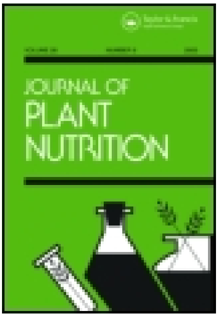

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Hydroponics: Its history and use in plant nutrition studies

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HYDROPONICS: ITS HISTORY AND USE IN PLANT NUTRITION STUDIES

KEY WORDS: soilless culture, solution culture, hydroponics, and plant nutrition.

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ABSTRACT

Hydroponics is a widely and frequently used technique for growing plants without soil, providing for a considerable degree of control of the elemental environment surrounding the root. The technique has an interesting history of development and use dating back into the mid 18th-century, although the growing of plants in nutrient rich water may have dated back into the early history of man. The determination of the essential elements required by plants were discovered using solution culture techniques. This paper discusses the past history of solution culture as well as its importance and use today.

HISTORICAL REVIEW

There are several excellent references one can refer which adequately presents the early work that was done with the soilless culture of plants. Hewitt[1] states that "Woodward in 1699 made the earliest recorded use of a water culture method without any solid substrate." During the 1700s several researchers attempted to determine what "caused" plants to grow. They experimented with various mixtures of soil and water. But it not until the 1800s when there was flurry of activity as a number of researchers began to more clearly understand plant growth and development. Men like, De Saussure, Sachs, Boussingault and Knop, conducted experiments which helped to determine that certian elements were contributors to plant growth. Knop (Table 1) devised a nutrient solution that was used for many years. These men made fascinating history. Those interested should refer to Russell[2], Hewitt[1] and Schropp[3] for more details.

Out of this early research came the basis for preparing and managing the nutrient solution. Knop's[4] standard solution provided the basis for further modifications by others. The emphasis was on improving the nutrient solution in terms of its osmotic pressure and balance of elements while at the same time keeping its constitution simple. It was equally important that no precipitate formed during its use and that plant growth was without the occurrence of stress. Numerous formula were recommended and

TABLE 1 KNOP'S NUTRIENT SOLUTION

Compound	g/l
KNO_3	0.2
$Ca(NO_3)_2$	0.8
KH_2PO_4	0.2
$MgSO_4 \cdot 7H_2O$	0.2
$FePO_4$	0.1

frequently modified by others[1]. The nutrient solution formula that has wide acceptance and use was proposed by Arnon and Hoagland[5] who based its elemental composition on the approximate proportions found to be absorbed by the tomato plant.

Sufficient aeration of the nutrient solution and the need to replenish it on a particular schedule were early recognized as important aspects for its proper management.

It was during the 100 year period from 1850 to the mid 1900s that all of the currently recognized essential elements required by green plants were discovered (Table 2). Most, if not all, of these discoveries were made using some form of soilless culture. The solution technique in particular, growing plants without any support media whatsoever, provided the researcher the opportunity to remove from the rooting medium even the slightest trace of the element under test. The success of this technique was determined how skillful one was in removing from the plant environment, particularly from the nutrient solution, the last trace of the element being studied. Today, the same interest exists as plant nutritionists attempt to determine if there are additional essential elements, or elements that may be beneficial to plant growth[6] but not "essential" as defined by Arnon and Stout[7] (Table 3).

The term, "hydroponics" is a relatively new term having been coined on the 1930s by Dr. W. F. Gericke[8], a University of California researcher who popularized the growing of plants without soil.

TABLE 2 ESTABLISHED ESSENTIALITY FOR THE ELEMENTS

MAJOR ELEMENTS			MICRONUTRIENTS		
Element	Year	Researcher	Element	Year	Researcher
Nitrogen	1750	not known	Boron	1927	Sommer
Phosphorus	1839	Liebig	Chlorine	1954	Broyer, Carlton Johnson & Stout
Potassium	1866	Birner & Lucanus	Copper	1931	Sommer
Calcium	1860	Knop	Iron	1843	Gris
Magnesium	1860	not known	Manganese	1897	Bertrand
Sulphur	1860	Knop	Molybdenum	1954	Broyer, Carlton, Johnson & Stout
			Zinc	1927	Sommer

Russell[2] states that by the 1860s, Knop had already established that the elements potassium, magnesium, calcium, iron, phosphorus, sulphur and nitrogen were necessary for plant life from his water culture experiments.

TABLE 3 ELEMENTAL ESSENTIALITY AS ESTABLISHED BY ARNON AND STOUT[7]

1. Omission of the element in question must result in abnormal growth, failure to complete the life cycle, or premature death of the plant.
2. The element must be specific and not replaceable by another.
3. The element must exert its effect directly on growth or metablolism and not by some indirect effect such as by antagonizing another element present at a toxic level.

SOILLESS CULTURE TECHNIQUES

There are a number of techniques that can be used to deliver the nutrient solution to the growing plant. Each is not without is advantages and limitations. These techniques may be divided into several catagories; such as, with and without a root supporting media and static aerated or flowing nutrient solution with or without its reuse. Sand or gravel culture, the nutrient solution either periodically flooding the growing bed or vessel or dripped through it, is still a widely used technique. However, this soilless culture procedure is not well suited where precise control of the elements is desired. A unique technique using perlite as the support medium and maintaining a constant level of nutrient solution at the bottom of the rooting container may be a more desirable modification of the typical gravel or sand bed procedure[9].

Where precise control of the elements in the nutrient solution is desired, the elimination of the root supporting media is necessary. Plants may be grown in an aerated nutrient solution or the plant roots placed in the path of flowing nutrient solution. A potentially new technique may be aeroponics, the suspension of plant roots in a mist of nutrient solution. All these techniques provide the means of carefully regulating the nutrient solution and allowing the user to monitor elemental absorption by plant roots.

Nutrient solution management is extremely important no matter which soilless culture technique is chosen. For most, it is common procedure to reuse the nutrient solution for a particular time period which may vary from several days upward to several weeks. However, during its use and reuse, the composition of the nutrient solution may change substantially. The pH may go up or down, and the concentration of certian elements change dramatically. Trelease and Trelease[10] found marked changes in the pH of the nutrient solution in 8 days of reuse, depending on the ratio of $NO3^-$-to $NH4^+$-ions in the nutrient solution. The rapid removal of P from the nutrient solution by several plant species has been demonstrated by Franco and Loomis[11]. An excellent review on the long term effects of reuse on the composition of the nutrient soluion and its potential affects on plant growth is given by Asher[12].

Another adverse potential problem with reuse is disease control and the accummulation of substances in the nutrient solution. Buyanovsky, Gale and Degani[13] have suggested ultra-violet radiation as a means for inactivating microorganisms in a circulating nutrient solution system, while filtering may be a useful technique for removing suspended substances.

Faced with potentially adverse effects on plant growth by reuse of the nutrient solution, the user may select one of several possible alternatives. The easiest procedure would be to use the nutrient solution in a one-way passage through the growing bed or vessel. However, the technique is quite wasteful in its use of water and essential elements. Another alternative is to increase the volume of nutrient solution per plant so that changes which occur are relatively small before replacement of the entire solution. However, such a procedure would require large growing containers and substantial quantities of nutrient solution.

Another procedure would be to monitor the composition of the nutrient solution with each use and make additions inorder to maintain its initial composition and pH. Such a monitoring system has been described by Ben-Yaakov and Ben-Asher[14]. Although monitoring may be quite easily done, the making of the proper adjustments may not be so easy, depending on the volume of nutrient solution and its schedule of use.

A method for controlling the ionic environment of plant roots has been developed by Asher, Ozanne and Loneragan[15]. The nutrient solution flows through the rooting vessel at approximately 700 ml/pot/minute. The pH and temperature of the nutrient solution are carefully controlled, and elements added to the solution through a drip-feed system at a rate approximately equal to the rate of uptake by the plants. Plants can be grown in relatively dilute solutions with very precise control of the elemental environment surrounding their roots. Using this flowing nutrient solution technique[15], studies on the uptake of K[16] and P[17] by various plant species have been precisely determined.

A similar system of flowing nutrient solution with controlled composition was used by Clement, Hopper, Canaway and Jones[18] to determine the uptake of nitrate-ions by perennial ryegrass and a similar study with the nitrate-ion on simulated swards of perennial ryegrass[19]. Another study using the same technique was reported for the elements, K and Na[20]. In each of these studies, fundemental principles of elemental uptake were explored and established which could not have been done without the use of the constant composition-flowing nutrient culture technique. Asher and Edwards[21] have discussed this in considerable detail, establishing limiting concentrations for 9 essential elements, and comparing these concentrations with those found in the soil solution and other nutrient culture procedures. Asher and Edwards[22] have developed the application of this technique for comparing dilute solution culture studies to problems of low fertility tropical soils.

There is evidence that how a nutrient culture study is conducted will markedly affect the results, particularly if plant elemental composition is one of the measured values. Spear, Edwards and Asher[23] studied the nutrition of potassium in cassava, and Wild, Skarlou, Clement and Snaydon[24] in four other plant species. Both experiments demonstrated that constant composition nutrient solution culture gave higher minimum plant K levels than what were obtained if the nutrient solution was allowed to be depleted in K before being renewed. Therefore, the practice of allowing the nutrient solution to become depleted before renewal may give questionable results when attempting to define plant elemental sufficiency.

THE NUTRIENT SOLUTION

Probably no other single aspect of the solution culture technique is as least understood as that associated with the constitution of the nutrient solution and its management. There are numerous formulas for preparing the nutrient solution. Hewitt[1] lists 160 different kinds based on various salt types and combinations of N sources. The formulas devised by Hoagland and Arnon[25] (see Table 4) are widely used in modified form. It is common to see the phrase "modified Hoagland's nutrient solution" in the literature, refering to their frequently cited University of California Circular 347[26].

Although the nutrient solution formula may be modified to suit particular plant requirements, the essential requirements for proper management are frequently overlooked or not understood. It is common to talk of the nutrient solution composition in terms of the concentration of the elements in solution without regard to how the nutrient solution is to be used, such as the volume of solution per plant and frequency of renewal. Cooper[27] states that "there is

TABLE 4. HOAGLAND'S NUTRIENT SOLUTION FORMULAS[25]

Stock Solution	to use, ml/l
Solution No. 1	
1 M KH_2PO_4	1.0
1 M KNO_3	5.0
1 M $Ca(NO_3)_2 \cdot 4H_2O$	5.0
1 M $MgSO_4 \cdot 7H_2O$	2.0
Solution No. 2	
1 M $NH_4H_2PO_4$	1.0
1 M KNO_3	6.0
1 M $Ca(NO_3)_2 \cdot 4H_2O$	4.0
1 M $MgSO_4 \cdot 7H_2O$	2.0

Micronutrient Stock Solution	g/l
H_3BO_3	2.86
$MnCl_2 \cdot 4H_2O$	1.81
$ZnSO_4 \cdot 7H_2O$	0.22
$CuSO_4 \cdot 5H_2O$	0.08
$H_2MoO_4 \cdot H_2O$	0.02

to use: 1 ml/l nutrient soln.

Iron

For Solution No. 1: 0.5% iron ammonium citrate
to use: 1 ml/l

For Solution No. 2: 0.5% iron chelate
to use: 2 ml/l

very little information available on this subject." In an interesting experiment, he obtained maximum tomato plant growth when tomato plants were exposed to 60 liters of nutrient solution per plant per week. Thinking that growth was being affected by root exudate, he studied the relationship between root container size and nutrient solution flow rate, finding that plant growth was affected by the size of the root container and the volume of nutrient solution flowing through the container. Cooper remarked that more fundemental research was needed to determine what is the best volume of nutrient solution and flow characteristics for maximum plant growth. He also stated that with the NFT method[27], "the tolerance of nutrient supply was found to be very great." This seems to be in agreement with Steiner[28] who feels that plants evidently have the ability "to select the ions in the mutual ratio favourable for their growth and development." Therefore, one of the unique features of the "flowing" nutrient solution system maybe the plant's access to an apparently larger volume of nutrient solution, i.e., increased contact with the essential elements and reduction in the concentration of inhibiting substances.

Other characteristics of the nutrient solution are equally important, such the pH, electrical conductivity, form of the elements (particularly for the elements N and Fe), and temperature. There is considerable variability among these characteristics as to their optimum. For example, the pH of the nutrient solution is thought to be best when kept between 6.0 and 6.5, although most nutrient solutions when constituted will have a pH between 5.0 and 6.0. It is fairly well known that if the nutrient solution drops below 5.0 or goes over 7.0, plant growth can be significantly reduced. In an interesting experiment, Ikeda and Osawa[29] found that N uptake, from either the NO_3^- or NH_4^+ form for 20 plant species in the nutrient solution ranging in pH from 5.0 to 7.0, showed some degree of N form preference at certian nutrient solution pHs.

The pH of the nutrient solution will affect the availability of certian elements, particularly the micronutrients, stimulating excessive uptake at a low pH, and resulting in removal from the nutrient solution by precipitation at high pH. Therefore, the control of the pH is important inorder to keep all the essential elements in solution. It is also believed that the pH of the nutrient solution is less critical in a flowing solution culture system than in one that is static, as long as the pH remains between 5.0 and 7.0.

pH control can be obtained by monitoring the nutrient solution and adding an acid or alkali as required to either lower or raise the pH. A considerable degree of control can be obtained by maintaining a certian ratio of NO_3/NH_4-ions, as suggested by Trelease and Trelease[10], or by using various combinations of either the mono- or di-phosphate salts of Ca or K[1]. Diurnal fluctations in pH will occur with the changing solubility of CO_2 in the nutrient solution[14]; however, these changes may not be sufficient to warrant periodic adjustment by additions of either an acid or alkali.

The electrical conductivity of the nutrient solution, or what is also referred to as its osmotic pressure, is important since it affects root growth. If greater than 50 millimolar (or about 1.00 atmosphere), water movement into the roots may be restricted. If the osmotic pressure of the nutrient solution is considerably greater than 1.0 atmosphere, water movement into the roots becomes severely restricted, causing wilting and if sufficiently severe, plant death.

The chemicals used to make the nutrient solution contribute to its osmotic pressure, although the "salt index" varies considerably from compound to compound. Hewitt[1] provides a very good discussion on the subject, noting that the literature on this subject is quite variable but, it is generally believed that the nutrient solution should be held to osmotic pressures between 0.5 to 0.75 atmospheres, although many plants can tolerant pressures up to 1.75 atmospheres.

Another use of electrical conductivity is as a means of determing the change in elemental content of the nutrient solution. Cooper[27] suggests that the nutrient solution for his NFT system should have a conductivity reading between 2 to 3 millimhos [frequently referred to as the Conductivity Factor (cF) = millimohs X 10]. If the cF drops below 20, then additional nutrient elements must be added to the nutrient solution to prevent a deficiency from occurring. Considerable care needs to be exercised in the use of conductivity readings for determining replenishment schedules since a cF reading gives no idea as to which of the essential elements have changed in concentration in the nutrient solution and by how much.

The form of the essential elements in the nutrient solution has primarily centered around the elements N and Fe. There is a growing interest on the effect of the form of N, whether NO_3^- or NH_4^+, on plant growth and development[30]. Cooper[27] found that NH_4^+ in the nutrient solution used for tomato was not desirable, although he found that some NH_4^+ could be included depending on the Ca level in the solution and the need for pH control[10]. The value and need for the NH_4^+-ion in the nutrient solution is a controversal one as can be seen by the number of papers on the subject found in the SYMPOSIUM ON RESEARCH ON RECIRCULATING WATER CULTURE[31]. It is probably sufficient to say that the inclusion of the NH_4^+-ion in the nutrient solution is desirable if its concentration does not exceed 25% of the total N present.

The maintenance of sufficient Fe in the nutrient solution can be a problem. The more common sources of Fe are ferric citrate or tartarate, or Fe EDTA. The concentration added to the nutrient solution can range from less than a ppm to several hundred[1].

The temperature of the nutrient solution can have a marked affect on yield, if less than 20°C (68°F) or greater than 30°C (86°F), as has been reported by Cooper[27]. For his NFT system, he found the optimum nutrient solution temperature to be between 26 to 27°C (79 to 80°F). Cooper also observed that he could reduce night time temperatures in the greenhouse for tomato if he heated the nutrient solution. Nutrient solution temperature affects water and elemental uptake by plants[32]. Plants can be wilted on a warm day by placing the roots into cold nutrient solution. As a general rule of thumb, the nutrient solution temperature should not be less than the ambient air temperature. The maximum nutrient solution temperature will vary with crop.

The elemental concentration in the nutrient solution, dependent on the formula used in its preparation, is commonly expressed in parts per million (ppm) or micromoles per liter (uM/l). For the sake of simplification, ppm will be used in this discusion. Hewitt[1] provides the best source of information on nutrient formulas. Asher[12] lists several nutrient solution compositions for formulas without N and with various combinations of NO_3^- and NH_4^+ (Table 5). Cooper[27] has given what he considers the "ideal" nutrient solution composition for his NFT system (Table 6).

It was Hoagland[33] who defined an optimum nutrient solution as "the minimum concentration which gave maximum yield and beyond which there was no further improvement." However, there is a difference between concentration and total supply which becomes a function on how the nutrient solution is used. Elemental utilization (uptake) becomes a function of three interrelated factors, the ratio of number of plants per volume of nutrient solution, flow rate and frequency of replenishment, as well as the rate of stirring which can be affected by the aeration intensity and balance between the major elements. Therefore, the elemental concentration becomes a much more critical than is at first seen.

TABLE 5 APPROXIMATE INITIAL CONCENTRATION OF INDIVIDUAL ELEMENTS IN NUTRIENT SOLUTIONS USED FOR SAND CULTURE AND SOLUTION CULTURE EXPERIMENTS.[12]

ELEMENT	NITROGEN-FREE SOLUTIONS		SOLUTIONS with N as NO_3^-		SOLUTIONS with N as NH_4^+		SOLUTIONS with N as both NO_3^- and NH_4^+		
	ppm								
Nitrogen									
NO_3^-	-a	-b	240c	190d	-e	-f	225g	55h	110i
NH_4^+	-	-	-	-	110	615	55	126	65
Potassium	250	75	150	100	37	160	150	160	235
Calcium	130	50	125	100	25	70	100	36	100
Magnesium	85	40	80	62	40	55	80	40	110
Phosphorus	85	30	30	42	15	205	30	70	85
Sulfur	154	94	62	47	47	215	62	112	100
Chlorine	285	28	0.5	3	62	-	0.5	9	246
Iron	26	0.09	0.4	1.7	1.7	0.2	0.4	1.7	0.9
Boron	4.2	1.1	4.2	4.6	4.6	5.2	4.2	0.4	0.4
Manganese	0.16	0.08	0.16	0.18	0.16	0.12	0.16	0.08	0.03
Zinc	0.01	0.006	0.01	0.01	0.02	-	0.01	0.01	0.01
Copper	0.004	0.002	0.004	0.015	0.02	-	0.005	0.015	0.0004
Molybdenum	0.01	0.003	0.001	0.005	-	-	0.001	0.004	-

a. Bond

b. Norris and Date

c. Hoagland's No. 1

d. Long Ashton

e. Sideris et al

f. Addom's "B"

g. Hoagland's No. 2

h. Mulder

i. Trelease and Treslease

TABLE 6 THEORETICALLY IDEAL CONCENTRATION (PPM) OF ELEMENTS IN NUTRIENT SOLUTION FOR NFT CROPPING.[27]

Element	Concentration, ppm
Nitrogen	200
Phosphorus	60
Potassium	300
Calcium	170
Magnesium	50
Iron	12
Manganese	2
Boron	0.3
Copper	0.1
Molybdenum	0.2
Zinc	0.1

Hewitt[1] provides a good discussion of this important aspect of the use of the nutrient solution. Asher and Edwards[21] also discusses this in some detail giving a table of composition of nutrient solutions used in various hydroponic systems (Table 7).

Currently, flowing nutrient culture systems[14-24] are being recognized as the technique for plant nutrition studies. In these systems a large volume of nutrient solution of the desired composition is circulated rapidly through the growing vessel with provision being made for either continuous or intermittent monitoring and adjustment of the nutrient solution composition. Edwards and Asher[34] showed that the minimum flow rate, F, that will just keep the concentration in a well stirred vessel of nutrient

TABLE 7 APPROXIMATE COMPOSITION OF NUTRIENT SOLUTIONS USED FOR VEGETABLE PRODUCTION IN VARIOUS HYDROPONIC SYSTEMS.[21]

ELements	Nutrient Film	Gravel Culture	Mist Culture	Drip onto Organic Mixture	Floating Water Culture	Mean All Culture Systems
	ppm					
Nitrogen	200	150	180	125	100	150
Phosphorus	40	50	65	70	60	55
Potassium	165	185	160	165	200	175
Calcium	150	110	110	85	65	105
Magnesium	133	80	60	85	85	90
Sulphur	-	110	50	165	185	125
Boron	-	0.008	0.014	0.004	0.004	0.008
Iron	0.8	1.2	1.2	0.6	1.2	1.0
Manganese	0.25	0.5	0.5	0.16	-	0.36
Zinc	-	0.1	0.06	0.012	0.012	0.046
Copper	0.01	0.03	0.06	0.012	0.012	0.026
Moylbdenum	0.002	0.001	0.0C2	-	-	0.001

solution, with D percent of the inlet concentration, is given by the equation:

$$F^{*} = \frac{100\ R}{D} \cdot \frac{u}{C}$$

where R is the weight of roots per pot, C is the inlet concentration and u is the rate of uptake per unit weight of roots. The value of F tends to increase as the solution concentration decreases from the region of sufficiency to deficiency. Consequently, the highest flow rates tend to be required under conditions of moderate to severe elemental deficiency, flow rates of 25 ml/vessel/s (2160 l/vessel/day) being required to limit depletion of the nutrient solution to a few percent of the inlet concentration.

Although there has been much researched and written about the nutrient solution technique, there is much that we don't know and have yet to learn. In addition to the flow rate aspects, the balance among the cations, and between the cations and anions in the nutrient solution related to uptake is equally important. Hewitt[1] provides an excellent discussion of this topic. One would surmise that the composition of the nutrient solution and the balance among the elements in the solution becomes less a factor influencing plant growth in rapidly flowing systems where the composition of the nutrient solution is carefully maintained at a particular composition. Therefore, the rapid flowing culture systems may be better suited for the growing of plants when studying some aspect of elemental plant nutrition. Similarly, the rapid flow system may be equally better suited for the commerical production of plants than other systems currently in use.

COMMERICAL APPLICATIONS

Probably no other aspect of plant production has caught the fancy of the public than soilless growing, normally thought of by the public as "hydroponics." Popularized in the 1930s by various books and writings on the subject, hydroponics became a widely used technique for growing vegetables on islands in the western Pacific during World War II[35]. Following the war, hydroponic gardens and complexes could be found in many areas of the United States, particularly in the south. But by the 1960s, most of these hydroponic businesses had disappeared, although the American's love affair with hydroponics had not ended. By 1970, there was renewed interest in hydroponics and hydroponic growing. A number of books on hydroponics appeared (Table 8) and hydroponic systems were available for sale. Primarily confined to greenhouse structures and the production of high cash crops, such as winter vegetables[36], the love affair blossomed again. But for those who dreamed of succeeding financially with their hydroponic greenhouses found their dream short-lived, and financial failure ran high. The reasons were many and hydroponic growing lost some of its luster.

During the 1970s, the best book to appear on soilless culture was by Resh[37], and the HYDROPONIC SOCIETY OF AMERICA (P.O. Box 516, Brentwood, California 94513) came into existence. The most significant research being done on soilless culture, primarily hydroponics, was being conducted at the Environmental Research Laboratory, (Tucson International Airport, Tucson, Arizona 85706) and at the Glasshouse Crops Research Institute (Littlehampton, England). In 1979, a SYMPOSIUM ON RESEARCH ON RECIRCULATING WATER CULTURE[31] was held, sponsored by the International Society for Soilless Culture (P.O. Box 52, 6700 AB Wageningen, The Netherlands) and the International Society for Horticultural Science. In 1979, the United States Dept. of Agriculture-Science and Education Administration published a bibliography on "Aquaculture and Hydroponics: 1968-1978"[38].

TABLE 8 LIST OF PUBLISHED BOOKS ON HYDROPONICS SINCE 1970.

Year	Author	Title	Publisher
1971	Hollis	Profitable Growing without Soil	Univ. Press, London
1973	Douglas	Beginner's Guide to Hydroponics	Drake Publishers
1973	Loewer	The Indoor Water Gardener's How to Handbook	Walker
1974	Saunby	Soilless Culture	Transatlantic Arts
1974	Bridwell	Hydroponic Gardening	Woodbridge Press
1974	Harris	Hydroponics: The Gardening without Soil	Purnell
1975	Swindells	A Guide to Water Gardening	Scribner & Co.
1975	Sherman	Hydroponic Gardening at Home	Nolo Press
1975	Dickerman	Discovering Hydroponic Gardening	Woodbridge Press
1975	Hudson	Hydroponic Greenhouse Gardening	National Graphics
1975	Dekome	The Survival Greenhouse: An Ecosystem	Walden Foundation
1976	Sullivan	Understanding Hydroponics	F. Warne
1976	Dutto	Water Gardening Indoor and Out	Crown Press
1976	Sherman & Brenizer	Hydro-Story: The Complete Manual of Hydroponic Gardening at Home	Nolo Press
1976	Guminska	The Hydroponic Culture of Plants	U.S. Commerce Dept.
1976	Douglas	Advanced Guide to Hydroponics	Drake Publishers
1977	Everall	Hydroponics	Burimingham Central
1977	Nicholls	Beginning Hydroponics	Running Press
1977	Jones	Home Hydroponics and How to do it	Ward Ritchie Press
1977	Douglas	Beginner's Guide to Hydroponics	Drake Publishers
1977	Harris	Hydroponics: Gardening without Soil	Purnell
1977	Schwarz	Guide to Commerical Hydroponics	Israel Univ. Press
1978	deBruijn	Hydroculture: Indoor Plants on Tap	W. Foulsham
1978	Resh	Hydroponic Food Production	Woodbridge Press
1978	Cooper	Commerical Applications of NFT	Grower Books
1979	Cooper	The ABC of NFT	Grower Books
1979	Koster	Hydroponic Gardening	Recmar Corporation
1979	Kenyon	Hydroponics for the Home Gardener	Van Nostrand Reinhold

Probably the most significant new development in soilless culture, or hydroponics, was the development and introduction of NFT-Nutrient Film Technique by Allen Cooper[27,38]. In NFT, plant roots are suspended in a channel for flowing nutrient solution. Several other bulletins and papers have been written about NFT and its application[40-42]. However, NFT is not without its problems - disease control, and the movement and proper aeration of the nutrient solution through the rooting channel - being major difficulties. Jensen[43] has recently reviewed new developments in hydroponic growing, describing systems and techniques of current interest and value.

The concept of "indoor farming" has been investigated and discussed[44,45]. A number of systems have been devised with the growing of plants in controlled environmental chambers, hydroponics being the chosen growing technique. One commerical system has been developed by the General Electric Company, called "GENOPONICS." Primarily designed for winter or all-year-round vegetable growing, the future for the successful commerical utilization of such "indoor farming" systems is highly speculative.

The future of hydroponics as a viable system for the commerical production of plants is considerably controversial. Several articles in the commerical press[46-48] have discussed this issue with no final settlement of the question. Although hydroponic systems offer the grower the opportunity to precisely control the rooting environment, the requirements for this control are considerable. Production costs for establishing and maintaining a hydroponic system are higher than for other more conventional growing techniques. Therefore, hydroponic growing has to be limited to high cash crops. It takes greater skill on the part of the grower to manage a hydroponic system and the margin of error quite narrow. Small misjudgements in procedures can result is significant crop losses.

Therefore, the question as to the future of the hydroponic technique as it is conceived and practiced today is yet to be settled. It is conceivable that the present techniques are not suitable for commercial applications and that the "ideal" hydroponic system has yet to be devised. The current systems that have been most widely used with relatively good success are the various bag culture techniques, using an organic root supporting media, such as sphagnum peat moss or pine bark, or an inert substrate like perlite, with the nutrient solution being dripped into the bag, usually in one-way passage. Systems that recirculate the nutrient solution, with or without the use of a root supporting media, seemed doomed to failure for a number of reasons which have been discussed in some detail in this paper.

There may be areas of the world where hydroponics may be the only system that can be used to grow successfully food crops which are important in human diets. The desert regions of the world may be such places where hydroponics has important application[49-51].

It is evident that the love affair with hydroponics has not wained and with continuing research and development, the commerically successful hydroponic system may yet emerge. There are those who think that aeroponics is the system of the future, although no commerical units have been brought into use and production. Therefore, the successful commericalization of hydroponics is still an open question, yet to be finally resolved.

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