instructor: D.J. Cantliffe, Lab instructor: E. Jovicich. Hort. Sci. Dept., Univ. of Florida, U.S.

Literature Cited

Cantliffe, D.J. 1998. Florida Protected Agriculture Project. 10 Aug 2005. http://www.protectedag.ufl.edu/,

Haman, D.Z., Smajstrla, A.G. and Pitts, D.J. 2002. Efficiencies of irrigation systems used in Florida nurseries. BUL312. 10 Oct. 2005. http://edis.ifas.ufl.edu/AE087

Hochmuth, G. and Cordasco, K. 1999. A summary of N, P, and K research with cucumber in Florida. Univ. of Fla., Inst. of Food and Agric. Sci. HS 749. 28 Sept 2005. http://edis.ifas.ufl.edu/CV226

Hochmuth, G.J. and Hochmuth, R.C. 2001. Nutrient solution formulation for hydroponic (Perlite, Rockwool, NFT) tomatoes in Florida. Univ. of Fla., Inst. of Food and Agric. Sci. HS796. 29 Sept 2005. http://edis.ifas.ufl.edu/CV216

Hochmuth, R.C., Davis, L.L.L., Simonne, E.H., Sargent, S.A., Laughlin, W.L. and Berry, A. 2004. Evaluation of twelve greenhouse Beit-alpha cucumber varieties and two growing systems. Acta Hort. 659:461-466.

Lamb, E.M., Shaw, N.L. and Cantliffe, D.J. 2001. Beit Alpha cucumber: a new greenhouse crop for Florida. Univ. of Fla., Inst. of Food and Agric. Sci. HS-810. 28 Sept 2005. http://edis.ifas.ufl.edu/CV277

Marfà, O. 1999. Soilless culture and fertilizer efficiency. Proceedings IFA Agricultural Conference on Managing Plant Nutrition, 29 June – 2 July, Barcelona, Spain.

Olson, S.M. and Simonne, E. (eds.). 2005. 2004-2005 Vegetable Production Handbook for Florida. Vance Publishing, Lenexa, KS. 328p.

Shaw, N. and Cantliffe, D.J. 2003. Hydroponically produced mini-cucumber with improved powdery mildew resistance. Proc. Fla. State Hort. Soc. 116:58-62.

Simonne, E., Studstill, D., Hochmuth, R., Olczyk, T., Dukes, M., Muñoz-Carpena, R. and Li, Y. 2003. Drip irrigation: The BMP era – An integrated approach to water and fertilizer management for vegetables grown with plasticulture. Univ. of Fla., Inst. of Food and Agric. Sci. HS 917. 29 Sept. 2005. http://edis.ifas.ufl.edu/HS172

Gilbert, C.A. and Simonne, E.H. 2005. Update and outlook for 2005 of Florida's BMP program for vegetable crops. Univ. of Fla., Inst. of Food and Agric. Sci. HS 917. 2 Oct. 2005. http://edis.ifas.ufl.edu/HS1013

U.S. Department of Agriculture. 1958. United States standards for grades of cucumbers. 29 Sept. 2005. http://www.ams.usda.gov/standards/cucumber.pdf

U.S. Dept. of Agriculture and National Agriculture Statistic Service. 2005. Florida agricultural facts. 15 Aug. 2005. http://www.nass.usda.gov/fl/

Tables

Table 1. Comparison of estimated information for field and greenhouse-grown crops of slicing and Beit Alpha cucumbers, respectively, in central Florida: a) selected crop information, b) marketable fruit yields, c) water, N, and K supplied, d) crop water, N, and K use efficiencies, and e) estimated crop value.

	Units	Field	Greenhouse	
a) Crop information				
Planting	(Month of the year)	Mid-End January	End January	
Time from seeding to first harvest	(days)	65	60	
First harvest	(Month of the year)	Mid March	Mid March	
Last harvest	(Month of the year)	End of March	Mid May	
Plant density	(plants/ha)	53,820	30,000	
Number of harvests	(no.)	9	27	
Crop season	(days)	70	105	
b) Marketable fruit yield				**Increase (%)**
	(t/ha)	31.2	270	765
	(number/ha)	135,639	2,310,000	1600
	(g/fruit)	230	115	
c) Amount used				**Increase (%)**
Water	(m^3/ha)	1,406	8,190	483
Nitrogen (N)	(kg/ha)	203	1,260	521
Potassium (K)	(kg/ha)	243	1,620	567
d) Efficiency				**Reduction (%)**
Water-use	(L/kg fruit)	45	30	33
	(L/fruit)	10	4	60
				Reduction (%)
N-use	(g N/kg fruit)	6.5	4.7	28
	(mg N/fruit)	1,495	545	64
				Reduction (%)
K-use	(g K/kg fruit)	7.8	6.0	23
	(mg K/fruit)	1,789	701	61
e) Fruit market price	($/kg)	0.40	1.54	
Crop value	($/ha)	12,479	415,800	

Table 2. Amounts of N and K applied to cucumber crops grown a) in the field and b) in the greenhouse throughout the spring crop season in central Florida and c) target nutrient concentration levels in the solution used to irrigate the greenhouse crop.

a)	Field				
	0 DAT[z]	1-7 DAT	8-21 DAT	22-64 DAT	65-70 DAT
Nutrient	kg/ha/day				
N	51[y]	1.1	2.2	4.0	2.2
K	73	1.1	1.6	3.0	1.6

b)	Greenhouse		
	0-15 DAT	16-30 DAT	31-105 DAT
Nutrient	kg/ha/day		
N	2.0	3.7	15.6
K	2.2	4.2	18.9

c)	Nutrient solution concentration levels (Greenhouse)[x]		
	mg/L		
N	110	130	156
P	50	50	50
K	119	148	189
Ca	134	158	175
Mg	40	48	48
S	56	66	66
Fe	2.8	2.8	2.8
Cu	0.2	0.2	0.2
Mn	0.8	0.8	0.8
Zn	0.3	0.3	0.3
B	0.7	0.7	0.7
Mo	0.06	0.06	0.06
EC[v]	1.6	2.0	2.4
pH	6-6.5	6-6.5	6-6.5

[z]DAT: Days after transplanting.

[y]Starter fertilizer (solid) was applied in two bands in soil beds by DAT 0. From DAT 1 to DAT 105, liquid fertilizers were injected after the last irrigation with water.

[x]Nutrients supplied were part of a complete nutrient solution used to irrigate plants on each irrigation event.

[v]EC: Electrical conductivity.