N 67-86321

Hydroponics or Soilless Culture

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Historically, hydroponics is not a new field; plant physiologists have known and used it for some 100 years. (Knop is credited with having originated the method around 1860.) During the late 1930's, a great upsurge of interest in soilless culture took place. Inevitably, some enthusiasts got carried away. Claims were made of enormous potential yields; skyscraper tops were said to be capable of producing enough food for all of their occupants; and closets, basements, garages, etc. were wishfully converted into fields for hydroponic culture. Numerous publications on the subject appeared during this period (see Bibliography).

Although, in fact, the yields obtained with soilless culture can be excellent (see Table 1), they are generally no greater than those obtainable in good soil without the addition of similar chemicals. It is probably easier in terms of effort involved to get high yields with hydroponics; the quality of the foodstuffs is satisfactory; and the seed produced is viable. Where no soil is available, such as in rocky areas, on steep hillsides and mountains, and on water and marsh surfaces, soilless culture is definitely advantageous (see Table 2). Where good soil and water are available, on the other hand, there are at present no special advantages to the use of hydroponics. Problems of insects and plant disease are no less, and the construction, control, and operations costs exceed those incurred with standard agricultural methods. In the future, with increasing pressure of population, the soilless culture of foodstuffs will in all probability come into much wider commercial use. (See Table 3 for locations in which hydroponics has been used commercially to date.)

Table 1. Comparative yields — agriculture vs hydroponics

Crop	Comparative yield			Location
	Agriculture[c]	Hydroponics	per ft^2	
Tomato	12 lb/plant	27.4 lb/plant	—	California
	10 lb/plant	22.5 lb/plant	—	India
Rice[a]	3000 lb/acre	9000 lb/acre	0.20	India
Potato	60,000 lb/acre	130,000 lb/acre	2.98	California
		140,000 lb/acre	3.20	India
Corn[b]	2000 lb grain/acre	6000 lb grain/acre	0.14	India
Lettuce	9000 lb/acre	21,000 lb/acre	0.48	India
Beet root	9000 lb/acre	20,000 lb/acre	0.46	India
French bean	210 lb/1000 ft^2	588 lb/1000 ft^2	0.58	India
Cauliflower	15,000 lb/acre	32,000 lb/acre	0.73	India

[a]Yields of rice up to 14,400 lb/acre have recently been reported under agricultural conditions.
[b]Yields of corn up to 304 bushels of grain/acre have been reported recently under agricultural conditions.
[c]Under average agricultural conditions.

Table 2. Advantages of soilless culture

Maximal yields (more research needed)
Use in areas where soil unavailable; steep hillsides, mountains, rocky, gravelly areas, unused paved areas, roofs, basements (light necessary), window boxes, verandas, etc.
Freedom from weed problem
Better control of diseases?
Better control of insects?
Elimination of salinity problems
Elimination of drainage problems

Table 3. Some locations where soilless culture has been used commercially

Location	Probable purpose or reason for use	Present position
Iwo Jima and Wake Island	Lack of good soil, economics (war)	?
Curacão	Lack of good soil	Not used now; fresh fruit and vegetables flown in
Bahrein	Lack of good soil	?
Iraq (Habbiniyah)	Lack of soil	?
India	Lack of good soil, shipping, economics, population density	Still underway in 1955
Japan	U.S. Army personnel food supply	Discontinued
	Substitute for soil	In use and interest increasing
United States	Cultivation of specialty crops, such as tomatoes, flowers, etc.	Many discontinued
England	Growing of carnations	?

Table 4. Methods of supplying nutrients[a]

Concentrated stock solutions of various salts
Packets of dry chemicals to known amounts of solution or sprinkled on top of bed
Compressed tablets
Synthetic resins, anion- and cation-saturated
Iron, as finely divided magnetite; also chelates
Frits, for Zn, Mn, B, Cu, and Fe
Perforated, plastic-coated chemical packets a possibility

[a]Fertilizer and technical grade salts can be used.

Table 5. Example of hydroponics nutrient solution

Compound	Mg/l	Nutrient supplied[a]	Total concentration in final solution[b] ppm	Satisfactory variations ppm
KNO_3	707.7	N K	N 198 K 273	50–400 50–400
$Ca(NO_3)_2 \cdot 4H_2O$	708.5	N Ca	Ca 120 Mg 24	50–400 12–120
$MgSO_4 \cdot 7H_2O$	246.5	Mg S	S 32 P 31	10–500 10–200
$NH_4H_2PO_4$	196.0	N P	Cl 3.50	1–50
KCl	7.4	K Cl		
H_3BO_3	1.54	B	B 0.27	0.1–0.5
$MnSO_4 \cdot H_2O$	0.93	Mn	Mn 0.27	0.1–1.0
$FeSO_4 \cdot 7H_2O$	1.11	Fe	Fe 0.22	0.1–1.0
$ZnSO_4 \cdot 7H_2O$	0.72	Zn	Zn 0.16	0.1–0.5
$CuSO_4 \cdot 5H_2O$	0.12	Cu	Cu 0.03	0.01–0.2
H_2MoO_4	0.016	Mo	Mo 0.009	0.01–0.1
Total	1870.4	13 elements	682.46	

[a]Thirteen elements are essential in variable amounts.
[b]Final solution contains about 2 g of total salts per liter.

The basic requirements for the growing of plants by the soilless culture method are as follows:

1. *Substrate*—gravel, sand, cinders, haydite, vermiculite, water.
2. *Nutrient solutions* (see Table 4 and example, Table 5)—chemicals in salt, tablet, or solution form (Table 6); synthetic resins; possibly fertilizer salts [KNO_3, $MgSO_4$, $CaH_4(PO_4)_2$, etc.].
3. *Water* (see Table 7).
4. *Air*—carbon dioxide and oxygen (Table 8).
5. *Light*—minimum, 2000 ft-c; optimum, 4000 ft-c (Table 9).
6. *Temperature*—acceptable range, 32-120°F; optimum range, 60-100°F (Table 10).
7. *Humidity*—25–90% preferred but not essential.

In addition to these basic requirements, protection must be provided against weather extremes, air pollution, and excessive radiation, as well as insects and disease. Also, some means must be devised of checking the nutrient solution periodically for conductivity, pH, etc., and of making appropriate adjustments. Table 11 presents a list of the types of containers that may be used for hydroponic plantings.

Table 6. Chemical mixture[a]

Major salt	Weight
Sodium nitrate ($NaNO_3$)	5 oz
Ammonium sulfate ($[NH_4]_2SO_4$)	3 oz
Calcium sulfate ($CaSO_4 \cdot 2H_2O$)	1.5 oz
Superphosphate ($CaH_4[PO_4]_2$)	3.0 oz
Potassium sulfate (K_2SO_4)	4.0 oz
Magnesium sulfate ($MgSO_4 \cdot 7H_2O$)	2.5 oz
Trace element mixture	0.5 g
Zinc sulfate	5.3 g
Manganese chloride	16.0 g
Boric acid	12.0 g
Copper sulfate	5.3 g
Iron sulfate	17.0 g

[a]Applied at rate of 2.0 oz per week to 9 ft^2 of trough space will provide sufficient nutrients.

Table 7. Water requirements of plants grown in open air[a]

Plant	Water transpired per lb dry matter[b] lb	Relative requirement[c]
Millet	187–367	1.00
Sorghum	272–303	1.14
Corn	253–495	1.31
Barley		1.94
Wheat	394–639	2.09
Oats		2.18
Rye		2.37
Legumes		2.81
Grasses		3.10

[a]In a closed system, water could be recycled.
[b]From Miller, *Plant Physiology*, 1938, p. 49.
[c]Affected by humidity, fertility (less water required for excellent than for poor ground), soil moisture (good moisture supply reduces water requirement), and diseases (leaf rusts increase water requirement). Under optimum conditions of humidity, fertility, etc., at least 100-150 lb of water would probably be required per pound of dry matter.

Research in hydroponics is currently being conducted quite vigorously. At Scripps, Drs. W. H. Thomas, F. T. Haxo, K. A. Clendenning, Ralph Lewin, and Joyce Lewin are culturing algae. The following are also reported to be doing work on algal culture:

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Table 8. Carbon dioxide requirements of plants[a] for photosynthesis

Normal content of air on Earth: 3 parts CO_2 in 10,000 of air (by volume) = 0.03%; higher in industrial areas, close to soil, and in soil (e.g., 5 to 10 times higher in soil).

Source of CO_2: respiration of plants and animals, organisms, combustion of wood, coal, petroleum, disintegration of rocks (e.g., $CaCO_3$), volcanoes, water in streams, oceans, etc.

10,000 l of air contain 1.7 g of carbon.

One acre of corn would need the CO_2 out of 20,000 tons of air where concentration of CO_2 is 3 parts in 10,000.

There is evidence that roots can absorb some carbon from dissolved CO_2 in the soil solution.

Photosynthesis can be increased by increasing the CO_2 of the air. (Warburg, using chlorella, obtained a proportional increase from 0.05 to 10% CO_2 in the air. Toxicity and other limiting factors come into play (i.e., light, stomata numbers, etc.).

When CO_2 is 10 to 15% in air, it inhibits growth.

For 610 lb dry matter, assuming 50% carbon content, 1,120 lb CO_2 would be required.

[a]In a closed system in equilibrium with man, CO_2 would be reused continually.

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Table 9. Light requirements of plants[a]

Midday intensity on clear day in temperate zone is 10,000 to 12,000 ft-c. (2,000 to 3,000 ft-c are sufficient for many plants.)
There is greater photosynthesis with intermittent light.
Light intensity, temperature, and CO_2 are all interrelated.
Wavelength: blue and red important—730 mμ upper limit; ultraviolet not important—390 mμ lower limit; green not important.
Ultraviolet beyond wavelength of 290 mμ is injurious.
[a]Photosynthesis $CO_2 + H_2O \rightarrow 1/6\ (C_6H_{12}O_6) + O_2\ \Delta H = 112{,}000$ calories.

Table 10. Temperature

For photosynthesis	Threshold temperature, −6 to −20°C. O_2 evolution ceases at 0 to 2°C for warm, temperate plants. O_2 evolution ceases at 4 to 8°C for subtropical and tropical plants. Photosynthesis, with no other factor limiting, increases up to 25°C.
For plant growth	Varies with plant, but optimum region is generally 70 to 90°F.

Higher plants are being investigated in Japan, at the University of California at Riverside, and in many other places, but mostly from a plant nutrition point of view.

Table 11. Types of containers

Redwood tanks or troughs
Concrete tanks or beds (asphalt coated)
Iron tanks or troughs (asphalt coated)
Plastic tanks, troughs, or containers
Brick structures
Puddled clay
Stones laid in pattern, outlined, and coated with nonerodible mud plaster, 4 ft wide and up to 100 ft long
Asbestos sheeting

Research is still needed to determine what combination of crops will produce maximum digestible nutrients per unit area and meet the necessary protein, carbohydrate, fat, etc., needs of man (see Appendix). Other problems requiring further study are those concerned with securing the maximum yields of usable crops per unit area (combination of nutrient levels, moisture, substrate character, light, temperature, CO_2, humidity, aeration, etc.; mechanical arrangements—stacking or layering to reduce space requirement); plant breeding to produce desired yield and quality; control of diseases and insects; and finding the simplest and best means of renewing and controlling nutrient levels, resins, coated nitrogen sources, etc. In addition, experiments should be performed under simulated Moon conditions on the recycling of CO_2, oxygen, and water; the effects of reduced gravity; radiation control; and on enclosure materials which will screen out harmful radiation but not useful wavelengths.

APPENDIX

Food Requirements of Man

The initial basic requirements for starting a hydroponics setup to support one man are as follows (see Table 1):

1. *Plant beds*—500–1000 ft^2, made of suitable plastic or other material. (Layering arrangements might decrease this area.)

2. *Substrate*—gravel, sand, soil-dust mixture.

3. *Water*—roughly 1000–2000 gal for 500–1000 ft^3 of gravel and sand.

4. *Chemicals*—20—40 lb for 1000—2000 gal of nutrient solution.

5. *Carbon dioxide*—303 g carbon per day for 756 g food = 1,102 lb carbon dioxide in enough air to give concentration that man can tolerate.

6. *Oxygen*—sufficient for man will supply plant root needs.

7. *Light source*—to provide 3000–4000 ft-c intensity if setup is underground.

8. *Heat source*—to maintain temperatures at 70–85°F if setup is underground.

9. *Enclosure material*—must be strong and permit transmission of useful light while screening out harmful radiation.

Table A-1. Basic dietary needs of man (154 lb or 70 kg; physically active)

Item[a]	Amount
Calories	3000
Protein	70 g
Calcium	1 g
Iron	12.0 mg
Vitamin A	5,000 I.U.
Thiamine	1.5 mg
Riboflavin	1.8 mg
Niacin	15.0 mg
Ascorbic acid	75.0 mg
Vitamin D	6.0 I.U.
Water	2.5 l
Salt	5 g
Iodine	0.15 to 0.30 mg
Phosphorus	Not in normal food
Copper	1 to 2 mg
Carbohydrates	595 g
Fat	77 g

[a]Total dry food: 756 g = 1.62 lb per day (610 lb per year). 0.10 to 0.60 lb dry corn can be produced per square foot. Assuming optimum, 610/0.60 = 1000 ft^2 of hydroponic surface per person, or about 1/40 acre, = plot 4 × 250 ft or 10 plots 4 × 25 ft. By appropriate layering or use of algae, the area occupied can be decreased.

In summary, the needs per man are: (1) 500–1000 ft^2 of plant surface to absorb carbon dioxide and fix food at 1.62 lb per day, (2) 1000–2000 gal water to provide 25% saturation of planting bed, (3) 3,636,000 lb air to supply 1,102 lb carbon dioxide at 0.03%, and (4) 20–40 lb chemicals (assuming reuse) to make up 1000–2000 gal nutrient solution.

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