Controlled-environment Horticulture in the Arabian Desert at Abu Dhabi

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A commercial-scale power-water-food facility, which utilizes desalted seawater for the irrigation of vegetable crops in controlled-environment greenhouses, was completed in January, 1972, at Abu Dhabi on the Arabian Peninsula. The integrated system there is a larger-scale version of one that has been operated in Mexico on the Gulf of California since 1966 by the Universities of Arizona and Sonora.

Those experiments at Puerto Penasco, Sonora, have been described by Hodges and Hodge (1) and Jensen and Teran (2). The goal in Mexico was to find economical means of using expensive desalted water and, at the same time, making a coastal desert agriculturally productive.

Results of the research at Puerto Penasco led the ruler of Abu Dhabi, Shaikh Zayed Bin Sultan Al Nihayan, to give the University of Arizona Environmental Research Laboratory (ERL) a grant to install a power-water-food complex in his small, arid country, 800 km south of Kuwait. Rainfall in Abu Dhabi averages less than 5 cm/year, and strong winds occur frequently. These constraints had severely limited cultivation, particularly on the coast. In the past, most of the shaikhdom's high-quality vegetables had to be imported.

The site selected by the ruler for the facility was Sadiyat Island, about 2.4 km off the mainland. Construction started early in 1970; that June, a research greenhouse was finished, and planting was initiated. The first 0.2 ha of commercial growing area was planted a year later.

Air-inflated polyethylene structures comprise half the 2 ha of horticultural enclosures. These pneumatic half-cylinders are connected to 2 central corridors, 1 of which may be seen in Fig. 1. Structured greenhouses cover the remaining 1 ha. Cultivated in the air-inflated greenhouses are low-growing crops that need no overhead support, such as lettuce, turnips (Fig. 2), peppers, eggplant (Fig. 3), radishes, etc. Cucumbers, tomatoes (Fig. 4), and string beans, because they are trained vertically on a cordon system, are grown in the structured houses.

The houses are evaporatively cooled with seawater, rather than freshwater. The seawater is distributed over the top of corrugated material, Asbesdek in the structured houses and Celdek in the air-inflated houses. Fig. 5 is a schematic drawing of the 2 systems. Air is exhausted in the middle of the structured houses; the negative pressure that this creates inside results in airflow into the house across the Asbesdek tower.

In the inflated greenhouses air is sucked through the Celdek by fans mounted in the end wall; the air is forced through the house and exhausted through the roof of the central corridor. Roof doors are utilized to modulate the internal pressure of the air-inflated houses. There are 2 corridors; 24 inflateds attached to each corridor, with air locks at each end of the corridor.

Average daily dry bulb temperatures reach a maximum of 34°C in June, but the wet bulb temperature continues to rise until September, decreasing the effectiveness of the cooling system. For example, in June at the maximum day temperature, a 5.5°C suppression of the ambient temperature can be attained, but only a 2°C differential would be possible in August. Another environmental parameter that is reduced by continuous operation of the cooling system is the night temperature, and this is extremely beneficial to most of the crops cultured. Heating systems are not necessary (the lowest record temperature in Abu Dhabi is 10°C). Conducive temperatures (24° day, 18°C night) have been maintained during the winter by regulating the amount of incoming air.

The prevailing wind, from the north, often reaches velocities high enough to move sand. Often the wind shifts in summer and comes from the south. This southerly wind is extremely dry, since it comes out of the desert, and causes rapid desiccation of plants growing outside. Thus, the greenhouse serves to protect the plants from blowing sands, drying winds and high and low temperatures, and the high humidity created by seawater cooling systems reduces water consumption.

Organic and inorganic materials are not abundant on desert coasts, and most conventional artificial media are low in bulk density, which makes transportation expensive. Therefore,

Fig. 1. Doors leading from central corridor into air-inflated greenhouse. Air is exhausted over head.

[1] Environmental Research Laboratory.

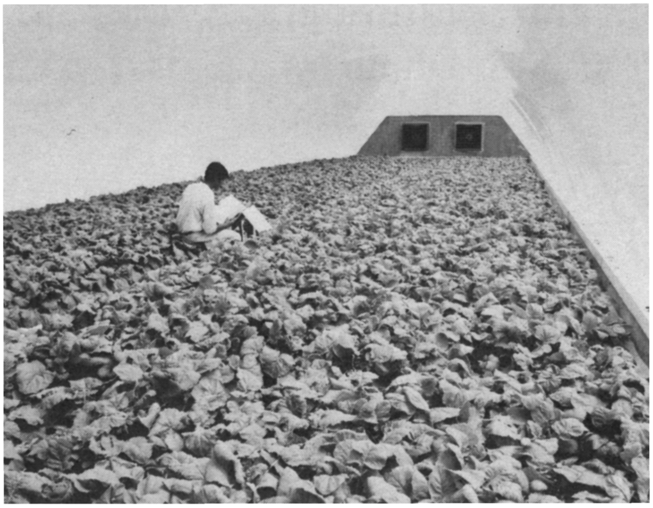

Fig. 2. **Temperature data being recorded inside an air-inflated house planted with turnips. Note fans in end wall.**

Fig. 3. **Local workers harvest eggplant inside an air-inflated house.**

Fig. 4. **Tomatoes are produced in structured greenhouse. Fruits are being harvested in foreground**

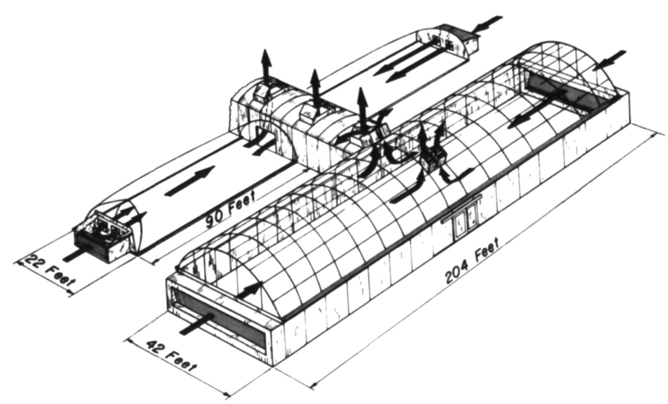

Fig. 5. **Schematic drawing of air-inflated and structured greenhouses shows air flow pattern.**

planting has been done in the indigenous sand. Sadiyat Island is composed of essentially fine calcium carbonate sand; the pH of the medium consequently is 8.3. The salts are not high, since the site is on a windblown dune. Because the sand is low in nutrients and cation exchange capacity, fertilizer is provided the plants at regular intervals by dissolving selected commercial-grade fertilizers in the distilled seawater. The finished solutions include all the elements required for plant growth except those taken from the atmosphere.

Two concentrated fertilizer solutions are proportioned into the irrigation system. One contains KNO_3, KH_2PO_4, $MgSO_4 \cdot 7H_2O$, $CuCL_2 \cdot 2H_2O$, H_3BO_3, $MnCl_2 \cdot 4H_2O$, MoO_3 and $ZuSO_4 \cdot 7H_2O$; the second is made up of $CaNO_3$ and chelated iron. The concentrated solutions cannot be mixed together, because precipitates will form, so they are diluted in a larger volume of water. The final concentration of each required element in ppm is N (144), P (62), K (156), Mg (48), Ca (165), S (64), Fe (5), B (1), Mn (0.4), Cu (0.02), Zn (0.09), and Mo (0.3).

Since the solution passes through small openings in the irrigation system, all the nutrients must be water soluble to avoid plugging. They also must be in the form most readily absorbed by plants, and thus available for uptake once they are applied. The only cations and anions applied are those the plant uses. No carrier ions are added. Thus, no salt residue builds up in the beds once the plant has removed the nutrients. The only residue left is that of the unused fertilizers. After 2 years of cropping, soluble salt levels have not increased significantly, apparently because insoluble salts of the residual fertilizers are formed at a high pH.

Any desalted water is costly. It is important, then, to use it as efficiently as possible. A plastic liner is placed beneath crops that are grown in double rows. The beds are 61 cm wide and 30.5 cm deep. This liner prevents water loss through percolation and lateral movement, and fertilizer loss through leaching. The water is applied near the roots by different systems. For double-row crops, a 1.3 cm polyethylene pipe runs down between the double rows and small capillary tubes distribute the solution to the base of each individual plant within the rows. On the other hand, such closely spaced crops as okra, cabbage and lettuce are watered with a plastic hose that is perforated at intervals equal to the spacing of the plants. The plants are irrigated 3-4 times daily, rather than once, in order to optimize the avilability of nutrients around the roots.

Early in the project a research greenhouse, consisting of 2 connected, inflated units, each 30.5 × 6.7 m, was erected, along with a 7570 liters/day desalting plant and power generators.

This allowed horticultural research to begin approximately 1 year before the commercial production.

Research during that year was concerned primarily with screening genetic materials for adaptation to the indigenous sand and to greenhouse environment, as well as with acceptability by the local market. Several types of vegetables were tried (Table 1), but only those of major importance will be considered here.

Cabbage was found to be extremely susceptible to leaf tip burn; especially in the summer, however, the cultivar 'Express Cross 50' showed excellent resistance. Romaine lettuce also proved to be susceptible to tip burn in the summer. For commercial production in the cooler months, the cos lettuces 'Parris White' and 'Parris Island' have been used primarily. So far, none of the lettuce cultivars or lines have exhibited resistance to summer bolting. Excellent results were obtained with some of the butter head types, especially 'Plenos' and 'Kropsalada' in the winter.

Due to the local preference for a short cucumber fruit, several short greenhouse types were cultivated. Most short types were found to be too spiney for the local market. The cultivar 'Rocket' was selected because of good yield and the fact the fruit can be harvested at a length of 30 cm with good shape. Some cultivars were not parthenocarpic; because they required pollination, they were discarded.

Yield differences among eggplant cultivars were rather small, and fruit color appeared to be an important criterion in selection. The preference is for darker purple fruit. For this reason 'Black Magic Hybrid' and 'Jersey King Hybrid' were chosen.

Several of the tomato cultivars that were tested produced well in the cooler months. The Hawaiian hybrids appeared to be superior in the warmer months and responded well to hormone sprays in July and August. 'N-65' has been used mainly in the large acreage. The market prefers a large fruit, and shape is not an important consideration.

Yields of hot and sweet type peppers differed considerably, and in general the latter was higher. Yield differences among 'Propa F_1 Hybrid', 'Danube', 'New Ace', 'Ace', and 'Bell Boy' were not significant. 'Bell Boy' and 'Danube' exhibited excellent vegetative growth and produced well-shaped fruit.

Yield data for the first year in the research greenhouses are presented in Table 2, and a comparison is made between field-grown crops grown in the U. S. and at the Abu Dhabi government farm at Al Ain, an inland oasis. Yields for the Sadiyat greenhouses generally are much higher than field culture. This, of course, may be attributed in part to the more ideal growing conditions inside. These yields are higher, too, than many conventional greenhouse operations. This probably is due to the warm climate and the high year-round solar radiation. Of course, the quality of greenhouse produce usually is higher than that of field-grown vegetables.

Cultural periods are presented in Table 3. Although many of these vegetables ordinarily are not greenhouse crops, greenhouse production of some of them would seem to be feasible. Market is an important consideration, of course, but yield/area/unit time is another important consideration in crop evaluation. Thus, to compare these crops, one can express the yields in kg/ha/day, as shown in Table 4.

Cucumbers had the highest production per day. Cucumbers and tomatoes are considered common greenhouse crops, but, surprisingly, many of the other crops yield as well as or better than tomatoes when compared on a kg/ha/day basis. Okra has the lowest rate and for that reason it has not been grown commercially in Abu Dhabi. Labor is another important consideration, and such crops as lettuce, cabbage and turnips require a much lower manpower input than do tomatoes. Hence, if a desirable market price can be obtained, many of these crops could be produced economically in a desert coastal region.

Summer production, a major interest in the present research, is impossible with lettuce, cabbage and broccoli, or at least with the cultivars and lines that have been tested. Eggplant, pepper and tomatoes lack viable pollen in the hottest months. Studies on fruit set

Table 1. Rating of vegetable cultivars and selections used on Sadiyat.

Cabbage (*Brassica oleracea* L. capitata group)		
	Superior	Express Cross 50
	Acceptable	Col Lambarda Morada, Green Boy, Harvest Queen, January King, K-K Cross, O-S Cross, Princess No. 39. Summer Pride, Titan.
	Unsatisfactory	Derby Day, K-Y Cross, Matadore No. 2, M-Y Cross, Perfection Cross, Stonehead.
Cucumber (*Cucumis sativus* L.)		
	Superior	Bestseller, Rocket, Sporu, Tetra
	Acceptable	Cherokee 7, F_1 Hybrid Burpless No. 30, F_1 Hybrid Burpless No. 33, F_1 Hybrid Forcing No. 37, F_1 Hybrid Forcing No. 38, F_1 Hybrid Forcing No. 40, Gemini 7, Get Set No. 14, Green King No. 29, Jet Set No. 20, Northern Delight, Simex, Smooth Set No. 8, Southern Cross, Taste Green No. 26.
	Unsatisfactory	Amus, Hokus, Levo, Tendergreen
Eggplant (*Solanum melongena* L.)		
	Superior	Black Magic Hybrid, Jersey King Hybrid
	Acceptable	F_1 Hybrid No. 1 Sakata, F_1 Hybrid No. 4 Sakata, F_1 Hybrid No. 23 Sakata, F_1 Hybrid No. 24 Sakata, Jersey King Hybrid, Long Beauty, Long Purple
	Unsatisfactory	Iraqui (local seed)
Lettuce (*Lactuca sativa* L.)		
	Superior	Kropsalada, Parris Island Cos, Parris White Cos, Plenos, Valmaine, Vdbustinate
	Acceptable	ALRC 1[z], ALRC 2[z], ALRC 3[z], Avenue, Avondefiance, Endive Deep Purple Heart, ERL 4[y], ERL 20[y], ERL 23[y], ERL 25[y], ERL 26[y], ERL 41[y], Little Gem Cos, Lobjoit's Cos, M-31 Romaine, Minetto, Windermere, Slobolt
	Unsatisfactory	Cobham Queen, ERL 6[y], ERL 7[y], Halabi, Kulanu, Laupile, Mildura, Romaine Dark Green, Ruby, Valrio, Valtemp
Pepper (*Capsicum annuum* L.)		
	Superior	Ace, Bell Boy, Danube, Green Horn, Long Thick Cayenne, New Ace, Propa F_1 Hybrid
	Acceptable	California Wonder, Cuban 202, Fresno Chili Pepper, Hungarian Wax, Jalapeno 202, Mexican Chili Ancho 207, Sweet Pepper Yolo Wonder Y
	Unsatisfactory	Red Chili Hot Pepper
Tomato (*Lycopersicon esculentum* mill.)		
	Superior	Floradel, Hybrid Master No. 3, N-52 Hawaii, N-65 Hawaii, Tropic
	Acceptable	Amberly Cross, Anahy, Best of All, Floradel Selection, Florida 2326, Kalohi, 68-R-52 Holland, Multicross A-12, Porter, Tropic 216, Vendor 346, 380-4-BK-1-D1-FDBK[x], 393-6-4-1-BK-2-1-BK[x], 393-9-D2-D3-SBK-BK[x], 393-9-D2-DBK-D5-BK[x], 393-9-D2-D1-BK[x]
	Unsatisfactory	Allround, Azes, Fury, Hotset, Hybrid Fukujym No. 2, Improved Harbot, Money Maker, Money Sprint, Pikopak, Porters Pride, Tropi-Gro, Tropi-Red

[x]Gulf Coast Experimental Station Selections

[y]Environmental Research Laboratory selections

[z]Arid Lands Research Center selections

Table 2. Comparative yield for a single crop grown in Sadiyat greenhouses vs. field grown.

Type of vegetable	Yields (tons/ha/crop) Sadiyat greenhouse	Good yield field grown U.S.[z]	Al Ain government farm[y]
Cabbage	70	27	49-70
Cucumber	229	27	20
Eggplant	240	19	30-49
Lettuce	56	24	20-30
Okra	52	11	30
Tomato	159	67	15-26
Turnip	157	22	15-20

[y]Yields supplied by Mr. Omar Baki of the Al Ain Department of Agriculture, Abu Dhabi.
[z]From: J. E. Knott, (3).

Table 3. Distribution of cultural periods for greenhouse and field grown vegetables.

Type of vegetable	No. days in nursery Sadiyat	Growing period, days Sadiyat greenhouse	Field[z]	Harvest period, days Sadiyat greenhouse	Field
Cabbage	22	51	62-110	1	1
Cucumber	14	83	90	55	30
Eggplant	17	181	130	125	40
Lettuce	23	38	70	4	10
Okra	18	142	118	109	60
Radish	--	30	30	4	1
Tomato	18	130	140	69	50
Turnip	--	65	40-75	1	1

[z]Comparative data for U.S. field grown vegetables. These numbers vary with cultivars, seasons and locations.

Table 4. Comparison of yields of various vegetable crops on a rate basis (tons/ha/day).

Type of Vegetable	Tons/ha/day
Cabbage	1.4
Cucumber	2.8
Eggplant	1.3
Lettuce	1.5
Okra	0.4
Tomato	1.2
Turnip	2.4

with hormones have shown that tomato fruit development can be stimulated with applications of 100 ppm beta naphthoxyacetic acid (BNOA) and boron. Due to the extremely warm might temperatures, the development of an adequate fruit load on the plant is still a problem. Thus, most research has focused upon selection of cultivars for production at high temperatures and humidities and at cultural practices that might enhance production. Dr. Hamdy Eisa is conducting a breeding program on Sadiyat on cucumbers, tomatoes and lettuce.

Since summer production of several of the leafy vegetables is impossible with the present technology, other crops have been investigated. For example, 'Malabar' spinach has been found to produce well in the summer and has been accepted well by the local consumers. 'Malabar' flowers during short days, which greatly suppresses vegetative growth in the winter. Rocket is another crop popular among the local population and it grows well in the summer months. It takes 25-30 days to produce this crop. Although the production of many vegetables is limited in the summer, it appears that some others can be produced.

Several infestations of white flies, aphids, leaf minors, thrips and mites were experienced after 1 year of growing. In most cases these are easily controlled by insecticides of low mammalian toxicity. Since agriculture, and therefore insect control had been practiced only on a small scale in Abu Dhabi, there appears to be no resistance to insecticides and many of the insecticides no longer effective in intensively-farmed areas are quite effective.

Plant diseases were not observed during the first year either. Since then, seedling diseases have been a problem with several crops. Cucumbers were susceptible to powdery mildew in the winter, but control was attained with a systemic fungicide. The past summer, cucumber mosaic virus (CMV) caused serious problems in cucumber production. Seed appears to have been the source of the innoculum, although strict precautions had been observed to prevent insect and disease materials from being transported to the island. An intense selection program for resistance to CMV has been initiated, as well as normal control measures.

One rewarding part of the University's program has been the training of the Abu Dhabians in horticultural techniques. At the outset 3 trainees were brought to the University of Arizona for classes in English, mathematics, general science and horticulture. On-job training in power plant and greenhouse operation and in plant husbandry also were emphasized at ERL in Tucson and later at the prototype in Mexico. Two of the trainees now play major roles in managing the greenhouses in Abu Dhabi, and the third oversees packing operations.

An expanded training program was initiated in Abu Dhabi, and 11 trainees were educated in several phases of the project. It is hoped that all these people will fill key jobs.

Altogether, 15 kinds of greenhouse vegetables have been sold locally, and each was evaluated for marketability as well as productivity. Last February a trial shipment of cucumbers, tomatoes, eggplant and peppers was air-freighted to Beirut, and a second (covered by Abu Dhabi television) was sent in March. The prices commanded in Lebanon were sufficient to make such exports realistic, once the local market is satisfied. Exporting could be especially attractive at a time (from mid-November through mid-March) when there is some harvesting at Al Ain.

Moreover, these trial shipments were of modest historic interest, because Abu Dhabi, before the power-water-food facility was erected, imported a substantial portion of its vegetables from Lebanon.

Projections were that the 2 ha of environmentally-controlled greenhouses would be able to produce an average of 1 ton/day of vegetables, and by the middle of 1972 this was being accomplished. The harvest of tomatoes alone in 1972 was expected to reach 155,000 kg, enough to supply almost 29,000 persons at U. S. levels of consumption.

Literature Cited

1. Hodges, C. N., and C. O. Hodge. 1971. An integrated system for providing power, water, food for desert coasts. *HortScience* 6:30-33.
2. Jensen, M. H., and M. A. Teran R. 1971. Use of controlled environment for vegetable production in desert regions of the world. *HortScience* 6:33-36.
3. Knott, J. E. 1953. Handbook for vegetable growers. John Wiley & Sons, Inc. New York.