PROCEEDINGS

FIRST ANNUAL CONFERENCE

HYDROPONICS: The Soilless Alternative

GOODMAN HALL
JACK LONDON SQUARE
OAKLAND, CALIFORNIA

OCTOBER 20, 1979

SPONSORED BY

HYDROPONIC SOCIETY OF AMERICA

P.O. BOX 516
BRENTWOOD, CALIFORNIA 94513

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FOREWORD

Hydroponics, the art and science of growing plants without soil, is a fascinating concept for many people. It stirs the imagination to realize that plants are not totally dependent upon soil for their growth and well being. Sharing information about Hydroponics led to the formation of the Hydroponics Society of America and the main aim of the society is to supply factual information about hydroponics to everyone interested in the soilless growth of plants. Providing a forum for a well balanced evaluation of the hydroponic process is also the goal of the organization. The by-laws of the organization are included in the appendex and they contain a more extensive discription of the societies goals and aims.

The society thanks the speakers for providing their papers so that they could be printed early and distributed the day of the symposium. Special thanks are also due to George and Mary Downey and Virgil Allison for their special efforts on behalf of the society, and to the other members of the Board of Trustees for their financial and moral support.

BUILDING THE BRIDGE FOR HIM

W. A. Dromgoole

An old man, traveling a lone highway,
Came at the evening cold and gray,
To a chasm deep and wide.

The old man crossed in the twilight dim
For the sullen stream held no fears for him
But he turned when he reached the other side,
And builded a bridge to span the tide.

"Old man," cried a fellow pilgrim near,
"You are wasting your strength with building here;
Your journey will end with the ending day
And you never again will pass this way.

"You have crossed the chasm deep and wide
Why build you a bridge at eventide?"
And the builder raised his old gray head
"Good friend, on the path I have come he said,
"There followeth after me today
A youth whose feet will pass this way.

"This stream, which has been as naught to me,
To that fair-haired boy may a pitfall be
He, too, must cross in the twilight dim-
Good friend, I am building this bridge for him."

We all hope that the bridge to learning more about hydroponics will continue to be built.

Paul W. Droll
President

PROCEEDINGS OF THE FIRST ANNUAL CONFERENCE ON HYDROPONICS: The Soilless Alternative

TABLE OF CONTENTS

FOREWORD i

TABLE OF CONTENTS ii

Presented at 8:30 a.m.

CONTAINERIZED GROWING SYSTEMS
FOR GREENHOUSE VEGETABLES
Tim D. Carpenter 1

Presented at 10:00 a.m.

THE NUTRIENT FLOW TECHNIQUE -
a versatile and efficient hydroponic growing method
Dr. Pieter Anne Schippers 21

Presented at 1:15 p.m.

SOILLESS CULTURE AT TEXAS A & M UNIVERSITY
Dr. John E. Larsen 46

Presented at 2:45 p.m.

THE INTERNATIONAL STATUS OF HYDROPONICS -
A Review of Soilless Techniques
Dr. Howard M. Resh 62

SPEAKERS LIST 84

OFFICERS/BOARD OF TRUSTEES 85

APPENDIX

CONSTITUTION AND BY-LAWS OF THE SOCIETY . . . 87

NOTICE

CONTAINERIZED GROWING SYSTEMS FOR GREENHOUSE VEGETABLES

TIM D. CARPENTER*

Growing vegetables in greenhouses has taken many avenues during the past 20 years. Soilless growing systems have taken every shape and form from gravel to water. Gravel culture systems were prevalent from World War II until the mid 1970's. During the late 1960's, gravel bed recirculating hydroponic systems were promoted to be the answer to the world's food shortage problems. Little did we know that a multitude of problems would be forthcoming within the next few years. Gravel appeared to be the practical solution to replacing soil with a substance that would never deteriorate. This was a simple answer to all soil growing problems. Since the gravel was practically inert and could be thoroughly cleaned there should be no diseases. On the second crop it was a simple matter of cleaning the gravel with chlorine and replanting another crop. Fertilization would be simplified by recirculating a balanced fertilizer formula in solution through the gravel and around the roots. Each day the nutrient solution would be checked for concentration and pH and adjustments would be made.

There seemed to be no end to the crops that could be grown using this method. Since tomatoes were always in high demand, and a high cash crop it was not long before hundreds and thousands of people were growing tomatoes either on a small or large scale. The product was excellent! Never before had there been such excellent tasting and appealing tomatoes on the shelves of the supermarkets. The price of tomatoes grown "hydroponically" was twenty to

*Tim D. Carpenter, President - Hydro-Gardens, Inc.

thirty cents higher per pound than those grown in the field and the demand was far exceeding the production. The number of people requesting information on this new development was astounding. Many were willing to invest their life savings in a small scale commercial greenhouse that was to create a new job and great income potential. In many cases the first year or first tomato crop was highly successful. This created even more interest and more demand for this type of growing process.

It was difficult for those selling greenhouses with hydroponic growing systems to do anything but sell. There was no time to worry about marketing, diseases, excess labor and maintenance. It was such an advanced systematic method of growing that anyone could do it without the least amount of experience. Therein lies the problem and the key to most of the failures. When the time came for the second crop, procedures were followed as before and the next crop was on the way. It was not to be as good as the first crop but there was little concern. The next crop would be better! The next crops production diminished even further and many businesses were starting to falter.

Several reasons contributed to most of the failures. First, the production was not quite up to expectations. Second, diseases were starting to take their toll on a crop that was very susceptible. A small infestation on the first or second crop went un-noticed but got an early start on the next crop. The use of chlorine to sterilize the gravel bed would not kill plant pathogens such as tomato mosaic virus or tobacco mosaic virus. Once the system was infested it spread rapidly through the roots that were damaged from planting in the hard gravel. The recirculating nutrient system helped spread the disease even faster and soon the production was down below the profitable level. The biggest problem was the fact that very few recognized mosaic virus since the plant did not die. Sometimes very few symptoms were apparent other than the low production. In the advanced stages the virus was easily recognizable. For many years researchers had been looking for disease resistant varieties for greenhouses but none were yet available. Third, labor was far more than anticipated in the areas of pruning, insect spraying, picking and packing, nutrient adjustments, and particulary in the area of marketing.

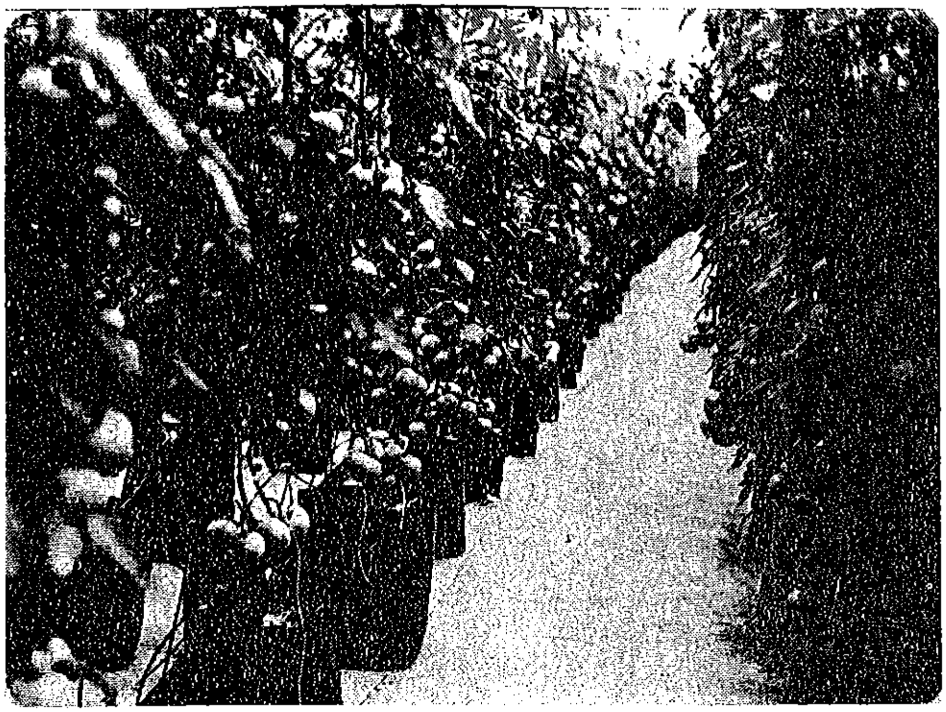
In 1975, the growth of the industry slowed considerably and new types of growing techniques were starting to take form. Growing in sand beds was supposed to solve the problems of the gravel bed systems with less initial cost outlay. However, the problems that caused failures in gravel bed systems were still there. Sand was a little easier to grow in, but the same diseases were creating tremendous losses in production. Sterilization was not any easier or better and recirculating the nutrient solution still created the same problems. Selection of the right type of sand was important and the feeding mechanism had to be changed. In many systems the nutrient was dripped into the sand and recirculated.

In other systems the nutrient solution was dripped into the sand and <u>not</u> recirculated but drained to the end of the row and discarded. The problem of disease transfer within the root system was <u>not</u> eliminated. Total sterilization became almost as difficult as soil sterilization and the cost was nearly as high. The only real differences were that the sand was very uniform, almost inert and easily managed with respect to moisture, aeration and nutrient control. The plastic liner underneath the sand bed allowed for total sterilization if proper sanitation control methods were followed.

The sand bed system was not inexpensive. Lining the entire floor of a greenhouse and covering it with 12 inches of clean, uniform sand was labor intensive. Drain lines had to be installed and the correct slope was important. Systems as large as 10 acres were installed in the U.S. as well as in the Mid-East, but sand bed systems never developed quite as rapidly as the initial gravel bed systems because they did not correct the basic problems.

In 1974, Hydro-Gardens decided to investigate drip irrigation systems in plastic pots using an inert growing media. This system came to be known as "The Top Spray Hydroponic System for Containerized Plants".

The top spray feeding system is designed to control watering and feeding for plants grown in pots or bags. The plastic bag simply replaces a plastic pot for economical reasons. It is extremely flexible and adaptable to large greenhouse plants such as tomatoes, European cucumbers,foliage and trees. The surface of the media in each container is sprayed with a uniform pattern of nutrient solution for a very short period of time, about 1 minute every 2 to 4 hours depending on the age of the plant, while any excess moisture drains out. The feeding schedule also varies with the type of plant, the climatic conditions and the choice of growing media.

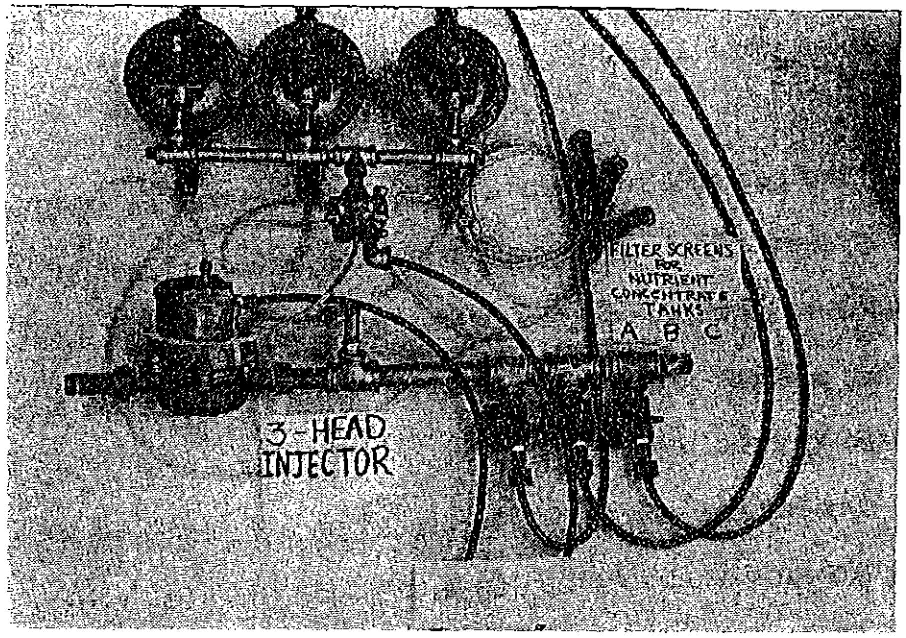


Nutritional balance can be regulated by monitoring the nutrition with testing by a plant tissue laboratory. Since every greenhouse cannot have a testing laboratory, it is necessary to set up standard feeding schedules with balanced nutrient formulas.

First, a water sample should be taken to verify essential and non-essential levels of elements in the water source. Once the plant is large enough to take a leaf sample, the nutritional balance can be monitored and small changes can be made as the plant matures and the seasons change. The most important factor of this hydroponic system is that one can regulate the nutrition on a daily basis with very little effort. The results are rapid since the nutrients are placed right at the root system. In the bag system the roots are contained so that each root is fed uniformly and adequately every time. If the proper media is selected, there is no water logging. The media cannot be oversaturated since the excess water drains out the bottom of the container. Under these conditions the plant can obtain maximum growth if the environment is controlled within the greenhouse.

The bag system is safe, simple and creates an ideal environment for the root system. Root zone temperature can be maintained at an optimum level; a tremendous advantage in the colder months. No extra heat is required since the bag absorbs and holds the heat. Cold water is not a problem and there is no need to heat the water or the soil. In many gravel bed systems and nutrient film systems the water must be heated when it is below 65 degrees F. The black bag maintains heat absorbed from the sun and holds a higher temperature. The plant root zone also absorbs heat from the ambient air temperature around the bag. This is extremely important with greenhouse vegetable crops. Many greenhouses that use soil as a media are heating the soil to maintain the higher root zone temperature. This function is naturally controlled in the bag system.

Fertilization is simplified tremendously by the use of a very accurate ratio feeder (injector). The amount of nutrient is carefully regulated automatically in volume and concentration to each plant. The pH is automatically maintained in the proper range with the injector system.



Supplements can be added easily with the injector and immediate results can be obtained. However, some supplements are best added to the media in the bag system. For example, tomatoes require a tremendous amount of calcium which is available in many forms. The most soluble form is calcium nitrate, which supplies high nitrogen as well as a high level of soluble calcium.

When high calcium is required in a nutrient film or sub-irrigation system, calcium nitrate must be used and the solution usually ends up with too much nitrogen. In a bag system, less soluble calcium compounds such as calcium phosphate, calcium sulfate or calcium carbonate can be added to the bags at any time without interfering with the other elements in the nutrient solution. Tomatoes require a lot of calcium, magnesium, phosphorus and potassium; but low amounts of nitrogen, particularly during the early stages of growth.

TOMATO
INJECTOR & NUTRIENT FILM FORMULA
CHEM-GRO
B-300 Series
4-18-38

Total Nitrogen (N)	4%
Available Phosphoric Acid (P2O5)	18%
Soluble Potash (K2O)	38%

Trace Elements

Iron (Fe)	.3%
Manganese (Mn)	.1%
Zinc (Zn)	.01%
Copper (Cu)	.02%
Boron (B)	.1%
Molybdenum (Mo)	.002%

Many growing medias are used with the pot or bag system. The most popular is a peat-lite or modified peat-lite mixture. These mixtures are ideal since they have good water and nutrient holding capacity and are light weight. Some of the more common medias being used are:

System No. 1

40% Peat moss, 40% vermiculite & 20% sand (recommended mix for subsequent planting of trees or shrubs)

System No. 2

75% Horticultural grade perlite + 25% vermiculite

System No. 3

1/3 Perlite, 1/3 shredded sphagnum peat moss, 1/3 vermiculite

System No. 4

Straight concrete aggregate perlite

System No. 5

Straight aged sawdust, preferably redwood (other aged sawdust if tested 1st)

System No. 6

50% shredded sphagnum peat moss, 50% vermiculite

System No. 7

Coarse washed sand

System No. 8

1/3 shredded sphagnum peat moss, 1/3 vermiculite, 1/3 aged sawdust

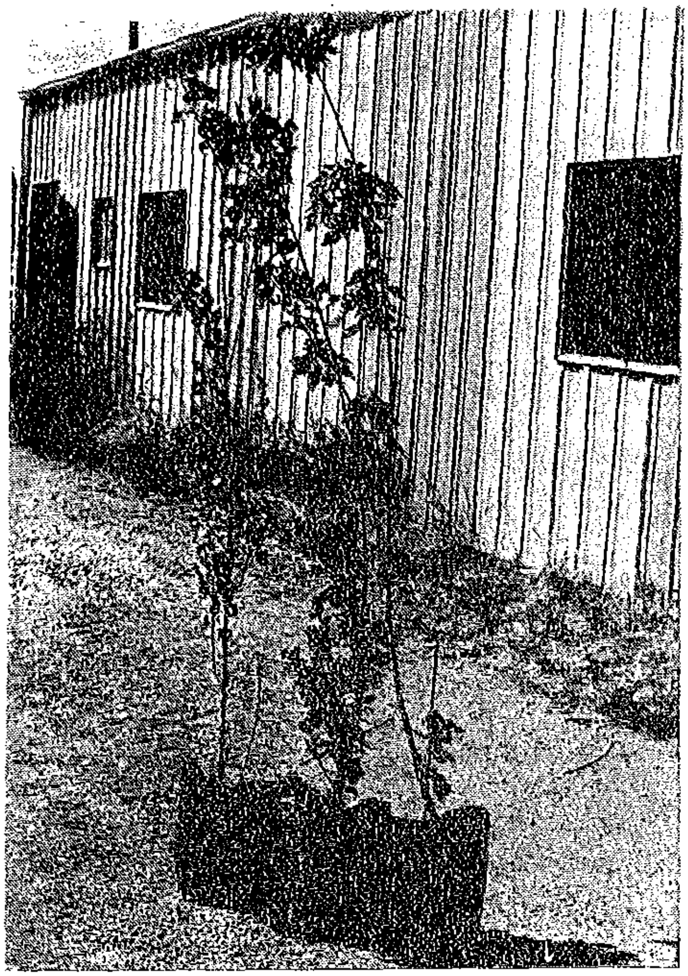
System No. 9

Light weight volcanic rock such as scoria, pumice, etc.

System No. 10

Rockwool

The most common mixture is a commercial grade peat-lite mix. This can be purchased at most nursery centers and greenhouse supply companies. However, it may be more economical for large operations to mix the media. The best lightweight mixture, for Hydro-Gardens, has been 40% shredded sphagnum peat moss, 40% horticultural grade vermiculite, and 20% coarse sand. Once the tomato or cucumber crop is finished, the main root system is cored out of the bag and a small tree is planted in the used bag of media. The tree, bag and media are subsequently sold.



A simple method would be to mix 1 - 6 cubic foot bale of sphagnum with 1 - 6 cubic foot bag of vermiculite and 3 cubic feet of sand. The percentage of each is not critical. Once the material is mixed it is very light weight and can be handled easily. This type of mixture does not wet easily the first time. Additional watering is required to initially wet the media and a wetting agent may be used if desired. After it has been wetted thoroughly, the number of feedings should be reduced. Peat-lite mixes can be purchased locally in most areas but care must be taken to insure that no high nitrogen starter fertilizer has been added.

Feeding schedules vary depending on the type of plant and media. Normally, tomatoes are fed for 1 minute, once per day at transplant if a peat-lite mix is used with a type "P" 1/8" spray tube. This spray tube delivers .07 GPM or about 8 ounces per minute. As the plant gets larger, the number of feedings per day is increased as needed. The spray tube should be situated so that it sprays evenly just across the top of the growing media placing the nutrient solution at the base of the plant. Slight adjustments may be needed from time to time to insure a proper spray pattern. Each bag has one spray tube and normally contains two tomato plants. Due to the space requirements, only one cucumber plant per bag should be grown. Each bag receives a set amount of water and nutrient at each feeding time.

Cucumbers require about twice as much water and nutrient as tomatoes. Two time per day for one minute may be sufficient on small plants, but must be increased about one feeding per day per week until 5 or 6 one-minute feedings are being given from sun-up to about 1 hour before sundown. At this point, the cucumber is producing. Slight adjustments may then be needed depending on the weather and day-length. Increases or decreases in nutrient concentration should be verified by laboratory analysis.

The following table gives a formulation for European cucumbers. The formula is supplemented with calcium nitrate and magnesium sulfate.

EUROPEAN CUCUMBER FORMULA
CHEM-GRO
B-300 Series
8-16-36

Total Nitrogen (N)	8%
Available Phosphoric Acid (P2O5)	16%
Soluble Potash (K2O)	36%

TRACE ELEMENTS

Iron (Fe)	.1%
Manganese (Mn)	.05%
Zinc (Zn)	.005%
Copper (Cu)	.01%
Boron (B)	.05%
Molybdenum (Mo)	.001%

Gravel and sand bed sub-irrigation systems, or any type of hydroponic system, can be converted to the TOP-SPRAY SYSTEM very inexpensively. If an existing sump nutrient tank is used, the pump size or pump quantity must be increased until the proper spray pattern is obtained. Most submersible pumps deliver large volumes at low pressure. Pressure equalization is done by the small 1/8" feeder tubes. A centrifugal pump would be a better selection for this type of system.

For new operations, large sump tanks are replaced by small concentrate tanks, an injector, and a sequence timer. The sequence timer and injector are capable of automating up to 1 acre of plants. With the use of an injector system there is very little water or nutrient wasted. The nutrient has to be checked only once every two weeks or as little as once per month! Once the pH is adjusted it remains constant until the entire nutrient concentrate is used up. Labor is reduced tremendously and plants respond much better to a stable nutrient solution.

In order to put the price of the entire greenhouse in perspective, it is necessary to break down the cost of the building, equipment and growing system. The following list has been prepared to give a estimated percentage of the costs for a 30' x 126' greenhouse if it were purchased from a commercial greenhouse supplier:

FRAME, COVERING, COOLING AND HEATING EQUIPMENT

30' x 128' GREENHOUSE

		% of Total Greenhouse Cost
1.	Frame, 2" square steel, galvanized with bows on 6' centers, 20 psf live and dead load.	30.0%
2.	Exhaust fans, 48" 1 HP with housing, automatic shutter & safety guard, (2 each)	15.0%
3.	Cooling pad system, complete with Kool-Cel pads (4" thick x 5' high x 24' long) and water distribution system, including pump, strainer & tank	10.0%
4.	Vent systems; solid rack & pinion type with aluminum frame, fiberglass body & mounting hardware	5.0%
5.	Vent controller, automatic motorized gear box and thermostat control and mounting hardware	2.5%
6.	Fresh air vents, motorized	1.0%
7.	Blower type heater with built-in air distribution system (350,000 BTU input for 80 degree F. differential)	15.0%
8.	Carbon Dioxide Generator and automatic controls	2.5%
9.	Thermostat control panel w/aspirator box	2.5%
10.	Covering, two layers U.V.R. polyethylene (3 year film) with inflation kit	5.0%
11.	Poly-locking devices, sides & ends	3.5%
12.	End wall covering (12 mil vinyl & accessories)	2.0%
13.	Plant Support system	6.0%
		100.0%

A galvanized steel frame including ends, base plate, doors and door frames cost less than $3,000.00. The frame is less than 1/3 of the total cost while the cooling, heating and covering equals 2/3 of the total cost.

Concrete floors are a luxury of the past for greenhouses. A new product by AMOCO called Pro-Pex ground cover is excellent for greenhouse floors. This material is impervious to weeds but allows water to seep through. The floor stays dry and the material is not slippery. This material is heavy enough for normal greenhouse traffic even with motorized carts and tractors. The cost is only $2400 per acre whereas concrete would be closer to $30,000 per acre!

The other critical cost factors are labor, plumbing, excavation, and the growing system. No one knows what a nutrient film system costs until it is complete. High installation costs, particularly in leveling the land and obtaining the proper slope are difficult to estimate in advance. However, the materials cost comparison between a "nutrient film" system and a "bag" system is important.

The cost of a nutrient film system has been estimated to be approximately $2,000 for a 35' x 124' greenhouse. The following table will give the cost of materials of a bag system.

MATERIALS COST OF A HYDROPONIC BAG SYSTEM

30' x 128' Greenhouse

600 5 gal. heavy duty bags with drain holes (2 plants per bag for

	tomatoes or one plant per bag for European cucumbers)	$ 84.00
600	Top spray feeders with 24" feeder line	84.00
600'	1" black poly pipe, 80 PSI	80.00
5	1" automatic valves, 24 volt	112.50
5	PVC tees, el's and poly adapters	30.00
30'	1" PVC Class 200 pipe	12.00
		$402.50

A fertilizer injector and a sequence timer operate this system. Injectors range in price from $340.00 to $1000.00. Sequence timers range in price from $395.00 for a 10 station to $695.00 for a 40 station, and can operate the feeding systems in 2 to 8 greenhouses! The size of both the injector and the sequence timer vary with your current building plans and should allow for any planned expansion.

The cost for a completely automated bag system with injectors, sequence timer, bags, feeders, piping and valves is only about .10 per square foot. The cost of a nutrient film system is approximately $.75 per square foot, or over 7 times as much.

The labor to install a bag system is approximately 20 manhours (not including filling the bags). Six hundred bags require 400 cubic feet on mix. These mixes can be almost any inert substance with the correct properties such as sawdust, sand, perlite, or peatlite. The growing mix can even be sterilized soil. The cost can range from $1.00 per cubic foot ($.65 per bag) to practically no cost at all with materials such as coarse sand or aged sawdust. Some of these mixes can be reused for other crops such as nursery stock after the tomato or cucumber crop is finished. There are almost 10 acres of greenhouse tomatoes and cucumbers in redwood sawdust in California at the present, and that number is increasing rapidly.

A summary of the advantages of the bag system are as follows:

* The slope of the land is not critical.
* Installation is extremely simple.
* Almost any growing media can be used.
* There is no daily adjustment of nutrient concentration or pH.
* The used bag of media can be sold at a profit.
* Since everything is above ground in black bags, there is no need to heat the nutrient solution. The bags actually absorb heat and create an ideal temperature for the roots.
* Since there is no recycling of nutrients, the loss of plants due to waterborne diseases such as pythium is virtually eliminated.

There are thirteen major problems associated with both field grown and hydroponically grown vegetables. White fly, aphids, leaf miners, pinworms, cutworms, nematodes, bacterial wilt, Fusarium wilt, pythium, Cladosporium leaf mold, viruses, poor fruit set, and nutritional disorders affect all crops in greenhouses and in the fields. In fact, most of these insects, diseases, and other problems are more difficult to control in the field than in the greenhouse.

Certainly there are diseases that are more prevalent in greenhouse tomatoes and some that are more prevalent in the field. In fact seven out of the thirteen are easily controlled, namely insects and leaf mold. Poor fruit set and fruit disorders are caused from a combination of factors affecting pollination, mainly low light conditions and high nitrogen. A grower may or may not be able to control these problems completely, especially in field tomatoes. However, if he is aware of the causes he may be able to reduce the losses.

Bacterial and Fusarium wilt are seldom seen in hydroponic tomatoes and I have yet to see either in a hydroponic bag system. If resistant plant varieties are used these two diseases will not be a matter of great concern.

This leaves only two out of thirteen as serious contenders for total crop infestations; Pythium and viruses. Pythium is more prevalent in warm climates, particularly when water temperatures are very warm (above 75*F). In a nutrient film system, this water temperature may rise to 80*F or more by flowing through a black tube. Nutrient film tubes should be black inside with white or silver on the outside with little or no light transmission through the plastic.

Once Pythium has infested a crop it is difficult to control. Root damage is the main cause of Pythium spread. If roots can be maintained in a healthy state, pythium appears to be easily contained. Several things are associated with poor root growth: low pH (below 6.5), low phosphorus, and generally unbalanced nutrition. Pythium is not something to be taken lightly. If you understand it you can usually avoid it most of the time.

One of the major diseases in greenhouse tomatoes is TMV (tomato mosaic and tobacco mosaic virus). The problem is that most growers do not even know they have it. The fact that a grower is using a hydroponic method of growing has no bearing whatsoever on the spread of this virus. This virus is spread mostly by touch (hands, pruning tools, etc.). It can also be spread by sucking insects, although this is controllable. It usually enters the greenhouse in the seed. In many cases TMV does not totally destroy the plants, but instead, reduces the production of the infected plants by 15% - 30%.

Viruses have been around as long as tomatoes and will always be a potential problem. The major concern of tomato seed companies at the present is to breed virus-resistant varieties that will produce heavily and still taste like a tomato. At the present time there are no completely resistant varieties in the world that are suitable for U.S. growers. Several new varieties are being developed, particularly by Holland seed companies. One U.S. company (Goldsmith Seed) has several good homozygous (single-gene) resistant varieties. One seed in particular that is very good is GS-130. There are several heterozygous (double-gene) resistant varieties on the horizon that offer hope for the tomato grower.

I think the biggest problem associated with hydroponic farming is the fact that new growers are led to believe that growing vegetables hydroponically is a simple task that anyone can do anywhere and expect high profits.

Hydroponics has a definite place in the agricultural world and will become more important in future years. Growing tomatoes hydroponically is fascinating, enjoyable, and can be profitable. The grower has to know what to expect so that he recognizes the potential problems before they become serious.

CONCLUSION

Much of the world's turmoil can be traced to man's quest for food. Food production has been far less than what is needed in most of the countries in the world and during the next twenty years humanity will be put to the greatest test. In 30 years the earth's population could be 7 billion compared to 4 billion today. In the past twenty years the United States has supplied over $25 billion in food to other countries. During the next 25 years we may be expected to feed as many people as we have fed since the dawn of history. This is a problem that we must address quickly and seriously.

We must double food production at a time when most countries are losing arable land. Over half the world's population goes to bed hungry every night. Can we produce enough food throughout the world to feed these people? We can if we continue to use the latest advancements in technology. We must continue to develop new methods of intensive agriculture, new fertilizers, more productive varieties of plants, new safe, effective pesticides. Also, we must make agriculture more economically viable to attract more interest into the industry.

No matter how productive we are, the United States alone cannot feed the world. We must help other countries to become capable of sustaining their own populations. We must plan for long term producton as well as short term production. Hungry people will not remain invisible or silent. No matter how remote their country may be, they are still aware of the better living conditions in other parts of the world. Hungry people have the power to start wars, revolutions and to topple governments. The United States has agricultural power and we must use it in the best interest of our own people as well as the rest of the world.

THE NUTRIENT FLOW TECHNIQUE -

a versatile and efficient hydroponic growing method

Dr. P. A. Schippers

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Presented at the Inaugural Meeting of the

Hydroponic Society of America

held in Oakland, California,

on October 20, 1979

Page

INTRODUCTION

1 PRINCIPLE OF NFT 1

2 DEVELOPMENT OF THE NUTRIENT FLOW TECHNIQUE AT THE LONG ISLAND HORTICULTURAL RESEARCH LABORATORY 2

3 CONSTRUCTION OF NUTRIENT FLOW SYSTEMS 5

3.1 GENERAL DESCRIPTION OF THE COMPONENTS 5
3.1.1 Growing bed 5
Is a substrate needed? 5
Size, shape and materials 5
3.1.2 Containers 6
Nutrient container 6
Receiving basin 6
Water container 6
3.1.3 Hardware 6
Pumps 6
Other parts 7

3.2 DETAILS OF VARIOUS SYSTEMS 7
3.2.1 Horizontal systems 8
Troughs for large plants 8
Channels for smaller plants 9
Flat bed system 10
3.2.2 Cascade system 10
3.2.3 Vertical system 11

3.3 TECHNICAL POINTS 12
3.3.1 Rubber stoppers and tubing 12
3.3.2 Float switch 13
3.3.3 Float valve 13
3.3.4 Pumps 13
3.3.5 Manifolds and feeding lines 14
3.3.6 Electric work 14
3.3.7 Suppliers 14

4 OPERATING A NUTRIENT FLOW SYSTEM 15

4.1 FERTILIZATION 15
4.1.1 Nutrient concentrations 15
4.1.2 Type of fertilizer 16
4.1.3 Frequency of fertilization 16
4.1.4 Requirements of different species 18

4.2 TROUBLESHOOTING 18

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INTRODUCTION

Hydroponics - the method of growing plants without soil - has had its ups and downs over the years. Many of these fluctuations have been caused by excessive claims expressed by overeager journalists and purveyors of hydroponic equipment and installations. For instance, it is claimed that yields of hydroponically grown plants can be five to fifteen times as high as those of plants grown in soil; that considerable savings in space can be achieved, without loss in yield per plant, by placing plants twice as close together as is normally the case; that plants in hydroponics grow 30% faster than those in soil; that the plant's requirement for water and fertilizer is only 10% of what is required with normal growing methods. And this list could be extended considerably.

It is quite evident to those applying and seriously studying hydroponic growing methods, that none of these claims can be fulfilled by any growing method, hydroponically or otherwise. It will be equally evident that there must be many disappointed people who found out that hydroponics is not the miracle method it was made out to be. This has undoubtedly contributed to many failures of hydroponic growing enterprises and to the questionable reputation hydroponics has as a technically and commercially viable growing method in the mind of a good number of people who are familiar with or even experienced in growing plants.

In spite of this, hydroponics has certain advantages over conventional growing methods, both for the amateur and for the professional grower of horticultural crops. One of the most important advantages for the commercial grower is that - at least with some hydroponic methods - measures to prevent certain diseases from occurring can be taken which are less time consuming, less expensive and more effective than is possible with conventional growing methods. Another important factor for both commercial grower and amateur is the elimination of any uncertainty about watering. Not only the uncertainty about how often and how much water to give is removed, but the possibility that some plants get too much and others not enough is no longer present. A third point is that fertilization is under almost complete control. This has, so far, only been a theoretical possibility, since most people would lack the skills - and probably also the inclination - to apply the chemical methods for the determination of the level of various nutrients which would be required to exert this control, but since very simple semi-quantitative tests for the determination of nitrate-nitrogen, phosphorus, potassium, magnesium, iron, calcium and chloride (in addition to the well known color reaction for acidity) recently have been developed, this possibility is now within reach of anybody, although there are still some technical difficulties.

As a last important advantage - the most obvious one - can be mentioned that, since soil is not needed, plants can be grown, commercially or as a hobby, virtually anywhere where there is sufficient light available. This harbors the possibility of turning areas into highly productive horticultural regions which previously would not come into consideration because of totally unsuitable soil.

Of the many hydroponic methods possible - stationary or non-stationary, recirculating or open-ended, with or without growing medium, flooding intermittently or flowing continuously, trickle irrigation or root misting - one will be extensively discussed in this paper, not only because it is commercially becoming more and more important, particularly in England, but also because of its practicality and enormous versatility. It developed from what in England has been called the nutrient film technique, but the development at the Long Island Horticultural Research Laboratory proceeded in a direction different from that in England and for this and other reasons, it is here called the nutrient flow technique. However, these methods are sufficiently similar that they can both be covered by the now famous abbreviation of NFT.

1. PRINCIPLE OF NFT

In 1973, Dr. Allen J. Cooper, working at that time at the Glasshouse Crops Research Institute (G.C.R.I.) in Littlehampton, England, published his first article on what he called the nutrient film technique in the May 5 issue of the English magazine "The Grower". He gave the following description: "The nutrient film technique is a simple system of hydroponic culture in which crop plants are grown with their root systems in black layflat polythene film through which nutrient solution is continuously circulated". Although the "layflats" have been superseded by other materials, the description is still valid for the system.

Fig. 1 shows a diagram of the principle of the technique as it is used by us today and as it was described by Cooper in one of his early articles. He later replaced it by a system with a continuously operating pump.

Nutrient solution flows from a nutrient container through a growing bed with a certain slope (preferably 2 or 3 in 100, except, of course, in the case of vertical systems) into a receiving basin. A float switch attached to the nutrient container switches the pump in the receiving basin on if the level of the solution in the former drops below a certain point. The pump is switched off as soon as the rising nutrient solution trips the float switch. A float valve in the receiving basin is connected to the water container and this keeps the volume of solution in the system constant: As much water is admitted through the float valve as is lost through transpiration and evaporation. In larger systems it would be practical to connect the float valve with the main water supply line, since this will make watering completely automatic.

2. DEVELOPMENT OF THE NUTRIENT FLOW TECHNIQUE AT THE LONG ISLAND HORTICULTURAL RESEARCH LABORATORY

Intrigued by the potential of the nutrient film technique as shown in the publications of Dr. Cooper we started our first experiments in the fall of 1975 by comparing this technique with more orthodox hydroponic systems in which 6" deep gravel beds with lettuce plants were flooded periodically with nutrient solution from the bottom (also called subirrigation) or from the top (as advocated by Mr. A. A. Steiner of the Netherlands, as it is supposed to give better aeration). It became soon clear that NFT was preferable, since no substrate was needed and no tricky connections had to be made between pipes and the plastic lining in the wooded troughs which we used. It was the most troublefree method, gave the same excellent growth and yields, and was from then on the only one used.

During 1976, crops such as tomatoes, cucumbers and lettuce, all seeded in Jiffy 7's or Kys Kubes, were grown in channels made of plastic (roof gutters, for instance), metal or wood and lined with black polyethylene. It was clear, however, that this would not be economical for crops of which the plants are, individually, of low value such as radish, beetroot, peas, spinach, etc. Since we did not see any economic justification in designing special channels to hold up this category of plants, it seemed most logical and simple to use a substrate as an anchoring medium for the roots. Various substrates such as gravel, bluestone, expanded clay, perlite and vermiculite, were used with lettuce as the test crop and perlite was the one which seemed to be the best choice because of its light weight, its excellent water holding capacity and its loose structure. It became the standard substrate and is not likely to be replaced by something else, although substrates such as expanded clays certainly have merit.

Later it was found that growth was better when lettuce was grown in cubes placed on top of a layer of one or two inches of perlite than when the plants were grown without a substrate. The influence on tipburn occurrence was even more clear: growing without a substrate made many lettuce varieties much more susceptible to this physiological disorder than growing them on perlite. The only area of concern is how the presence of perlite would affect sterilization, if that would be needed.

In the course of 1976 methods were developed for the analysis of the nutrient solution which are relatively simple and fast, but still too complicated for the grower. The use of specific ion electrodes for nitrate potassium, calcium and, sometimes, ammonia proved to be satisfactory, but the specific electrode for divalent cations, which we intended to use for the determination of calcium plus magnesium, was not reliable. A good and rapid spectrophotometric method is in use for the determination of phosphate.

During 1977, a great number of experiments was carried out mostly with lettuce, in which, among other things, the feasibility of rootzone heating was investigated, with promising results. The most interesting experiments, however, were those designed to save greenhouse space. These resulted in successful growing of lettuce in vertical pipes through which the nutrient solution dripped down, moistening and feeding the plants. Twenty-five to thirty plants were accommodated in each pipe of five feet length. Although technically feasible, commercial application does not seem imminent in this stage, at least not with lettuce, since differences in light intensity, even if the pipes are spaced quite far apart, cause differences in growth between top and bottom plants which are too large. Other crops which are harvested over a longer period, such as strawberries, peas, beans, etc. may offer better prospects.

The idea of making better use of the vertical dimension in the greenhouse, particularly for low growing crops, was investigated in a different way which seemed to give better quality and more even size of lettuce. In this "cascade" system, growing troughs of plastic pipes which were cut open were suspended above each other, up to eight high. The nutrient solution entered the high end of the slightly sloping top pipe, exited at the low end of that pipe into the next one, etc., until it ended up in the receiving basin from where it was pumped up to the nutrient container. This system was very successful with lettuce, radish, peas and other crops and will be researched further.

In the same year a hydroponic garden proved the feasibility of the application of NFT in the open. Many vegetables and flowers were grown and even root crops such as potatoes, carrots and chicory flourished in a range of bed shapes and sizes with and without perlite.

In 1978, NFT systems were built which would be applicable and practical under the commercial conditions on Long Island. Tomatoes were grown in a 125' x 35' glasshouse and cucumbers in a 25' x 50' double-layer polyethylene greenhouse in which "conventional" (horizontal) NFT units had been built with readily available materials. The material cost, including pumps and other hardware amounted to roughly $.50 per square foot of greenhouse area. Both crops were grown very successfully, even though a case of root death occurred in the tomatoes. Only one of the three systems in the glasshouse was infected and this infection had clearly started in one area and spread through this one system. However, yields were only affected in a minor way and the few plants which initially showed severe wilting recovered later.

In the same year a test kit was developed which measures, in a semiquantitative way, some aspects of the status of the nutrient solution. By means of very simple drop tests color reactions show the pH and the concentrations of phosphorus, iron and nitrate-nitrogen.

A recent development was the use of movable gutters for lettuce. By adapting the distances between the gutters to the space requirements of the plants at various stages of growth the plant population in a greenhouse can be increased by approximately 50%, a prospect which looks extremely attractive. In this system a batch of plants is moved, at intervals of one or two weeks, from one side of the greenhouse to the other at increased spacings and the abandoned section is occupied by the next batch which is seeded a week or ten days later. Obviously, this system can only work for crops which the grower seeds and harvests at regular time intervals.

Other promising recent developments are the use of one channel for two rows of tomatoes, by doubling the number per channel and leading the plants alternately to the left and the right, occupying ultimately the same area as in the conventional double row system. It will be clear that considerable savings in material costs are possible in this way. Another method now under investigation is the use of triple channels. The outside two channels are normally planted with tomatoes which are grown until they reach the wire at about 7' height. When harvest is about halfway done, a succeeding crop is planted in the middle channel with the number of plants double the normal number. When the outside plants have finished bearing, they are removed and the new crop will start producing in a short while. This system of growing has certain advantages over the conventional way of continuous harvesting of the same crop in that always young plants are grown which produce higher yields of larger sized and better quality fruit than the crop of old plants. Theoretically, it would be possible to use the outside channels again for a third crop, etc., but this has not been tried yet.

As a last development has to be mentioned the further expansion of the test kit with simple determinations of potassium, magnesium, calcium and chloride.

3. CONSTRUCTION OF NUTRIENT FLOW SYSTEMS

It will be clear from Fig. 1 and the explanatory text pertaining to that figure that a nutrient flow system is simple to construct and maintain. Many variations in size and type of construction are possible, but they have all several features in common. These will be dealt with in the following general description of the components of the system. Later the various systems will be described in greater detail.

3.1 GENERAL DESCRIPTION OF THE COMPONENTS

3.1.1 Growing bed

The growing bed can have a variety of sizes, shapes and positions, depending on what crops are grown and on how one wants to make use of the available space. Therefore, details will be given later, and only some general comments will be made at this point.

Is a substrate needed? Commercially it would be most attractive to use beds without a substrate, since this would facilitate removing the old crop, replacing the plastic lining in the bed and planting the next crop, all within hours. For crops such as tomatoes and cucumbers, which are supported by twine, this would be the preferred way of growing.

This system could be used also for crops of which the plants can stand by themselves, such as lettuce seeded in peat blocks, but the use of a layer of 1 or 2" of perlite still has to be considered as an attractive alternate, since as has been mentioned before, the size and quality of the heads is better when the plants are grown on perlite. As lettuce, so far, has not shown any diseases carried through the system with the nutrient solution, considerations of sterilization are not as important as with tomatoes and cucumbers.

Crops for which using peat blocks would be economically undesirable would have to be sown directly into the bed. In these cases the use of perlite would be inevitable, unless some inexpensive system of support could be devised.

Size, shape and materials. In general, the width of individual troughs for crops such as tomatoes and cucumbers does not have to be more than 6". For lettuce, channels of 3" wide would be sufficient. Pipes used in the cascade system (see 3.2.2) are usually filled with perlite and they should be at least 2" in diameter if crops with fairly small root systems are grown (e.g. radish). A diameter of 3" or more will accommodate a larger variety of crops. In the vertical systems (see 3.2.3) the pipes, which have no substrate, should not be wider than 2", since the nutrient solution sometimes bypasses the roots of some plants if the pipes are wider.

If troughs in the horizontal systems are made of wood or metal, they should be lined with 4 mil black polyethylene to make them waterproof or to prevent corrosion.

In the flatbed system (3.2.2.), sheets of plywood or masonite - if necessary reinforced to give them the needed stiffness - are used which are lined with 4 mil black polyethylene.

3.1.2 Containers

Nutrient container. In small systems it is most convenient to use readily available plastic containers such as 6, 10 or 20 gallon trash cans, painted with several layers of white paint to protect the plastic against the destructive action of the sunrays which make the plastic brittle after a while. In these small systems the volume of the nutrient container contributes significantly to the total volume of nutrient solution contained in the system.

In larger systems of commercial size, most of the nutrient solution will be in the receiving trench and the size of the nutrient container is not as important as the shape of it. As has been mentioned in Chapter 1, the float switch will move down and up, switching the pump on and off, respectively. In order to reduce the frequency of pumping the volume of nutrient solution between the high and the low limit in the nutrient container should be as large as possible. Since the vertical dimension is fixed through the movement of the float switch, a large volume can only be obtained by having a wide and long nutrient container rather than a high and narrow one. A 20 or 30 gallon metal drum, for instance, placed on its side and provided with the necessary holes, is an excellent nutrient container if its inside is either plasticized or painted with an asphalt paint. It is, however, also possible to build a wooden container in the form of a tray and line it with plastic.

Receiving basin. In this case also we have to make a distinction between small and large systems. In the former, plastic containers are again the best to use, but for commercial systems the receiving basin should consist of a trench, at least a foot wide and a foot deep, dug into the ground and lined with 6 mil black polyethylene. Although more expensive, it would be preferable to line this trench with lumber before lining it with plastic. Such a receiving basin holds a large amount of nutrient solution and is excellent from the point of view of prevention of diseases. After every crop of tomatoes or cucumbers the solution can be pumped out, the plastic can be replaced and the new crop can be started under clean conditions.

Water container. Again we have to make the same distinction. In small systems a plastic trash can is a good container, but in systems of commercial size the float valve should be connected directly to the water supply line.

3.1.3 Hardware

Pumps. We found two types of pumps most satisfactory, a small submergible pump with an output of about 70 gallons per hour at a 5 ft head and a circulating pump with an output of about 200 gallon per hour at a 5 ft head. The advantage of the first is that it is standing on the bottom of the receiving basin and will work independently of the amount of solution in the basin. It is also noiseless, which under certain conditions may be important. Its disadvantages are that it is somewhat more expensive and that it can not lift very high. It is, therefore, unsuitable for vertical systems in which the lift would be more than 7 feet.

The circulating pump is less expensive and stronger. It can lift up to 10 feet, although, at that height, it loses quite a bit in capacity. It is noisier and needs special care in installing. If the receiving basin is not too high, this pump can be placed on the bottom (secured against falling over!) if the motor is located higher than the rim of the basin, so the motor will not get wet if the basin for some reason is overflowing. With deeper basins, however, the pump has to hang in the solution with the motor, again, above the rim of the basin. The drawback is that when the water level gets too low, the propeller will be running in air and this may damage the motor. The best solution, we found, was to mount the pump in a polyurethane raft with the motor above the raft and the propeller under it.

This pump is strong enough to be used in small commercial greenhouses (say, 25 x 50 ft), but in larger ones it would be advisable to use a heavier type. Considering the price of these pumps, having two instead of one pump for added safety would be no luxury.

An important point to remember is that the capacity of the pump should be considerably larger than the total quantity of solution discharged through the inlets into the troughs. Suppose that the inflow in 32 troughs in a greenhouse is ½ pint per minute per trough, then the total inflow is equal to (32 x ½ x 60)/8=120 gallon per hour. If the pump has this capacity at a "head" equal to the difference in height between the location of the pump and the inlet of the return hose in the nutrient container, then the pump can barely keep up. Any intentional or accidental increase in rate of inflow will result in the nutrient container slowly emptying out! Therefore, it is advisable to have the capacity of the pump at least twice or three times as high as the expected maximum quantity flowing into the troughs.

Other parts. The float switch does not need any comment, except perhaps that it ordinarily is sold without float ball, float rod, and nuts. The float valve, however, needs some discussion. In small systems a small float valve is used which is connected to the water container with rubber tubing. In larger systems in which the float valve is connected with the water supply line a larger type is recommended, particularly if tomatoes and cucumbers are grown, since these crops can transpire large quantities of water. Since rubber tubing cannot withstand the pressure of the normal water supply line, the connection between this line and the float valve has to be made with brass tubing.

Some other items are needed for the construction of various systems, but this will be discussed in the sections dealing with these systems and in the section on technical points.

3.2 DETAILS OF VARIOUS SYSTEMS

In the following pages details will be given of several systems which worked very well, but this does not mean that these details have to be copied to the letter if one wants to build a certain system. Various other ways of construction are possible and may even be better. This depends mainly on (1) the local availability of suitable and inexpensive materials, (2) on where the system will be located and (3) on personal preference.

3.2.1 Horizontal systems

These will probably be the most commonly used ones, since they are the easiest and least expensive to install. They can be used under many different conditions and in many locations, and they are suitable for a great variety of crops. Three subsystems which can be used for different types of crops will be discussed.

Troughs for large plants Troughs without substrate can be used for crops such as tomatoes and cucumbers which are supported with the help of twine.

One of the least expensive ways to make the troughs is to nail 4" wide strips of 1/8" masonite as sides against a bottom of 1" x 6", or even 3/4" x 6" pine. If these troughs are made in sections of 8 or 12 feet length, they are easily moved around which is a big advantage if one wants to grow a different crop requiring a different spacing. These sections do not have to be joined together as long as the ends have a common support, for instance, a cement block.

The troughs are lined with polyethylene cut so wide that a foot of plastic hangs over one side. After the plants have been planted, incisions can be made at the location of the plants and the slips of plastic so formed can be flipped over to the other side, excluding light from the channels. It is important to keep as much of the nutrient solution in the dark as possible, since this will prevent the growth of algae. Algae are easily transported by the solution and may clog up the inlet tubing.

Placing the troughs across the width of the greenhouse had the advantage that they can be relatively short which is easier in obtaining the right slope. A more important advantage is that a long receiving trench can be dug which insures that there will be sufficient nutrient solution per plant available. This trench is lined with lumber and polyethylene. The latter should be cut quite wide, so the excess can be used as a "lid" on the trench to keep the light out.

The larger the volume of the nutrient solution is, the slower the nutrients are depleted. Therefore, periods between fertilization can be stretched out, which is more convenient. Since in large systems without substrate most of the nutrient solution is in the trench and relatively little in the beds and in the nutrient container, it follows that the receiving trench should be as large as possible. Its size should be based on the number of plants in the system. For tomatoes and cucumbers twice as many gallons of nutrient solution as there are plants in the system would be an excellent volume, although good results can also be achieved with smaller quantities per plant.

In general, the flow into the receiving basin has to be watched rather than the inflow in the troughs, particularly on hot days when transpiration is high. If no solution is coming out of the troughs, even if the inflow seems to be sufficient, it means that the water is used up somewhere along the trough and that plants at the end of the trough will be in trouble very soon, if they are not already.

The nutrient container can be a metal drum of, say, 35 gallon, placed on its side, about 7 ft high. An opening cut out of the top is needed to paint the inside with asphalt paint. A float switch has to be mounted on one of the flat sides after a hole has been drilled for the float switch lever to go through. Another hole is needed for the hose coming from the pump.

Recently we have turned to a wooden channel as a nutrient container, which is a little easier to handle and has the advantage that the plastic lining can be replaced and that cleaning therefore is not needed after a crop. The connection between the 4 mil black polyethylene and the hose from the pump can be made with a hose repair kit plus silicone sealer. Of course, a hole is needed in the wooden box for the hose to pass through. Since there is not much strength needed, the box can be made out of plywood. The size is dependent on the number of troughs being fed. Although no hard rules can be given, it seems to us that at least one gallon volume would be needed for every outlet present. At a rate of inflow of one quart a minute the container would then be emptied out in about four minutes.

Feeding lines of 1" PVC pipe are usually wide enough. Rubber tubing, inserted in the pipes with the help of rubber stoppers (See 3.3.1) can be used as inlets. The flow is best regulated by screw clamps.

Although for smaller systems the same type of trough can be used, other materials are also suitable, for instance, plastic or aluminum roof gutters, but in the latter case one has to make sure that the metal does not come into contact with the nutrient solution since this is fairly corrosive and several materials are toxic to the plant.

In smaller units the use of perlite as a substrate can often be justified more easily than in large systems. For non-commercial growers it would certainly be recommended.

For growing of root crops, the use of perlite is necessary. Fairly deep channels are needed with a thick layer of perlite, e.g. 8" for potatoes, 6" for large carrots and 4" for the smaller type carrots.

Channels for smaller plants In principle, the same system can be used, but the troughs would be narrower and shallower. However, the price of such a system would be relatively high because of the large number of channels needed. It may be better to use the flat bed system (see next section) or to construct channels by nailing at the proper distances, one-by-two's with their narrow sides on a sheet of plywood and forming channels by pushing the plastic down between the strips.

In these channels, plants such as lettuce in peat blocks can be grown without a substrate, but placing the blocks on a layer of 1" or 2" of perlite in the channels gives better results and adds safety, because drying out will not occur so easily if the inlet tube of a channel is clogged.

A variation of this system which shows promise commercially is to have moveable channels which enable the grower to accommodate more plants in the greenhouse by adapting the spacing to the requirements of the plants at various ages. In this system, the channels are gradually moved from one side of the greenhouse (at close spacing) to the other side (at wide spacing), as has been described in Chapter 2.

Flat bed system This system is useful for small plants which are seeded directly in place, which means most vegetables not mentioned before, such as radish, beetroot, peas, beans, spinach, chives, etc.

It consists of a sheet of plywood or masonite with a rim on three sides, lined with plastic and filled with a couple of inches of perlite.

At the low end, a nylon screen prevents the perlite from falling into the receiving basin. It is also possible to have a rim at the low end with an opening in the center through which the nutrient solution can run into the receiving basin. This opening has to have screening too. In the latter option, the nutrient solution can run into a container, and a trench-like receiving basin is therefore not needed. In the former case the nutrient solution runs out over the full width of the bed. It can run into a trench, but it can also run into a piece of gutter which carries the solution into a container.

An inlet tube should be used for each foot width of the bed. This means that either several inlet tubes have to be connected to the nutrient container, or a manifold has to be made with only one connection to the nutrient container.

The advantage of this system, which makes it the best system for amateur growers, is that a blockage in one of the inlet tubes does not matter very much, since the other inlets still provide more than enough water to keep the bed moist. Another advantage is the large quantity of moisture in the perlite which serves as an insurance against drying out of the plants if the pump fails for whatever reason.

3.2.2 Cascade system

The cascade system is essentially a trough system in which a number of troughs is located above, instead of next to, each other and the nutrient solution runs through the troughs successively. This system is used for fairly small plants. Perlite is normally used to support the roots, but it is also possible to use a sort of trellis as a supporting structure. This trellis could, if made sufficiently sturdy, at the same time serve as a support for the troughs. Fig. 2 shows a small system. For larger units, with 20 ft. long pipes instead of 5 ft shown in Fig. 2, the construction would have to be much sturdier.

It is not advisable to make the troughs much narrower than 3" if perlite is used. Channels without perlite can be 2 or 2½" wide if they are sufficiently stiff. If they are not, they require a more extensive supporting system.

The most suitable material is PVC-pipe, although it is not the least expensive. A strip of about 1 or 1½" should be cut out lengthwise with a circular saw or a jig saw. End caps, glued on, give a water tight seal. A hole of 5/8" diameter is drilled in the bottom at the low end a stopper with rubber tubing is inserted to lead the nutrient solution into the next pipe. If perlite is used, a piece of nylon screening material over the outlets will prevent perlite from entering and clogging the tubing.

Four pipes above each other at one foot distances can very easily be accommodated, with six pipes the structure gets already a little high and it is not very convenient to work with a structure of eight pipes, although we have done that on occasion.

In order to use space more efficiently, it is advisable to use a hole in the ground, lined with lumber and polyethylene, as a receiving basin.

The nutrient container has to be placed higher than the top end of the highest pipe. It does not have to be very large, but this depends on the number of vertical structures which it has to serve. A plastic tub of about eighteen inches diameter is sufficient for 15 or 20 outlets. It is easy to calculate how large a volume in the nutrient solution is needed between upper and lower limits of the float switch if the flow out of each outlet is assumed to be about half a pint or one pint per minute.

3.2.3 Vertical system

Plants, seeded in peat blocks, are grown in holes in a PVC pipe with a 2" diameter. They are fed and watered by nutrient solution dripping in at the top of the pipe (Fig. 3).

If one row of pipes is built, the receiving basin can be a trench in - or a wooden frame on - the ground, lined with plastic to make it water proof and covered with plastic (with a hole under each pipe) to keep the light out.

About the nutrient container the same can be said as in the previous section.

The feeding line of 1" PVC-pipe and the growing pipes should be attached to a frame sturdy enough to hold the weight of pipes and plants.

If the system will consist of several rows of pipes, a manifold may be needed to feed the lines and the supporting structure may become somewhat complicated. It depends so much on the particular situation that it is not possible to give much advice on how to construct it. A channel, e.g. a roof gutter lined with plastic, under each row can carry the nutrient solution to the receiving basin.

The holes in the growing pipes can be made with a jig saw and should be a little narrower than the growing blocks (Jiffy 7's are very suitable), so the blocks can be clamped in the holes. Heating the pipes, e.g. with a hot air blower, makes the material soft and pliable and it may be possible to make the planting holes more in the form of a cup which would prevent the nutrient solution from running down on the outside as sometimes happens. This technique is still so new that much experimentation is needed with regard to type of hole, distances between holes and distances between pipes.

The rate of flow should be about a drop of solution every second or perhaps a little faster.

Finally, it should be mentioned that a growing block is not strictly necessary. If plants have been seeded in perlite, they can be taken out when they are large enough to be handled and the base of their stems can be wrapped in a strip of foam plastic after excess perlite has carefully been rinsed off. The foam plastic "collar" will keep the plants in the holes. The same system works also very well with rooted cuttings.

3.3 TECHNICAL POINTS

3.3.1 Rubber stoppers and tubing

Since it is better to avoid contact between metals and nutrient solution, not only because of the corrosive action of the solution, but also because some metals may be toxic to plants, much use is made of rubber and plastics. Although one has to get used to working with these materials, they are easy to handle.

PVC-pipes are rather indestructible, so they do not need much maintenance. Polyethylene plastic, used as lining or to keep the nutrient solution in the dark, will deteriorate and has to be replaced occasionally. This will give no trouble. Rubber stoppers and tubing, also materials which deteriorate after a while, are a little more difficult to replace and some pointers on their replacement will be given here.

We have found that, if a system is in continuous use, the rubber can usually be used for two or three years, but if the system is changed or rebuilt, or the materials are taken apart and put back together again, the cracks which have developed over time may result in leaks.

For working with rubber stoppers some experience is needed in the use of cork borers. The borers are fairly expensive, mainly because a whole set has to be bought instead of the two or three which are needed and because a sharpener is also necessary.

There are several holes to be drilled in plastic containers and this can also very well be done by the cork borers, but the most important use of cork borers is to drill holes in rubber stoppers which serve to make the connections between tubing and containers or between tubing and pipes. Before discussing this, something should be said about the size of tubing which works best. We have made manifolds of polyethylene pipe with "spaghetti"-tubing and lead weights as inlets, but we found that they clogged up too easily. The same happened with various narrow sizes of tubing. The most satisfactory rubber tubing has an inside diameter of 5/16" and a wall thickness of 1/16". This may get clogged up too, if the screw clip is fairly tight, but obstructions can be flushed out very easily when the screw clip is opened up a little. Therefore, this is the only size of tubing which we use, except for the hose running from pump to nutrient container for which a ½" garden hose serves very well.

When drilling holes, it is essential to sharpen the cork borer after every hole or after every two holes, since it rapidly becomes dull. The size of borer is selected by finding the largest size cork borer through which the tubing will not pass. This is the #7 borer for the 7/16" (outside) diameter tubing. The size of the stopper depends on the size of the hole in the container of pipe in which the stopper has to fit. If the holes have been drilled with a small size hole saw (5/8" diameter, the size which we prefer), a #2 stopper will fit. This size of hole can also be made with a #11 cork borer.

With the #7 (sharpened) borer a hole is drilled in the #2 stopper by pressing and turning. Lubrication with water will greatly facilitate this. If the stopper is placed on a piece of rubber (e.g. another stopper), the rim of the borer will not be dulled too much when it comes out at the other end. One should never place the stopper on something hard, since it will damage the cutting edge of the borer and it will cost some time and effort to sharpen it again.

After the hole has been drilled and the cylinder of rubber has been removed with the help of the pin which comes with the borer set, the cork borer next in size (in this case #8) is inserted through the hole. This will need some force, since this borer is a little too large, but it will help again if some water is used for lubrication. When the borer appears at the other end, the tubing can be inserted, since it should fit into this borer, and the borer is removed. This is the most practical way to insert the tubing in the stopper.

3.3.2 Float switch

The float switch can be attached in the nutrient container either with a piece of wire or with the help of a bolt and nut, but in the latter case a hole has to be drilled in the switch for the bolt to go through. It is important that the float switch is attached very firmly, because if it moves a little, the lever can get caught along the rim of the hole through which it enters the nutrient container. The switch should be mounted in the position as shown in Fig. 4. The lever should be bent down somewhat, so that the pump is switched off before the solution reaches the lever hole.

The direction of the stream of water out of the hose coming from the pump should be directed away from the float ball. If this is not done, nutrient solution may gradually seep into the ball, making it heavier and heavier until it is so deep in the water that it does not trip the float switch in time and the nutrient solution will keep coming out of the lever hole until the system is empty, and the pump will still continue to run.

3.3.3 Float valve

Installing the small type of float valve which is normally used in small systems in the receiving basin will not cause any difficulties. If 5/16" (i.d.) rubber tubing is used, one will find that this fits exactly around the threaded end of the float valve and no further tightening is needed. The brass ring and hexagonal nut coming with this valve are not needed.

If the float valve is connected to the water supply line instead of to a water container, brass tubing is needed and some plumbing has to be done. In this case the brass ring and brass nut have to be used.

Larger float valves may need special connections.

3.3.4 Pumps

It has been mentioned before that metals should not come into contact with the nutrient solution. This is not completely possible since most pumps have some metal parts which will touch the solution. The circulating pump which we normally use has a stainless steel shaft which is in contact with the solution. Other pumps which we have also used, e.g. sump pumps, have a brass bottom which stands in the solution. Neither of these metals seem to corrode very much or have a toxic affect on the plants.

The only other thing to be said about pumps is that the sump pump type should be fastened in such a way that it cannot be knocked over, since the motor is not allowed to become wet.

3.3.5 Manifolds and feeding lines

In several cases manifolds have to be constructed, e.g. in the flat bed system (optional) and in the vertical system if several row of pipes are used. What will be discussed about manifolds is also pertinent to feeding lines.

The best material to use is 1" PVC pipe, although we have also used the less expensive polyethylene pipe. The latter, which comes in rolls, is hard to straighten out, however.

Holes can be made with a 5/8" hole saw and outlets are made with the #2 rubber stopper plus 5/16" (i.d.) rubber tubing. One end can be closed with a #6½ stopper, the other end can be connected to the nutrient container through a #6½ stopper with rubber tubing.

3.3.6 Electric work

The only electric work is to connect wires to the float switch before it is mounted and to splice this wire into the lead of the pump. One should be careful that the splice is made in such a location that it cannot get into the receiving basin.

3.3.7 Suppliers

One of the main difficulties in getting an NFT-system started is to locate equipment and materials which usually had to be bought from rather diverse sources. The only company now specializing in a complete line of equipment is the first one mentioned in the following - probably very incomplete - list.

Hydroponic Growing Systems, P.O. Box 252, Calverton, N.Y. 11933	Complete line of equipment, including fertilizers and nutrient test kit.
W. W. Grainger, 5959 W. Howard St. Chicago, Illinois 60648 (Main office, 141 locations, wholesaler!)	Float valves, float switch, pumps.
Fisher Scientific Co., 711 Forbes Ave. Pittsburgh, Pa. 15219 (Main office, more than 20 locations) V.W.R. Scientific, Inc., P.O. Box 1050 Rochester, N.Y. 14603 (and about 20 other locations) Arthur H., Thomas Co., P.O. Box 779 Philadelphia, Pa. 19105 and similar laboratory supply houses.	Rubber tubing, rubber stoppers, clamps, some pumps, etc.

Slater Supply Company, Inc., 143 Allen Blvd., Farmingdale, N.Y. 11735 Al Saffer & Co., Inc., Pearl & Williams Sts. Port Chester, N.Y. 10573 Brighton By-products Co., Inc., P. O. Box 23, New Brighton, Pa. 15066 A. H. Hummert Seed Co., 2746 Clouteau Ave. St. Louis, Missouri 63103 and similar greenhouse supply companies.	Plastic film, perlite, fertilizers.

4. OPERATING A NUTRIENT FLOW SYSTEM

4.1 FERTILIZATION

For a long time the opinion has prevailed that, because the buffering capacity of soil was absent, keeping the nutrients at the right level would be one of the most risky parts of hydroponic growing. Recent research, in England and by us, has shown that this is not the case at all, but that the concentrations of the various nutrients can fluctuate widely without affecting the growth of the plants. This simplifies fertilization considerably.

In contrast with soil, however, it is not possible to give the fertilizer which is needed by a crop all in one portion at the start of the growing season. Instead, fertilizer has to be added frequently. This may seem troublesome, but it has a good side also, because it is possible to give the plants exactly the amounts of nutrients which it needs and at the time that it needs them.

4.1.1 Nutrient concentrations In hydroponics we should not talk about the rate of fertilization, as is done with growing in soil, since this is not very important. Important is the nutrient concentrations for which we should be aiming when fertilizing. We find the following concentrations satisfactory.

nitrate-nitrogen (NO_3-N)	200 ppm*)	iron (Fe)	5 ppm
phosphorus (P)	50	borium (B)	0.5
potassium (K)	200	manganese (Mn)	0.5
magnesium (Mg)	50	molybdenum (Mo)	0.1
calcium (Ca)	200	copper (Cu)	0.05
		zinc (Zn)	0.05

*) 1 ppm = 1 part per million = 1 mg per liter = 1 ounce per 7500 gallons. 10,000 ppm = 1%

The concentrations of nitrogen, phosphorus and potassium are mentioned (always in this order) on the label of the fertilizer. If a dilution is made of 1:1000 (=1 gram of fertilizer per liter of nutrient solution, or 1 ounce per 7.5 gallon), the nitrogen concentration of a fertilizer with the formulation 5-11-26 in the solution will be 50 ppm. Unfortunately, it is still a habit to express phosphorus and potassium as their oxides instead of as P and K. Therefore, the percentages on the labels for these nutrients have to be multiplied by 0.4 and 0.8, respectively, to get the percentages of elemental phosphorus and potassium.

4.1.2 Type of fertilizer Although it is possible to save some money by using a combination of agricultural fertilizers instead of fertilizers which are especially designed for hydroponic growing, it is doubtful whether this would compensate for the extra trouble of calculating and mixing, except, perhaps, for very large hydroponic operations. Apart from that, extra care has to be taken in the supply of trace elements and some knowledge of chemistry is required.

Of the hydroponic fertilizers on the market we have had extensive experience only with Hydrosol, manufactured by Robert B. Peters Co., Inc., 2833 Pennsylvania Street, Allentown, PA, 18104. It has the formulation 5-11-26 which means that the nitrogen concentration is low. The label does not mention calcium, so this has to be given with another fertilizer, for which we use Viking Ship brand calcium nitrate, distributed by Wilson & Geo. Meyer & Co., 270 Lawrence Avenue, South San Francisco, California 94080. This has the formulation 15.5-0-0.

If one gram of each fertilizer is given per liter of nutrient solution (one ounce per 7.5 gallon), the concentrations of N, P and K will be 205, 0.4 x 110 and 0.8 x 260 or 205, 44 and 208 ppm. The other nutrients will be present in the following concentrations in ppm: 190 calcium, 30 magnesium, 3 iron, 1 boron, 1 manganese, 0.3 zinc, 0.1 copper and 0.1 molybdenum.

We find the iron concentration occasionally on the low side for tomatoes and some other crops. In such cases Sequestrene 330 Fe (from Geigy Agricultural Chemicals, Saw Mill River Road, Ardsley, New York 10502) is added which contains 14.2% Fe_2O_3, or 0.7 x 14.2 = 9.8% Fe. A dilution of 1:20 000 would give 5 ppm iron in addition to the 3 ppm given with the Hydrosol.

"Pronto" Gro Hydroponic Special (8-5-16), manufactured by Pronto Plant Food Co., Wisner, Louisiana 71378, with which we have limited - but favorable - experience, contains more potassium and less nitrogen than the Hydrosol plus calcium nitrate combination. It is also a two-part fertilizer.

4.1.3 Frequency of fertilization This has always been a difficult question for authors on hydroponics and the usual answer is to discard the nutrient solution periodically, the intervals depending on the personal preference of the author.

In commercial hydroponic growing enterprises the answer is often to fertilize as soon as the conductivity of the solution drops below a certain level.

We are happy with neither answer. The former is too vague and leads to waste of nutrients and water, the latter is still not sufficiently accurate, since the conductivity of the solution is not only based on fertilizer salts, but also on salts which are not used by the plants. Since the pure water lost through transpiration by the plant is replaced by tap or well water which is far from chemically pure, the result may be a gradual buildup of salts not used by the plants. Because of the high calcium concentration in our well water (about 80 ppm), the calcium concentration in our nutrient solutions after several months can run as high as 800 ppm.

It would, therefore, be much better if the fertilization could be based on something which is not only more specific, but also simple enough and inexpensive for a grower to be used. We believe that the methods of semiquantitative tests which we have developed for phosphorus, iron, nitrate-nitrogen, potassium, magnesium, calcium and chloride fulfill these requirements.

Before going into this, however, something should be said about the pH (or degree of alkalinity) of the nutrient solution. A fresh nutrient solution of Hydrosol and calcium nitrate may have a pH of 6.0 (slightly acidic). When the nutrients are down to about a quarter of the original level, the pH may have risen to 7.0 (neutral). When fertilizers are added, the pH will drop, not to the original level, however, but, for instance, to 6.2. Again, it will rise, e.g. to 7.2, and after fertilization it will be something like 6.4. So, in the course of several weeks the solution becomes more and more alkaline, with the result that certain nutrients precipitate and become unavailable to the plant. The first one to do this is usually iron and it will show up in yellowing of the developing young leaves.

In order to prevent this, some acid has to be added now and then. According to the results of a little experiment, a quantity of 0.0133 ml of battery acid (sulfuric acid with a specific gravity of 1.25) per liter of nutrient solution will bring the pH down by half a point. This is approximately equivalent to 5 ml of battery acid (or about one fifth of an ounce) per 100 gallon (or about two ounces of vinegar or 47 Bayer aspirins per 100 gallon!).

The pH test is another test which can easily be done and is used in conjunction with those mentioned before.

The tests for pH, phosphorus, iron, nitrate-nitrogen and magnesium are carried out in the wells of a porcelain spot plate, those for potassium, calcium and chloride in glass vials. In the first case two drops of the necessary reagents (mostly one, but sometimes two) are added to two drops of solution on the plate and the color which develops gives an indication of the concentration of the nutrient concerned. In the latter case two drops of reagent are added to five drops of solution in the vials and the degree of cloudiness is an indication of the nutrient concentration.

Comparison of color and cloudiness with those obtained with solutions of known concentrations will give an idea about the concentration level.

For most purposes, particularly for hobby growers, it is sufficient to do a pH test and to base the decision about fertilizer application on the result of the phosphorus test. Commercial growers would want more information and for them the tests for pH, nitrate-nitrogen, phosphorus, potassium and iron would be a minimum. An occasional test for magnesium and calcium is also advisable, and the chloride test would be helpful for those who have a rather salty water supply.

Even though solutions with known concentrations will help in estimating the concentrations, their main function is to give the grower experience in assessing the colors. After experience had been gained, these solutions can be used to check one's judgment periodically.

The main difficulty with the test kit is that some of the reagents consist of - or are dissolved in - strong acids, which means that they have to be handled very carefully and, even more important, that they have to be kept out of the hands of unauthorized persons. This, however, is not the case with the reagents for pH and phosphorus, suitable for hobby growers.

Commercial growers are strongly advised to have a complete analysis done periodically, e.g. once a month, particularly with longstanding crops such as tomatoes and cucumbers, in addition to these tests. This can be done by private companies if the land grant college in the state concerned does not offer this possibility.

4.1.4 Requirements of different species In some books on hydroponics it is said that the composition of the nutrient solution should be adapted to the specific requirements of the plant grown. However, we have not had any reason to follow this advice, since growth of all species of vegetables, annuals and foliage plants which we have grown has nearly always been excellent. (The only crop with which we have not been successful is sweet corn and we do not know yet what the reason for this is). We tend to think, however that there may be some differences in iron requirements between species and we often give tomatoes more iron than other vegetables.

Since it is not necessary to give each species its own diet, a variety of different plants can be grown in the same system and this is for us normal practice. However, it is quite possible that cases of incompatibility may be discovered caused by root exudates of one species being toxic to the roots of others.

4.2 TROUBLESHOOTING

Once in a while something goes wrong, particularly with a new and untried system such as described in these pages. The following "schedule" may help in determining the cause of the trouble. It is based on personal experience!

Symptom	Accompanied by	Possible cause
1. Water on floor.	Nothing special; possibly float switch admits water faster than normal.	1. Slow leak (e.g. somewhere in bed), but float valve can keep up with it until water container is empty.
2. Water on floor.	Pump running continuously, nutrient container empty, growing bed dry, water container empty.	1. Solution has been running next to receiving basin; 2. Solution has been running out of nutrient container next to bed instead of in it; 3. Float switch stuck in "down" position, nutrient solution escaped through lever hole; 4. Float switch level broken off in down position;

Symptom	Accompanied by	Possible cause
2. (Con't)		5. Float switch ball too heavy because partially filled with nutrient solution; 6. Leak in nutrient container, growing bed or receiving basin.
3. Water on floor.	Nutrient container empty, growing bed dry (pump not running).	1. Float switch stuck in "up" position; 2. Float switch level broken off in "up" position; 3. Pump defect; 4. Power failure; 5. Failure in electric system (e.g. bad connection in "splice").
4. No inflow in bed.	Nutrient container empty, growing bed dry (pump not running).	1. Same causes as in 3, but receiving basin is large enough to hold the extra nutrient solution.
5. No inflow in bed.	Nutrient container empty, growing bed dry, circulating pump running continuously.	1. Not enough water in system; water level too low for circulating pump.

These symptoms are found in small systems with a container as receiving basin. For large systems with a trench as receiving basin, the situation is usually different in that there is hardly ever a continuously running pump. This is caused by the fact that as much water will be admitted from the water supply line as nutrient solution is lost out of the system. If the leak is in an inconspicuous spot, a lot of fertilizer may be lost, unnoticed at first. A clear sign of trouble is when the float valve keeps admitting water at a fairly high speed on dark days or at night when transpiration is very low.

Sometimes, one will find a lower fluid level in the receiving trench, because the solution leaks out of the system faster than the float valve can admit it. However, this should be accompanied by a very fast inflow through the float valve. Therefore, it is good policy to watch the float valve action closely in large systems.

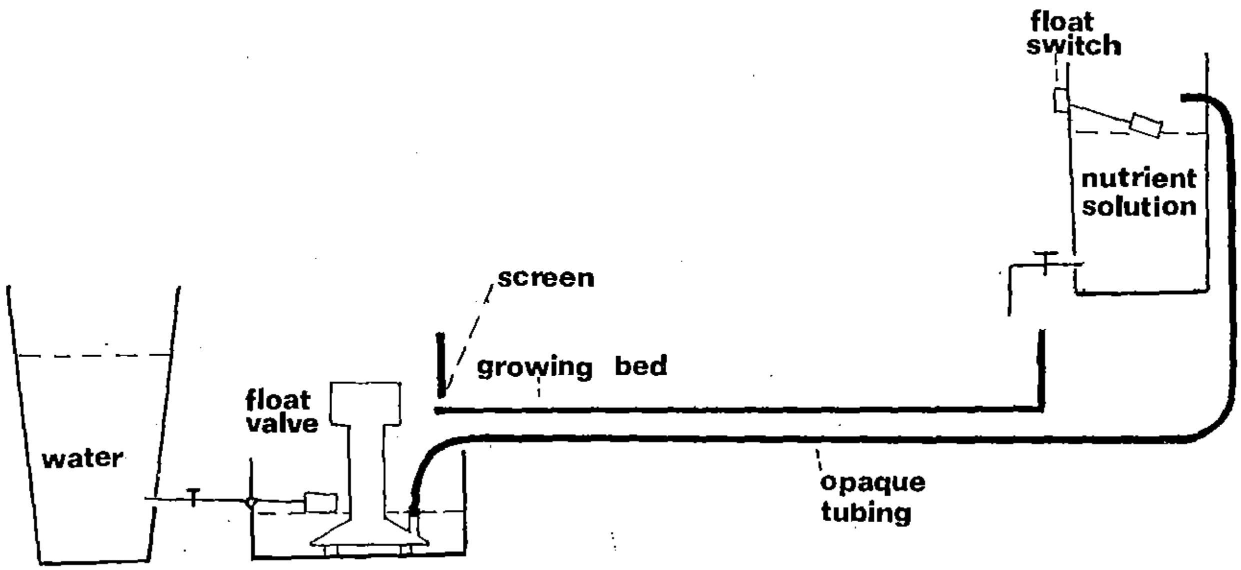
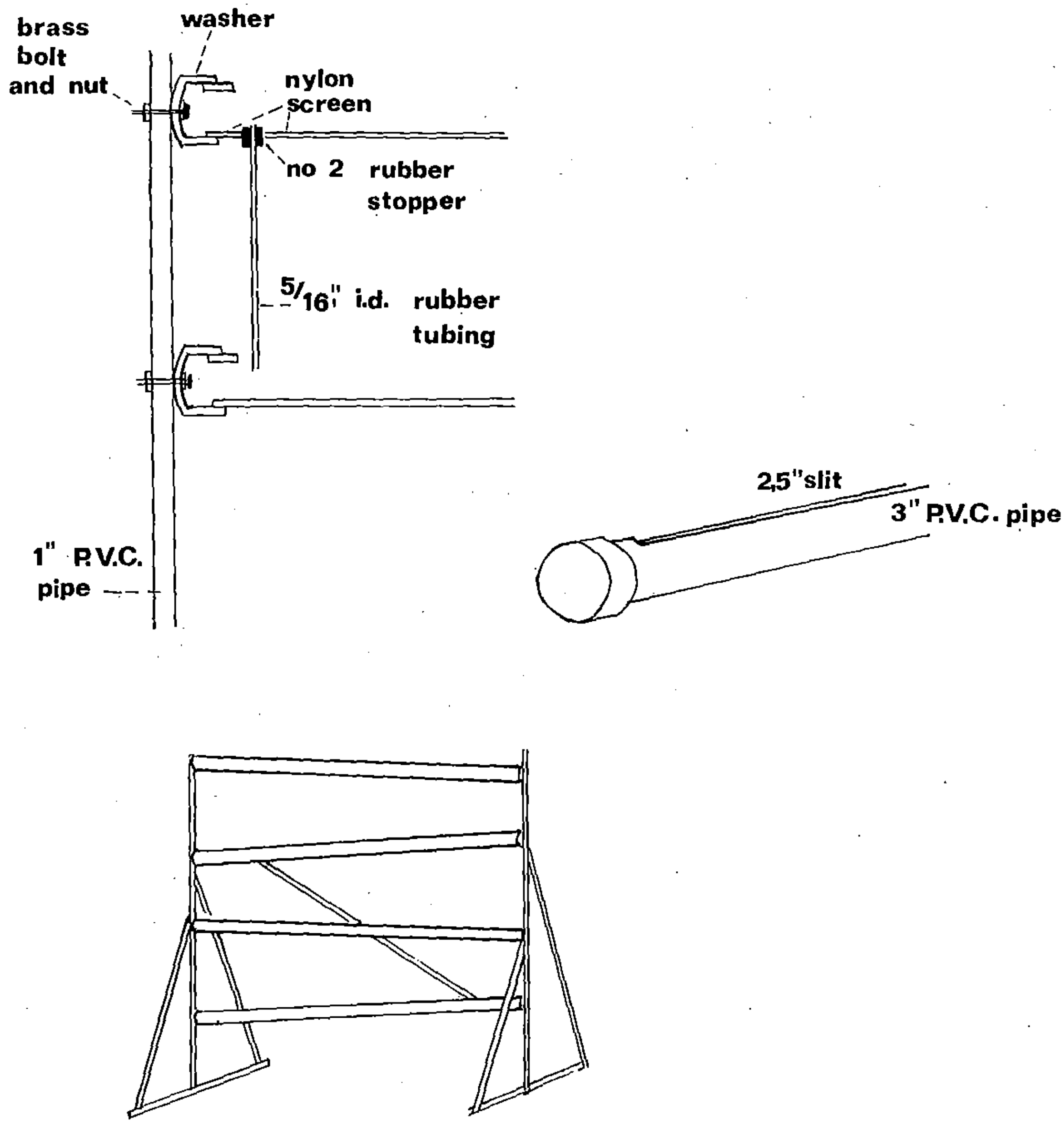

float
switch
nutrient
solution
screen
growing bed
float
valve
water
opaque
tubing

Figure 1



brass
bolt
and nut
washer
nylon
screen
no 2 rubber
stopper
5/16" i.d. rubber
tubing
1" P.V.C.
pipe
2,5"slit
3" P.V.C. pipe

Figure 2

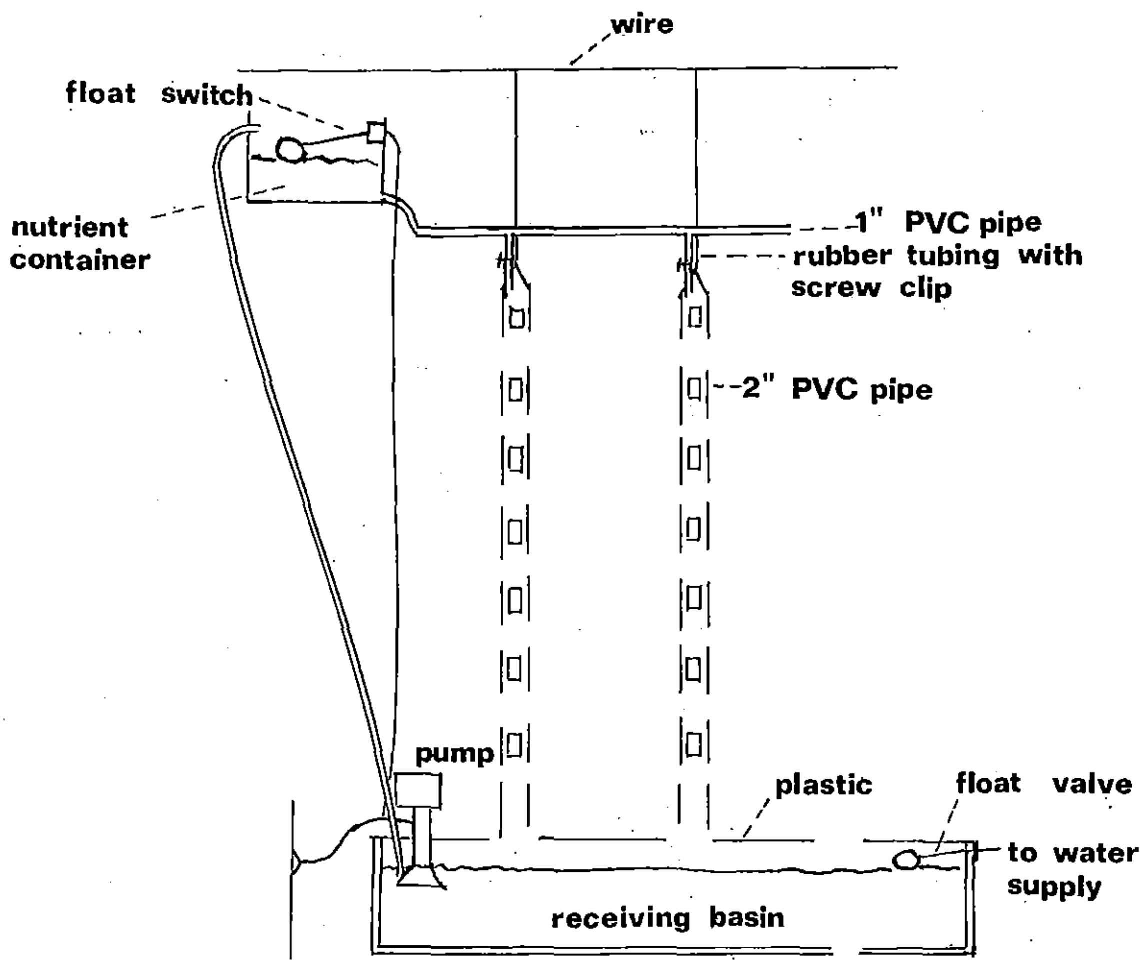

wire
float switch
nutrient container
1" PVC pipe
rubber tubing with screw clip
2" PVC pipe
pump
plastic
float valve
to water supply
receiving basin

Figure 3

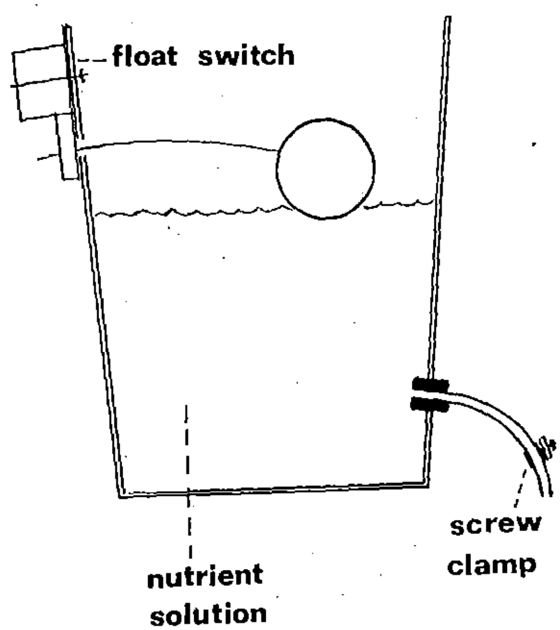


Figure 4

SOILLESS CULTURE AT TEXAS A&M

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While the growing of plants in water without soil dates back several centuries BC, research on plants to determine their make up and source of componets emerged with the developments in the field of chemistry primarily in the past 150 years.

Investigations in plant nutrition required that in order to prove the essentiality of an element, the element must be eliminated from the root environment. Since soil is very complex in make up and often contains a relatively high percentage of the elements making up the earth, the logical method taken to study plant nutrition was to eliminate the soil and grow the plants in the water solution in which the nutrient elements in solution could be controlled.

The first studies of nutrient elements in water solution were made by Sachs (1860) and Knop (1861) in Germany. Gericke (1929) in California started the first commercial adaptation of water culture on tomato production. Later, Setchell at University of California coined the term hydroponics. Because of aeration problems, water culture did not prove to be practical commercially until the advent of the nutrient film technique researched by Cooper (1973) in England.

The popular articles which have appeared in the news media since Gericke's trials as well as advertisements of promoter's greenhouse hydroponic systems claim that hydroponically grown crops yield one-third more to triple or greater than that in soil. Usually the comparisons have been of crops hydroponically produced in the greenhouse with that in soil in the field. For example, 100 tons or more of tomatoes per acre in greenhouse hydroponics compared to 30 tons in soil in the field. Also, automation is usually stressed concerning one advantage of hydroponics over that of soil.

In our greenhouses at Texas A&M we have made comparisons of soil produced tomatoes with that in gravel, sand and peatlite mix. The irrigation of all were automated with time clocks and pumps, and with the exception of gravel culture, the same drip irrigation system was used. The same nutrient solution was used for all; except that since the soil also supplied nutrients, we lowered the nutrient solution concentration in the soil to about half that for the other media. As a result, we were unable to obtain greater tomato yields in the soilless culture over that of soil and the yields were greater than 150 tons per acre rate for a one year period.

Gravel culture --- The chief soilless culture technique used during and following World War II. It was used by the armed forces to produce fresh vegetables overseas.

The big expansion of gravel culture occurred in this country between 1965 and 1975. Very few of these systems are being installed today because of their high cost compared to that of others.

Most gravel culture systems consist of plastic film lined troughs, 24 to 30 inches in width, and filled with 6 to 10 inches of gravel. A drain line, usually of 3 to 4 inch diameter plastic pipe, is cut at intervals of 1 to 2 feet about 1/3 to 1/2 way through the pipe and the cut part is laid on the down side. The bottom of the bed slopes about 2 inches from the side of the bed to the drain pipe in the middle. The lengthwise slope is usually about 3 inches per 100 feet. The particle size of the gravel varies from 1/4 to 5/8 inches or mixtures in this size range and should be non-calcareous.

The gravel beds are flooded by pumping the nutrient solution from a reservoir into the drains of the troughs usually via a flume across the ends of the troughs. Flooding stops about 1 inch below the surface of the gravel in order to discourage algal growth on the surface of the bed and to prevent adding any more humidity to the greenhouse atmosphere than necessary.

To prevent anaerobic conditions which interferes with root action, the roots should not remain underwater more than about 30 minutes. Therefore, the flooding of the gravel beds should be accomplished in less than 15 minutes so that the bulk of the solution can be drained within the next 15 minutes. The ends of the drain lines should have free flow back to the reservoir and should not have to drain back through the pump which would greatly slow the flow of the nutrient solution.

Most European gravel culture systems are constructed so that the nutrient solution is delivered in a flume at one side of the troughs and the solution must pass through the gravel to a flume on the other side where it drains back to the reservoir. The nutrient solution thus flushes out any old solution remaining between irrigations.

To counteract any harmful effects of incomplete flushing of the nutrient solution in the gravel by irrigating through the same tube by which the solution drains back to the reservoir, we at Texas A&M irrigated the gravel culture every 2 hours during the daylight period whether needed or not from standpoint of water. Our experimental annual yields of marketable fruit when insects were not a problem have been in the range of 30 to 37 pounds per plant with a spacing of about 4.0 square feet per plant.

There are several methods of maintaining the concentration of nutrients in the nutrient solution. One method in use in many small commercial gravel units during the harvest season for tomatoes is to fill the reservoir with nutrient solution (which normally holds about 2 gallons per plant) and irrigate with it for 3 days while refilling the reservoir with water each night. On the fourth day, one half the nutrients required originally are added to the reservoir and irrigation is continued through the seventh day while refilling the reservoir with water each night. On the eighth day the solution is discarded and the above repeated on a weekly basis. At the beginning of a crop following transplanting the solution is used for longer periods before additions of nutrient solution and before discarding it.

The method used at Texas A&M was to fill the reservoir with nutrient solution at the start of the crop and to refill the reservoir with a premixed nutrient solution on a daily basis. The total dissolved salts as measured by conductivity was checked twice weekly. When the salt level increased in the range of 3000 to 3500 ppm, the solution was discarded and a new solution made. Previous trials showed that yields started dropping when the total salt level of the nutrient solution exceeded 3500 ppm. For a tomato crop being harvested, it normally required 3 to 4 weeks before the solution climbed to about 3500 ppm. The full nutrient solution in our tap water when first made usually tested 2200 ppm. Our tap water has 525 ppm of total dissolved solids of which 207 ppm is sodium, 70 ppm of chloride, and the balance mainly bicarbonates.

A few growers have a complete chemical laboratory for testing the nutrient elements in their solution. Tests of one or more nutrient elements are made on a daily to twice weekly basis depending on the elements and then the nutrient solution is adjusted back to the desired concentration. This requires considerable time and expense for equipment, but for a large installation with better quality tap water than that at Texas A&M, it should well be profitable.

Some growers have calcareous gravel in their troughs and did not presoak the gravel with a phosphate solution which many authorities recommend. As a result, whether presoaked with phosphate or not, and whether chelated micronutrients are used or not, some micronutrient deficiency usually appears at sometime during each tomato crop.

Sand Culture - Early studies on plant nutrient elements utilized sand culture, and it is still being used for this purpose today. Its use commercially in greenhouses was introduced in the late 1960's at the Environmental Research Laboratory, University of Arizona. The nutrient solution is not recycled like that in gravel, but a drip irrigation system is employed. Sufficient solution is applied per day to satisfy the needs of the plant, to take care of the water loss from the evaporation from the surface of the sand, and to leach from 25 to 50 ml per plant out the drain lines under the sand.

The concrete or builders sand that is most used contains a wide range in particle sizes, varying from very fine sand to the 2 mm size. However, the bulk of the sand (more than 80%) is less than 1 mm in diameter such as that in our Texas A&M University greenhouses. When an 8 inch depth of our sand is saturated with water and then allowed to drain free out the bottom, about 3 inches of sand in the bottom remains saturated with capillary water. Also the bottom 3 inches remain saturated when the sand is 12 inches deep.

One purpose of having daily leachate from the drains is to assure that the bottom 3 inches of sand is kept saturated so that roots will not enter the drains. Roots will not penetrate the saturated area because of the lack of oxygen. Sometimes the saturated area becomes reduced and gives off sulfide odors when examined. This reduced area has caused no apparent problem with our crops.

We have experimented at Texas A&M (1) with whole floor sand culture which had 10 to 14 inches of sand over the top of 1¼ to 3 inch drain lines between each pair of rows, (2) with 30 inch wide troughs containing 8 inch depth of sand with 2 to 3 inch drain lines under the middle of the troughs, and (3) with pots of sand of 1, 2 and 5 gallon capacity. The yields of tomatoes were not significantly different in an experiment comparing sand in 1, 2 and 5 gallon pots and sand in troughs with 1 cubic foot of sand per plant. The average of all treatments was 31.5 pounds per plant with 4 square feet of floor space per plant and grown from August 1 through June 23, Table I. In another experiment the yields of tomatoes from plants in troughs with 8 inch depth of sand were not any different from those in whole floor sand averaging 12 inches in depth. With the exception of the 1 and 2 gallon pots, all sand culture was irrigated with a complete nutrient solution at 2 hour intervals during the daylight period and also once around midnight during the warm months of May and June.

To prevent a water stress in the tomato plants in 1 and 2 gallon pots of sand, it was necessary to irrigate them at 1 hour intervals, especially as the plants became loaded with fruit and harvest was imminent.

All irrigations were programmed for clear weather. The amount of nutrient solution was not reduced during dull, cloudy weather when water usage by the plant was relatively low and consequently, leaching was voluminous.

Because of the relatively high sodium content of our tap water, the leachate was checked periodically for total dissolved salt, and the sand leached with tap water whenever the salts approached 3500 ppm. Usually no leaching was necessary before the beginning of harvest but was required at 4 to 6 week intervals after harvest began.

Most of the sand available for sand culture in Texas is highly calcareous. Ours at Texas A&M tested 25% calcium carbonate. While no problems were encountered with visual nutrient deficiencies because of the calcareous sand, we were unable to stop the splitting of ripening fruit during warm weather by increasing the concentration of copper in the nutrient solution from 0.2 ppm to 0.5 ppm with copper sulfate as the copper source. In noncalcareous gravel copper sulfate was very effective in reducing this problem. However, when chelated copper in the nutrient solution at 0.5 ppm of copper was compared to the same copper concentration from copper sulfate in calcareous sand, the splitting of ripening fruit was reduced from around 50%

with copper sulfate as source of copper to less than 5% with chelate copper as source of copper. Calcareous sand is apparently highly effective in reducing the solubility of nonchelated copper and thus the availability of the copper for the roots of the tomato plant.

One advantage of whole floor sand over sand in troughs is that a crop such as lettuce can occupy the entire floor area except for a foot path at intervals of 50 feet or less depending on the width of greenhouse. Whereas, lettuce in troughs is normally not an economic crop because of insufficient utilization of the greenhouse floor space.

Table I. Yield of marketable tomatoes in pound per plant *with plants spaced at 4 square feet

	Pots			Trough
Media	One gal.	Two gal.	Five gal.	1 cu ft.
Sand	30.6	31.4	31.9	32.3
Rice hulls	----	----	34.2	33.3
Pine bark	----	----	32.9	33.2
Cedar chips	28.8	29.5	30.7	28.7

*Tropic variety seed 8/1/75, transplanted 8/19/75, harvested 10/24/75 - 6/23/76.

Other Media - While I consider any growth media that does not contain soil, especially when the materials supply little, if any, of the nutrient elements required by plants, as a form of hydroponic or soilless culture, others do not if they contain any of the organic materials. Some of the materials that are used in the growth media have an ability to hold nutrient elements like that in most soils. They are the peat mosses, vermiculite, the composted or partially composted organic materials such as pine and hardwood barks, cedar chips and the various types of sawdust and crop residues. Other media like sand and gravel that do not hold nutrient elements are perlite, pumice, calcined clay, rice hulls, and many noncomposted wood products and crop residues.

There are very few nurseries and growers of ornamental plants that do not use some type of soilless culture growth media. Two important advantages of excluding soil from the growth media is light weight and consistent uniformity whereby the same growth results can be obtained crop after crop.

The production of greenhouse tomatoes and cucumbers in growth media consisting of mixtures of organic materials with or without inorganic ones has been away from the high volume troughs of near 1 cubic foot of media per plant to the smaller individual containers of 2 to 5 gallons per plant. Since our research at Texas A&M (Table I) showed relatively little difference in tomato yields due to conatiner size, considerable savings in cost of media can be realized by the grower.

Nutrient Solutions - There are some 16 elements that have been proven to be essential to the life cycle of plants. The ones we generally do not consider with the preparation of the nutrient solution are carbon which is supplied mainly from carbon dioxide in the air; oxygen which is supplied primarily by oxygen in air (O_2), that in water molecule (H_2O), and that in carbon dioxide molecule (CO_2), and hydrogen from that in the water molecule (H_2O). While these 3 elements make up the bulk of the plant's weight, oxygen is of concern in hydroponics or soilless culture in that it is necessary in the root area in order for the roots to be able to absorb the nutrient elements. Hydrogen is of concern since it is part of the water molecule which is necessary for solution and transport of the nutrient elements. Carbon dioxide in a greenhouse can be very limited especially during periods when the greenhouse is not ventilated. We start ventilating our greenhouses at Texas A&M when the greenhouse temperature rises to 68 degrees. This often provides carbon dioxide for growth some 15 to 30 minutes before the temperature rises to 75 degrees which is the temperature that many growers set their thermostats for their first phase of ventilation.

There is no one best nutrient solution formula from the standpoint of an exact concentration of each nutrient element. Hoagland and Arnon (1938) in California, Withrow and Withrow (1948) in Indiana, Steiner (1968) in The Netherlands, as well as many others have devised formulas, most of which have somewhat similar concentrations of nutrient elements. We have produced excellent crops with all we have tried. However, the Steiner formula is the one we have employed in our soilless culture systems since 1972. Steiner used 31 ppm of P, but we increased it to 48 ppm since the original concentration was too low as determined by tissue analysis. It was also necessary to vary the micronutrient concentrations for specific crops. For example, strawberries will show marginal necrosis on the older leaves if the boron greatly exceeds 0.5 ppm.

Tables II, III, and IV give the nutrient concentrations for the Steiner solution and the materials we use for preparing it. The recipe as given in Table III and IV can be used for practically all vegetable and ornamental crops. The information in Table V is useful for substituting carriers of nutrient elements when one's normal supply is temporarily unavailable or for preparing a nutrient solution for a specific crop or purpose.

Nutrient Solution Storage - The nutrient solution applied by drip irrigation in our Texas A&M greenhouses has been pumped directly from a holding tank in the dilute, ready to use form without the use of an injector or proportioner. To keep labor of mixing nutrient solution low, the holding tank should have at least a capacity to supply the plants for 7 days during periods of maximum water use. We consider about 3 gallons of nutrient solution per plant per week under our lowest humidity periods are normally sufficient for tomato plants producing fruit and still setting fruit. Cucumbers normally require more solution per plant per day than tomatoes. However, since cucumbers usually are planted at a less dense population than tomatoes, the solution use per unit area is about the same.

Table II. The Concentration of Nutrient Elements in the Steiner Nutrient Solution as Used at Texas A&M

Major nutrient	ppm	Micronutrient	ppm
Nitrogen (N)	166-175	Iron (Fe)	3.0-4.0
Phosphorus (P)	48-50	Manganese (Mn)	0.5-2.0
Potassium (K)	280-300	Boron (B)	0.5-2.0
Calcium (Ca)	180	Zinc (Zn)	0.2-0.5
Magnesium (Mg)	48-50	Copper (Cu)	0.2-0.5
Sulfur (S)	166-	Molybdenum (Mo)	0.1

Table III. Recipe for 100 Gallons of Steiner Nutrient Solution

Material	Grams	or	Ounces	ppm of Element
Potassium nitrate (13-0-44)	67		2.4	24N 65K
Calcium nitrate (15.5-0-0)	360		12.7	147N 180Ca
Potassium magnesium sulfate	167		5.9	80K 48Mg 37S
Potassium sulfate	140		5.0	154K 63S
Chelated iron (Fe 330-10% Fe)	11.5		0.4	3Fe
	Milliliters			
Phosphoric acid (75%)	50ml			48P
Micronutrient Concentrate	200ml			See Table IV

Table IV. Recipe for 16 Liters of Micronutrient Concentrate Which Makes 8000 Gallons When Diluted

Material	Grams	ppm of Element When Diluted
Manganese sulfate (27½% Mn)	55.0	0.5
Boric acid	86.5	0.5
Zinc sulfate (36% Zn)	16.8	0.2
Copper sulfate (25% Cu)	24.2	0.2
Molybdenum troxide (66% Mo)	4.6	0.1

Table V. Parts per million (ppm) of nutrient element in solution when specified amount of fertilizer compound is dissolved in 1 gallon of water*

Fertilizer	Fertilizer and Element Percentage	Amount per gal.	ppm of element in solution						
			N	P	K	Ca	Mg	S	CL
Potassium nitrate	13.75-0-44.5 (36.9K)	1 g	36		97				
Potassium sulfate	0-0-50 (41.5K, 17S)	1 g			110			45	
Muriate of potash	0-0-60 (49.8K, 45Cl)	1 g			131				119
Mono Pot. phosphate	0-22.8-28.7	1 g		60	75				
K-Mag or Sul-Po-Mag	0-0-22 (18K, 11Mg, 22S)	1 g			48		29	58	
Mono Cal phosphate	0-46-0 (20P, 13Ca)	1 g		53		34			
Calcium nitrate	15.5-0-0 (19Ca)	1 g	41			50			
Calcium chloride	77-80% $CaCl_2$ (28Ca, 64Cl)	1 g				74			169
Ammonium nitrate	33.5-0-0	1 g	88						
Ammonium sulfate	21-0-0 (24S)	1 g	55					63	
Urea	46-0-0	1 g	121						
Nitric acid	70% HNO_3 (15.5N)	1 g	41						
Nitric acid	70% HNO_3 (.209g.N/ml)	1 ml	55						
Ammo. polyPhosphate	15-60-0 (26.2P)	1 g	39	69					
Diammonium Phos.	18-46-0 (20P)	1 g	47	53					
Phosphoric acid	75% H_3PO_4 (23.7P)	1 g		62					
Phosphoric acid	75% H_3PO_4 (.363g.P/ml)	1 ml		96					
Gypsum (Cal sulfate)	(18.6Ca, 14.9S)	1 g				49		39	
Epsom salts	(9.9Mg, 13S)	1 g					26	34	

*For all practical purposes, 3.5 ounces of the fertilizer compound dissolved in 100 gallons of water yields the same ppm of element in solution as those given above for 1 gram per gallon.
(28.35 grams - 1 ounce)

Some growers use two tanks, each with a capacity of about a gallon or less per plant. One tank holds the ready to use solution and the other is used for storing a solution of 6X concentration. Thus when both tanks are full, they have in effect the equivalent of about a 2 week's supply. Theoretically, some of the elements will precipitate out of the solution at a lower concentration than 6 times. However, several growers have successfully used this method and claim no precipitates have formed. One grower tried an 8X concentration after first using 6X, but complained of considerable residue at the bottom of the tank, which proved to be precipitates of some of the nutrient elements. Therefore, do not concentrate the Steiner solution more than 6 times in one solution.

Proportioners - There are several types of proportioners in use by growers in their soilless culture operations. Some are preset at the factory and cannot be changed such as metering one part of concentrate into 100 parts of water. Others have variable settings from 1 to 25 to as wide as 1 to 200.

To concentrate a complete nutrient solution for use in proportioners, the nutrient solution must be divided with the calcium and the iron kept separate from the phosphates and sulfates. Normally the calcium nitrate and iron chelates are concentrated in one solution and the remaining ingredients concentrated in the other solution. Most nutrient solutions, when separated into 2 solutions in this manner can be concentrated 100 times.

The 2 concentrates are metered into an irrigation line by means of a twin head proportioner or two proportioners connected together in a series. One grower with 50,000 square feet of greenhouse had a twin head proportioner set at 1 to 100 with two 500 gallon tanks for the concentrates. Thus, when the tanks are full, the nutrient solution concentrates represent 50,000 gallons of dilute nutrient solution. A 50,000 gallon tank can make a good sized swimming pool; and if made of concrete, it can be a sizeable investment compared to 2 small tanks and a proportioner.

Nutrient Solution Use - For greenhouse tomato production in Texas, we have found that increasing the concentration of some of the micronutrients such as copper mentioned earlier, has been helpful in improving yields and quality of the fruit. When trying to set fruit on tomato plants during December, January and sometimes February, increasing the manganese up to 2.0 ppm has prevented the manganese deficiency symptom of the bloom buds failing to develop into normal blooms. It is quite possible that the reason for the low uptake of Mn is due to the cooler media temperature experienced at this time of the year rather than short day length or some other factor.

Boron is another micronutrient that often becomes deficient in greenhouse tomatoes. However, the deficiency appears not to be due necessarily to an insufficient supply of B to the roots, but rather to an excessive uptake of nitrogen by the plant which in some way interfers with the translocation of boron from the lower part of the plant to the growing point where it is needed. The first indication of excessive nitrogen-boron deficiency syndrome is a slight downward curling of the new leaves at the top of the plant and as the condition increases, more severe curling occurs and the top of the plant has a balled appearance. The internodes between leaves do not lengthen. Lateral shoots are produced in abundance even occurring on the midrib of the leaves as well as at the ends of blossom clusters. The main stem is large and often cracks longitudinally with a dark streak in the cracks. At this stage die back of the growing tips sometimes occurs as well as yellow to brown to black necrotic areas on tips of the youngest leaves. It is usually very difficult to determine the original growing tip of the plant.

When only slight to moderate balling of the new leaves at the top occurs, increasing the boron in the nutrient solution from 0.5 ppm up to 1 or 2 ppm or 1 to 3 sprays at 5 day intervals of about 50 ppm of boron applied to the top 8 to 9 leaves of the plant will usually alleviate the symptoms. Neither increasing the boron nor boron foliar sprays helps much when the symptoms are severe. Decreasing the available nitrogen is the primary correction method.

The original method of controlling the N-B syndrome in soil was to limit the soil moisture, which limited the root growth, which in turn limited the nitrogen uptake. This control method also can apply to most soilless culture methods. However, if the root zone moisture is not increased little by little as the plant develops, it appears that the roots become too severely limited by the time the fifth or sixth cluster comes into bloom and too little N is available for the heavy fruit load and further development of new fruit. As a result, the fifth and sixth, or sixth and seventh clusters abort most of their blooms.

A method we have tried successfully in lowering the available nitrogen in soil is with an application of one to two teaspoons of sucrose per plant watered into the soil. The sugar causes a temporary biological tie up of the nitrogen but becomes available again in 7 to 10 days. In one case, sugar was applied 3 times at weekly intervals before the plants tolerated the high available nitrogen in the soil, the reason being that new growth and fruit set resulted in a higher demand for nitrogen by the plants.

In most soilless culture techniques, large amounts of nutrients are not added to the growth media as sometimes done in soil but are supplied by daily irrigations of a more or less complete nutrient solution. To control the nitrogen available to the young tomato plants, we at first dropped 50 to 60 precent of the nitrogen out of the nutrient solution, leaving 70 to 80 ppm in solution and kept all other nutrients at 100 percent. This required an additional source of calcium since calcium nitrate was the main source of most of the nitrogen and usually the only source of calcium.

A Texas grower simplified the nitrogen control problem by lowering not only the nitrogen but the entire nutrient solution to 40 to 50 percent of the original. We now routinely start our young plants on a low concentration and increase it to 80 to 100 percent by the time 12 to 15 fruit have set on each plant or normally when the fourth cluster is blooming. However, if enough low concentration nitrogen nutrient solution is available to the roots, the plant can still go into the N-B syndrome as many growers have observed with plants that accidently receive much more nutrient solution than others. However, with sand culture in beds or whole floor, which require that the bottom 3 inches or so to be kept saturated with capillary water, there is no problem in keeping the N-B syndrome under control with a low percentage of the total nutrient solution.

While the concentration of the total nutrient solution can be varied to control the N-B syndrome, the concentration is also important in controlling fruit quality. For example, we produced tomatoes in sand and gravel culture at Texas A&M during a fall crop on "half Hoagland" solution. The plants grew luxuriantly with large fruit ripening in October. However, the consumers complained that the fruit were mealy with a bland taste.

From previous soil culture experience I had learned that mealy fruit was associated with too high soil moisture especially during the winter. Also the best tasting fruit for my taste buds were those produced on soils in which growers had a problem of keeping the salts low because the water used was high in total salts. Therefore, we reasoned that a low-salt concentration of the nutrient solution must be the factor involved in the poor quality fruit.

The concentration of some of the "half Hoagland" plots were increased to 100 percent, and some were changed to the Steiner formula. Within 10 days, the fruit from plots with the higher concentration of nutrient solution were juicy, non-mealy, with a reasonable tart taste, while those on "half Hoagland" were still mealy and bland tasting.

We did not use a solu bridge or conductivity meter to check the nutrient solution concentration when we conducted this test in 1972. However, since that time we have kept many records on the salt levels of various plots in regards to the daily leachate from sand culture and other media in trough culture as well as the nutrient solution for gravel culture. It appears that the total salts in the nutrient solution should not be much lower than about 2000 ppm in order for us to produce the quality of tomatoes our customers desire.

When reducing the nutrient concentration to control the N-B syndrome, it is important that the total salt level in the nutrient solution be increased to near 100 percent at least 10 to 14 days prior to harvest. If a green mature fruit is predetermined to be mealy because of having been produced with a low salt nutrient solution, no treatment given the plant will change the fruit quality during the period it ripens which may be 10 to 14 days after it reaches the green mature stage.

Nutrient deficiencies - What happens when you leave out one of the essential nutrient elements in the nutrient solution? One might accidentally omit a nutrient element carrier or omit it because you were temporarily out of the compound. The length of time before the effects show on a plant may vary considerably between different nutrient elements and between different soilless culture techniques. The growth media which holds nutrient elements like that in soil may be very slow to show the effects on a plant of some micronutrients while only a few days may be needed for a major nutrient such as nitrogen. The larger the plant and the heavier the fruit load, the faster the effect of omitting a nutrient element.

In general, each nutrient element results in a specific visual deficiency symptom when not supplied in a sufficient amount necessary for the development of the plant. In most cases the references on mineral deficiencies provide those symptoms taken from studies on young plants and these are not necessarily the symptoms a grower has on tomato plants, for example, that have a heavy fruit load.

In working with growers and from my commercial experience, I have seldom observed nutrient deficiency symptoms on young tomato, cucumber, or lettuce plants. Therefore, in our studies at Texas A&M on greenhouse tomatoes, we decided to first grow the tomato plants the best we knew how with 4 to 5 clusters of fruit set per plant before we initiated the removal of a nutrient element from the nutrient soluton.

We have observed the visual deficiency symptoms for most of the essential nutrient elements. We did not try to obtain those for chlorine deficiency since it was difficult to eliminate it from the solution when it finally was proved essential for the life cycle of plants. We did try to obtain those for sulfur and produced plants in gravel without a sulfur source for 2 months without obtaining any visual difference in foliage or yield and quality of fruit from that of the control plots. Apparently (1) we were unable to wash all the sulfur residues out of the gravel beds by top flushing with water, (2) the plants were able to reutilize the sulfur within the plant readily, or (3) we had too many sulfur impurities in the technical and CP grade nutrient chemicals. Whatever the reason, we decided that sulfur was a minor major element.

The following description of visual nutrient deficiency symptoms may be typical of those described in most references. However, the symptoms given for tomatoes are taken from our observations on our studies at Texas A&M. All are for a deficiency of a single element. While more than one element might be deficient in the same plant, usually the visual symptoms of one element will be dominant over the visual expression of any other.

A visual nutrient deficiency symptom on a plant may not necessarily be due to a low supply in the nutrient solution but could be the result of root damage from a disease, nematodes, toxicity, or some other factor. When a deficiency symptom appears on only a very few plants, check the roots for a healthy appearance. If they are tan to brown colored or show some obvious problem unfamiliar to you, enlist the aid of your county Extension agent and your State Extension Plant Pathologist for a diagnosis and possible correction.

For a multiple harvest crop such as tomatoes and cucumbers, it is usually never too late to correct a nutrient deficiency unless it is at the end of the crop. Usually more and better quality fruit results when any deficiency is corrected. However, for the single harvest crop such as lettuce, it is usually too late to correct the deficiency and have high quality produce at harvest once the deficiency appears. If the crop is closely observed daily, it may be possible to catch the nutrient deficiency symptom in its early stages and do something about it before much harm is done. The use of a well balanced nutrient solution should eliminate visual deficiency symptoms except for those casued by root problems mentioned earlier.

The Steiner nutrient solution as modified with increased phosphorus (Table II) has been used at Texas A&M on tomatoes in gravel culture; on tomatoes, cucumbers, lettuce and strawberries in sand culture; on various garden vegetables and strawberries as well as tomatoes, cucumbers and lettuce in organic media and mixtures of organic media; and on sundry ornamental plants in mixtures of various organic growth media. We have had no problems with the formula for any of the plants except tomatoes.

As previously mentioned for tomatoes, increasing the boron from 0.5 to 1.0 or 2.0 ppm helped with the N-B syndrome, increasing the copper to 0.5 ppm corrected the fruit splitting problem during warm weather, increasing the manganese to 2.0 ppm corrected the manganese deficiency that often occurs during the winter season on plants producing a crop through the winter, and increasing the zinc to 0.5 ppm helped to keep the leaves much larger after the plants loaded up with fruit. We again decreased the manganese back to 0.5 or 1.0 ppm for the warmer months. Sometimes it was necessary to increase the iron an extra 1.0 ppm when manganese was supplied at 2.0 ppm. To date we have found no reason to alter the formula in Table II for other vegetables and ornamentals that we have produced in soilless culture media.

A variation of supplying nutrient elements to soilless culture media with good tomato production is that of omitting the calcium, magnesium and most of the sulfur from the nutrient solution and then supplying these elements in the media as dolomitic limestone and gypsum. In most cases the dolomitic limestone and gypsum have been added each at the rate of 10 to 15 pounds per yard of mix. The growth media mixes have normally been sphagnum peat moss or pine bark or both blended with about 40 to 50 percent by volume of vermiculite. We have also tried this for tomatoes in sand culture with noncalcareous sand. While the tomato plants grew well to the first bloom stage, we were unable to carry them through to harvest because of lack of greenhouse space. However, I see no reason why the addition of dolomitic lime and gypsum added to the mix cannot successfully substitute for the calcium, magnesium, and sulfur in the organic type mixes as well as sand culture whether the sand is calcareous or not.

Another variation of soilless culture which has been used primarily with ornamentals is the addition of slow release fertilizers to the growth media and the addition of water only during the production of the plants. At Texas A&M the micronutrients were added in the slow release form as fritted trace elements and only the major elements employed in the nutrient solution. We had some degree of success with it on tomato production. However, we were not able to control the boron release. Too much was released initially which caused some toxicity of boron on young plants and then was followed by an insufficient amount released and a deficiency. We were employing large amounts of course, fritted trace elements in the range of 1 to 2 mm size particles at one-half to one pound per plant. Our theory was that the micronutrients as fritted trace elements mixed with the growth media should supply the needs of many crops.

Recently, Whitcomb at Oklahoma State University developed a successful growth media for ornamentals in which the major elements are supplied by mixtures of a slow release fertilizer, dolomitic limestone, and gypsum and the micronutrients supplied by a patented formula. Tomatoes have been produced successfully in pots, in cages and the plants not pruned. However, I am not aware of any being grown by his method when the plants are pruned to a single stem.

Continued new developments in the field of hydroponics and soilless culture for both food and ornamental crop production will bring even more automation and labor saving methods. Promoters have long claimed that only simple 1, 2, 3, etc. steps have to be followed in order to produce high yielding profitable crops in their special hydroponic greenhouses. The steps, while not necessarily so simple, are resulting in more trouble free production. While the profit picture is becoming more and more clouded with high energy costs, developments in solar greenhouse heating will help reduce this cost and provide more of an advantage for greenhouse production in the "Sun Belt".

Nitrogen (N) - Restricted growth of tops and roots and especially lateral shoots. Plants become spindly with general chlorosis or entire plant to a light green and then a yellowing of older leaves which proceeds toward younger leaves. Older leaves defoliate early. Generally, veins show purpling on underside of younger leaves when deficiency is severe in tomatoes.

Phosphorus (P) - Restricted and spindly growth similar to that of nitrogen deficiency. Leaf color is usually dull dark green to bluish green with purpling of petioles and the veins on underside of younger leaves. In tomatoes, younger leaves are yellowish green with purple veins with N deficiency and darker green with P deficiency. Otherwise N and P deficiencies are very much alike.

Potassium (K) - Older leaves show interveinal chlorosis and marginal necrotic spots or scorching which progresses inward and also upward toward younger leaves as deficiency becomes more severe. In tomatoes, the fruit often ripens unevenly or show blotchy green to yellow patches on red ripe fruit. Fruit sometimes fall off the plants just prior to ripening.

Calcium (Ca) - Leaves show slight chlorosis to brown to black scorching of new leaf tips and die-back of growing points. The scorched and die-back portion of tissue is very slow to dry so that it does not crumble easily. In addition to the above for tomatoes, the first symptom is usually blossom-end-rot of the fruit. Boron deficiency also causes scorching of new leaf tips and die-back of growing points, but calcium deficiency does not promote the growth of lateral shoots and short internodes as does boron deficiency.

Magnesium (Mg) - Starts with interveinal chlorotic mottling or marbling of the older leaves which proceeds toward the younger leaves as the deficiency becomes more severe. The chlorotic interveinal yellow patches usually occur toward the center of leaf with the margins being the last to turn yellow. In some crops the interveinal yellow patches are followed by colorful orange to red coloring. As the deficiency increases in severity, the interveinal chlorosis is followed by necrotic spots or patches and marginal scorching of the leaves. On tomatoes being harvested, the interveinal chlorotic yellow patches usually do not start on the oldest leaves but on those toward the middle of the plant.

Sulfur (S) - Resembles nitrogen deficiency in that older leaves become yellowish green and the stems thin, hard and woody. Some plants show colorful orange and red tints rather than yellowing. The stems, although hard and woody, increase in length but not in diameter.

Iron (Fe) - Starts with interveinal chlorotic mottling of immature leaves and in severe cases the new leaves become completely lacking in chlorophyll but with little or no necrotic spots. In tomatoes the chlorotic mottling on immature leaves sometimes starts first near the bases of the leaflets so that in effect the middle of the leaf appears to have a yellow streak.

Manganese (Mn) - Starts with interveinal chlorotic mottling of immature leaves and in many plants it is indistinguishable from that of iron. On fruiting plants, the blossom buds often do not fully develop and often turn yellow or abort. As the deficiency becomes more severe, the new growth becomes completely yellow, but in contrast to iron, necrotic spots usually appear in the interveinal tissue. In tomatoes which show some interveinal chlorotic mottling due to a manganese deficiency, some of the bloom buds on the flowering trusses show incomplete development and do not develop into blooms. During the short days of December and January the plants often show no blooms at all.

Zinc (Zn) - In some plants the interveinal chlorotic mottling first appears on the older leaves and in others it appears on the immature leaves. It eventually affects the growing points of all plants such as rosette of fruit trees and formation of abnormally small leaves. In tomatoes the interveinal chlorotic mottling is the same as that for iron and manganese except for the little leaf. When zinc deficiency onset is sudden such as the zinc left out of the nutrient solution in NFT, the chlorosis can appear identical to that of iron and manganese without the little leaf.

Boron (B) - Starts with slight chlorosis to brown to black scorching of new leaf tips and die-back of the growing points similar to calcium deficiency. Also the brown and black die-back tissue is very slow to dry so that it can be crumbled easily. Both the pith and epidermis of stems may be affected as exhibited by hollow stems to roughened and cracked stems. In tomatoes, in addition to scorching of new leaf tips, die-back of growing points and cracked stems, the plant has very close internodes with prolific lateral shoot development even on midrib of the leaves and on the flower truss. Mildest symptom is shown on mature fruit which have from minute cracks in the skin on the shoulders to heavier concentric cracking on the shoulders.

Copper (Cu) - Leaves at top of the plant wilt easily followed by chlorotic and necrotic areas in the leaves. In tomatoes, leaves on top half of plant show unusual puckering with veinal chlorosis and absence of a knot on leaf where petiole joins the main stem of plant beginning about 10 or more leaves below growing point. The splitting of fruit during ripening, especially under warm temperatures, is an indication of low copper.

Molybdemum (Mo) - Older leaves show interveinal chlorotic mottling, become cupped and thickened. Chlorosis continues upward to younger leaves as deficiency progresses.

Hydroponic Society of America Conference
San Francisco, Calif., Oct. 20, 1979.

The International Status of Hydroponics-A Review of Soilless Techniques - Dr. Howard M. Resh

INTRODUCTION:

There are many types of hydroponic systems used successfully throughout the World today. The choice of system depends upon the availability and cost of the medium. Water quality and supply can also be a determining factor as to whether a closed (re-cycled) or open (non returnable) system should be used.

While water culture is really true hydroponics by definition (hydro-water, ponos-working), the other techniques are also termed the same, but, should be called soilless culture. At present the nutrient film technique (NFT) is the only true hydroponics being used commercially. The NFT system has the potential commercially of becoming a universal hydroponic system. That is, it may be used successfully in all parts of the World. It eliminates our dependence upon the availability of local media in our decision as to which soilless culture system should be used. Nonetheless, its costs may be high in some areas where there is an abundance of good local medium. For example, sand culture is the most appropriate system to use in desert areas.

In the following review of the international status of hydroponics the high cost of media was often a major capital outlay in setting up a hydroponics operation.

GRAVEL CULTURE:

Gravel culture is one of the most widely used soilless systems. Many of the early commercial operations used gravel culture because it was plentiful in the regions of the World where hydroponics was first introduced. In the 1930's W. F. Gericke set up commercial operations using gravel culture. These first trials were followed by establishment of hydroponic farms in non-arable Pacific islands during the 1940's to help feed World War II troops.

Today some of the largest commercial hydroponic farms in the United States use gravel culture. For example, Hydroculture Inc. of Phoenix, Arizona has over 20 acres of gravel culture greenhouses. They built a large number of individual quonset type greenhouses of approximately 3500 square feet each.

These type of greenhouses are constructed of aluminum framing with fibreglass cladding (covering) (SLIDES 1,2). Initially, a nutrient reservoir is constructed at one end (SLIDE 3) and concrete pathways are poured between the beds perpendicular to the nutrient tank (SLIDE 4). Beds are dug out of the underlying medium between the walkways (SLIDE 5). A vinyl liner is placed into the beds once they are properly levelled and graded (SLIDE 6).

A subirrigation system is used where perforated pipes are placed in the bottom of the vinyl lined beds (SLIDES 6,7). The pipe allows rapid movement of water laterally and vertically into the beds. This rapid irrigation cycle allows adequate oxygenation of plant roots and complete drainage between cycles. This is accomplished by use of a common plenum into which water is pumped from the nutrient tank and drained into upon return (SLIDE 8). The fall of the water back into the tank during the drainage cycle aerates the nutrient solution (Figs. 1 & 2).

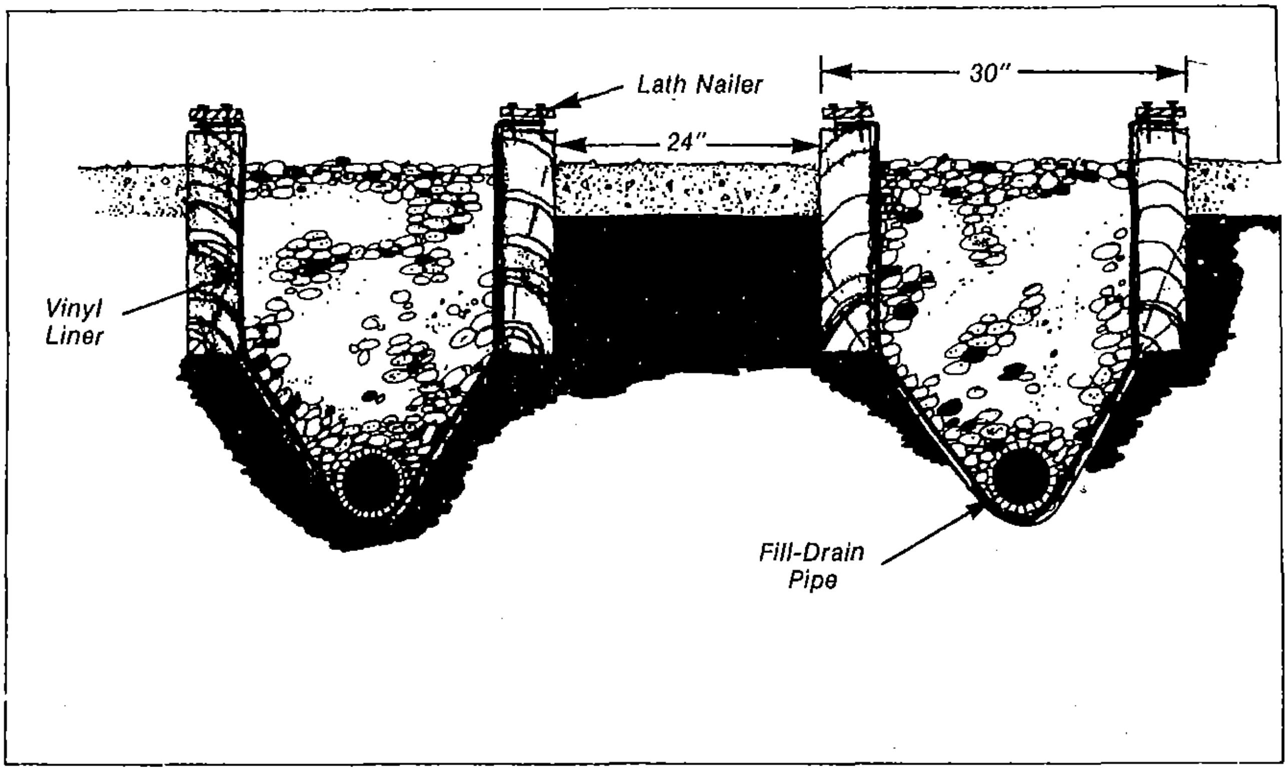

Fig. 1. Cross section of a subirrigation gravel bed.

(Courtesy of "Hydroponic Food Production"- Woodbridge Press, Santa Barbara, Calif.)

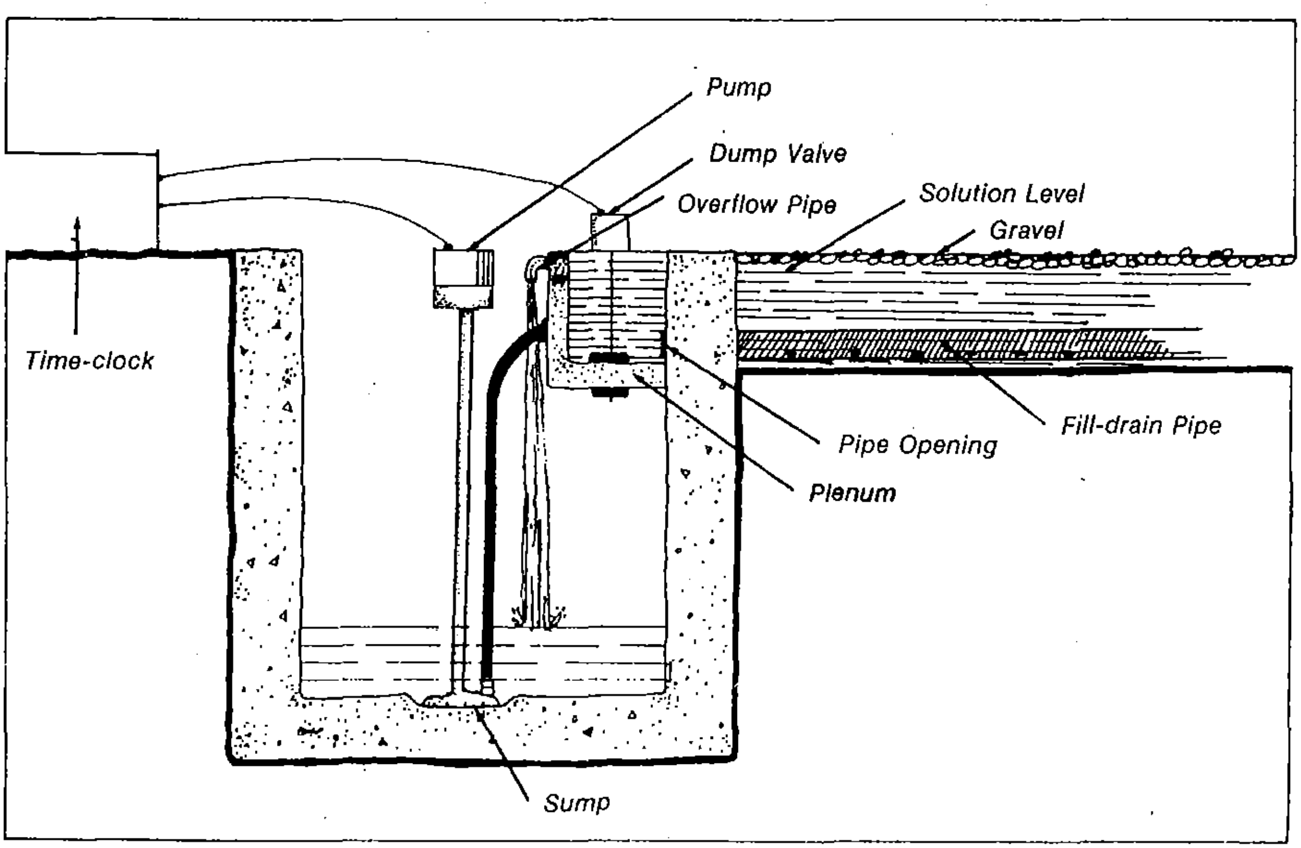

Fig. 2. Cross [illegible]

The greenhouses are fully automated for environmental control. Temperature is controlled by use of gas-fired unit heaters and 48-inch diameter exhaust fans on one end with evaporative cooling pads on the opposite end (SLIDES 9-14). A fan-jet convection tube system is used for mixing of the greenhouse air in an effort to maintain more uniform temperatures and to regulate relative humidity. Carbon dioxide generators are installed to maintain CO_2 levels at 1200 ppm (parts per million). This is about 3 to 4 times the normal ambient level. Carbon dioxide enrichment is particularly beneficial under poor winter light conditions.

While such individual greenhouses may be suitable for conditions in Arizona, they are not economical in more northerly latitudes such as Canada. In colder climates the cost of heating and labour are the greatest costs of greenhouse operation. A gutter-connected type of greenhouse reduces heat loss and a more efficient central heating system with a boiler and hot water piping throughout the greenhouse can be used (SLIDE 15). Gutter-connected greenhouses can also be automated for harvesting tomatoes by use of an overhead conveyor chain to reduce labour costs (SLIDE 16).

SAWDUST CULTURE:

In British Columbia 90% of the greenhouse tomatoes are grown in sawdust culture. Two methods, sawdust beds and sawdust bags are most commonly used. Recently a few growers are using 11 litre plastic patio pots as they can be re-used for a number of crops.

Beds are generally constructed of rough cedar sides staked with rebar supports. A trench is dug of a V-, round-, or slant-bottom configuration then lined with 6-mil black polyethylene or 20-mil vinyl. A perforated drainage pipe is placed on the bottom or underneath the beds and the beds filled with a Douglas Fir or Hemlock sawdust.

A trickle feed system is used for distributing the nutrient solution along the top of the beds (Fig. 3) (SLIDE 16).

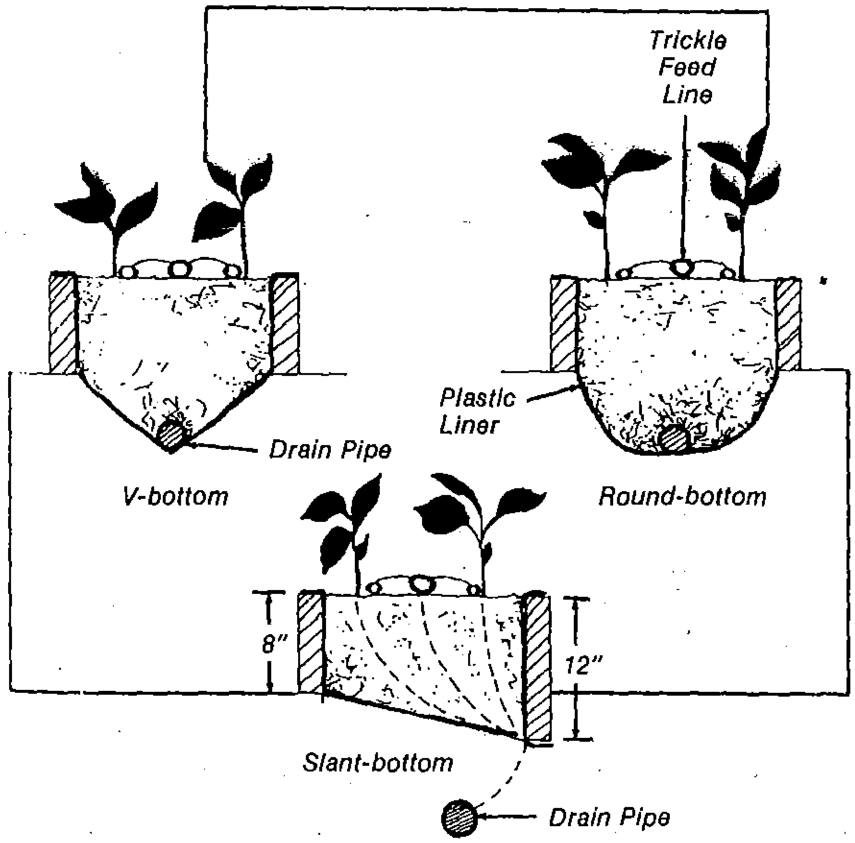

Fig. 3 Cross sections of sawdust culture beds.

(Courtesy of "Hydroponic Food Production"-Woodbridge Press, Santa Barbara, Calif.)

Plastic "kitchen catcher" bags filled with sawdust can be used instead of beds. These bags are replaced with each new crop (SLIDES 17,18).

Sawdust culture, unlike the cyclic or closed system used in gravel culture, is an open or non-returnable system. Supporters of this culture claim that such an open system guards against rapid spread of root diseases such as Fusarium and Verticillium wilts which can occur in a closed gravel cultural system.

Sawdust culture systems generally use a trickle feed system rather than the subirrigation system used with gravel culture. Either a nutrient reservoir or a proportioner (fertilizer injector) is used to feed nutrients and water through the trickle feeding system. Some growers prefer the nutrient reservoir over an injector system because they know exactly what quantities of fertilizers are put into the tank and therefore the chances of a mistake are less than that of a proportioner where they must depend entirely on its mechanics.

These same principles of sawdust culture are applied to the growing of flowers and foliage houseplants in pots using a medium of peat, pumice and sand (SLIDES 19-21). Almost 100% of the potted flowers and foliage plants grown in greenhouses in British Columbia use a soilless medium of peat, pumice or vermiculite and sand.

COSTA RICA:

Hydroponics has been adopted by several growers in Cost Rica to overcome problems with nematodes and other soil-borne pests. In some cases the sub-irrigation gravel culture system is used. While very favourable temperatures eliminate the need for a heated greenhouse, a covering is still required to protect crops from heavy tropical rains. It also allows for the control of aerial diseases and insects through the use of various pesticides. Whenever a cover is used for the protection of crops in the tropics the problem of excess heat accumulation arises. To allow for proper cooling, covering structures (greenhouses) must allow adequate natural ventilation. Generally, the use of exhaust fans and cooling pads are not acceptable in none highly technical countries due to operating and maintenance costs. For this reason, open-sided greenhouses of a saw-tooth configuration with large overhead openings are used to allow maximum ventilation so that little heat build-up will occur (SLIDES 22,23).

Beds are constructed of a local asbestos concrete roofing material (SLIDES 24-27). These large "tubs" form a perfect trough when set upside down on the ground. Some experimental work has also been done using column culture. The columns are constructed of 6-inch diameter asbestos pipe with holes placed at one-foot centres on four sides of the pipe (SLIDES 28,29). The pipes are placed in a collecting trough and filled with a gravel medium. Water and nutrients are fed from the top with a trickle feed system.

While hydroponics is used as a commercial method of growing tomatoes, lettuce, peppers and a few other vegetables in Costa Rica, operations are few and of relatively small size when compared to traditional soil-grown vegetables. Costa Rica has a basic agricultural economy due to its suitable climate and soils. For this reason, there is an abundance of fresh vegetables on the market and prices are very low. Prices for tomatoes in 1976 were between 15 to 20 cents (U.S.) a pound. Such prices are much too low to support the higher capital costs of growing hydroponically. Also, labour is relatively low, therefore, automation is not as necessary as it would be in a society with high labour costs.

BAHAMAS:

In the Bahamas there is very little agricultural industry. Almost all of the vegetables consumed there are imported from the United States. The soils are calcareous, that is, the Islands are basically made up of fine sand which is composed of broken sea shells. Because of this type of soil and lack of fresh water vegetable growing is limited.

With the large tourist population in past years, there was a very great demand for fresh vegetables. Such a buoyant market and non-arable land sets an ideal situation for the use of hydroponics for intensive production of vegetables. An American citizen saw this need in the 1960's and set up a sub-irrigation gravel cultural system there on a 5-acre site (SLIDE30). He imported gravel from the United States which cost over $30 a cubic yard landed in Freeport. He constructed his beds of fibreglass on the site and set up the entire system without a greenhouse cover since annual rainfall in the area was low (SLIDES 31,32). The operation did well for a number of years and supplied most of the domestic market for tomatoes. Production after several years, in fact, exceeded the local demand and arrangements were being made to export some of the product to the United States and neighbouring islands. Within 3 to 4 years vegetable production had paid for the initial capital outlay and profits were being realized.

Without warning the government of the Bahamas became unhappy with the hydroponics farm. The government used the excuse that the hydroponics operation was competing against growers on other islands of the Bahamas. They levied a 30% tariff on the tomatoes. When the tariff did not effectively reduce the market for the hydroponic tomatoes, the government took over the operation by force without any monetary compensation.

Since that time the hydroponic farm has been abandoned. Recently a local resident has been operating about ½acre of it and selling tomatoes to the local market. But, with increased political problems and government instability, tourists have not been going to the Bahamas. As a result, even ½ acre of the hydroponics operation over supplies the local market. The present operator of the hydroponics farm applied to the government for permission to export tomatoes to the United States and neighbouring islands, but even that has been denied.

This is a lesson to those interested in setting up any agriculture venture in foreign countries. Governments have the tendency to change quickly without any previous notice and often such changes lead to drastic policy changes regarding foreign ownership of industries.

GRAND CAYMAN:

Grand Cayman like many of the other Caribbean islands is composed of calcareous sand which is non-arable. Coupled with this is the extreme shortage of fresh water. Like most of these islands, its primary industry is tourism. As a result, a good market exists for fresh vegetables. All of these factors point to a favourable location for a hydroponics farm. In addition, Grand Cayman has a very stable government favourable to outside investors and has no corporate taxes.

A stock promoter and several investors started a hydroponics project in Grand Cayman about 1973. They knew very little about the technical aspects of growing plants hydroponically. They set up well-designed European style greenhouses with open sides for natural ventilation (SLIDE 33). They did not, however, anticipate the problems associated with a calcareous sand medium. With several crop failures they imported peat to mix with the sand and grew the plants in plastic pots (SLIDES 34-36). Their problems soon multiplied with the discovery that their fresh water was becoming saline. By 1976 they had separated their fresh water lens from its main body and it was being replaced by sea water at 10,000 ppm of sodium chloride. By this time the project was abandoned as they had tried unsuccessfully for 3 years to produce tomatoes.

The local market was excellent for the sale of their product, but this demand could never be met. The government of Grand Cayman badly wanted the project to become successful. Even local banks with substantial loans in the project were very lenient with payments as they supported the project and still hoped it might become successful.

Upon visiting their operation, I recommended that they first purchase a small desalination plant to overcome these immediate salt problems (SLIDE 37). Once they could get some production and gain credibility, additional capital could be acquired from local banks or other financial institutions to expand the project to enable it to meet the market demand.

Then they could also locate a new well on the main lens several miles away and pump water to the hydroponics site.

However, with lack of confidence in the possible success of the project, investors were not willing to carry it further. I expect by now the entire operation has simply been abandoned.

The failure of this project was due mainly to lack of technical help. Someone with experience in hydroponics and growing of vegetables would have checked on the water source, its capacity, the needs of the hydroponic farm and the medium available.

SUPERIOR FARMING CO.:

Sand Culture has proven to be one of the most successful methods of soilless culture. Sand culture has a number of advantages over gravel culture. It is a non-returnable system, therefore, spread of root diseases is reduced. Sand is one of the most common media in non-arable regions of the World. It can be fully automated by use of trickle or ooze irrigation systems and fertilizer injectors.

Two methods of constructing a sand culture system are by use of plastic-lined beds and by spreading sand over the entire greenhouse floor (Figs. 4 & 5). Beds are generally built as above-ground troughs with wooden sides lined with six-mil polyethylene or 20-mil vinyl. Drainage is by a perforated 3-inch PVC pipe placed in the bottom of the bed. The second method of spreading sand over the floor lined with 6-mil polyethylene is much cheaper in construction costs. A 12- to 16-inch depth of sand is sufficient. Drain pipes of 3-inch PVC are placed on the polyethylene at 4 to 6 feet spacing before the sand is back filled (SLIDES 40-43).

Some commercial operations using sand culture are: Superior Farming Co., Tucson, Arizona with 11 acres (SLIDE 44); Quechan Environmental Farms, Fort Yuma Indian Reservation, Calif. with 5 acres; Kharg Enviromnental Farms, Kharg Island, Iran with 2 acres (SLIDE 45); Arid Lands Research Institute, Abu Dhabi, United Arab Emirates with 5 acres and presently expanding to 21 acres (SLIDE 46); Sun Valley Hydroponics, Fabens, Texas with about 10 acres. The Environmental Research Laboratory, a branch of the University of Arizona, has worked closely with many of these projects in developing commercial sand culture operations.

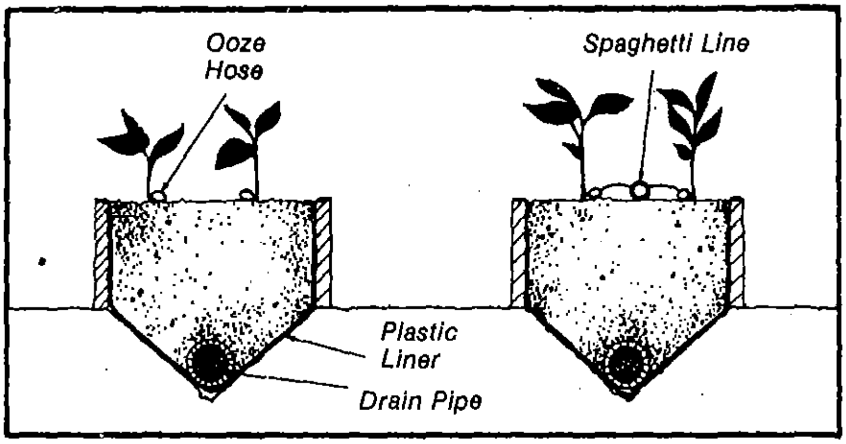

Fig. 4. Cross section of sand culture beds.

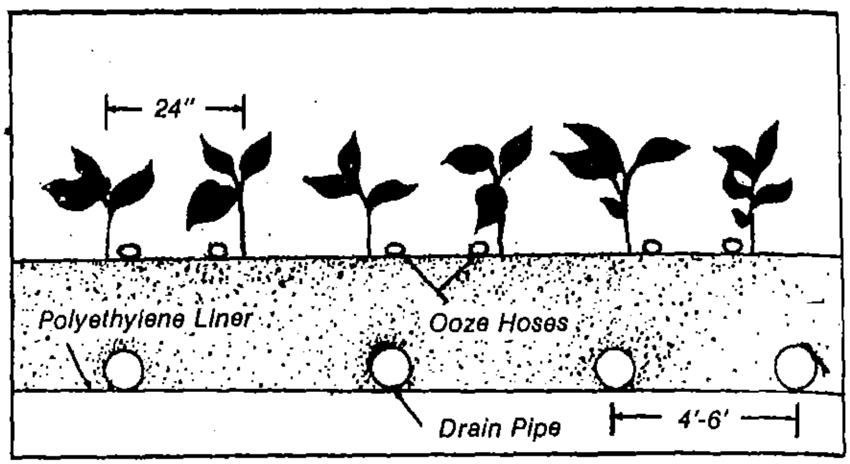

Fig. 5 Cross section of greenhouse floor design of sand culture.

(Courtesy of "Hydroponic Food Production"-Woodbridge Press, Santa Barbara, Calif.)

In the Middle Eastern countries such as Abu Dhabi large desalination units are used to desalt the sea water and use it for irrigation. These commercial operations are fully automated for temperature control by use of exhaust fans and evaporative cooling pads, for watering and fertilizers by use of injectors and trickle feed systems and even packing and grading machines for cucumbers and tomatoes (SLIDES 47-50).

Superior Farming Co. of Tucson ships most of their produce to the east coast of the United States. Their market has been fairly stable with prices averaging over 50 cents a pound. This sand culture operation is an example of how well a hydroponic farm can be set up and operated when technical people are employed and sufficient capital is spent initially to construct an efficient project.

CANARY ISLANDS:

In the Canary Islands large "greenhouses" supply the winter tomato crop for Europe (SLIDE 51). Most greenhouses are constructed of polyethylene. The main purpose of the greenhouse is to protect the plants from desiccation during sand storms.

They use the existing volcanic soil and feed the plants a nutrient solution by use of trickle irrigation. While this is not a true soilless system it closely represents one since the soil is relatively non fertile and most nutrients must be supplied through an elaborate irrigation system. It is operated very similar to a sand culture system.

Most of the islands use large desalination plants to desalt sea water for the entire island's water needs (SLIDES 52,53) With such costly water is is expected that a trickle irrigation system should be used to conserve water. The combination of hydroponics with the watering systems is expected. Numerous hydroponic greenhouses use the native volcanic cinders. Tomatoes are the principle crop while some cucumbers and flowers are also grown (SLIDES 54-56).

VENEZUELA:

Venezuela's largest city, Caracas, with about 3 million people is located within a mountain range. There is no flat land nearby where vegetables can be grown.

Most field grown vegetables come from the Lara province near Maracaibo. These vegetables must be trucked over 500 miles to the Caracas market. For this reason produce is of very poor quality and often in short supply. Prices are extremely high, tomatoes over $1 a pound, lettuce $2 to $2.50 per head and strawberries $1.50 to $2.00 per pound.

Lettuce, strawberries and flowers can only be grown at high altitudes (over 5000 feet) where temperatures are cool. The only regions having such a suitable climate are extremely steep and conventional farming is very difficult (SLIDE 57). All tillage, harvesting, etc. is done manually. The soils are infested with many insects, diseases and nematodes due to the very mild tropical climate. As a result, crop production is low and of poor quality. Combined with these problems is the constant presence of dysentry amoeba on the crops. This makes fresh salads risky for many people especially foreign tourists and business people.

With an enormous market nearby in Caracas and these problems of climate, terrain, diseases and pests, hydroponics is the answer. In this way crop production can be maximized over a unit area.

In Venezuela it is very difficult and expensive to obtain peat, gravel and other artificial media suitable for growing hydroponically. While even sand is expensive, it is the only suitable medium. Coarse silica sand used by the glass industry can be purchased for about $50 a cubic meter (slightly greater than a cubic yard) of which 75% of this cost is trucking for over 24 hours from its source at Valera (about 500 miles away).

Hidroponia Venezolana S.A. has a 2-acre sand culture operation growing head lettuce (SLIDE 58). They use a sub-irrigation system in raised beds. Beds are constructed of metal stands with bricks mortared together as a base (SLIDES 59-61). It is sealed with asphalt paint and initially a 4-inch layer of crushed brick is placed on that with several drain tile lines (SLIDES 62-65).

This allows adequate drainage. Then about 5 inches of silica sand is spread over the bricks level with the sides of the beds. The beds are raised due to the irregular topography and high cost of grading the soil. Also, during tropical rainstorms flooding of the beds is avoided. Once the sand is placed, small seedlings about 3-4 weeks old are positioned by use of plastic guides (SLIDES 66-68). They are spaced at one-foot centres (SLIDE 69). Fully mature lettuce is ready to harvest within 7-8 weeks.

A sub-irrigation system with elaborate pumping and cisterns for nutrient tanks make up the nutrient feed system (SLIDES 70-80). It has taken the owner close to 5 years to get the farm operating smoothly. The principal problems were lack of technical help. He originally used a poor medium of crushed brick and local non-silica sand. Once he found a good source of sand and a person capable and willing to manage the project success has been good. However, he is still faced with one other problem - weather. During the wet season, from May through October, daily torrential rains cause centre rot of the lettuce heads just as they reach marketable size. This results in losses of greater than 60-80% of the crop (SLIDES 81,82).

He has been advised to build a greenhouse for protection against the rains. However, under tropical conditions when the sun shines it gets very hot, especially in greenhouses. Once again a form of natural ventilation is essential to avoid very costly operating expenses for fans, cooling pads, etc.

We designed a special saw-tooth greenhouse which would allow free movement of air through the vertical open roof vents and through the side walls. Polyethylene drop curtains could be mounted on these vertical walls and roofs so that the entire structure could be sealed off during cold temperatures and during fumigation periods. The arch of the roof was to be covered with corrugated fibreglass.

In Venezuela the economy is governed by its oil industry. There is a lot of capital available , but, very little is invested in agriculture because it is easier to earn a quick return on real estate and development. For this reason the country depends largely on importation of their food. A strong central marketing agency has been set up to handle the importation, shipping and distribution of food. Consequently, growers are forced to accept whatever prices for their produce that the agency wishes to pay. The agency manipulates the price to growers to the benefit of the food brokers without any government controls. The price to the grower can be very low. For example, a grower may get less than 25 cents for a head of lettuce that sells to the consumer for $2.00 to $2.50. The only way to avoid this central market is to sell directly to large restaurants and possibly some independent food stores. But, the two main food chain stores are also very influential in the central market, so to break into the large retailers is difficult unless they will join with a very progressive grower.

Hidroponia Venezolana S.A. sells independently to top-rated restaurants and receives on an average of between $2.00 and $2.50 a head of lettuce. However, unless they are able to break into the large food chain stores their market will be limited to the production from less than 5 acres. The alternative is to grow a number of different crops such as tomatoes, strawberries and flowers.

Venezuela has basically a stable democratic government with free elections. Nonetheless, during an election year financial institutions are reluctant to commit themselves to new projects. A large expansion to the hydroponics project was pending on such funds. With the election taking place last December the government changed to the opposition party. With that change new policies have to be established. Since the new government did not take office until April of 1979, new policies will not be established until the end of this year. Then financial institution can work out their loan tactics. Funds for the project, therefore, will be delayed until at least early spring of 1980.

Once again politics plays a major role in the initiation and subsequent success of a hydroponics project in a foreign country.

SACK CULTURE AND COLUMN CULTURE:

Sack culture is a soilless technique to increase plant density and therefore production on a unit area by growing plants vertically. Polyethylene sacks of black layflat (6-mil thickness) of about 6-inch diameter and 6 feet in length are filled with a peat-vermiculite mixture. Both ends of the "sacks" are tied to shape the medium into a sausage-like form (Fig. 6).

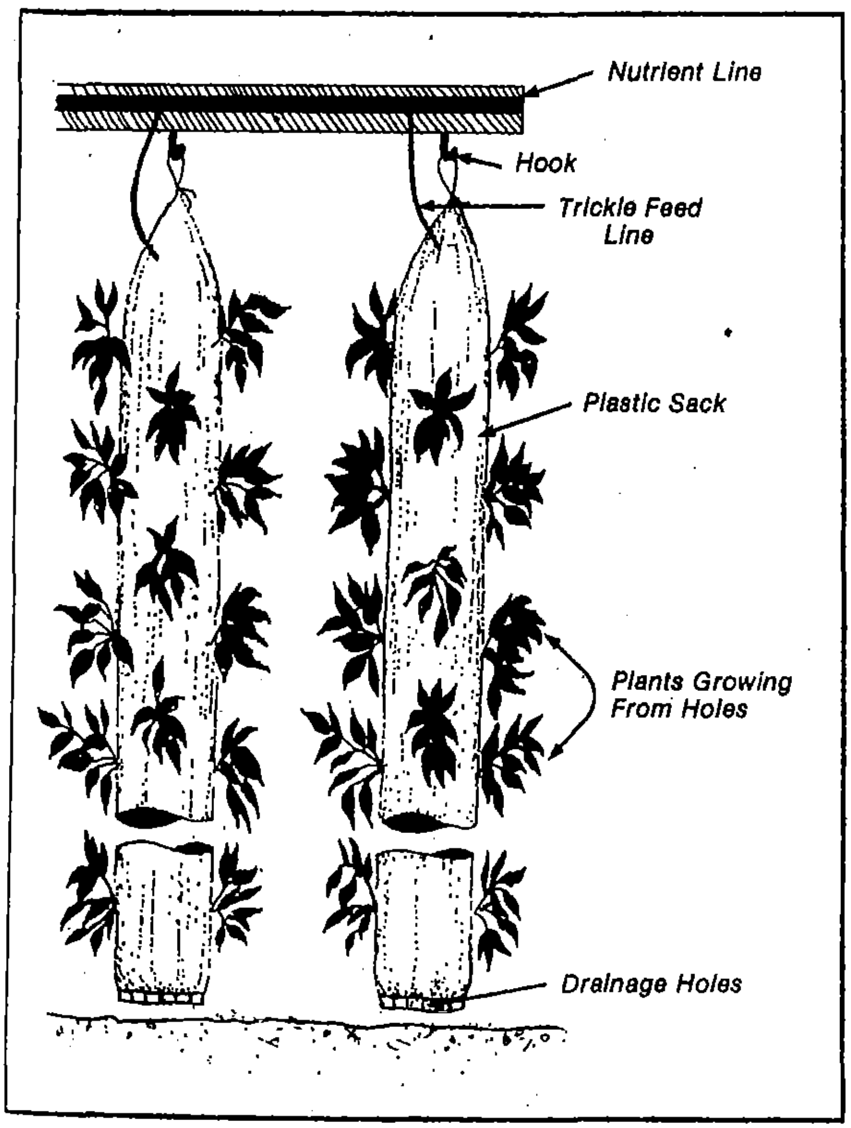

Fig. 6. Schematic of hanging sack culture system.

The top end is tied to the greenhouse superstructure and the sacks are hung at 3 feet spacing within and between rows (SLIDES 83-85). Watering and nutrients are fed into the sacks in 3-4 places by a trickle feeding system. This system, like sand and sawdust culture, is an open (non-returnable) one. Watering and feeding cycles are from 2 to 5 minutes, giving a volume of about one litre of nutrient solution per sack per irrigation cycle.

This cultural system has been used for tomatoes, peppers and eggplants, but, is particularly suitable to the growing of lettuce and strawberries which normally require a lot of greenhouse floor area with little utilization of the vertical space (SLIDES 86-90).

At present one operation in Italy is using sack culture on 20 acres of polyethylene greenhouses. All of the irrigation and feeding system is programmed from a central "electronic brain" controller (SLIDE 91).

A type of column culture has been used in the Canary Islands growing strawberries in barrels (SLIDE 92).

A sack culture system was set up as a pilot project of 2500 square feet in Venezuela utilizing an old chicken house superstructure (SLIDE 93). The structure was reinforced to support the weight of the sacks and an irrigation trickle feeding system was installed (SLIDES 94-96). In Venezuela it was extremely difficult to obtain suitable layflat polyethylene and appropriate media such as peat and sawdust. The polyethylene sacks that were finally acquired were too weak to support this weight of the medium. Consequently, many of them broke.

Strawberries were planted in December, 1978 and growth was satisfactory. However, the problem with breakage of the sacks hindered the progress of the experiment. Since the cost of peat and the sacks was so high, a more permanent system such as column culture should be used as was described earlier under "Costa Rica". Asbestos concrete or PVC pipes of 6-inch diameter could be placed vertically in a collecting bed.

After perforating them at the same centres as would be done in the bags, the columns could be filled with sand as well as the collecting beds underneath. A trickle feeding system would be used to supply water and nutrients to the top of the column. Water would drain down to the collecting beds below. The collecting beds could be used to propagate strawberries for the next crop or to sell to other growers since at present all such stock is imported from Europe and the United States.

A lot of potential exists for the sack culture and/or column culture techniques in areas such as Venezuela where terrain is steep and suitable climatic zones limited.

HOBBY GREENHOUSES:

Hydroponics can be enjoyed by the backyard gardener as well as the apartment dweller. At present there are a number of companies building hydroponic backyard greenhouses and small apartment units.

The greenhouses use basically a gravel culture system. Some use a sub-irrigation system, but, our company, Western Aquaponics Ltd., uses a trickle feed system (SLIDES 97-115). We have found that this method eliminates the use of valves which are necessary for flooding the beds with the sub-irrigation system. In addition, it allows us to use a much smaller nutrient tank since all of the void spaces of the gravel need not be filled at one time.

Over the past five years this trickle system has proven to work well with pea gravel (¼-inch diameter particle size). No drainage pipes are required in the bottom of the beds as the bed lengths are relatively short (no greater than 24 feet).

Average annual production for a 10½ ft. by 12 ft. hydroponic greenhouse has been 1000 pounds of tomatoes (68 plants), 2000 cucumbers or 1000 lettuce, or a combination of crops, such as 400 pounds of tomatoes, 700 cucumbers and 400 lettuce (SLIDES 116-126).

Of course, any crop can be grown hydroponically, but, we generally recommend growing high value fresh crops such as those mentioned plus chard, herbs, Chinese vegetables, etc.

For the backyard gardener the gravel culture method is easier to care for than a sand or sawdust culture system as sterilization between crops can be easily carried out with the use of a pint of household bleach in the nutrient tank followed by flooding the beds for ½ hour.

The problem of root build-up in the bottom of the beds does occur and it is necessary to turn over the gravel by hand between crops to remove all roots. This is not a difficult task for the backyard gardener as it only takes about an hour to do it. Nonetheless, because of our policy to minimize all manual work for the hobbiest we now have tried using eleven-litre patio pots filled with pea gravel(SLIDE 127). A one-inch thickness of pea gravel is first placed in the bottom of the beds then the pots placed on top of this gravel. The reason for the pea gravel underneath the pots is to allow plant roots to grow out of the bottom of the patio pots and spread into this one-inch layer of gravel. If no gravel is used under the pots, the roots of the plants in the patio pots will not grow over the dry vinyl liner and subsequently the plants become root bound with blossom-end rot occuring in tomatoes.

Between crops the patio pots can be lifted out of the beds and emptied and all roots easily removed from the gravel.

The next step in the backyard greenhouse hydroponics is to convert to a NFT system (SLIDES 128,129). Results with trials using NFT have been excellent. We are now going to manufacture a plastic extrusion giving us the desired configuration to allow good drainage of plant roots. Clean-up between crops with the NFT is very simple in that the root mat can be pulled out and the NFT canal wiped down with a mop and household bleach.

Our aim in backyard greenhouses is to minimize work through automation and simplify crop turn-around yet maximize production.

Some very ambitious hobbiests spend a considerable amount of money building a hydroponic system into their own homes. One person built one wing of his house with skylights and high intensity discharge artificial lighting for growing tomatoes, cucumbers, lettuce and peppers in sawdust culture (SLIDES 130-135).

APARTMENT UNITS:

Apartment units are becoming increasingly in demand by indoor gardeners. The simplest units may be made from a seed flat with an inverted bottle of nutrient solution at one end. The nutrients are absorbed by capillary action through the medium. The cost of such a unit is less than $10. It is mainly used for growing lettuce and herbs (SLIDE 136). Larger units may be constructed using a time-clock and water pump, but, the cost of these components makes the price of the units in excess of $100. Small units of approximately two cubic feet should sell under $50.00 to attract a large number of buyers. In order to accomplish this price range, time-clocks and water pumps must be avoided. The standard practice is to use a fish aquarium air pump with a series of polyethylene tubes to distribute the nutrient solution in the growing medium. The height to which this air pump will lift water and force it through tubes is very limited (usually a 6-inch lift). To accomplish this the apartment units consist of a nutrient reservoir underneath the medium contained by a partition within the unit. Generally, a medium of vermiculite or perlite is put in as a 4-inch base and topped with 3" - 4" of porous gravel such as heated, expanded clay or pumice. This porous material allows better water retention and capillary action to move water laterally.

These units may be constructed of a dense styrofoam, wood with a plastic liner, or plastic (SLIDES 137-141). These units are particularly suitable for the growing of leafy vegetables such as spinach, lettuce, chard and herbs.

Limitations on the type of crop that may be grown is due to the light limitations of an indoor environment. Artificial lights should be used. Cool white high output fluorescent lights are the best for growing these crops. Such lighting is insufficient to grow fruit-bearing crops such as cucumbers and tomatoes. However, tomatoes can be grown over the summer months if the unit is moved outside on a balcony during this period. To do this you can start the seeds in March and raise the small tomato plants under artificial lights indoors until the last frost. Then start by moving the unit outdoors during the day and bringing it indoors at night. This will harden off the plants. In a two cubic feet unit about 6 to 8 tomato plants can be grown by spreading and trelising the plants along the balcony to give them one-foot spacing.

By following this procedure you can get a two-month start on growing tomatoes over the standard outdoor gardening practices. These plants may remain outside until fall frosts. Generally, tomatoes take about 3 months to bear from the time of seeding. Therefore, by using the apartment hydroponicum, ripe tomatoes will be ready by June if seeded in March. The plants will continue to bear through the summer until fall frosts occur.

Over the late fall and winter months start a new crop of leafy vegetables to grow under the artificial lights indoors.

CONCLUDING REMARKS:

To be successful growing hydroponically always remember that hydroponics is applied plant nutrition. It provides us with precise regulation of watering and nutrition which enables us to grow higher yields of crops in a given area.

But, do not be misled that hydroponics is the ultimate answer which eliminates the need to understand basic plant agriculture. Too often people think that if you grow hydroponically you need not worry about insects, diseases or any environmental factors such as light, relative humidity or temperature which can limit production. In order for hydroponics to work optimally you must also optimize these other limiting factors. Hydroponics will minimize your problems with diseases and insects in the medium, but, will not eliminate their presence on aerial parts of the plants. You must always be vigilent for such problems and maintain other environmental factors such as light, temperature and relative humidity at optimum levels to reduce these problems.

While hydroponics is a very simplified method of growing for the backyard and indoor gardener who simply purchases a prepared nutrient mix, commercial hydroponics requires highly skilled technical people. The plant's nutrition must be tuned-in with changes in climatic factors, plant maturity and all environmental factors controlling plant growth. Hydroponics allows such a technical person to adjust the plant's nutrition to optimum levels under any given environmental conditions so that production may be maximized.

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CONSTITUTION

and

BY-LAWS

of the

HYDROPONIC SOCIETY OF AMERICA

ARTICLE I
PURPOSES

Section 1.PURPOSES-The purposes of the Hydroponic Society of America (hereinafter referred to as the "Society"), are to promote and encourage national and international interest in scientific research and education in hydroponics through:

(a) The sponsorship of an annual meeting to provide a forum for research reporting, lectures, and public discussion on hydroponic research;

(b) the dissemination of hydroponic knowledge through publications of various types;

(c) the participation and offering of leadership in national and international hydroponic matters;

(d) the development of mutual understanding among individuals and organizations concerned with the science of hydroponics;

Provided, however, that no part of the net earnings of the Society shall inure to the benefit of any private member or individual having a personal or private interest in the activities of the Society; no substantial part of the activities of the Society shall be carrying on propaganda or otherwise attempting to influence legislation; and the Society shall not participate in or intervene in (including the publishing or distributing of statements) any political campaign on behalf of any candidate for public office.

ARTICLE II
MEMBERSHIP

Section 1.ELIGIBILITY-Any person, corporation, partnership or unincorporated association in sympathy with the objects and purposes and cooperating with the aims of the Society shall be eligible for membership in accordance with the By-Laws and the rules and regulations from time to time in effect. There shall be no limit to the number of members.

ARTICLE II
MEMBERSHIP

Section 2.CLASSES OF MEMBERS-Members shall be divided into classes as follows:

ACTIVE MEMBERS. This class shall consist of persons actively interested in promoting the objectives of the Society. Benefits of Active Membership include unlimited access to information made available by the Society and privileges such as voting, holding elective office, serving on committees, participation at annual meetings, publishing in the Society's publications (subject to acceptable standards).

ASSOCIATE MEMBERS. This class shall consist of persons interested in affiliation with the Society, but who do not wish to be active in the Society. They shall enjoy all other rights and privileges of Active Membership except that they shall not be eligible to hold office or to participate in the nomination and election of Society officers.

STUDENT MEMBERS. This class shall consist of students with an interest in hydroponics at any educational institution, provided their full-time student status is certified at the time of application and annually thereafter. Benefits of Student Membership shall include access to the Society's information, attendance at meetings of the Society, and all other privileges except holding elective office or voting in the nomination and election of Society officers.

SPOUSE MEMBERS. This class shall consist of spouses of Society members who wish to have all the privileges of membership applicable to the class of their spouse.

AFFILIATE MEMBERS. This class shall consist of organizations interested in promoting the objectives of the Society. Affiliate Membership benefits shall be determined by the members. Affiliate Memberships shall be in the name of the institute, but a representative should be designated as the person to receive the Society's mailings.

Section 3.ADMISSION TO MEMBERSHIP-Membership shall commence upon acceptance of a person or organization as a Member by the Board of Trustees or by a committee duly authorized by the members.

ARTICLE II
MEMBERSHIP

Section 4. ANNUAL DUES-The rate of annual dues for all Classes of Members of the Society shall be determined by the Board of Trustees.

Section 5. DURATION OF MEMBERSHIP-Membership in the Society shall continue until terminated by death, failure to pay the annual dues, or as otherwise provided in these By-Laws. Termination of membership from any cause whatsoever shall operate as a release and termination of all right, title and interest in the property and assets of the Society but Members shall continue to be liable to the Society for any indebtedness due upon the termination of membership.

Section 6. RESIGNATIONS-Any Member may withdraw from the Society by giving written notice of resignation to the President or Secretary. Such resignation shall become effective upon the receipt of such notice by the President or Secretary or upon such date after the receipt thereof as may be specified in the notice.

Section 7. SUSPENSION AND EXPULSION OF MEMBERS-Any Member may be suspended or expelled for cause by a vote of the Board of Trustees at any meeting of the Board. Provided, however, that written notice of the proposed suspension or expulsion and a copy of the charges preferred against such Member shall have been mailed to such Member at his last known address as shown by the books and records of the Society, at least thirty days prior to the date of the meeting of the Board at which such suspension or expulsion shall be considered.

ARTICLE III
MEETINGS OF MEMBERS

Section 1. ANNUAL MEETINGS-An annual meeting of the Society shall be held at such time and place as may be designated by the Board of Trustees.

Section 2. SPECIAL MEETINGS-The Board of Trustees or the President may, and shall upon the written request of one-fourth of the Society Members, call a special meeting of the Members for one or more specific purposes.

ARTICLE III
MEETINGS OF MEMBERS

Section 3.NOTICE OF MEETINGS-Notice of each annual meeting and each special meeting of members shall be mailed at least 30 days preceding the date of the meeting to each member at his last known address as shown in the books and records of the Society.

Section 4.QUORUM-Ten percent of the Active Members of the Society, as determined by members present or proxy, shall constitute a quorum for the transaction of business at an annual or special meeting. In case there shall be less than a quorum present at any meeting, the presiding officer may adjourn the meeting to a later date and notice of such adjourned meeting shall be given in the same manner as notice of the original meeting.

Section 5.VOTING-Each Member present shall be entitled to one vote on each question submitted at an annual or special meeting of the Members of the Society. All questions at all meetings at which a quorum is present shall be decided by a majority vote of the Members present, except as otherwise provided by law. A Member shall be entitled to vote by written proxy for election of officers and changing the Constitution and By-Laws.

ARTICLE IV
BOARD OF TRUSTEES

Section 1.NUMBER AND QUALIFICATIONS-The Board of Trustees shall consist of fifteen members elected at the Annual Meeting. The President, the Vice President, the Treasurer, the Secretary and the Chairmen of the Membership, Program and Publications Committees shall be members by virtue of their office. Eight Board Members shall be elected as Members at Large at the Annual Meeting.

Section 2.VACANCIES-Vacancies existing on the Board of Trustees that bring the total members of the Board to less than nine members, from whatever cause arising, shall be filled for the unexpired term by vote of the members of the Society at a duly constituted meeting.

Section 3.POWERS-The Board of Trustees shall have all the powers conferred upon it by law, by the Constitution and By-Laws, and shall constitute the Board of Trustees of the Society. Without limiting the generality of the foregoing, but by way of illustration, the Board is authorized:

ARTICLE IV
BOARD OF TRUSTEES

(a) To manage the property and affairs of the Society;
(b) To determine the scope and extent of the activities of the Society and to define and carry out policies approved by members;
(c) To adopt such rules and regulations for the conduct of the meetings of the Board
(d) To accept contributions;
(e) To manage funds of the Society;
(f) To audit bills, disburse the funds of the Society, establish one or more offices, purchase equipment and supplies;
(g) To elect, appoint and employ such officers, agents and employees as the Board shall deem necessary or desirable, and to delegate such powers of the Board as may lawfully be delegated;
(h) To advise and cause to be carried into effect all measures which the Board may deem proper and expedient to promote the objectives and purposes of the Society.

Section 4.MEETINGS OF THE TRUSTEES-The Board of Trustees may meet without notice immediately after the annual meeting of Members, provided a quorum be present. Special meetings of the Board of Trustees may be held at any time at the call of the President or five members of the Board. Notice of any special meeting shall be given in such manner as may be determined by the Board of Trustees from time to time, or in default of any such determination, by causing at least fifteen days' notice of the time and place of any such meeting to be given to all Trustees personally or by mail, telegraph, telephone, radio or cable. Regular meetings of the Board of Trustees may be held without notice at such times and places as the Board from time to time may determine.

Section 5.QUORUM-At any meeting of the Board of Trustees, a majority of the Trustees then in office shall constitute a quorum, and the vote of a majority of the Trustees present at any meeting at which a quorum is present shall be necessary for the transaction of any business. If there is less than a quorum present at any meeting, the meeting may be adjourned by those present. Notice of any adjourned meeting shall be given in the same manner as notice of the original meeting.

ARTICLE V
COMMITTEES AND REPRESENTATIVES

Section 1.GENERAL-There shall be standing committees of the Society designated as follows: Publications; Membership; Finance; and Program. The Chairman of each committee shall be elected by the Members at the Annual Meeting. The Chairman shall appoint and determine the number of members with the approval of the Board of Trustees. Each committee shall consist of at least two members in addition to the Chairman. Those appointed shall serve from the close of the Annual Meeting held the year in which they are elected or appointed until the close of the Annual Meeting held in the year in which their term expires, unless otherwise specified in the By-Laws. Duties and responsibilities of committees and representatives of the Society shall be as set forth in the Operations Manual.

Section 2.FINANCIAL COMMITTEE-There shall be a Finance Committee consisting of appointed members. The Treasurer shall serve as Chairman of the Finance Committee.

Section 3.PUBLICATIONS COMMITTEE-There shall be a Publications Committee consisting of appointed members.

Section 4.MEMBERSHIP COMMITTEES-There shall be one Membership Committee for all categories of membership, consisting of no less than two appointed members in addition to the Chairman.

Section 5.PROGRAM COMMITTEE-There shall be a Program Committee charged with the responsibilities of organizing and administering the annual meeting and working in conjunction with the Board of Trustees to arrange for special events that will be of interest to the members of the Society.

Section 6.SPECIAL AND AD HOC COMMITTEES-When approved by the Board of Trustees or a majority of the members, Ad Hoc Committees shall be appointed.

ARTICLE VI
OFFICERS

Section 1.ELECTION OF OFFICERS-Members shall elect annually a President, a Vice President, a Treasurer and a Secretary. Officers, except as stated above, shall hold office for a term of 1 year and until their successors are elected and qualified, two elective offices may not be

ARTICLE VI
OFFICERS

held concurrently by the same person, and no person may serve more than two consecutive terms in the same elective office. A vacancy in any elective office of the Society which occurs during the year for any reason shall be filled by an election of the members at a duly constituted meeting.

Section 2.PRESIDENT-The President shall be the chief executive officer of the Society and a member of the Board of Trustees. The President shall have the general powers of supervision and management usually vested in the office; subject, however, to the right of the Board of Trustees or members to delegate any specific power or powers to any other officer or officers of the Society.

Section 3.VICE PRESIDENT-The Vice President shall assist the President in all business of the Society.

Section 4.TREASURER-The Treasurer shall be responsible for the financial affairs of the Society and shall report the financial position of the Society at the annual meeting. The Treasurer will be the Chairman of the Finance Committee.

Section 5.SECRETARY-The Secretary shall keep the Society records, including minutes of all meetings and report all business of the Society as requested by members.

ARTICLE VII
NOMINATIONS AND ELECTIONS

Section 1.ELECTION OF OFFICERS-Election of officers shall be by the members at the annual meeting.

Section 2.TERMS OF OFFICE-Terms of office begin at the close of the annual meeting following the election, and end at the close of the next annual meeting. Two elective offices may not be held concurrently by the same person, and no person may serve more than two consecutive terms in the same elective office.

ARTICLE VII
NOMINATIONS AND ELECTIONS

Section 3.VACANCIES-A vacancy in any elective office of the Society which may occur for any reason shall be filled by an election by the members at a duly constituted meeting for the unexpired term.

ARTICLE VIII
MISCELLANEOUS PROVISIONS

Section 1.FISCAL YEAR-The fiscal year of the Society shall end on the 31st day of December of each year.

Section 2.EXECUTION OF CHECKS, ETC.-All checks, drafts, notes and orders for the payment of money shall be signed by such officers or agents as the members may from time to time designate.

Section 3.WAIVER OF NOTICE-Any notice required to be given by these By-Laws may be waived by any person entitled thereto.

Section 4.OPERATIONS MANUAL-There shall be an Operations Manual which specifies the operating policies and procedures of the Society and shall serve as the official reference on all matters of Society operations. The Manual may be amended or revised at the discretion of the Board of Trustees and or members at a duly constituted meeting.

ARTICLE IX
AMENDMENT OF BY-LAWS

Section 1.AMENDMENT BY MEMBERS-These by-laws may be altered, amended or repealed only by members of the Society, by two-thirds vote, as set forth in the following section of this article.

Section 2.AMENDMENT AT MEETINGS OF MEMBERS-These by-laws may be altered, amended or repealed at any duly called meeting of members at which a quorum is present by a two-thirds vote of members present at the meeting,

ARTICLE IX
AMENDMENT OF BY-LAWS

provided the members are given official notification of the proposed change(s) at least 30 days in advance of the meeting. Official notification shall be authorized by the Board of Trustees or the President upon written request by one-fourth of the Society's members. However, the requirement for 30 days' advance notice may be waived by a two-thirds vote of members present at any duly called meeting of members at which a quorum is present, provided the vote to waiver is taken on a motion duly made and seconded for that purpose before a vote is taken on any amendment that may be proposed.

As adopted by the founding members of the HYDROPONIC SOCIETY OF AMERICA on this day of November 8, 1978.

Paul [illegible]
James Pelt
Robert LeTourneau
Mary Downey
Bernard C. Berger
Theodore Hemmons
Scott A Ramos
W. George Downey
Clarence T. Anderson
Robert Bailey
Virgil M. Allison
Brent E. Wadsworth

David H Peal
Milburn E. Bishop

H.S.A. BOARD OF DIRECTORS 1986-1987

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ATLANTA, GA

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PACHECO, CA

STEVEN SCHWARTZKOPF
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SAN JOSE, CA

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MENLO PARK, CA

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STEVENSON, CA

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PLEASANT HILL, CA

GARY HICKMAN
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STOCKTON, CA

GEORGE DRAGAN
31 CRAGMONT WY.
WOODSIDE, CA

EDEL RAITH
361 TEXAS ST.
SAN FRANCISCO, CA

ANNE LOHMANN
36 SANTA BELLA RD
ROLLING HILLS, CA

PAST PRESIDENTS OF H.S.A.

1978 - 1979	PAUL W. DROLL
1979 - 1980	PAUL W. DROLL
1980 - 1981	PAUL W. DROLL
1981 - 1982	VIRGIL M. ALLISON
1982 - 1983	VIRGIL M. ALLISON
1983 - 1984	DAVID H. PEAL
1984 - 1985	DAVID H, PEAL
1985 - 1986	DALE BERGSTEDT
1986 - 1987	DALE BERGSTEDT/ JOSEPH W. O'BRIEN