Work that water! Hydroponics made easy

David Midmore and Wu Deng-lin

This simple system, which builds on the principle of isolating the nutritive solution in which 'water' roots grow from the evaporative effects of the environment, can be invaluable in situations where space is limited and/or soil quality is poor.

The main advantage of hydroponics (or any water system) is the concentrated use of water, harvested from a large area and used intensively over a smaller area.

Water-use efficiency (WUE) is maximized in a crop when all water used passes through the plant and exits as transpiration. WUE is defined as the weight of harvested product per unit volume of water supplied. The gross components of the water-balance equation below emphasize the importance of reducing run-off and drainage, and of maximizing rainfall and irrigation capture.

Input *Losses*

$$I + R + De = E + T + RO + Dr$$

where I = irrigation; R = rainfall; De = depletion, i.e. from soil-water storage; E = evaporation; T = transpiration; RO = run-off; and Dr = drainage.

Hydroponic production systems minimize evaporation, run-off and drainage. Hydroponics, or the growing of plants without soil (literally, 'working water'), capitalizes on the use of nutritive solutions contained within reasonably fixed and confined structures — usually protected by glass or polyhouse infrastructure which control water inputs and outputs, particularly in high rainfall areas. Glass/polyhouses affect production in four ways. They:

- prevent rain-induced dilution of hydroponic solutions;
- reduce direct heat;
- protect against pests and diseases; and
- improve product quality for premium pricing.

Collecting rainwater from glass/polyhouse roofs immediately improves WUE, but the main advantage of hydroponics (or any system other than rain-fed) is the concentrated use of water, harvested from a large area (for example, a watershed) and used intensively over a smaller area (for example, in a glasshouse). If rainfall is insufficient to support a particular crop the extra requirement for water can be sourced from a watershed nearby. Of course, water is usually taken from a stream, river, or man-made water-collecting system. The same principle is applied in cities, where water is collected from roof-tops for use in urban horticulture or hydroponics.

So much for the arguments that justify irrigating plants. Hydroponics further improves WUE by obviating both drainage and evaporation from the soil — both important components in the water-balance equation. Final WUE depends almost entirely upon the transpirational water-use efficiency of the species being grown which, in turn, is dependent upon particular characteristics of the species that govern the rate of photosynthesis per unit of water transpired (for example, the photosynthetic system attributable to the species, the dimensions of leaves, their degree of hairiness, etc).

Other farming practices, such as the use of sub-surface trickle irrigation, or of sub-surface clay pipes/pots or simply mulching with polyethylene sheeting or vegetative materials, are all prime examples illustrating the reduction of the soil-evaporation component of the equation.

David Midmore

Keep it simple

At the beginning of the 1990s, we developed a simple hydroponics system which built on the principle of isolating the nutritive solution, in which 'water' roots grow, from the evaporative effects of the air.[1] White polystyrene boxes, that reduce the heat load of the solution within, are lined with black plastic, both to make them airtight, and to prevent algal growth. As Table 1 illustrates, alternatives, such as wooden boxes or sunken concrete basins, have also been successful. The boxes are fitted with tight polystyrene or wooden lids, and the lids are perforated so

1. Midmore, D. J. 'Simple hydroponics for food security.' *ILEIA Newsletter* 10, Leiden 1994.

that small pots can be inserted. The perforation plugs are kept for future occasions when species choice dictates that fewer plants be grown per box/lid.

The pots are filled with an inert medium — alternatives include smoked-rice hulls, perlite, moss, crushed brick, or anything that is inert and porous. The pots must have many slits to enable root emergence beyond the pot. Most commercial hydroponic solutions work well with this system, although the solution composition may be customized to get an extra 10 to 15 per cent yield over a multipurpose solution. At planting, the level of the nutrient solution should be approximately 2 to 3cm above the base of the pot. The solution then rises by capillarity, satisfying the requirement of the young seedling.

This is the only stage in this system when evaporative loss of water can occur — up to 3cm per box if the young plants do not transpire much during the first two weeks after sowing/transplanting. Once the seedling is established, its root system gains access to the solution, lowering the solution level faster than by capillary rise and evaporation alone. When the solution level recedes below the base of the pot, capillary rise and evaporation are non-existent, and all water loss is via transpiration. The solution transpired is replenished periodically (weekly or twice-weekly), or instantaneously (with a ballcock system), but never to the original level. The system depends on the functioning of an 'aerial-root' layer above the solution level since the solution is not aerated. Raising the solution to the original level, just above the base of the pot, would 'flood' the aerial roots, causing irregularities in root metabolism.[2, 3]

Seasonal water use

Experience in tropical Taiwan shows that WUE in the autumn and winter plantings was nearly six times greater than during the summer plantings, regardless of species. This is partly because of the greater, instantaneous transpirational demand in summer (more water is transpired per unit of CO_2 absorbed in photosynthesis), and partly because of the debilitating effect of high summer temperatures.

Oxygenation is a critical issue for circulating systems during hot summers, as the solubility of oxygen declines with increased temperature, yet respiration-induced plant demand for oxygen increases. This seasonal constraint, although irrelevant to our simple hydroponics system, affects concentration and electrical conductivity of the solution as transpiration outstrips uptake of the nutrients. Choosing salts with low osmotic potential can reduce this problem, as can replenishment with a weaker solution.

Type of box	*Solution temperature (max °C)*	*Total fresh weight (kg/m²)*
Polystyrene	28± 2	7.15
Wooden	29± 2	6.80
Wooden plus insulator	29± 2	6.51

Table 1. Various boxes used for simple hydroponics, their solution temperature and leafy amaranth yield under tropical conditions.

Species, solutions, and spacing

Nutrient uptake by plants varies with species and this disadvantage is exacerbated with long-season and perennial species. While the supply of nutrients within the soil is well-protected, this is not the case for hydroponics solutions. Plant elemental analysis at maximum growth gives a good guide to plant-nutrient requirements, and to the approximate proportions of each nutrient required. Carrying out a plant analysis before growing in hydroponics will enable the grower to determine whether proportional element concentrations are in balance with the supply solution and, during growth, analysis can determine whether there are sufficient nutrients. Alternatively, a nutrient-balance equation, based upon the content of nutrients removed from the solution, allows comparison between species (see Table 2). Our data show clearly the variation among species, in this case leafy vegetables, in their WUE (lettuce > mustard > paitsai); their nutrient uptake per litre of solution transpired; and their differences in total nutrient uptake. There was notably little differential removal of nutrients among the solutions, justifying our dependence on a single solution.

The rate at which the solution is consumed is influenced by the stage of plant growth, the population density, and the morphology and height of plants supported by the particular hydroponics box. At any stage before complete canopy (i.e. leaf) cover over the box-lid by a short-stature plant species (e.g. lettuce), the solution-consumption rate will be proportional to the population. For taller

The application of the system, once the principles are understood, is only limited by the needs in hand — and the imagination of the proposed user.

2. Midmore, D. J. 'Sustainable and ecologically sound vegetable-growing in peri-urban farming (with reference to the system of hydroponics).' *Entwicklung and Landlicher Raum* 4/95, 1995.

3. Sundstrom, A. C. *Simple Hydroponics for Australian Home Gardeners*, Thomas Nelson, Melbourne, 1980.

	Paitsai	Species Lettuce	Mustard	A	B	C	D	E
				Solutions*				
WUE g/l	6.99	9.00	7.89	7.77	8.00	7.73	7.92	8.40
g N/l transpired	0.31	0.25	0.22	0.26	0.27	0.26	0.26	0.25
N consumption g/container**	6.36	2.66	3.53	4.37	4.39	4.23	3.95	4.13
Dry weight g/container**	144	101	126	123	124	125	117	129

* A and E double NO_3 of other solutions, D one third and E double PO_4 of other solutions.
** C container surface area = $0.184 m^2$

Table 2. Nutrient removal, WUE, and yields for three vegetable species in five contrasting nutrient solutions in Taiwan (no interactions evident), calculated by the nutrient balance formula (= nutrients removed from the solution during growth, minus remaining nutrients in the solution, plus original content of nutrients in the solution).

David Midmore

about the authors

David Midmore is the Professor of Plant Sciences at Central Queensland University, Rockhampton, Qld 4702 Australia. E-mail: <d.midmore@cqu.edu.au>

Wu Deng-lin is a Research Assistant at the Asian Vegetable Research and Development Centre, PO Box 42, Shanhua, Tainan, Taiwan 741. E-mail: <dlwu@netra.avrdc.org.tw>

species, which can extend their foliage beyond the limits of the surface area of the hydroponics box, the consumption rate will still be proportional to the population even after full canopy has developed. But, as the ratio of horizontal surface area to vertical side area is reduced, the transpiration per unit of container-lid surface area from the canopy greatly exceeds evaporation from a flat, open evaporation plan of the same surface area. Hence water use by isolated tall plants in our hydroponic system will be greater than by isolated shorter species.

While knowledge of these variations helps growers understand and manage the supply of nutritive solution to plants, it is also important to be economical in the use of hydroponic boxes. For example, instead of placing hydroponic boxes flush against each other, with perhaps two tomato plants per box, one could omit every other box (a 'chessboard' distribution), with each box supporting four tomato plants. The yield and water consumption should be the same as with the two-plants-per-box set-up, provided the population per unit of overall area is constant; but replenishment of water per box would be double in the four-plants-per-box system. This concept may be extended to other tall plant species, for example runner beans.

Table 3 illustrates how yield and WUE vary independently. Apparently, WUE for both Chinese cabbage and tomatoes is greater at the lower population per box, a result duplicated in other experiments. The most likely reason is unimpeded growth in the leafy vegetable at low population, and less competition for fruit growth in the tomato.

Water sources

Access to good-quality water may actually be a constraint to hydroponics vegetable production. Poor-quality wastewater will probably reduce the yield potential of hydroponically grown plants, but the value-adding as a result of utilizing wastewater adds an economic value to a commodity which requires expenditure (short or long-term) for its disposal. Working on this premise, we looked at the possibility of utilizing fermented pig effluent in Taiwan, and wastewater from a thermal power-station in Australia. The data on pig effluent suggested an excessive level of NH_4+ - N, but other macronutrients were in reasonable supply. A leaf amaranth crop was grown under a range of NH_4+ concentrations — a times-one dilution of the effluent was found to be satisfactory for amaranth.

The use of water from the power-station was also successful — even with undiluted power-station water, Chinese-cabbage yields were not markedly less than those of hydroponic solution without power-station water and, apparently, the power-station water at 1:1 and 3:1 induced greater yield than without the wastewater.

The above examples illustrate the possible high WUE in intensive hydroponic production, in relation to container structure, seasons, species, solutions and populations. Water-use efficiency of the most efficient, field-based systems may closely match that of simple non-circulating hydroponics, but the latter is far easier to manage and, therefore, make less of a demand on modern technologies such as trickle tape and soil water-measuring devices.

Naturally, questions of economics arise with all hydroponic options, especially in relation to comparisons between in-field or in-pot glasshouse production. Considerations of diluting wastewater also need to be costed, but the application of the system, once the principles are under-stood, is only limited by the needs in hand — and the imagination of the proposed user. The system outlined here is now being promoted successfully in half of Vietnam's provinces, by small co-operatives. ■

Population (plants/m²)	Chinese cabbage Dry weight (g/m²)	Chinese cabbage WUE (g/l)	Tomato Fresh weight (g/m²)	Tomato WUE (g/l)
5.6	-	-	1755	26.2
11.1	94	4.26	2027	29.1
22.2	114	2.99	1873	21.8
33.3	121	3.13	2232	20.8
44.4	123	2.79	1665	17.3

Table 3. Marketable yields and water-use efficiencies of Chinese cabbage and tomatoes at different population densities.