亞蔬非循環式水耕栽培法†

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AVRDC Noncirculating Hydroponics System

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SUMMARY

The AVRDC soil science unit developed a noncirculating hydroponics system which requires neither aeration, nor any check of pH, EC, temperature or nutrient. Once the facility is established, the only input required is the addition of nutrients once every three weeks. Composition of nutrient solution need not change for each crop.

During 1986, soybean, sweet pepper, large-fruited tomato, melon, and cucumber were all successfully grown during the summer. Yields of the latter three were 3.1 kg (average fruit wt: 150 g), 2.34 kg, and 4.72 kg/plant, respectively.

INTRODUCTION

Hydroponic plant culture can be superior to soil culture in many respects: (1) land is unnecessary, only water must be available; (2) no hazard from continuous cropping; (3) chemical free product; (4) shortened growth period; and (5) high yield and better quality.

Modern hydroponic systems are fully computerized and automatically control pH and electric conductivity (EC) adjustments, air and solution temperature measurement and adjustment and, if necessary, automatic nutrient analysis and compensation, and a CO_2 supplier. Various systems to provide aeration and nutrient have been developed: pumping, circulation, flowing, misting, dripping, etc.

While the demand for a substantial increase in vegetable production in the humid tropics has arisen worldwide, it is well known that vegetable production is very low in the humid tropics. There are many reasons for this shortfall: the wide distribution of infertile and problem soils; the high rate of disease and insect infestation; poor soil and water management, the lack of simple but effective technologies to overcome these constraints; and probably the worst, the lack of funds and trained personnel.

† This work has been undertaken solely at AVRDC and will be formally reported in the AVRDC 1986 Progress Report.

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Hydroponics would appear to be very promising system to overcome many of these constraints. However, the utilization of hydroponics is still limited to institutes involved in scientific research and some cash vegetable crops because of the costly facilities required, their high running cost and the need for highly educated personnel. Therefore, if a hydroponic system which does not require either costly facilities, high running cost or highly educated personnel could be successfully developed, it would contribute to a substantial increase in vegetable production in the humid tropics.

The objective of this research project is, therefore, to develop a hydroponic system which requires neither costly facilities nor intensive care, and is easily operable by farmers in the tropics.

CURRENT HYDROPONICS AND THEIR CONSTRAINTS

Hydroponic systems are generally categorized into either the batch system or flowing or circulating system. The first type is commonly referred to as water culture, while the other is named according to the medium used as a sand, gravel, rockwool, vermiculite, peatmoss etc., culture. Whether or not the system adopted is successful depends on the extent to which it can meet the following requirements:

(1) avoid a great fluctuation of nutrient concentration in the culture solution;
(2) maintain the solution pH in the range of 5 to 7.5;
(3) avoid a sharp increase in solution EC (below <2 mmohs);
(4) maintain an adequate solution temperature; and
(5) provide a continuous oxygen supply.

In the batch system, pH and EC adjustment, and nutrient and water compensation are frequently required. The circulating system, which is generally installed with automatic pH and EC adjustment equipment, requires more space and facilities, and also has a very high running cost.

In summary, the major constraints of present hydroponic systems are the necessity for daily control of solution pH, EC, nutrient concentration, and the continuous supply of oxygen.

PRINCIPLES OF NONCIRCULATING HYDROPONICS

1) Background

The concept of noncirculating hydroponics was developed through the cultivation of tomato on beds raised one-meter high. Although water consumption of these tomato plants grown on high beds was only one-sixth to one-tenth of those grown on low beds only 25 cm high, the former produced a higher fruit yields than the latter.

In addition, the root systems were totally different from each other. Plants grown on the low bed were less tolerant to water stress than those grown on the high bed. This suggests that the root systems of plants are easily adaptable to its water environments. If this is true, then two root systems with different functions—one for oxygen uptake and another for water and nutrient uptake—can be developed from the same plant. Thus, the most serious constraint in hydroponics, that is aeration, can be overcome.

2) How to Develop Diverse Root Systems

(a) Seedlings

The seedlings must be very healthy with active rooting. To minimize transplanting shock, soil should not be used as the seedling media. Instead, smoked rice husks (SRH), and vermiculite, or their mixture, are highly recommended as appropriate seedling media.

(b) Netting

To seperate roots responsible for oxygen uptake from roots for water and nutrient absorption, a net is set at 12 to 15 cm below the top cover where plants are held (see Fig. 1). The roots of the plant are initially forced to grow inside a wide open area between the top cover and the net. After the roots reach the net, they start growing laterally and branching vigorously. Thus, a sizable portion of roots spread above the net before passing through to reach the nutrient solution below. The roots above the net require two to three times as much oxygen as those below the net and since their main function is aeration they are called O roots.

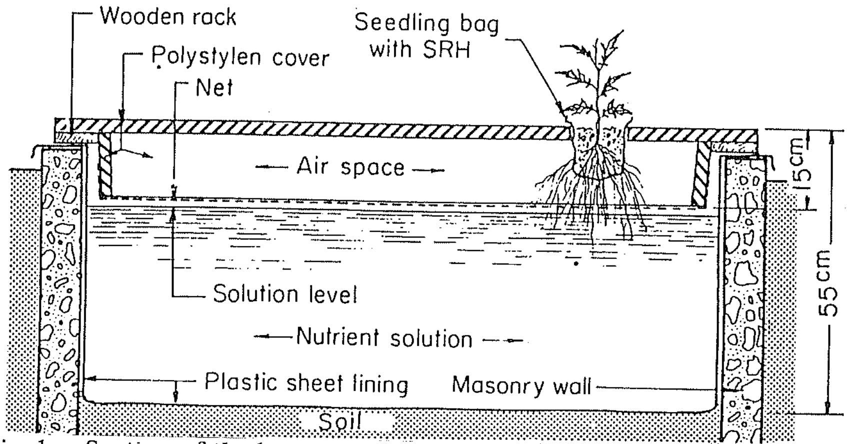

Fig. 1a. Section of the large growing unit in non-circulating hydroponics.

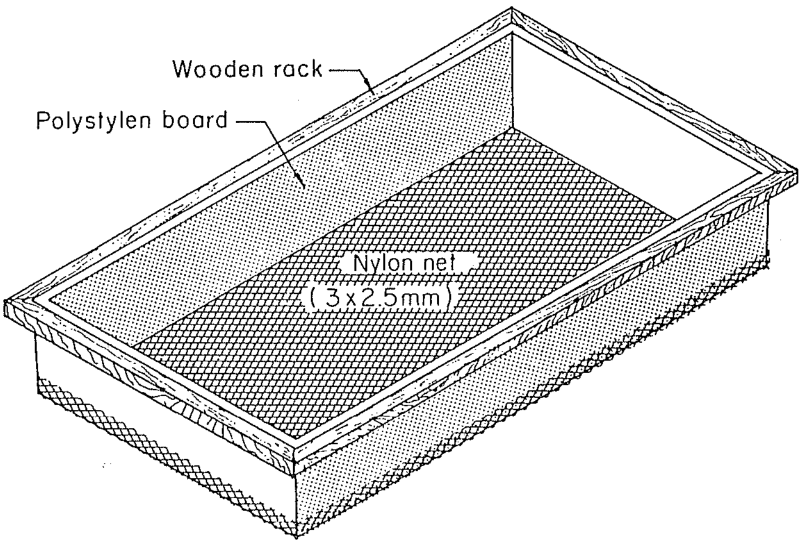

Fig. 1b. The wooden rack with net.

The success of this noncirculating hydroponics system is dependent on the speed and quantity of O roots developed. The net setting is a key technique for this system and it performs two important roles: first, in the separation of the O roots from the water nutrient roots (WN roots) and secondly, in the acceleration of lateral root growth and branching.

(c) Water management

Water management is another essential technique to properly develop the two different types of roots. During the period from one to two weeks after transplanting, the water level of the solution must be kept 5 to 10 cm above the net to immerse the seedling roots completely. (The period of immersion and the water level change based upon the growth stage of the seedlings.) The water level should be decreased as plants grow and ultimately be set at 1 to 2 cm below the net until harvest.

In the noncirculating system, however, WN roots should elongate only to a depth of 15 cm into the solution due to the limited amount of dissolved oxygen. The amount of water absorbed by plants increases greatly with plant growth, hence the water level recedes sharply daily from the fruit enlarging stage to harvest. WN roots which have stopped elongating because they have reached the nutrient solution start growing once again as the water level recedes. Although the roots below the net elongate, the length of the roots immersed in the solution remain almost the same. The portion of the roots which is increased between the net and the solution are principally O roots.

We have confirmed that after the roots were allowed to elongate by decreasing the water level for one week, and then water was added to return the water level to the original height, that within a couple of hours the tomato plants started to wilt and never recovered. The tomatoes were suffocated by the water. When WN roots are exposed to air, they take only 2 to 4 days to be converted to O roots. Therefore, when crops with vigorous top growth (especially tomato) are cultivated by this system using a small container under high population density and high temperature, it is recommended to install a simple water sensor, or some other device to automatically supply water and, thereby, keep the water level constant.

3) Nutrient Supply, pH and EC Control

(a) Nutrients

Unlike current hydroponic systems, the final goal of our noncirculating system is to simplify all of the procedures as much as possible. Thus, the following principles were tested.

(1) A nutrient solution with the same composition is used for all crops.

(2) The frequency of replenishment of the nutrient solution and/or nutrient supply (fertilizer) is dramatically reduced.

(3) A locally available fertilizer mixture is used as the sole/major source of nutrient.

Regarding principle (1), various types of crops have been grown satisfactorily with the same nutrient solution in different seasons, i.e. tomato (processing and fresh market), melon, cucumber, strawberry, sweet pepper and vegetable soybean. Therefore, the same nutrient solution can be used for most vegetables.

The key to principle (2) depends on the container size, that is, the amount of nutrient solution stored. When, for example, 24 tomato plants were cultivated in a 200 x 150 x 50 cm^3 large container (1,500 kg of solution), fertilizer must only be applied every three weeks during the first month after transplanting, after which time frequency is increased to once evey two weeks until harvest. When a 50 x 40 x 20 cm^3 small container (40 1) is used, however, fertilizer must be added once a week, and, in summer cultivation, twice a week.

Concerning principle (3), compound fertilizers produced by the Taiwan Fertilizer Co. have been tested (No. 1 ($N-P_2O_5-K_2O = 20-5-10$) and No. 43 ($N-P_2O_5-K_2O-MgO = 15-15-15-4$) mixture). Although acceptable yields were obtained in tomato, melon and cucumber with this fertilizer (containing the compound fertilizer mixture plus micronutrients), this fertilizer mixture was apparently inferior to a nutrient solution specially prepared at AVRDC. (See fertilizer section which follows for the composition of the AVRDC solution.)

(b) pH and EC

Since the variation in the pH of the solution during one month of cultivation is within one unit, practically no pH adjustment is needed with the AVRDC noncirculating system. In circulating systems that constant pH adjustments suggests aeration or solution circulation (oxygen supply to the roots immersed in the solution) accelerates root growth into the solution, and consequently, a substantial increase of root mass in the solution results in a sharp increase of nutrient uptake by plants (especially N), hence resulting in a great change in pH. On the other hand, in the noncirculating hydroponic system, root elongation is limited only to a depth of 15 cm into the nutrient solution due to the limitation of the oxygen supply, thereby minimizing both nutrient fluctuation and change in pH.

Also, no control of EC is required in the noncirculating system.

ESTABLISHMENT OF A NONCIRCULATING HYDROPONIC SYSTEM

The minimum requirements for this system are as follows:

1) *Container:* Three container prototypes—one suitable for commercial production (Fig. 1) and two for home production (Figs. 2 and 3)—are illustrated.

For commercial production, containers should be made of bricks or a similar material. It is desirable to construct the container as deep as 50 to 60 cm below the surface in order to keep the solution temperature low. The bottom must not necessarily be constructed of bricks. According to our experience, a 0.3mm plastic sheet is strong enough to avoid leakage of the nutrient solution from the bottom for a year.

For home production, a plastic container (any shape) available locally can be used. The container in Fig. 2 is 50 x 40 x 30 cm^3 and holds 40 1 of nutrient solution. This is sufficient for two melons, cucumber, tomato plants and four sweet peppers etc..

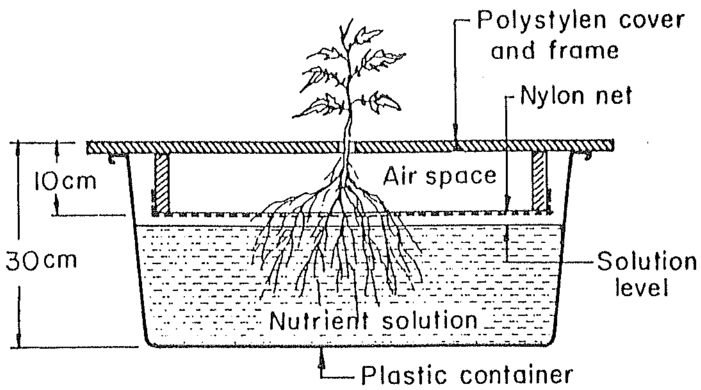

Fig. 2a. Section of small growing unit in noncirculating hydroponics.

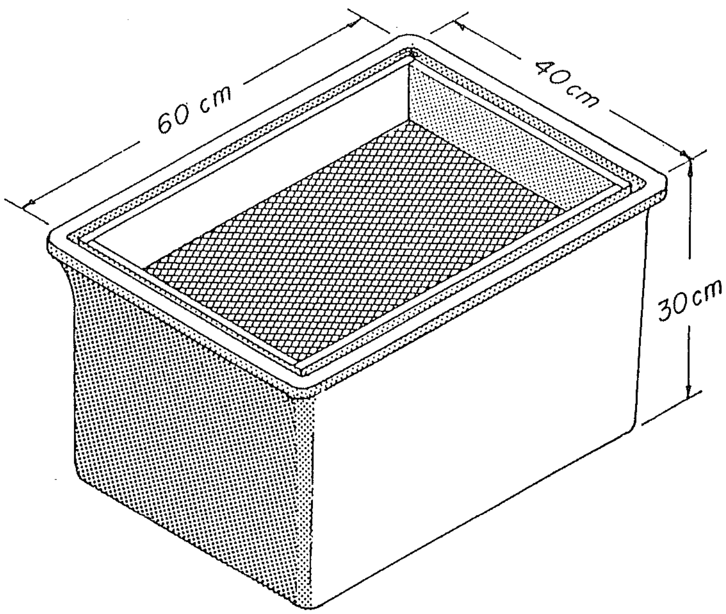

Fig. 2b. The plastic container with net.

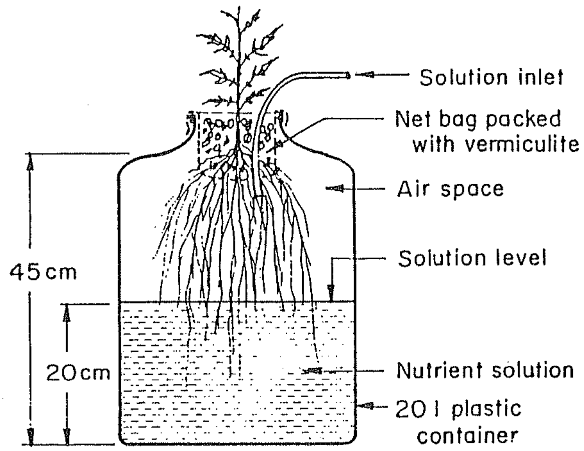

Fig. 3. Small growing unit (20 liter plastic container) in which constant level of solution is maintained throughout tomato growth stage.

2) *Net:* This is the most important component of the physical structure of the system. As is illustrated in Figs. 1b and 2b, wood is used only for the skeleton of the rack to strengthen the structure. Light materials such as polystyrol are used for both the top cover and sides to reduce the weight and to keep out heat and light. The bottom of the frame is netted. With this structure the O roots are forced to grow inside an open area between the top cover and the net. The polystyrol used for the top cover and sides also aids in the development of O roots by maintaining the level of humidity in the open area relatively high.

For home production, since the rack floats on the surface of the nutrient solution, it is entirely made of polystyrol, thereby automatically adjusting to the water level.

The netting used in this system is the type commonly used for the cultivation of tomato and Chinese cabbage seedlings. The mesh size of the net is important and the net with 3 mm x 2.5 mm is recommended for most vegetables. As previously explained, the net plays two important roles. In order to support healthy growth of plants throughout the growth period, the most important technique is how and where to net. In Fig. 4, some examples are given.

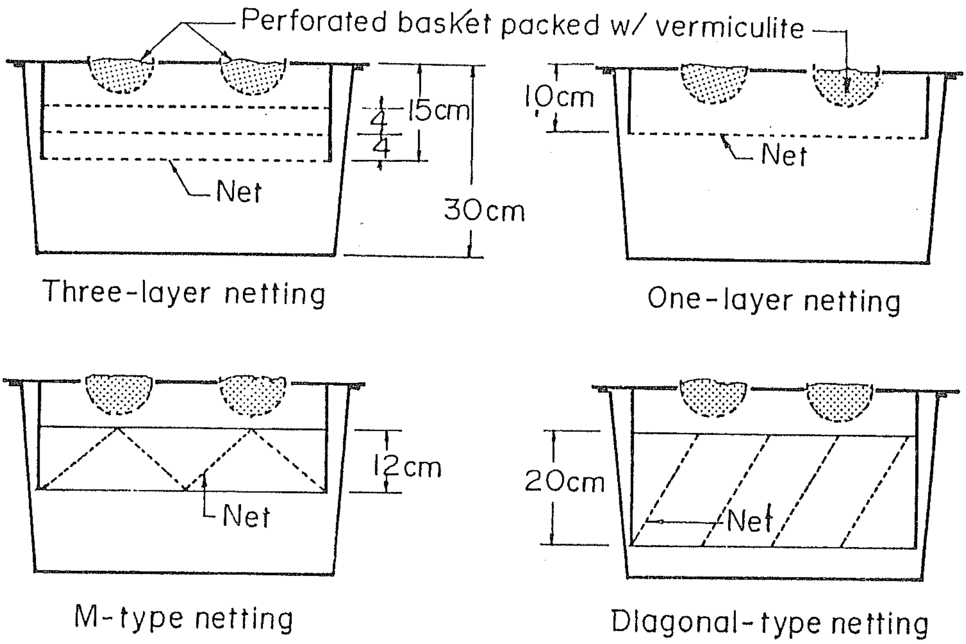

Fig. 4. Various types of netting in small containers.

3) *Seedling bag*: Seedlings prepared in SRH or vermiculite and placed in the nutrient solution are generally strong enough to minimize transplanting shock and to shorten the period of establishment. During summer cultivation, however, seedlings sometimes do not grow well in a greenhouse due to high temperature which causes a sharp decrease in the amount of dissolved oxygen in the solution and a great respiration loss of carbon assimilates. The seedlings are damaged before their roots reach the net and start vigorous elongation and branching. To avoid this hazard, we have developed a net bag seedling culture.

A bag, 8 cm in diameter and 15 cm in length is made from the same net that is used for the netting (Fig. 5). It is packed fully with vermiculite or SRH and seeds are sown directly on it. They are then cultivated with the culture solution for 3 to 4 weeks. Since after 3 to 4 weeks many roots have already passed through the net bag, the seedlings are transplanted together with the net bag and allowed to grow until harvest. Initial growth retardation in the summer cultivation is completely overcome by this net bag seedling culture.

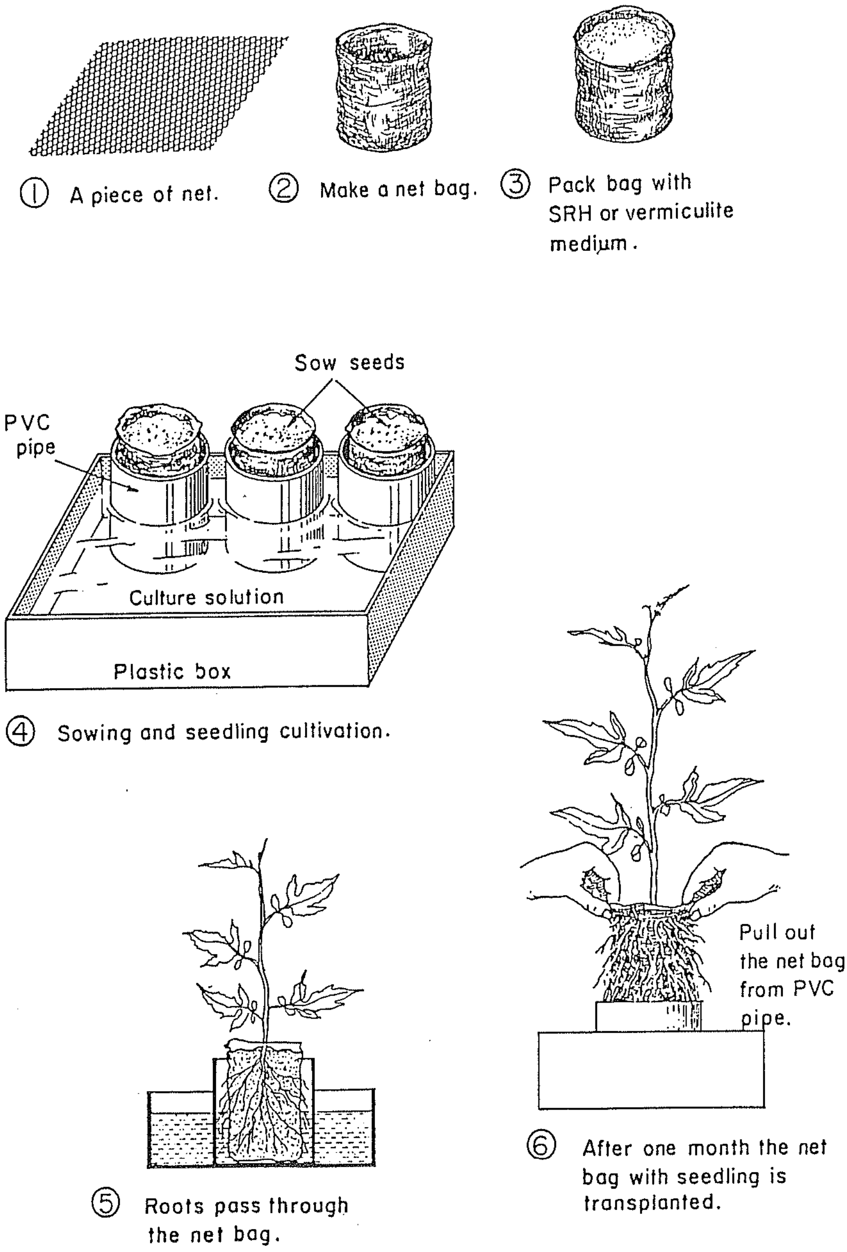

Fig. 5. Procedures for net bag culture of seedlings.

4) *Fertilizer:* The composition of the AVRDC culture solution is provided in Table 1. As mentioned during discussion on nutrients above, a commercial fertilizer mixture tested was inferior to the AVRDC solution which was specially prepared. A solid compound fertilizer and BASF (Foliar Nitrophoska) are also used in this system.

Table 1a. Constituents of Nutrient Solution*

Element	Chemical formula	Concentration (ppm)	Amount (g/l solution)
N	$Ca(NO_3)_2 \cdot 4H_2O$	70.0	0.59
	KNO_3	30.0	0.22
P	K_2HPO_4	15.0	0.09
K	KNO_3	38.0	–
	K_2HPO_4	83.8	–
Ca	$Ca(NO_3)_2 \cdot 4H_2O$	100.0	–
	$CaCl_2 \cdot 2H_2O$	50.0	0.18
Mg	$MgSO_4 \cdot 7H_2O$	48.6	0.49

*Using 4 N H_2SO_4 to adjust the pH value to 6.0.

Table 1b. Constituents of Stock Solution for Microelements*

Element	Chemical formula	Concentration (ppm)	Amount (g/l solution)
Fe	Fe-EDTA**	3.00	2.2600
Mn	$MnSO_4 \cdot H_2O$	0.50	0.1540
Cu	$CuSO_4 \cdot 5H_2O$	0.02	0.0079
Zn	$ZnSO_4 \cdot 7H_2O$	0.05	0.0220
B	H_3BO_3	0.50	0.2860
Mo	$Na_2MoO_4 \cdot 2H_2O$	0.01	0.0025

*Nutrient solution is prepared by adding 10 ml of stock solution to each 1 l solution.
**Fe-EDTA = $C_{10}H_{12}N_2O_3NaFe.\ 3H_2O$

5) *Simple net house:* For commercial production, the AVRDC noncirculating hydroponic system should be placed inside a simple net house to prevent insect and disease infection. See Fig. 6 for illustration of a simple net house. An iron pole is the best material to use as framework for the net house. Polyvinylchloride (PVC) pipes reinforced with cement, also provide a strong structure. Alghough bamboo may be easily available locally, is not strong enough to resist typhoons. The roof consists of a clear plastic sheet. The sides are completely surrounded with a fine net to keep undesired insects out and desired ones, such as bees, in. The construction cost using iron poles for a simple net house of 18 x 3 x 2.5 m was about US$ 1,400.

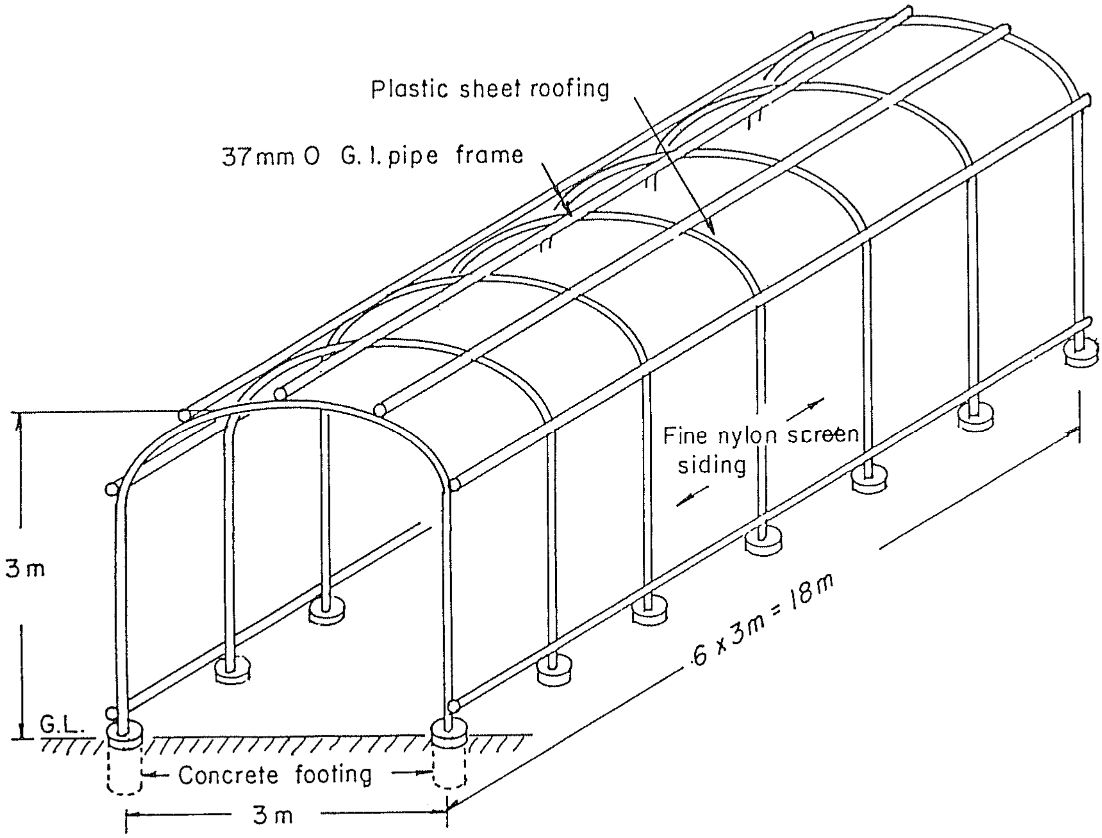

Fig. 6. A simple net house.

AUTOMATIC WATER (OR SOLUTION) SUPPLY DEVICE

a) Floating ball

This device is commonly used in the water storage area of a household toilet. In the system, three different root systems, each with different functions, are developed, namely, O roots, nutrient roots (N roots), and water roots (W root).

The nutrient solution is kept in a plastic container (50 x 15 x 15 cm^3) and put inside a large wooden box (see Fig. 7). A plastic basket with net at its bottom was used as a netting rack. Initially, the nutrient solution is applied, not only inside the container but also outside it, within the wooden box up to the level at which seedling roots are completely immersed in the solution. Due to the net at the bottom of the basket, first, roots develop uniformly in the basket, then pass through the net into both outside and inside the solution container as the level of solution diminishes. A floating ball is set at 3 to 4 cm below the top of the container, in order that when the solution level recedes several cm below the present level, water is automatically supplied from a water reservoir to return it to the desired level. Thus, the solution outside the container is gradually diluted with water and finally, turned into pure water. At the same time, the nutrient solution is successively supplied as needed into the container; consequently, N roots are separated from W roots.

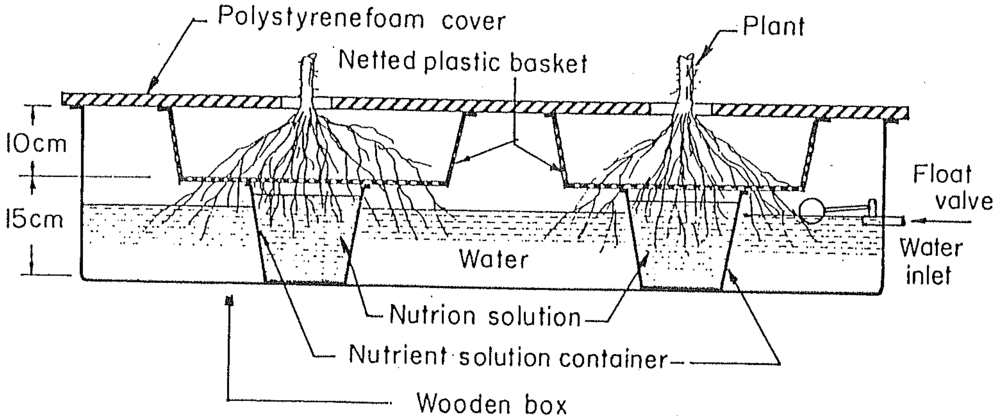

Fig. 7. Floating ball system.

There are two advantages in this system:

1) Because water is mainly absorbed through W roots, uptake of the nutrient solution by plants is much less than in other noncirculating hydroponic systems, and hence, decrease the frequency of the nutrient supply.

2) Since both W roots and N roots are floating on the surface of the solution, sufficient oxygen can be also supplied to these roots; therefore, plants show very vigorous growth even under summer greenhouse cultivation.

b) Water sensor

A precise, but inexpensive, water sensor is now available. One Taiwan-made set costs only US$ 40. A Japanese-made product is also on the local market for US$ 140. As illustrated in Fig. 8, the solution level can easily be controlled by this sensor at any height desired. This system has already successfully produced more than 3 kg of large-fruited tomato (average weight 130 g) during midsummer cultivation.

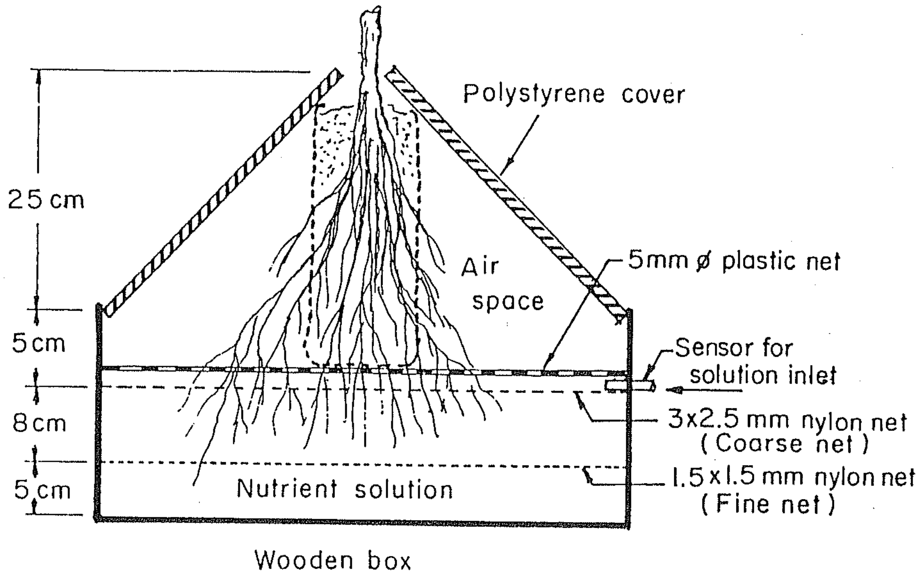

Fig. 8. Solution level controlled by a water sensor.

GROWTH PERFORMANCE AND YIELD OF SOME VEGETABLES USING NONCIRCULATING HYDROPONICS

a) Vegetable soybean

Plants which produce more protein than carbohydrate require considerable oxygen for their growth. Soybean accumulates nearly 40% of its protein in its seeds, and yield loss by flooding is enormous because of its high demand for oxygen.

In noncirculating hydroponics, however, soybean growth was very vigorous throughout the growth period, and no flood damage was apparent. It was noted that nodules were formed only on O roots. Vegetable soybean cultivar G 9038 was transplanted on 12 March 1986 and harvested on 5 May 1986. Thirty 10 day old seedlings were transplanted to a wooden container ($90 \times 120 \times 40$ cm^3, holding 400 l of nutrient solution, hereafter referred to as medium container) while 56 plants were grown in a large concrete container ($2 \times 1.5 \times 0.6$ m^3, 1500 l, referred to as large container) which was placed in a simple net house. Yield and yield components are presented in Table 2.

When fertilizer was supplied at R5 stage, the nutrient solution accidentally leaked out and this resulted in the drying up of fully developed leaves in the large container. Although soybean yield was higher in the medium container than in the large container, seed number per pod was extremely low because mutual shading of leaves came to be very serious at R4 stage due to vigorous top growth.

Table 2. Yield and Yield Components of Vegetable Soybean

Container size	Average pod No.	Pod wt (g)	Seed wt (g)	100 Seed wt (g)	Seed/ Pod (g)	Total seed wt (g/plot)	Yield (ton/ha)	Plant No./ plot area
	--------per plant-------							
Medium[z]	30.9	62.9	31.1	28.3	1.1	960	8.9	30 plants/1.08m^2
Large[y]	32.2	128.1	58.7	34.5	1.7	1890	6.3	56 plants/3.0m^2

[z] Placed in greenhouse.

[y] Placed in a simple net house constructed in field No. 28.

b) Cucumber

Cucumber has been considered to be very sensitive to all external factors and difficult to grow in hydroponics. The optimal range of solution pH is narrow (from 6.5 to 6.7) while its nutrient uptake is great. This causes a great fluctuation of both pH and nutrient concentration.

In the noncirculating hydroponics, however, cucumber proved to be one of the easiest crops to cultivate. It is highly recommended to use the seedling bag in summer cultivation to avoid transplanting shock. Cucumber growth with the seedling bag was better than that without it. In the first trial, 48 seedlings were transplanted to the large container on 14 March 1986 and fruits were ready to be harvested one month after transplanting. During the first two weeks of harvest, cucumbers produced 256 fruits with a total weight of 23.3 kg and the average fruit weight was 91 g (Table 3). The yields decreased sharply from six weeks after the first harvest because 48 plants were transplanted to only 3 m^3 container, thereby mutual shading of leaves hastened their senescence. After most of lower leaves fell out, the plants recovered completely and produced fruit actively again. Thus, even at five months after transplantng, about 15 kg of fruits were harvested.

In the second trial, the number of plants transplanted was reduced to half of the previous trial. Twenty-four seedlings cultivated in a net bag were transplanted to the large container on 8 May 1986 and fruits were ready to be harvested three weeks later. Since mutual shading was minimized, the plants yielded more than 110 kg of cucumber during the 100 days of cultivation.

Table 3. Cucumber Yield in Noncirculating Hydroponics. Spring to Summer, 1986

Date	Fruit No.	Cucumber Fruit No.	Yield	Cucumber Yield	Average Fruit Wt
	----------First Cultivation----------				
			g		
April 30	256	256	23320	23320	91
May 14	115	371	10090	33410	88
30	182	553	13960	47370	77
June 14	102	655	6360	53730	62
30	77	732	5910	59640	77
July 14	59	791	5220	64860	88
31	141	932	15080	79940	107
August 20	128	1060	15040	94980	117
	----------Second Cultivation----------				
June 14	97	97	9650	9650	99
30	177	274	22400	32050	127
July 14	270	544	29340	61390	109
31	387	931	34140	95530	88
August 20	140	1071	17710	113240	126

c) Melon

Similar to cucumber, melon developed very long, but less branched roots which were characterized by big and voluminous root hairs. Due to the root hairs, the roots floated on the surface of nutrient solution even without a net. But the net was very effective to develop O roots hence this is one of the most promising crops for cultivation in noncirculating hydroponics. In an early summer trial (transplanted on 8 May 1986 and harvested several times from 2 July to 20 August), 24 plants produced 38 fruits which weighed 56 kg, in 100 days cultivation. The average fruit number and fruit weight per plant were 1.58 and 1,480 g, respectively. Similarly, 24 melon plants which were transplanted on 17 July 1986 and harvested on 8 September yielded 25 fruits with the total weight of 41.8 kg. The duration from transplanting to harvest was 53 days.

Melon was also grown in the small container ($40 \times 30 \times 35$ cm^3) in a greenhouse at midsummer successfully. Although air temperature inside the greenhouse went up to 45°C, the small container provided two plants with enough space and nutrient, consequently, each plant yielded two fruits with an average weight of 1.75 kg. Melon requires high temperature and light intensity for healthy growth and is also very susceptible to fusarium wilt, gumny stem blight and powdery mildew. Cultivation in a net house and sparse planting are highly recommended.

d) Tomato

Tomato is one of the most popular vegetables being cultivated in hydroponics. Tomato plants have tremendous rooting ability, and easily root directly from stem whenever placed under a high humid condition. In summer, however, yields decrease sharply due to high temperature and flooding in the tropics and cultivation by hydroponics was far more difficult than cucumber or melon. Fortunately, this difficulty can be overcome by:

1) using net bag for seedling preparation;
2) avoiding a great decrease in water head (more than 5 cm from the pre-set) by a simple system of automatic water supply; and
3) minimizing fluctuation of nutrient concentration in the solution.

In the summer of 1986, we succeeded in harvesting nearly 3 kg of large-fruited tomato using the AVRDC noncirculating hydroponics system. The average fruit weight was 130 g, but the largest one exceeded 200 g.

e) Leafy vegetables

Several leafy vegetables have been grown using the small container with different netting systems. Growth rate of these vegetables was very fast and they were ready to be harvested within one month after sowing. Only basal fertilizer was necessary.

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摘　要

亞洲蔬菜研究發展中心土壤系，已發展出一套簡易的非循環式水耕栽培系統；此系統不需要通氣設備，亦不必隨時調整溶液的酸鹼值、電導度、溫度及養分成份。一旦設備完成後，惟一所需的管理為三週一次的施肥，並且營養溶液的配方可適用於各種作物。

於 1986 年的夏季，已栽培成功大豆、甜椒、番茄（大果）、洋香瓜及小黃瓜。後三者的產量分別達 3.1 公斤（平均果重 150公克），每棵 2.34 公斤及 4.72 公斤。

討　　論

林學正（台南區農業改良場）問：

氧根與營養吸收根（水養根）在解剖上有何不同？

氧根浸入水中會有吸收功能嗎？

馬清華答：

目前我們尙未進行其解剖的研究，但其外觀是完全不同。氧根上有很多的根毛，就如高博士所說的一樣，看來像發霉一樣，氧根在溶液中有無吸收是非常重要的，也就是我們一直強調維持一定的水位。在溶液中的營養根當水位下降時會轉換成氧根，當氧根再浸入溶液時，無法恢復爲營養根，所以他會很容易的爛掉。

余增廷（農林廳）問：

水根和營養根應該沒有不同吧？

馬清華答：

實際生理我不懂，在外觀上水根量少，比較長和粗；營養根需吸收養份，發展的比較發達。

高德錚（台中區農業改良場）問：

1.若用自來水作配料而不添加微量元素，則鐵缺失之問題如何解決？

2.當大規模栽培時，若僅利用浮球補水，則營養液濃度之變化極大，請問如何解決？

3.上位根形成氣根時，一旦浸水，極易死亡。

馬清華答：

我們已朝這個方向努力，即使使用很純的蒸餾水都不見得會出現微量元素的缺乏病狀，故我們認爲自來水內應可供應，但我不能確定。目前台肥已有很簡單的配方，這也是我們的目標—簡化配方。

番茄的水位，事實上那個系統是水和營養份分離的系統，自來水的水位用浮球控制，營養液即無控制，在小規模上，營養液不斷的補充，ＥＣ是會升高，因在我們的溶液配方裏，pH 的升高範圍在6.5－7.5左右，故不需調整。但ＥＣ在小容器時升太高，則幾週即倒掉換新的溶液；若大面積則不更換溶液，尙生長良好。但在大規模上仍應朝配方簡單的目標研究。