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Leafy Asian vegetables

and their nutrition in hydroponics

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Contents

Introduction

The Asian vegetable industry in Australia has grown rapidly and currently contributes about six percent to the value of the broader vegetable industry. The fast development of this industry is due to the increasing use of hydroponic systems for plant production. This guide has been written to help growers of leafy Asian vegetables better manage the nutrition of their hydroponic crops to maximise yields, and to improve the efficiency of their production systems.

This guide describes several hydroponic systems, and how to manage them for growing a range of leafy Asian vegetables. It also describes symptoms of nutrient disorders and how to correct (and prevent) these in hydroponic systems.

Leafy Asian Vegetables and their Nutrition in Hydroponics does not cover all the essentials of hydroponic farming. These are dealt with in other publications; some are listed at the end of this guide.

Some terms used in this guide

Nutrient solution or hydroponic solution

This is the solution used in the hydroponic system that provides water and nutrients to the plants. It is made by mixing water with the stock solutions.

Stock solution

This is the concentrated solution of mixed nutrients which is added to (diluted with) water to make the nutrient or hydroponic solution.

Huett's lettuce formulation

This is a commercial recipe for making stock solutions using fertilisers and water as ingredients. It is commonly used for hydroponic lettuce production.

EC (electrical conductivity)

This is a measure of the total concentration of all the chemical elements contained within a solution. A stronger (more concentrated) solution has a higher EC than a weaker solution.

pH

This is a measure of how acid or alkaline a solution is. The pH scale runs from 0 – 14. A lower value is more acid, a higher value is more alkaline. Fresh water is neutral at a pH of 7.

Substrate

This is a soilless medium for supporting growth but it does not provide any nutrition to the plant. Some substrates include coconut coir, perlite and rock wool.

Transpiration

This is the loss of water from plants, mainly from leaves, through tiny pores called stomata. The movement of many nutrients from the roots to the shoots occurs through the transpiration stream.

NFT (nutrient film technique)

This is the type of hydroponic system in which plants are placed in a sloping irrigation channel with a film of nutrient solution flowing over the roots. The nutrient solution is collected in a reservoir and is continually pumped back to the start of the channel.

Hydroponic systems

A hydroponic system supplies nutrients to the crop roots in solution with the irrigation water. The nutrient solution is still, or it is recirculated using a pump, and plant roots can be suspended in the solution or contained within a soilless substrate. All hydroponic systems need to provide plant roots with enough nutrients, water and oxygen for good growth. Some different types of hydroponic systems suitable for the production of leafy Asian vegetables include still solution hydroponics, substrate hydroponics with recirculating solution and nutrient film technique (NFT).

Still solution hydroponics

Still solution hydroponics is the simplest form of hydroponics and only requires adding enough nutrient solution to a tank to last the duration of the crop. It is ideal for short term leafy crops. In the system, described by the Hawaiian researcher B. A. Kratky, the plants are supported by substrate within a small tube-stock pot. The bottom of the pot is immersed in the nutrient solution which supplies the plant with nutrients and water through capillary action. The nutrient solution level drops as it is used by the crop until 10% of the original solution is left. Extra water or fertiliser is not usually added, as raising the water level may damage the crop by reducing aeration to the upper part of the root system. One essential requirement of the system is to start with good quality water with a low concentration of salts. This is important because as the crop grows the fertiliser salts in the water will continue to concentrate in the remaining solution.

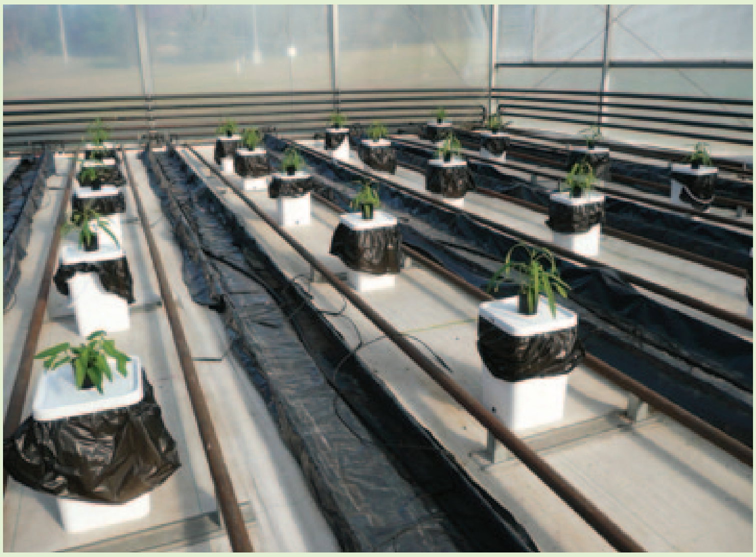
The advantages of this system are that it is inexpensive to set up and maintain, and it requires no solution management and no electricity.

Still solution hydroponics. The level of nutrient solution drops as the crop uses it for growth. The crop is then harvested.

CASE STUDY

Kang Kong in still solution hydroponics

Kang Kong, also known as water spinach or water convolvulus, *Ipomoea aquatica*, is a vegetable used widely in Asian cuisine. It is naturalised in Australia, but can be a weed in tropical areas. In temperate areas, growth of this plant is limited by winter temperatures, frost, and fungal diseases. However, hydroponic production of this species in a tank is ideal because it can be isolated from areas where it can be a potential weed, and it can be produced in a greenhouse which can provide the conditions for a longer season, particularly in cooler areas.



An experiment with Kang Kong growing in still solution hydroponics.

In this case study, we describe production of Kang Kong in still hydroponics. Production in NFT was tested but it was unsuccessful due to the prolific growth of roots in the hydroponic channel which impeded the flow of the nutrient solution.

Kang Kong was grown from seed in seedling trays, although cuttings could easily be used. The seedlings were then placed in a tube-stock pot which was fixed into the lid of a 20 L tank lined with a black garbage bag to prevent algal growth. The tank was filled with nutrient solution made to a formula commonly used for hydroponic lettuce. The solution was filled up to the crown of the roots and not refilled for the entire crop.

The plants were harvested after three months with about 4 L remaining in the tanks. As the solution was used by the crop, the remaining salts became more highly concentrated. The EC of the tanks at the start of the experiment was about 1.6 dS/m and this increased to about 10.0 dS/m at harvest. Each plant yielded between 500-700g shoots. They could have been cut earlier (about 20-30 days after planting) and regrown with the remaining solution, producing a higher total yield. The crop was grown in a heated greenhouse over winter (13-25°C). Faster growth could be expected in summer, but the starting solution would probably need to be less concentrated to give plants at better chance at coping with the hotter temperatures.

Recirculating solution hydroponics

Using hydroponic systems that recirculate nutrient solution for Asian vegetable production will require more set up and investment in technology than either field or still solution systems. A high level of skill and care is also required to manage the nutrition of the crops in these systems.

Substrate culture

In substrate culture, plants are grown in a soilless medium. The substrate does not have any nutrient value for plant growth and should be stable enough to last for the duration of the crop. Additionally, the substrate needs to have enough water holding capacity to maintain moisture around the roots, and it must provide enough aeration to prevent water logging. Good substrates include coconut coir, perlite, and rock wool. Sawdust or mixes with composted pine bark are not ideal substrates, as these are not of a consistent quality and can decompose easily. Substrates must be replaced when each crop is planted to prevent disease problems.

Water and nutrients are fed through an irrigation system and are applied to the plants growing in the contained substrate from drippers. The runoff drains into a tank and is collected and pumped back to the drippers. It is important to have a screen filter installed into the irrigation system so that substrate particles do not block the drippers. In systems with substrate and recirculating nutrient solutions, frequent irrigations and a high percentage of run-off will help prevent the composition of the nutrient solution from getting out of balance too quickly.

CASE STUDY

Centella in a substrate system with a recirculated nutrient solution

Centella (*Centella asiatica)*, also known as pennywort, is used in traditional medicine, and as an ingredient in salads, or is blended into a health drink in some Asian cuisines. With its creeping habit, it is unsuited to production in NFT as it impedes the flow of nutrient solution down the channels. However, Centella can be grown successfully in an inexpensive substrate system. In this study, plants were grown in a mix of coir and perlite, in a crate, positioned directly over a tank which captured the runoff from holes in the crate. The solution was pumped from the tank below and back up to the drippers feeding the crop. Several of these crates can be placed over a larger tank, or each crate and tank unit can be connected with irrigation piping, and the pump located in one of the end tanks.

Centella growing in substrate, placed over a tank, with recirculating nutrient solution pumped from the tank to drippers above the crop. Several of these units can be joined with irrigation pipe and the pump located in one of the end tanks.

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Above: Detail of the system used for Centella, showing the coir and perlite substrate mix, the tank containing the nutrient solution, and the pump to deliver the nutrients up to the drippers. The solution drips back into the tank through the base of the crate.

An alternative system for Centella production is to grow plants in substrate placed on a gently sloping bench. Nutrient solution is delivered via drippers placed on the substrate and the runoff drains to a collection point, then into a tank with a pump that redirects it back to the drippers.

Above: A leafy bean crop growing in shallow substrate on a sloping bench, fed a nutrient solution through dripper tape.

Nutrient film technique (NFT)

In NFT, plants are supported in a gently sloping shallow gully and the roots are suspended in a flowing stream of nutrient solution. After passing down the gully, the nutrient solution is collected in a closed tank and pumped back to the top of the gully to continuously recycle the nutrient solution. Asian vegetables grown commercially in this type of system include Pak Choy, Buk Choy, Coriander and Bunching Onion. Crops such as Kang Kong and Centella are not suited to this method as the roots are prolific and block the flow of solution down the channels.

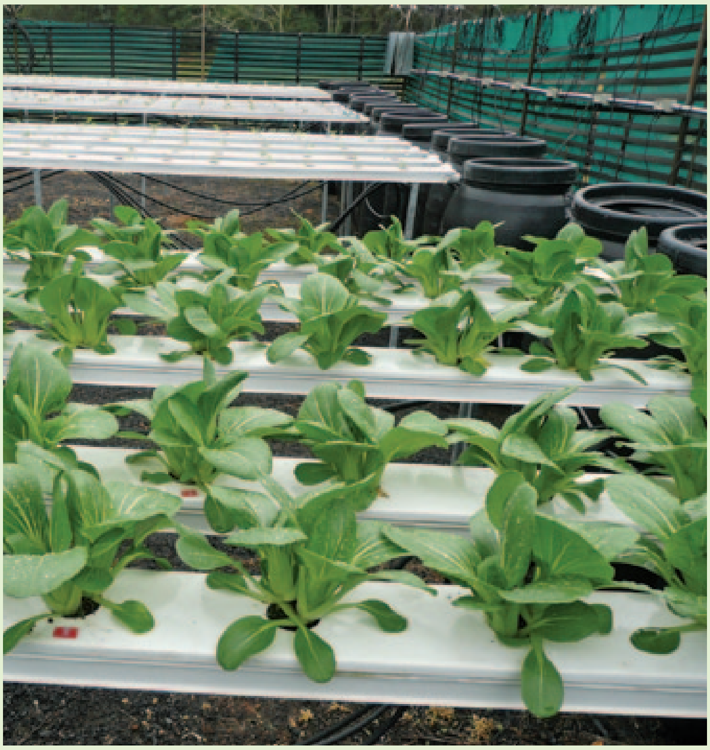
The NFT systems typically used in Australia consist of PVC channels 10-15 cm wide, with rectangular bases, and fitted with plastic covers containing plant holes. About 4-8 channels are arranged on a bench of between 4-24 metres long (less than 20 metres is recommended) and these are erected on a marginal slope (about 1.5–2.0°), to allow nutrient flow back into the recirculation tank. The movement of nutrient solution down the gullies also ensures that the nutrient solution is sufficiently aerated. The channel must not sag or pool at any point along its length to ensure that good aeration is achieved. The flow rate (1-2 L/minute) depends on the flow-rate of the pump, the size of the crop and the number of benches being used at one time. The tanks used typically range from 4000 to 10000 L, each supplying between 28-35 benches, sometimes more. It is better to have a number of smaller tanks rather than one larger tank as this reduces the risk of entire crop loss in the event of mechanical breakdown or disease outbreak in one system.

CASE STUDY

Leafy Asian vegetables in NFT

In this study, ten types of leafy Asian vegetables were produced in NFT:

- Thai Basil (variety Siam Queen)
- Bunching Onion
- Coriander
- Choy Sum
- Mustard Cabbage
- Pak Choy (varieties Sumo, Yangtze, and Miyako)
- En Choy, and
- Tat Soi.



Pak choy plants growing in nutrient film technique (NFT).

The Huett's lettuce formulation (common in lettuce production), was used to make the nutrient solution. Experiments determined that production of these vegetables is suitable at concentrations of nutrient solution between 1.5-2.5 dS/m, with Mustard Cabbage preferring a higher concentration range (2.5-3.5 dS/m). Managing the nutrient solution in these concentration ranges is an efficient practice as it allows for optimum growth but using the least amount of fertilisers.

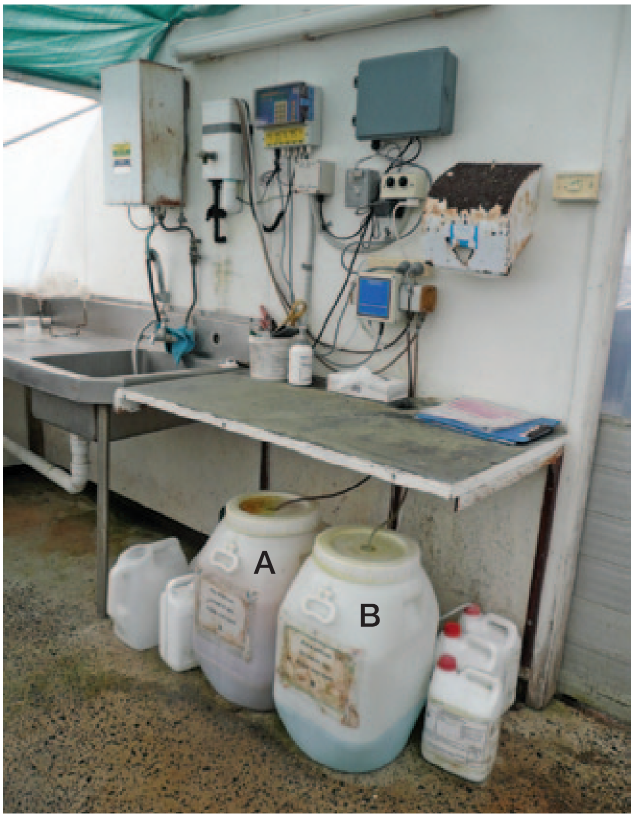
The nutrient solution

Preparing the nutrient solution

Plants require large amounts of the macronutrients: nitrogen (N), potassium (K), calcium (Ca), magnesium (Mg), phosphorus (P) and sulphur (S), and smaller amounts of the micronutrients: chlorine (Cl), iron (Fe), boron (B), manganese (Mn), zinc (Zn), copper (Cu), nickel (Ni) and molybdenum (Mo). This is reflected in the concentrations of macronutrients and micronutrients that are found in commercial hydroponic solutions. An example is the solution made up according to Huett's lettuce formulation (**Table 1**). The nutrients are present in solution as either positive or negative ions, but nitrogen can occur in the form of the negative ion nitrate ion (NO_3^-) and in the form of the positive ion ammonium ion (NH_4^+). Other negative ions include phosphorus as orthophosphate ($H_2PO_4^-$) and sulphur as sulphate (SO_4^{2-}). Other positive ions include potassium (K^+), calcium (Ca^+) and magnesium (Mg^{2+}).

For those new to hydroponics, an easy option is to buy and use a prepared hydroponic fertiliser solution. It is also important to ensure that it contains sufficient amounts of calcium and magnesium. The content of calcium should be as much as the amount of nitrogen, or no less than 70% of the amount of nitrogen. Magnesium needs to be at a content of about 20-30% of the amount of calcium present. Avoid fertilisers that contain urea, or those that have over 10% of total nitrogen in the ammonium form.

It is often practical for growers to prepare concentrated stock solutions which can then be stored before being diluted and delivered to the crop. In this case two different stock solutions (labelled A and B), are required to avoid precipitation of calcium phosphate, calcium sulphate and iron phosphate in these highly concentrated solutions. The stock solutions are 100 to 200 times stronger than the solution given to plants. Stock solutions also need to be kept out of the cold, ideally between 27-30°C to prevent precipitates forming. Most nutrient solution formulations in use commercially are generally similar in composition. We have demonstrated that one of these, Huett's lettuce formulation, is suitable for a range of leafy Asian vegetables (**Table 2**).



Tanks A and B containing concentrated stock solutions are shown here with a nutrient controller mounted on the wall to automatically dispense the stocks into fresh water to make the working nutrient solution.

Table 1: Composition of the nutrient solution made according to Huett's lettuce formulation at an EC of 1.6 dS/m. The amount of ammonium in the solution accounts for up to 3% of the nitrogen. The concentration of nutrients increases when the solution is made at a higher EC or strength.

Nutrient	N	K	P	Ca	Mg	S	Fe	Mn	Zn	B	Cu	Mo
Concentration (mg/L)	116	201	22	70	20	26	2.5	0.22	0.15	0.21	0.03	0.01

Table 2: Standard 'Huett' lettuce formulation. Recommended starting and top-up solutions are the same. Equal volumes of A and B stock solution are to be used. For the starting solution, to 1000 litres of water add 3.4 litres of A and 3.4 litres of B.

Solution	Compound	Elemental composition (%)	Stock solution (g compound/L) #pH>6.0	Stock solution (g compound/L) pH<6.0
A	Calcium nitrate $Ca(NO_3)_2 - H_2O$	18.8 Ca 15.5 N	109	109
	*Iron chelate (Fe EDTA)	13.2 Fe	5.6	5.6
B	+(MAP) Mono-ammonium phosphate ($NH_4H_2PO_4$)	12.2 N 26.9 P	8.7	Nil
	Potassium dihydrogen phosphate (KH_2PO_4)	28.7 K 22.8 P	16.3	29.0
	Potassium nitrate (KNO_3)	38 K 13 N	133.3	133.3
	Magnesium sulphate ($MgSO_4 . 7H_2O$)	9.8 Mg 13 S	58.1	58.1
	Boric acid (H_3BO_3)	17.7 B	0.35	0.35
	Zinc sulphate ($ZnSO_4.7H_2O$)	22.7 Zn	0.2	0.2
	Manganous sulphate ($MnSO_4.H_2O$)	32.9 Mn	0.2	0.2
	Copper sulphate ($CuSO_4.5H_2O$)	25.6 Cu	0.035	0.035
	Sodium molybdate ($Na_2MoO_4.2H_2O$)	39.7 Mo	0.01	0.01

* Adjust amount of iron chelate depending on elemental Fe content of chelate.
\+ Increase amount in stock solution if pH is drifting upward in recirculating system.
\# If pH of nutrient solution in recirculating system is greater than (>) 6.0.

Basic principles for managing the nutrient solution

Nutrients arrive at the root surface of plants driven by transpiration (water evaporating from leaves) or via a concentration gradient that develops as nutrients are removed by roots. Nutrient movement into the roots is affected by the rate of transpiration, by root membrane transport properties and by the nutrient composition of the root zone solution. Most nutrient uptake occurs rapidly during the day and less rapidly at night.

A recirculating hydroponic solution needs good management so that the composition does not get too far out of balance, as water and nutrients are being taken up by the crop. Unlike soil systems, hydroponic systems offer no buffering capacity against changes in the root zone. This is an important risk in hydroponic crop production.

Achieving balance in water and nutrient uptake is regulated by plants but this ability is limited. For example, on a hot or windy day, transpiration (water expired through leaves) is so rapid that nutrients build up at the root surface and can cause water to move out of the roots. This is known as 'osmotic drought', and symptoms of fertiliser toxicity can result. This could be prevented by lowering the concentration (EC) of the nutrient solution during hot and windy weather so that plants effectively have access to more water. Managing the nutrient solution well, and taking into account the climatic conditions, are keys to preventing nutrient disorders in hydroponic crops.

It is important to be aware of the sensitivity of plants to rapid changes in nutrient concentrations around roots and the resulting consequences. For example, when the phosphorus level in the nutrient solution is low, the plant becomes accustomed to this low level. If the solution is then replaced or topped up the phosphorus-starved plant responds to the new elevated phosphorus level by increasing the influx of phosphorus into the roots.

For a short time (a few hours) phosphorus is moved rapidly into shoots until shoot levels are elevated. Because of this rapid movement of phosphorus into shoots, the levels in the roots remains low for sometime and this prevents the normal regulation of phosphorus intake into the roots. Consequently too much phosphorus can be taken up by the plant and can become toxic.

Managing waste nutrient solution or runoff

If discarding used nutrient solution, take care that this does not become a serious environmental problem. A simple and effective treatment of waste water can be achieved using a constructed reed bed (Badgery-Parker, 2003).

Controlling nutrient solution concentration (EC)

The electrical conductivity (EC) of a solution is a measure of the total concentration of all the chemical elements contained within, and can be easily measured with a portable meter. A stronger solution has a higher EC than a weaker solution. Common units of measurement of EC include deciSiemens per metre (dS/m) and the equivalent milliSiemens per centimetre (mS/cm). Other meters express electrical conductivity as CF units (1 dS/m = 10 CF units), and total dissolved solids (TDS) with the unit of parts per million (ppm). The EC value indicates the total strength of the solution but nothing about the balance of nutrients within it, so, its use in the management of hydroponic solutions is limited. The raw water used for the hydroponic solution may itself contain dissolved nutrients which will contribute to the strength of the solution. A water quality test will ascertain which nutrients are present and their concentrations, and should be taken into account when making up the hydroponic solution. If the water quality is too poor, it may need to be treated before use (reverse osmosis filtration process), or diluted with high quality water.

The target EC of a nutrient solution can vary according to the crop being grown, stage of growth and climatic conditions. We grew a number of Asian vegetables in an NFT system at different nutrient solution strengths (ranging between 0.5 – 5.5 dS/m) and showed that most (Basil, Choy Sum, Tat Soi, Coriander and three varieties of Pak Choy) grew best in the nutrient solution managed in an EC range of 1.5-2.5 dS/m. Only Mustard Cabbage produced greater yields at a higher EC range of 2.5-3.5 dS/m.

Controlling nutrient solution pH

The acidity or alkalinity of a nutrient solution is indicated by its pH and can be easily measured with a portable meter. A pH measure of 7 is neutral, with values above this being alkaline and values below this being acidic. The pH of hydroponic solutions should be 5.5-6.5. However, as the plants use the solution, the pH of the solution can drift. In a leafy crop, it is more likely that the pH will drift upwards because they tend to take up large amounts of the negative nitrate ion. To maintain its balance between positive and negative ions, the plant pumps out negative ions of hydroxyl (OH^-) or bicarbonate (HCO_3^-) ions which has the effect of raising the pH. Nutrient deficiencies can occur below pH 5 and above 7.5, due to the pH affecting the availability of some nutrients.

Huett's lettuce formulation can be modified to adjust the pH downwards if it exceeds 6.5. This is achieved by increasing the proportion of ammonium in the formulation (Table 2). Other chemicals can be used to adjust the pH of the solutions being delivered to the crop. To reduce the pH, phosphoric acid or nitric acid is used, and to increase the pH, potassium bicarbonate or potassium hydroxide is used. Potassium bicarbonate is the safest chemical to handle for increasing pH. Be aware that as these chemicals are added to adjust the pH, they themselves are a nutrient which in some cases may adversely unbalance the nutrient solution.

Take care to calibrate the pH meter frequently and to store it according to the manufacturer's instructions. This will ensure that readings are accurate.

Analysis of nutrient solution

Certain nutrients (including potassium, nitrate and sodium) are useful to monitor on-farm in either the hydroponic crop or in the nutrient solution. This will assist in deciding when to modify or replace the nutrient solution. Here, we describe the measurements that can be made on the hydroponic solution. For the greatest efficiency in managing the timing of nutrient solution modification and replacement, a regular analysis of the hydroponic solution is needed, and this can be obtained from a commercial laboratory.

Potassium can drop to undesirably low levels in nutrient solutions but it is easily measured using colorimetric test strips. These are dipped into the solution and turn an orange colour at an intensity equivalent to the concentration of potassium in the solution. The strips are read by eye next to a colour scale to estimate the concentration. These are inexpensive (about $1-2 per test) and can indicate the need to supply more potassium, but they do not have the accuracy of a laboratory analysis.

The nitrogen supply available in hydroponic solutions can be indicated by the nitrate concentration, and this can drop to low concentrations as plants use the nitrate for growth. The composition of nitrogen in Huett's lettuce solution (Table 2) is 116 mg/L. Up to 3% of this nitrogen is present as ammonium ions which are very rapidly taken up by plants. The remainder (approximately 113 mg/L) is present as nitrate ions. Nitrate ions can be measured in the solution with colorimetric test strips. They turn purple-violet at an intensity equivalent to the concentration of nitrate in the solution. The strips are read by eye next to a colour scale. A portable instrument that is available (called a reflectometer), can also be used to measure the test strips with greater accuracy. The solution may have to be diluted to bring the nitrate concentration to within the range of the test. The test strips measure the whole nitrate ion (NO_3^-), and not just the nitrogen (N). For a solution with 113 mg/L nitrogen as nitrate, the nitrate concentration will be 113 x 4.43 = 501 mg/L. This accounts for the oxygen and the nitrogen in the nitrate ion.

The nitrate test strips shown here have been dipped into solutions containing different concentrations of nitrate. The concentration of the solution is indicated by the intensity of the purple colour that develops on the test strip.

Sodium ions (Na^+) are important to monitor in the recirculating nutrient solution for those with poor quality raw water. Raw water should contain less than 30 mg/L sodium. Fortunately, many leafy Asian vegetables are moderately salt-tolerant, unlike more sensitive crops such as lettuce. The level of sodium in nutrient solution should not exceed 100 mg/L for lettuce, and 150 mg/L for leafy Asian vegetables. Sodium is rapidly taken up by sensitive crops and is associated with a decline in potassium uptake. This is important, because in recirculating systems, potassium concentrations can drop to a level below that required for optimum growth.

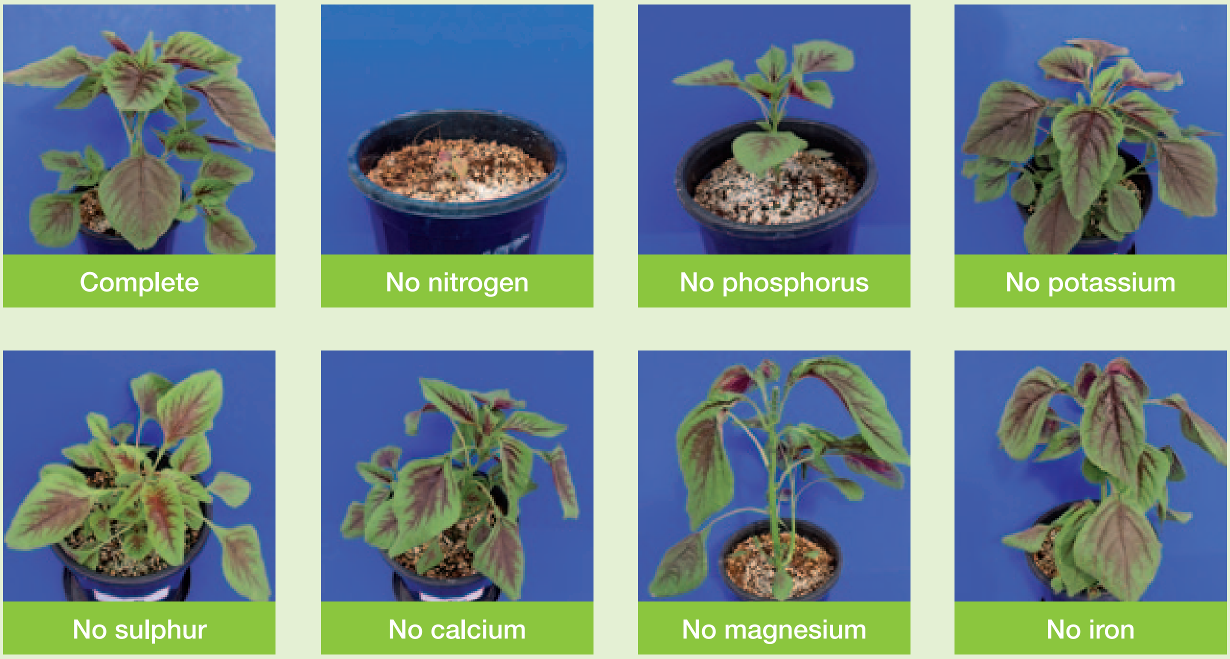
There are meters available to measure potassium, nitrate and sodium in your nutrient solutions but some meters on the market will not be suitable for measuring in hydroponic nutrient solutions. This is because some nutrients (other than the one being measured in the recirculating system) may interfere with the accuracy of the reading. For each instrument, know which ions are potentially interfering, and the concentrations at which they interfere with the reading accuracy. Compare these with their typical concentration the hydroponic solution being used (if present) to evaluate the suitability of the meter for your purpose. The most accurate meters are more likely to be the most expensive.

Nutrient disorders of leafy Asian vegetables

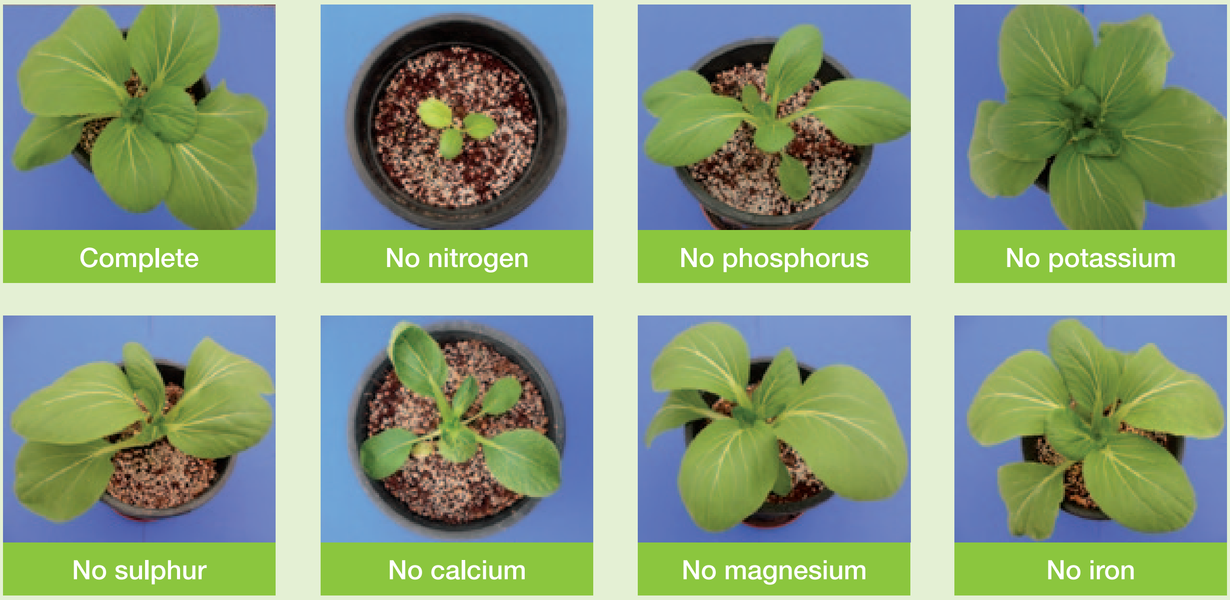
Diagnosing a nutritional problem is not easy to do, particularly when you consider that symptoms only occur once the problem is well established. Deficiency symptoms can include reduced growth, and yellowing (chlorosis) or scorching (necrosis) of new growing tips, new leaves, or old leaves, or a combination of these. The yellowing and scorching symptoms can be confined to parts of the leaf or can be spread across the entire leaf.

The importance of individual nutrients to plant health is clearly demonstrated when the supply of each nutrient is removed from the feed given to plants. The following pictures show the response of En Choy, Pak Choy, and Tat Soi plants to the elimination of nitrogen, phosphorus, potassium, sulphur, calcium, magnesium, or iron, compared with plants fed a complete solution.

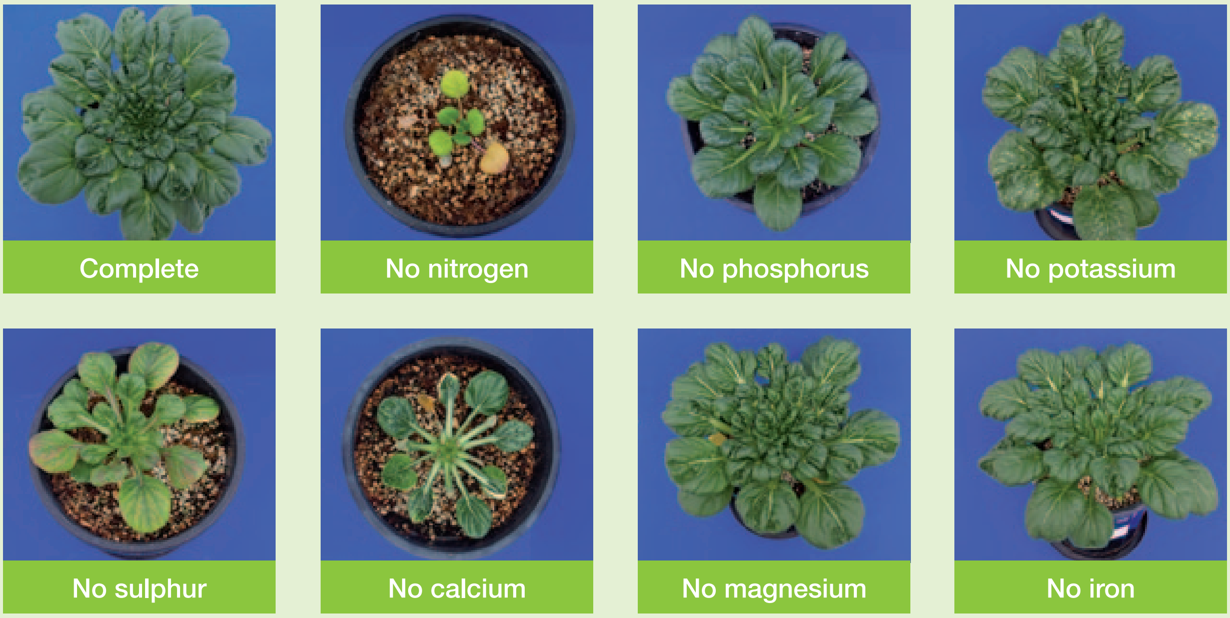
These reveal that nutrient deficiency responses are not always the same among different vegetable types. The responses common to the three vegetables are severe stunting from nitrogen deficiency and moderate stunting from phosphorus deficiency, thus highlighting the importance of these two nutrients to growth. However, symptoms of potassium deficiency, for example, are not consistent among the three vegetable types, with only Tat Soi exhibiting the typical deficiency symptoms of scorching on old leaves.



Above: The response of En Choy plants to the elimination of nitrogen, phosphorus, potassium, sulphur, calcium, magnesium or iron from the nutrient solution, compared with plants fed a complete solution.



Above: The response of Pak Choy plants to the elimination of nitrogen, phosphorus, potassium, sulphur, calcium, magnesium or iron from the nutrient solution, compared with plants fed a complete solution.



Above: The response of Tat Soi plants to the elimination of nitrogen, phosphorus, potassium, sulphur, calcium, magnesium or iron from the nutrient solution, compared with plants fed a complete solution.

Some general principles apply to visually diagnosing nutritional deficiencies in plants. However, it is wise to keep in mind that the exception is more often the rule. Old leaves are usually first affected by deficiencies of the most plant-mobile nutrients: nitrogen, phosphorus, potassium and magnesium. These nutrients are remobilised from the old leaves to provide the nutrients needed for new growth.

Deficiencies of the least mobile nutrients (iron, calcium, copper, boron, molybdenum and zinc) tend to be associated with symptoms in newer leaves since these nutrients cannot be easily remobilised from older leaves. The deficiency of moderately mobile nutrients (sulphur and manganese) can produce symptoms in both young and mature leaves.

Nitrogen deficiency

Symptoms: Plants are weak and severely stunted and older leaves become uniformly pale or yellow. Reddening of older leaves and stems can also occur.	
Possible causes	**Correction**
Incorrect preparation of nutrient solution.	Check records, check nitrate concentration in solution, have solution analysed, replace solution if needed.
Nutrient solution is low in nitrogen and is due for replacement.	Check nitrate concentration in solution and replace or top up solution if needed.
Nutrient solution strength is too low.	Increase solution strength (EC) or replace solution more frequently.

Nitrogen deficiency in Tat Soi (left) and Mustard Cabbage (right), showing yellowing and reddening of older leaves.

In Kang Kong severe nitrogen deficiency results in stunted and evenly pale plants (left). Mild nitrogen deficiency reduces growth (middle) compared with a well fed plant (right). *Photo by Jenny Ekman.*

Phosphorus deficiency

Symptoms: Plants are stunted, leaves are small, and older leaves are dull and lack lustre compared to new leaves. Other symptoms can include grey-green or purple colouring of older leaves.	
Possible causes	**Correction**
Incorrect preparation of nutrient solution.	Check records, have solution analysed, and replace solution if needed.
Nutrient solution is too alkaline.	Adjust solution to pH 5.5-6.0.
Nutrient solution strength is too low.	Increase solution strength (EC) or replace solution more frequently.
Nutrient solution is low in phosphorus and is due for replacement.	Have solution analysed, and replace or top up solution as required.
Low temperatures.	Increase overnight temperature (> 15°C) if practicable.

Phosphorus deficiency in En Choy. Older leaves are dull and lack lustre compared to new leaves.

Potassium deficiency

Symptoms: Plants are slightly stunted. Yellowing or scorching of old leaves occurs at the edges and between leaf veins.	
Possible causes	**Correction**
Incorrect preparation of nutrient solution.	Check records, check potassium concentration in solution, have solution analysed, replace or modify solution if needed.
Nutrient solution is low in potassium and is due for top up or replacement.	Check potassium concentration in solution, have solution analysed, replace or top up solution as required.
Nutrient solution strength is too low.	Increase solution strength (EC) or replace solution more frequently.

Potassium deficiency in Tat Soi. Old leaves have scorching at the margins and between leaf veins.

Calcium deficiency

Symptoms: Scorching of growing tips and the margins of new leaves. Leaves cup as they expand. Yellowing between the leaf veins can precede scorching and leaf death.	
Possible causes	**Correction**
Incorrect preparation of nutrient solution.	Check records, have solution analysed, replace solution if needed.

Left: Calcium deficiency in Pak Choy showing leaf cupping following marginal scorching, and yellowing between leaf veins. Similar symptoms were observed in Tat Soi but not in En Choy.

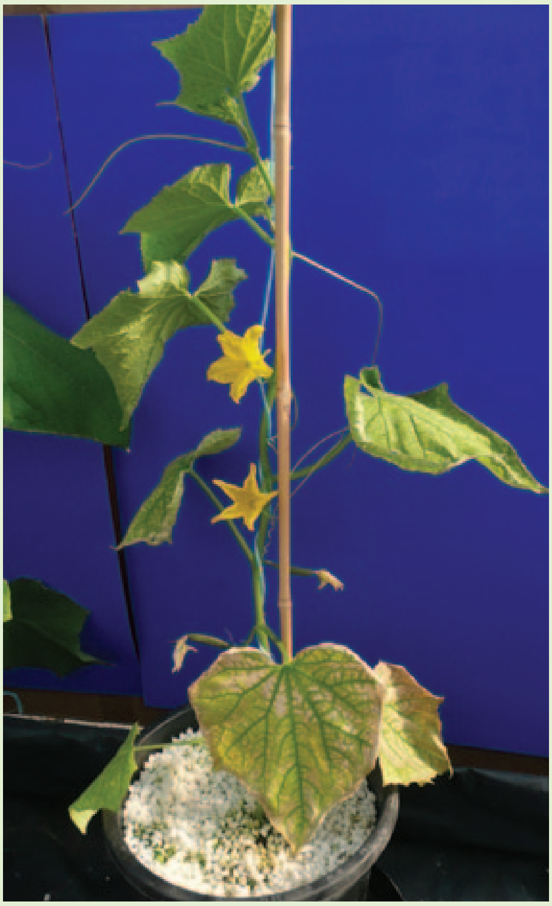
Iron deficiency

Symptoms: Yellowing of young leaves between leaf veins.	
Possible causes	**Correction**
Incorrect preparation of nutrient solution.	Check records, have solution analysed, replace solution if needed.
Nutrient solution is too alkaline.	Adjust solution to pH 5.5-6.0.
Low temperatures.	Increase overnight temperature (>15°C) if practicable.

Left: Iron deficiency in Pak Choy showing a net-like pattern of yellowing. Here, the deficiency is not apparent in the newest leaves but rather, in recently expanded leaves. Both Pak Choy varieties grown in this experiment showed similar symptoms, but no symptoms were observed in Tat Soi or En Choy.

Magnesium deficiency

Symptoms: Mild growth reduction. Yellowing and scorching of oldest leaves between the veins, progressing inwards from margins. Leaves sometimes remain green at the base of the blade.	
Possible causes	**Correction**
Incorrect preparation of nutrient solution.	Check records, have solution analysed, replace solution if needed.



Right: Magnesium deficiency in cucumber. Scorching of older leaves between veins follows yellowing. In the same experiment, symptoms of magnesium deficiency in En Choy, Pak Choy and Tat Soi did not occur, and only slight growth reduction was observed.

Zinc deficiency

Symptoms: Leaf size and stem length are restricted, and yellowing occurs between leaf veins and can progress into scorching between veins.	
Possible causes	**Correction**
Incorrect preparation of nutrient solution.	Check records, have solution analysed, replace solution if needed. Do not over supply zinc as it can be toxic.

Boron deficiency

Symptoms: Yellowing and scorching occurs between leaf veins at growing points.	
Possible causes	**Correction**
Incorrect preparation of nutrient solution.	Check records, have solution analysed, replace solution if needed. Do not over supply boron as it can be toxic.

Copper deficiency

Symptoms: Leaves are a dark blue-green colour.	
Possible causes	**Correction**
Incorrect preparation of nutrient solution.	Check records, have solution analysed, replace solution if needed.

Sulphur deficiency

Symptoms: Yellowing and purpling of areas between veins of new and old leaves. Older leaves show marginal scorching.	
Possible causes	**Correction**
Unlikely to be deficient in nutrient solution.	Have solution analysed, and replace solution if needed.

Left: Sulphur deficiency in Tat Soi. Symptoms are yellowing and purpling of areas between veins and purpling of leaf stems. Older leaves show marginal scorching. Under the same conditions, Pak Choy and En Choy suffered some growth reduction only. This deficiency is unlikely to develop in hydroponics since a number of sulphur compounds are used in the nutrient solution.

Manganese deficiency

Symptoms: Yellowing between leaf veins (mottling), progressing to scorching.	
Possible causes	**Correction**
Incorrect preparation of nutrient solution.	Check records, have solution analysed, replace solution if needed. Do not over supply manganese as it can be toxic.

Nutrient toxicity

Symptoms: Fertiliser excess can cause wilting and death of seedlings and growing tips, marginal yellowing and scorching of leaves, and burning of roots. Other symptoms of toxicity of specific nutrients include yellowing between veins of new leaves (typical of iron deficiency), and pale spots progressing to dead patches between veins of old leaves. Margins of old leaves can be pale and become scorched, with scorching spreading over the entire leaf. It is difficult to determine which nutrient is toxic based on a visual diagnosis.	
Possible causes	**Correction**
Incorrect preparation of nutrient solution.	Check records, have solution analysed, replace solution if needed.
Nutrient solution strength is too high for the conditions.	Check records, check EC in solution, and gradually lower EC if required.
Nutrient solution is high in phosphorus as a consequence of frequent pH adjustment using phosphoric acid.	Have solution analysed, and replace solution if needed.
Sodium has built up to high levels in the nutrient solution.	Check sodium concentration in solution, or have solution analysed, and replace solution if needed.
An excessive supply of a micronutrient has been delivered in attempting to correct for a deficiency.	Have solution analysed, and replace solution if needed.

Sodium toxicity in Tat Soi showing scorched patches on leaves.

Wilting of Mustard Cabbage after being irrigated with a solution containing a high concentration of fertiliser.

References and further resources

Books

Badgery-Parker J. 2003. *Managing waste water with a wetland.* NSW Industry and Investment, Orange.

Huett, D. 2003. *Managing nutrient solutions in hydroponics.* NSW Industry and Investment, Orange.

Papers

Badgery-Parker J. 2002. Managing waste water from intensive horticulture: a wetland system. Online.

Available:http://www.dpi.nsw.gov.au/agriculture/horticulture/greenhouse/water/general/management, 16/03/2011

Kratky, B. A. 2004. A suspended pot, non-circulating hydroponic method. *Acta Horticulturae* 648, 83-89.

Kratky, B. A. Three non-circulating hydroponic methods for growing lettuce. Online. Available: http://www.smallfarms.ifas.ulf.edu, 9/03/2011.

General reading for hydroponic farmers

Practical Hydroponics and Greenhouses (quarterly magazine), Casper Publications Pty Ltd, Narrabeen, NSW.