Nutrient management of Asian vegetables

Dr Sophie Parks
NSW Department of Industry and Investment

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FINAL REPORT

NUTRIENT MANAGEMENT OF ASIAN VEGETABLES

Dr Sophie Parks

Gosford Primary Industries Institute
NSW Industry and Investment
Locked Bag 26 Gosford NSW 2250

Horticulture Australia Ltd. Project VG 07153

Nutrient management of Asian vegetables

Organisation: NSW Industry and Investment

Project Leader:
Sophie Parks Research Horticulturist
Gosford Primary Industries Institute
NSW Industry and Investment

Key Personnel:
Lorraine Spohr Biometrician
Gosford Primary Industries Institute, NSW Industry and Investment

Basem Al-Khawaldeh Technical Officer (Author)
Gosford Primary Industries Institute, NSW Industry and Investment

Carly Murray Technical Officer
Gosford Primary Industries Institute, NSW Industry and Investment

Joshua Jarvis Technical Officer
Gosford Primary Industries Institute, NSW Industry and Investment

Jenny Ekman Research Horticulturist
Gosford Primary Industries Institute, NSW Industry and Investment

David Midmore Professor, Faculty of Sciences, Engineering & Health, Central Queensland University.

March 2011

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The purpose of this report is to pass on information concerning the nutrient management of Asian vegetables in production.

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We would also like to thank those who participated in workshops and those who provided valuable feedback on the project.

Media summary

The Asian vegetable sector has grown rapidly in Australia and now contributes six percent to the value of the vegetable industry. Leafy Asian vegetables such as pak choy, choy sum and gai lan are amongst the most significant crops grown, and increasingly, they are being produced in hydroponic systems. The production of some crops in hydroponics, such as lettuce, is well understood. However, little is known about how to efficiently grow Asian vegetables in hydroponics for high yields and high quality produce.

This project has made a significant contribution to the understanding of the nutrition of leafy Asian vegetables in production. In hydroponics, the target concentration of the recirculating nutrient solution has been determined for ten Asian vegetable varieties. By aiming for these targets, as part of fertiliser management, high production efficiency will be achieved and the risk of nutrient disorders occurring will be reduced. As part of the project, nutrient disorders have been documented as an aid to growers in the identification of plant symptoms.

Further research is required to make monitoring of plant nutrients easy to conduct on-farm, including the identification of suitable plant parts for sap extraction. Some on-farm testing of the hydroponic solution is currently possible but information also needs to be developed on the wide range of portable instruments on the market and their suitability for measuring nutrients in hydroponic solutions and potentially measuring nutrients in plant sap. This aside, the industry can act now to improve production efficiency in this sector by promoting the benefit of nutrition management of Asian vegetables and of the available methods for achieving this.

Technical summary

The Asian vegetable sector has grown rapidly in Australia and now contributes six percent to the value of the vegetable industry. A recent development within the industry is the fast adoption of hydroponic systems for the production of leafy Asian vegetables. However, to date, there has been a poor understanding of the nutritional requirements of these vegetables in production, making it impossible to provide guidelines on how to grow them for optimal yields and with the greatest efficiency. An added challenge for the industry is the implication, from previous studies, that leafy Asian vegetables are produced with excessive amounts of fertilisers, causing undesirably high concentrations of nitrate in market vegetables.

This project aimed to improve our understanding and management of nutrition in the production of some leafy Asian vegetables, with a particular emphasis on nitrogen. To achieve this we determined some plant responses to fertiliser of a number of leafy varieties grown in hydroponics. We also investigated the potential for the simple monitoring of plant nutrients on-farm.

This project determined the target concentration range of hydroponic solution for ten varieties of leafy Asian vegetables. The targets were specific to hydroponic solution made according to the Huett's lettuce formula (common in lettuce production), for plants produced in the type of hydroponic system known as nutrient film technique (NFT). The research highlights that managing the nutrient solution to these targets is a key tool in fertiliser efficiency and the prevention of nutrient disorders. This method will also prevent the uptake of nitrate beyond the requirement of plants.

Although the rate of fertiliser used can affect plant nitrate concentrations, this work showed that many Asian vegetables, particularly those of the Brassicaceae family, have an inherently high requirement for nitrate compared with other vegetable types. They contain similar concentrations of total nitrogen to other vegetables but store more of their nitrogen as nitrate. The responsiveness of plant nitrate levels to the fertiliser supply was demonstrated in pak choy, en choy and coriander, and can be utilised to develop an on-farm plant test to assist with making decisions about fertiliser management. Challenges to this include determining an appropriate plant part to sample that is indicative of shoot nitrate concentration. The leaf petiole of coriander, and main stem apex of en choy are both suitable candidates but the leaf petiole of pak choy has been determined as not suitable.

Further research, required to make monitoring of plant nutrients easy to conduct on-farm includes evaluating the suitability of a number of portable instruments for measuring nutrients in plant sap and in hydroponic solutions. This is important because nutrients other than the one targeted for measurement in the recirculating system may interfere with the accuracy of the reading of these instruments.

Greater awareness amongst growers of the benefit of improving the management of Asian vegetable nutrition, and of the methods available for achieving this, is a priority, and will be possible through existing channels for industry extension.

1. Introduction

To date, growers have not had the means to optimise fertiliser management in Asian vegetables. To complicate this, the industry has recently adopted hydroponics as a growing system, alongside field production. There is little information about the nutritional requirements of these vegetables and therefore there are no standard guidelines available. Additionally, practical management tools need to be developed, from simple on-farm plant tests to standard laboratory tests, for Asian leafy vegetables.

Paramount to nutrition management in Asian vegetables is the management of nitrate. A high level of nitrate in leafy vegetables is undesirable for reasons of public health and vegetable quality. Human dietary nitrate is largely obtained from vegetables and at high levels is considered harmful to human health (Santamaria 2006). Although nitrate is relatively non-toxic, it is readily converted to nitrite and N-nitroso compounds that are toxic and have been associated with the potentially fatal methaemoglobinaemia in infants and gastric cancer and bladder cancer (Abdel Mohsen et al. 1999, Mensinga et al. 2003). Vegetable quality is also compromised as increasing application rates of nitrogen (N)-containing fertilisers can increase the incidence and severity of bacterial soft-rot in vegetables. This has been demonstrated in Chinese cabbage (Warner et al. 2004) and some susceptible broccoli cultivars (Canaday and Wyatt 1992).

In Europe, widespread evidence of nitrate accumulation in leafy vegetables led to the European Union (EU) developing limits on fresh nitrate concentrations (Santamaria 2006). Currently, these limits do not prevent the sale of produce exceeding the limits within an EU country, however export to another country is not permitted. In Australia, these limits are not in place. The vegetable industry's current action on nitrates in vegetables is timely.

It is important that growers have the means to manage the nutrition of their leafy Asian vegetable crop. The project *Nitrate and nitrite in Australian leafy vegetables* (VG04019) identified that approximately half of the leafy Asian vegetables purchased in the market place have an undesirably high nitrate concentration (Parks et al., 2008). This is possibly due to the naturally high uptake of nitrate by brassica vegetables, to which most Asian leafy vegetables belong, combined with excessive use of fertilisers in the production of these vegetables. Excessive application of N fertilisers to horticultural crops is a demonstrated problem in Australia indicated by high concentrations of nitrate in runoff recorded from market gardens (Pionke et al. 1990). Unfortunately at present, little information exists for growers on the management of nitrate in Asian vegetable crops.

Plant testing is the only way to establish if nitrate has accumulated in excess to requirement as there are no obvious symptoms of toxicity. Too much nitrate may compromise the crop, demonstrated for example in grain amaranth which had excessive plant height, increased lodging and delayed crop maturity at high nitrate fertilizer rates (Myers, 1998). This further emphasises the importance of fertilizer efficiency in vegetable production. The development of sufficiency ranges for nitrate is a possibility for a number of Asian vegetables given that the plant nitrate concentration is influenced by the rate of nitrate fertiliser for example, in amaranth (Teyker et al., 1991; Walters et al., 1988) and pak cho (Luo et al., 2006). Used on-farm, the developed sufficiency ranges would provide a guide as to whether or not the crop requires nitrogen fertilizer.

Several on-farm techniques are available for rapid analysis of plant sap nitrate (NO_3^-N) and these have been adapted for a number of vegetable crops such as pumpkin, potato, lettuce, and capsicum (Huett and White, 1992a; Huett and White, 1992b; Olsen and Lyons, 1994; Studstill et al., 2003). Other nutrients routinely measured in plant sap include potassium (K) in pumpkin (Studstill et al., 2003) and in tomato (Taber and Lawson, 2007), and phosphate in maize (Silvestre et al., 2003) and oilseed rape (Major and Barraclough, 2003).

2. Aims

This project aimed to improve our understanding and management of nutrition in the production of some leafy Asian vegetables, with a particular emphasis on nitrogen.

To achieve this, we determined some plant responses to fertiliser of a number of leafy varieties grown in hydroponics. We also investigated the potential for the simple monitoring of plant nutrients on-farm.

Experiments were designed to:

2.1 Compare ten Asian vegetable varieties in their growth responses and shoot nitrate to fertiliser rate. Varieties included: Thai basil (Siam Queen), bunching onion, coriander, flowering choy sum, mustard cabbage, pak choy (varieties Sumo, Yangtze and Miyako), en choy and tat soi.

2.2 Determine the relationship between N fertiliser rate and N nutrition in four Asian vegetable varieties (coriander, en choy, pak choy and kang kong).

2.3 Determine the relationship between N fertiliser rate and nitrate monitored in leaf petioles of three Asian vegetable varieties (coriander, en choy, pak choy).

2.4 Determine the suitability of the main stem as an index tissue for nitrate monitoring of en choy.

2.5 Develop symptoms of nutrient disorders in some Asian vegetables to provide growers with a visual aid in the management of crop nutrition.

2.6 Determine the suitability of the Huett’s lettuce formula, common in lettuce production, for the nutrient solution in the hydroponic production of leafy Asian vegetables.

3. Methods

3.1 Growth and shoot nitrate response of ten Asian varieties to the concentration of nutrients in hydroponics.

The experiment was conducted in a fully automated greenhouse at Gosford Primary Industries Institute in winter (Figure 1). Mean minimum and maximum daily temperatures inside the greenhouse ranged between 4.4 and 17.1 ^{o}C.

Ten types of Asian vegetables were used in this experiment: Thai basil (Siam Queen), bunching onion, coriander (*Coriandrum sativum* L.), flowering choy sum, mustard cabbage, pak choy (*Brassica rapa* varieties Sumo, Yangtze, Miyako), red amaranth (en choy) (*Amaranthus tricolor* L.) and tat soi. Seeds were germinated in seedling trays containing grow wool.

Seedlings, germinated approximately seven weeks previously, were planted out into one of five nutrient film technique systems (NFT). Each system contained four channels, with 10 plant holes per channel. Each system was supplied with nutrient solution by two 70L interconnected tanks. Between one and four plants were planted per hole depending on the vegetable type. The nutrient solution concentration treatment was achieved using Huett's lettuce recipe (Table 1), maintained at different concentrations in solution. The electrical conductivities (EC) levels were: 1) 0.5-1.5, 2) 1.5-2.5, 3) 2.5-3.5, 4) 3.5-4.5 and 5) 4.5-5.5. The treatments were not replicated.

Figure 1. Hydroponic systems in the greenhouse set up to investigate the performance of ten varieties of leafy Asian vegetables at different strengths of nutrient solution.

Table 1. Standard 'Huett' lettuce formulation. Recommended starting and top-up solutions are the same. Equal volumes of A and B stock solution were used. For starting solution, to 1000 litres of water 3.4 litres of A and 3.4 litres of B was added.

Solution	*Compound*	*Elemental composition (%)*	***Stock solution (g compound/L)***	
			#pH>6.0	***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) ammonium phosphate ($NH_4H_2PO_4$)	12.2 N 26.9 P	8.7	Nil
	Potassium dihydrogen phosphate ($KH_2 PO_4$)	28.7 K 22.8 P	16.3	29.0
	Potassium nitrate (KNO_3)	38 K 13 N	133.3	133.3
	Magnesium sulphate ($MgSO_4$)	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

*Amount of iron chelate adjusted depending on elemental Fe content of chelate.
+Amount in stock solution adjusted if pH drifted upward in system.
#When pH of nutrient solution in recirculating system is greater than (>) 6.0.

At maturity, plants were harvested and dried. The nitrate concentration of shoots was measured in the dried plants using flow injection analysis (NSW Industry and Investment Diagnostic Analytical Services, Wollongbar, NSW).

3.2 Effect of N fertiliser on N nutrition and growth of coriander, en choy, pak choy and kang kong.

3.2.1 Coriander, en choy, pak choy

Three species were chosen for experimentation in a commercial sized NFT system based on their success in the first trial and because they each represented a different plant family. These were pak choy (Brassicaceae), coriander (Apiaceae) and en choy (Amaranthaceae).

Plants were grown hydroponically using nutrient film technique to deliver accurate supplies of nitrate to roots (Figure 2). The system was located out doors at Gosford Primary Industries Institute in spring. Mean daily temperatures ranged between 8.0 and 24.5 ^{o}C. Nutrient solutions contained nitrogen supplied at five rates: 30, 50, 100, 200, 300 mg N/L as nitrate, which is equivalent to 2.14, 3.57, 7.14, 14.29 and 21.43 mmol N/L as nitrate. Nitrate sources included sodium nitrate, magnesium nitrate, calcium nitrate and potassium nitrate, depending on the treatment. Other nutrients were (mmol/L) K 6.3, Ca 3.8, S 1.3, Mg 1.3, P 1.6; and (µmol/L) Fe 145, B 18.5, Mn 7.1, Cu 1.4, Zn 4.5, and Mo 0.5. The concentrations of Na (3.4 µmol - 9.1 mmol/L) and Cl (3.4 µmol - 7.5 mmol/L) varied with N level. Each supply rate was replicated six times with an individual 100L tank per channel recirculating the solution. Solutions were regularly monitored to maintain nitrate concentrations as close as possible to the nitrate treatment level. At maturity plants were harvested and dried, and sent to Wollongbar for nitrate-N and total N analysis.

Figure 2. An outdoor hydroponics system showing en choy growing, set up to investigate the nitrogen nutrition of en choy, pak choy and coridander.

3.2.2 Kang kong

Kang kong, unsuited to an NFT system, was grown in still water tanks according to the method of Kratky (2004). The experiment was conducted in a fully automated greenhouse at Gosford Primary Industries Institute in winter (Figure 3). Mean daily temperatures inside the greenhouse ranged between 4.4 and 17.1 ^{o}C. The 20L tanks were filled with nutrient solution at the beginning of the experiment and not replaced or replenished. Kang kong seedlings were placed into a hole in the tank lid with the crown of the roots suspended just above the nutrient solution. Nutrient solutions at the start of the experiment contained nitrogen supplied at five rates as per coriander, en choy and pak choy in the NFT system (3.2.1). There were five replicates per nitrate treatment. The crop was terminated when the solution neared the bottom of the tank. Plants were harvested and dried, and sent to Wollongbar for nitrate-N and total N analysis.

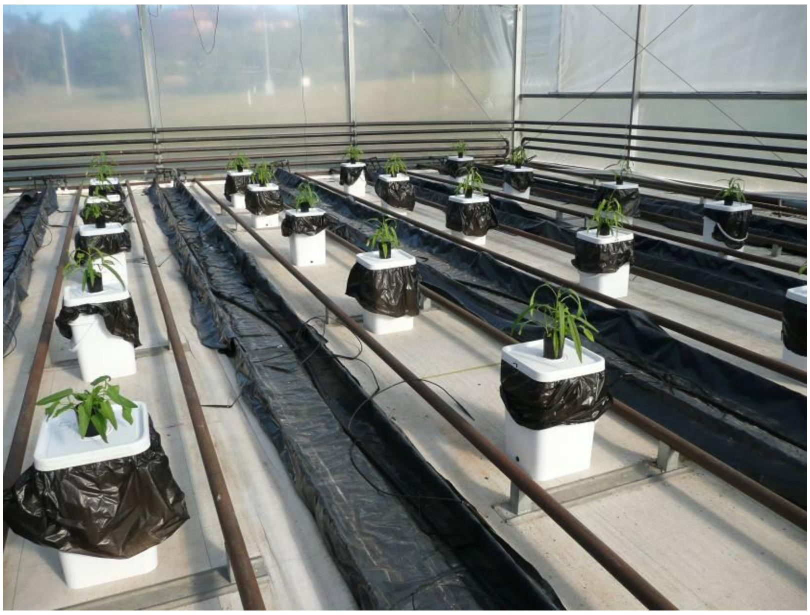

Figure 3. Kang kong growing in tanks containing still hydroponic solution.

3.3 Effect of N fertiliser on nitrate in petioles of coriander, en choy and pak choy.

Plants were grown in the system described in 3.2. At maturity, plants were harvested and the total fresh weight of plants was recorded. The petioles and/or stems were removed from these and then sent to AgVita Analytical (Tasmania) for the extraction of sap and analysis of nitrate.

3.4 Effect of N fertiliser and sample preparation on nitrate in stems of en choy.

Phase 1 of the experiment was conducted in a plastic covered tunnel greenhouse at Gosford Primary Industries Institute in spring. The greenhouse was passively ventilated using side wall vents. Mean daily temperatures inside the greenhouse ranged between 15.7 and 24.8 ^{o}C.

Seedlings of en choy, *Amaranthus tricolor*, were planted into 24 Autopot® units (Figure 4). These consisted of two 254 mm pots containing perlite, with each pair of pots sub irrigated with nutrient solution from an independent 40L tank. Each unit contained 20 plants. The nutrient solution contained the 2 nitrate treatments; N supplied at 100 (N100) or 200 (N200) mg/L, as nitrate. Other nutrients were (mmol/L) K 6.3, Ca 3.8, S 1.3, Mg 1.3, P 1.6; and (µmol/L) Fe 145, B 18.5, Mn 7.1, Cu 1.4, Zn 4.5, and Mo 0.5. The concentrations of Na were 7.9 x 10^{-5} and 2.0 mmol/L for N100 and N200 respectively, and the concentrations of Cl were 2.5 and 3.4 x 10^{-3} mmol/L for N100 and N200 respectively. The 24 units were arranged in a completely randomised design with 12 replicates of the two nitrate levels. An experimental unit comprised two units for each nitrate level in order to have sufficient stem material for nutrient analysis.

Figure 4. The autopot systems used to grow en choy in the greenhouse. Each pair of pots is subirrigated with hydroponic solution from an individual tank.

Plants were harvested five weeks after planting. Shoot fresh weight was recorded prior to preparation of stems for analysis.

Phase 2 of the experiment involved 2 storage types which were achieved by placing stems from each N treatment into either the refrigerator compartment (4^{o}C), or freezer compartment (-20^{o}C) in three replicate combined refrigerators/freezers overnight. A split plot design with 3 replicates was used, with the two storage types as the main plots. The factorial treatment structure allowed the main effects of storage type, nitrate and their interaction to be tested.

Samples were analysed at a commercial plant analysis laboratory (AgVita Analytical, Devonport, Tasmania, Australia) for NO_3^-, B, Ca, Cu, Fe, K, Mg, Mn, Mo, Na, P, S and Zn at room temperature. The sap was extracted with a custom made hydraulic press, filtered and diluted, and then analysed using flow injection analysis (Lachet, Loveland, USA) for NO_3^- and using inductively coupled plasma spectroscopy (Varian Analytical, Mulgrave, Australia) for B, Ca, Cu, Fe, K, Mg, Mn, Mo, Na, P, S and Zn.

Statistical analysis
The effect of nitrate level on fresh weight (yield) was tested after Phase 1 of the experiment using analysis of variance in GenStat(2009). For Phase 2, a similar analysis was used to test the effects of storage type, nitrate level and their interaction on each element at the P=0.05 significance level.

3.5 Developing symptoms of nutrient disorders in some Asian vegetables

The trial was conducted in a fully automated greenhouse at Gosford Primary Industries Institute in spring. Mean daily temperatures inside the greenhouse ranged between 18.0 and 25.0 ^{o}C.

Nutrient deficiencies were imposed on Asian vegetable seedlings using nutrient solutions missing a key nutrient. The method is described by Ross (1974). Deficiencies imposed included N, P, K, Ca, Mg, S and Fe and these were grown alongside plants fed with a complete nutrient solution. Cucumber plants were included as a standard crop

Seeds of pak choy (Sumo and Miyako), en choy, tat soi and cucumber were germinated in seedling trays containing seed raising mix. For each deficiency treatment, approximately ten plants were each grown in a 200 ml pot containing inert potting mix (perlite). Nutrient solution treatments were watered into the pots manually on a need-to or weekly basis. When visual symptoms of the nutrient disorders were displayed, photos were taken and the symptoms were described (Figure 5).

Figure 5. Calcium deficiency symptoms in tat soi.

4. Results

4.1 Growth and shoot nitrate response of ten Asian varieties to the concentration of nutrients in hydroponics.

The growth response of Thai basil, bunching onion, coriander, flowering choy sum, mustard cabbage, pak choy varieties Sumo, Yangtze and Miyako, en choy and tat soi to the nutrient concentration in hydroponic solution is shown in Figure 6. Generally, the dry weight of shoots tended to increase in response to an initial increase in nutrition but higher solution strengths were associated with reduced growth, or with a growth plateau. There appeared to be no growth response pattern in bunching onion.

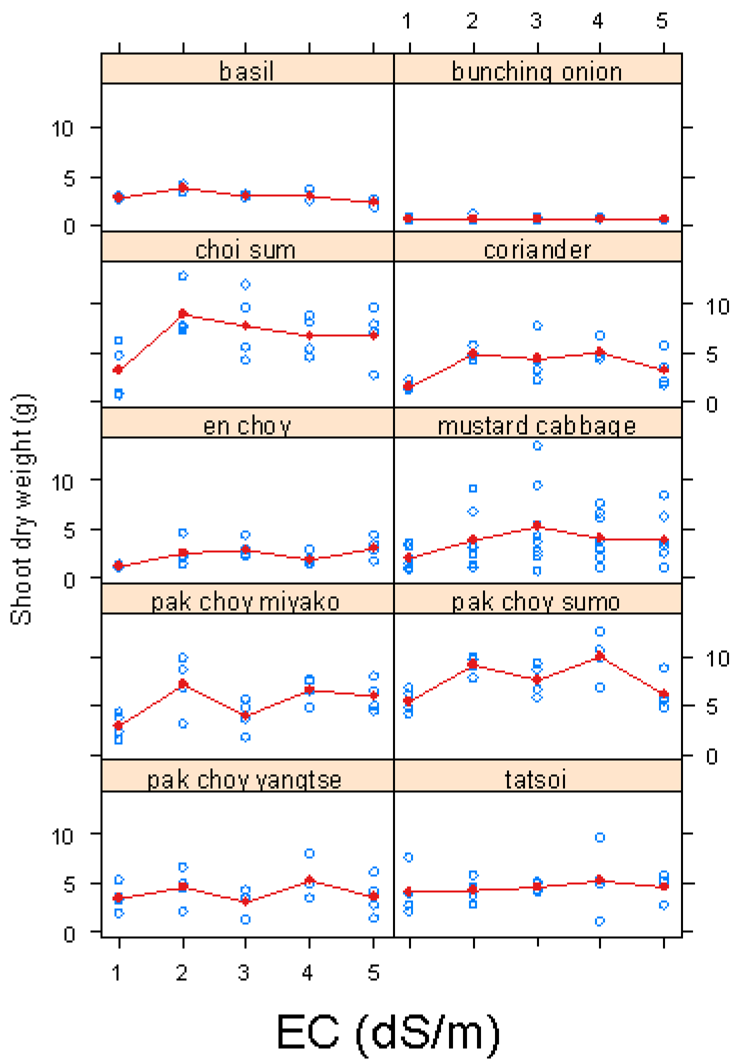

Figure 6. Growth response of some leafy Asian vegetable varieties to the strength of nutrient solution.

The shoot nitrate response of Thai basil, bunching onion, coriander, flowering choy sum, mustard cabbage, pak choy varieties Sumo, Yangtze and Miyako, en choy and tat soi to the nutrient concentration in hydroponic solution is shown in Figure 7. Generally, the nitrate concentration of shoots tended to increase strongly in response to an initial increase in nutrition. Increasing the nutrient concentration to 2.5-5.5 (dS/m) did not appear to affect the nitrate concentration of shoots.

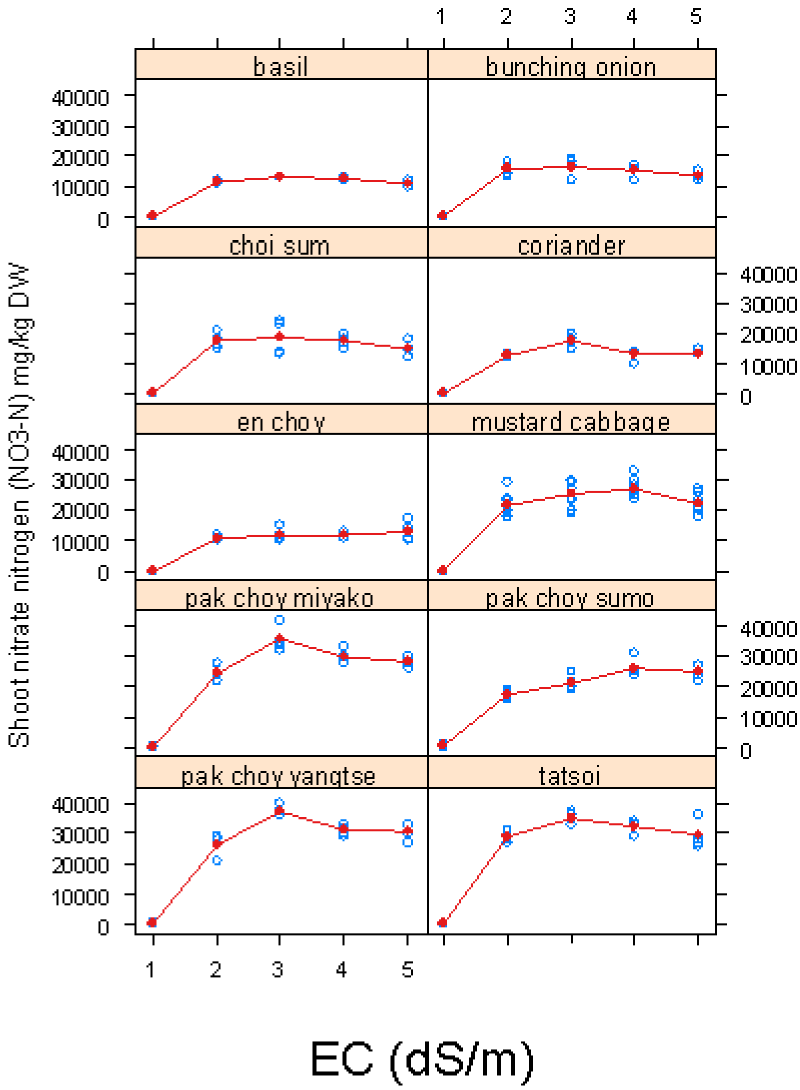

Figure 7. Response of shoot nitrate of some leafy Asian vegetable varieties to the strength of nutrient solution.

4.2 Effect of N fertiliser on N nutrition and growth of coriander, en choy, pak choy and kang kong.

The growth response of coriander, en choy and pak choy to the nitrate concentration in recirculated hydroponic solution is shown in Figure 8. Generally, the dry weight of shoots tended to increase in response to an initial increase in nitrate supply but higher solution strengths were associated with a growth plateau.

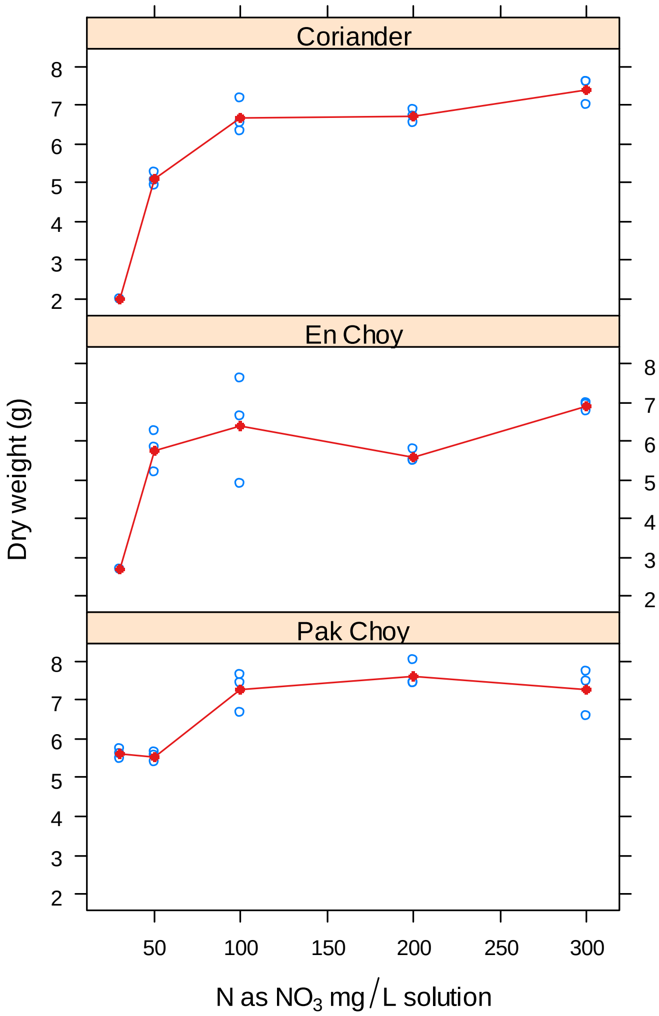

Figure 8. Growth response of coriander, en choy and pak choy, to the concentration of nitrate in solution.

The shoot nitrate response of coriander, en choy and pak choy to the nitrate concentration in recirculated hydroponic solution is shown in Figure 9. The nitrate concentration in shoots gradually increased in coriander and pak choy, in response to increased nitrate in solution. The shoot nitrate concentration of en choy increased dramatically between a nitrate-N supply of 50 and 100 mg/L and increased gradually beyond this.

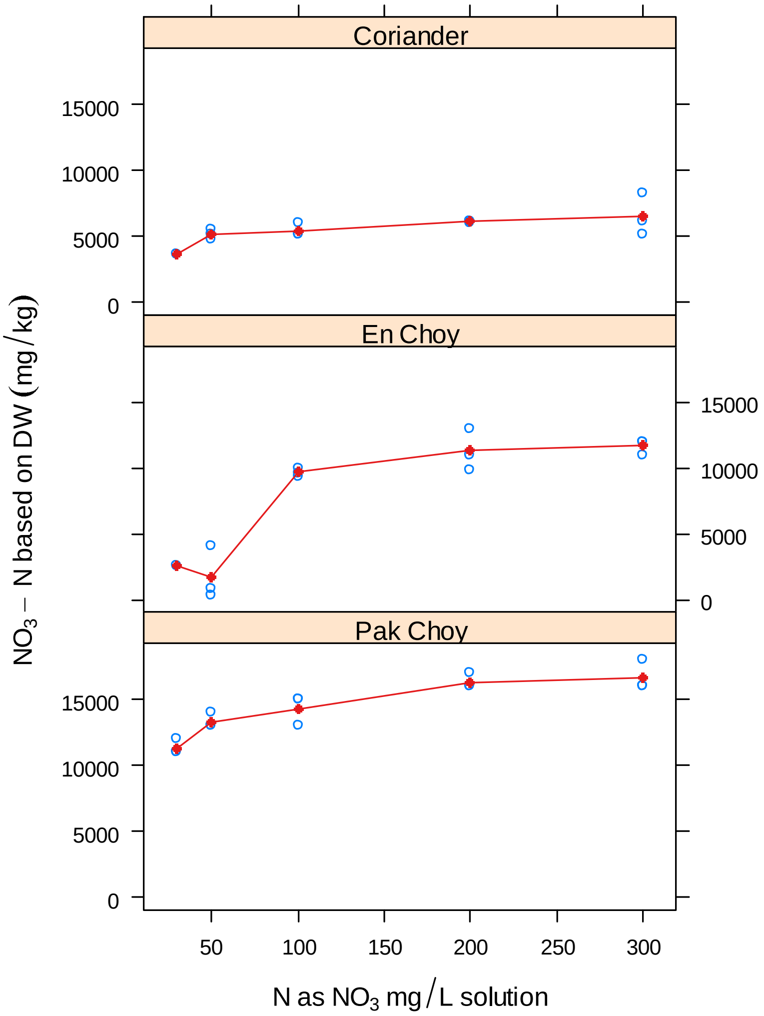

Figure 9. Shoot nitrate response of coriander, en choy and pak choy, to the concentration of nitrate in solution.

The total nitrogen response of coriander, en choy and pak choy shoots to the nitrate concentration in recirculated hydroponic solution is shown in Figure 10 and was similar to the shoot nitrate response. The total nitrogen concentration in shoots gradually increased in coriander and pak choy, in response to increased nitrate in solution. The total nitrogen concentration of en choy shoots increased dramatically between a nitrate-N supply of 50 and 100 mg/L and increased gradually beyond this.

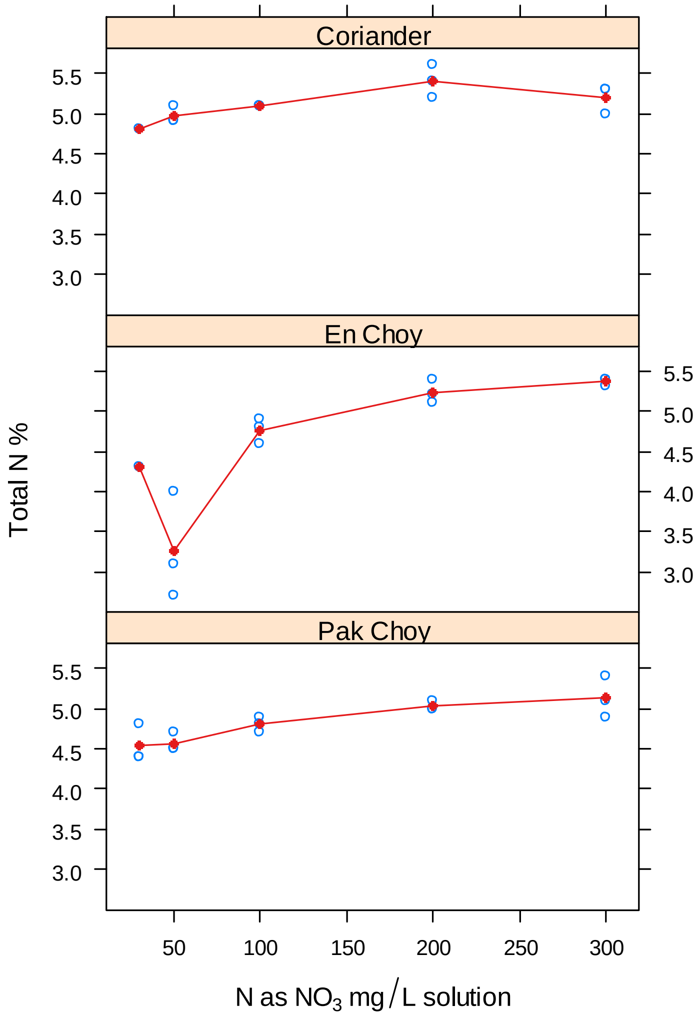

Figure 10. Shoot nitrogen response of coriander, en choy and pak choy, to the concentration of nitrate in solution.

The response of growth, and the shoot nitrate and total nitrogen response, of kang kong to the initial concentration of nitrate in still hydroponic solution, is shown in Figures 11, 12 and 13. Growth dramatically increases at a starting solution concentration of 50 mg/L nitrate-N and slowly declines at higher concentrations. Shoot nitrate and total nitrogen increases dramatically with higher nitrate concentrations in the starting solution. This reflects that in solutions with starting concentrations above 50mg/L nitrate-N, the solution EC and nitrate concentration increased dramatically with time as the crop used the solution for growth (data not shown).

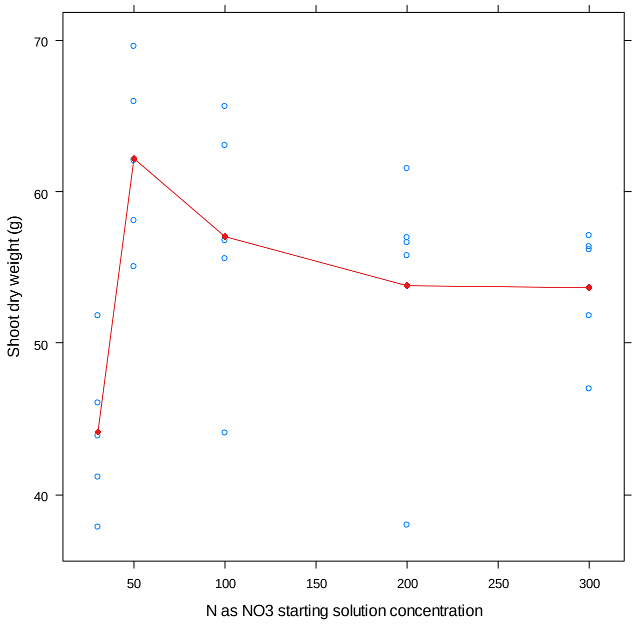

Figure 11. Growth response of kang kong to the concentration of nitrate in solution.

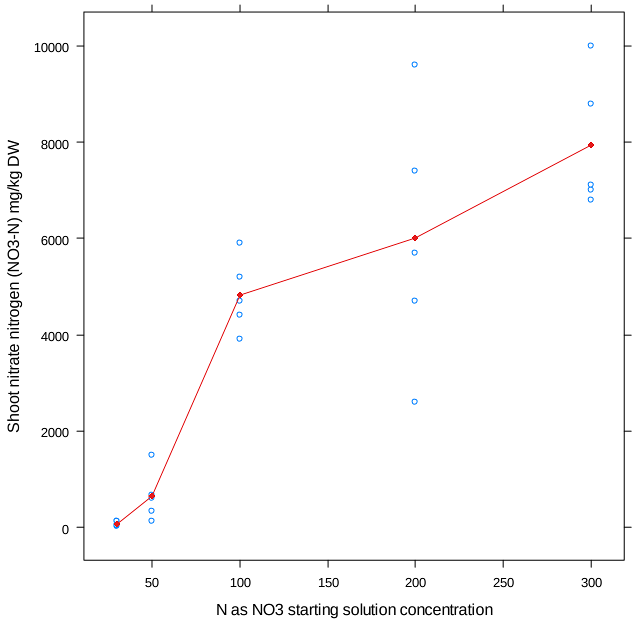

Figure 12. Shoot nitrate response of kang kong to the concentration of nitrate in solution.

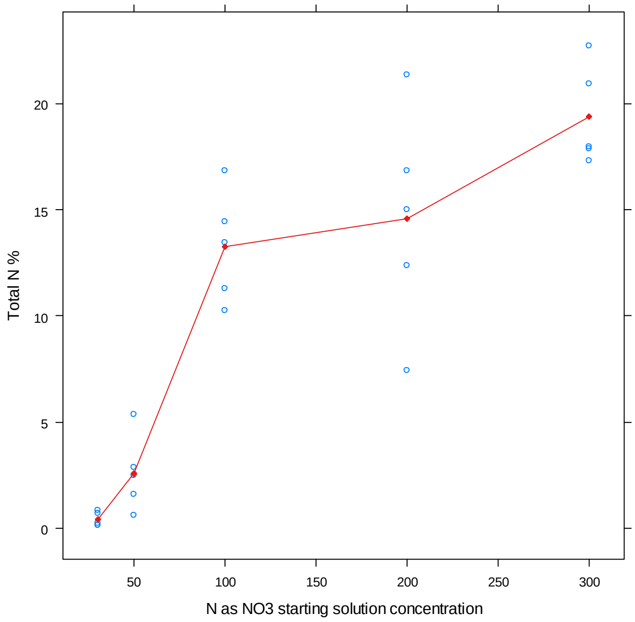

Figure 13. Shoot nitrogen response of kang kong to the concentration of nitrate in solution.

4.3 Effect of N fertiliser on nitrate in petioles of coriander, en choy and pak choy.

The petiolar nitrate response of coriander, en choy and pak choy to the nitrate concentration in hydroponic solution is shown in Figure 14. The petiolar nitrate concentration gradually increased in coriander, in response to increased nitrate in solution. The petiolar nitrate concentration of en choy increased dramatically between a nitrate-N supply of 50 and 100 mg/L and increased gradually beyond this. The petiolar nitrate concentration in pak choy did not appear to be affected by increased nitrate in solution.

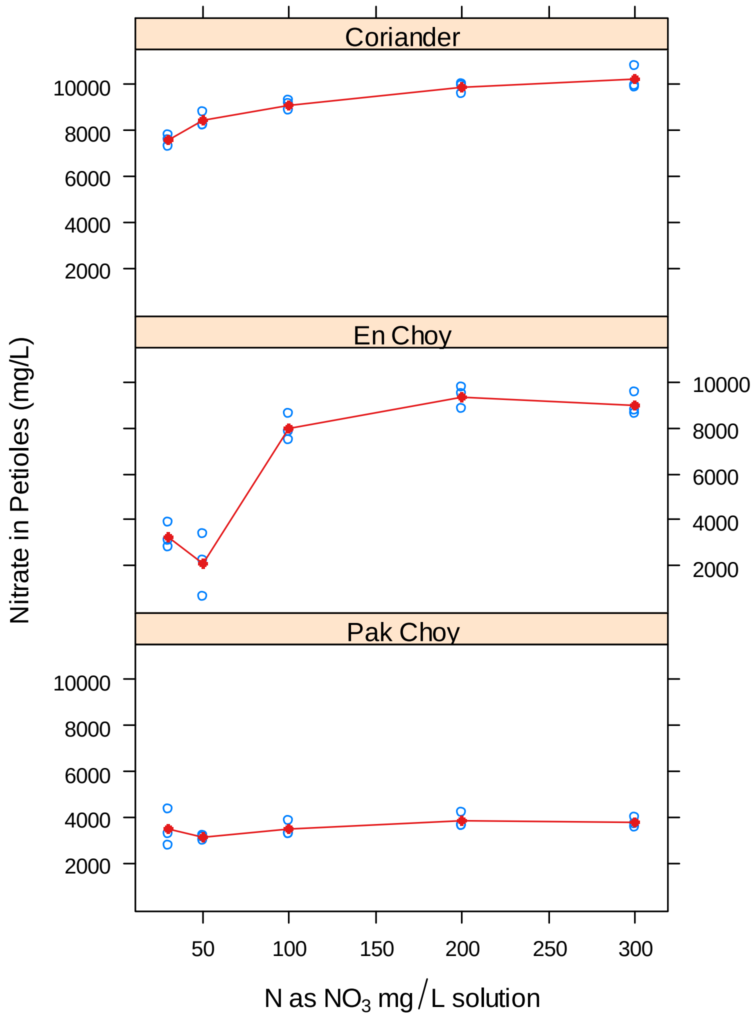

Figure 14. Petiolar nitrate response of coriander, en choy and pak choy, to the concentration of nitrate in solution.

4.4 Effect of N fertiliser and sample preparation on nitrate in stems of en choy.

The nutrient concentrations of refrigerated and frozen stems of en choy grown at two nitrate rates (100 and 200 mg/L N) is shown in Table 2. Sap nitrate from both refrigerated and frozen-thawed stems did not differ but was significantly increased by additional nitrate fertilizer. Shoot growth was correspondingly higher with additional nitrate. B, Ca, Fe, Mg, Mn, Mo, Na and S were significantly affected by frozen storage but K, P and Zn were not.

Table 2. Effect of storage location (refrigerator or freezer), and the nitrate-N level (100 or 200 mg/L) in the hydroponic solution, on the concentration of nutrients in extracted stem sap (mg/L).

	Storage location of harvested plant stems						
	Refrigerator (4^{o}C)		Freezer (-20^{o}C)				
Nutrient measured in stem sap	Grown at N fertiliser rate 100 (mg/L)	Grown at N fertiliser rate 200 (mg/L)	Grown at N fertiliser rate 100 (mg/L)	Grown at N fertiliser rate 200 (mg/L)	Storage location effect	N fertiliser rate effect	Interaction of Storage & N fertiliser rate effect
	Concentration of nutrient in stem sap (mg/L)						
NO_3^-	928.3	5766.7	981.7	5983.3	n.s.	*	n.s.
B	0.78	0.84	1.29	1.05	*	n.s.	n.s.
Ca	332.0	261.3	114.7	96.7	*	n.s.	n.s.
Cu	5.02	4.49	5.09	4.69	n.s.	n.s.	n.s.
Fe	9.75	5.03	5.31	3.24	*	*	*
K	6500.7	5414.3	6203.7	5344.3	n.s.	*	n.s.
Mg	595.0	436.0	479.7	378.7	*	*	n.s.
Mn	4.38	1.47	3.38	1.30	*	*	*
Mo	0.97	0.73	0.53	0.46	*	*	n.s.
Na	345.7	720.7	366.7	837.7	*	*	n.s.
P	923.3	480.3	977.0	555.0	n.s.	*	n.s.
S	447.0	295.0	331.3	257.0	*	*	*
Zn	5.87	3.21	6.35	3.21	n.s.	*	n.s.

n.s. = not significant
* = significant at $P<0.05$

4.5 Developing symptoms of nutrient disorders in some Asian vegetables.

Symptoms of reduced growth and pale leaves, in response to nitrogen deficiency, are shown in Figures 15 and 16 for en choy and kang kong. Symptoms of potassium deficiency are described in an excerpt from *Leafy Asian vegetables and their nutrition in hydroponics* (Appendix 2). Other nutrient disorders of Asian vegetables, including deficiencies of phosphorus, calcium, magnesium, iron, zinc, boron, copper, sulphur and symptoms of fertiliser toxicity are also described in the guide.

N-30 **N-50** **N-100** **N-200** **N-300**

Figure 15. Bunches of 3 stems of en choy grown with 30 – 300 mg/L nitrate-nitrogen (photo by J. Ekman)

Figure 16. Kang kong grown with 30 – 300 mg/L nitrate-nitrogen (photo by J. Ekman)

5. Discussion

This project has made a major contribution to the understanding of the performance and management of leafy Asian vegetables, in terms of their nutritional requirements in commercial production. This includes demonstrating that the current methods used to manage lettuce in hydroponics are equally suitable for preventing the excessive uptake of nutrients, including nitrate, in leafy Asian vegetables. The following discusses and summarises this contribution.

5.1 Good management of the nutrition of leafy Asian vegetables is required for an efficient production system.

The experimental work of this project shows that excessive fertiliser rates can be used without any apparent negative affect on crop growth and quality of leafy Asian vegetables. Thus, it is easy to be inefficient in the production of these vegetables. This highlights the importance of nutrient monitoring as an invaluable tool in making the production system more efficient, more profitable and at less risk of nutritional disorder problems.

This project has successfully demonstrated ten types of leafy Asian vegetables in NFT using Huett's lettuce formula for the hydroponic nutrient solution. The vegetable types grown in NFT included Thai basil (variety Siam Queen), bunching onion, coriander, flowering choy sum, mustard cabbage, pak choy (varieties Sumo, Yangtze and Miyako), en choy and tat soi. The solution was used in an experiment to determine the target EC of the nutrient solution for each vegetable variety in NFT. The target EC can vary according to the crop being grown, stage of growth and climatic conditions. We grew the Asian vegetables 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 between 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. Managing the EC of the solution to these targets, is the simplest way to prevent excessive uptake of nutrients by the growing crop.

5.2 The nitrate concentration in shoots depends on the leafy variety grown and the amount of N fertiliser applied.

Varieties of leafy Asian vegetables differ in the nitrate concentration of their shoots when grown under the same fertiliser conditions. The varieties evaluated in this project can be separated into three groups based on their shoot nitrate concentration (Table 3). The experimental work has shown that the Brassicaceae varieties have the highest concentrations of nitrate compared with those from other plant families (Alliaceae, Amaranthaceae, Apiaceae and Lamiaceae). Even en choy, belonging to the same family as the known nitrate-accumulator silverbeet (Amaranthaceae), had a lower nitrate concentration range than the Brassicaceae varieties.

Table 3. Leafy vegetables in the experiment grouped by their nitrate concentration in shoots

Nitrate concentration range of vegetables (mg/kg dry weight)		
10,000-20,000	**20,000-30,000**	**30,000-40,000**
Choi sum Coriander En choy Basil Bunching onion	Pak choy Sumo Mustard cabbage	Pak choy Miyako Pak choy Yangkse Tat soi

The high nitrate concentration of Brassicaceae varieties does not reflect a higher requirement for nitrogen, simply that they store a high proportion of their total nitrogen content as nitrate. For example, en choy and pak choy have a similar sufficiency level of total nitrogen at about 4.8%, yet the corresponding nitrate concentration is about 10,000 mg/kg for en choy and about 15,000 mg/kg for pak choy (on a dry weight basis).

The uptake of nitrate beyond that required for marketable growth occurred in all three species chosen for further study of nitrogen nutrition. En choy, pak choy and coriander, representing three different plant families (Amaranthaceae, Brassicaceae and Apiaceae), increased their nitrate uptake in response to increased nitrate in solution. The implication of this for commercial nutrient management is that plant nitrate can be used to indicate if fertiliser supplies are inadequate, sufficient or excessive.

5.3 There is good potential for on-farm plant tests, as tools in the nutrient management of leafy Asian vegetables, but further work is required.

Investigation of N nutrition in some Asian vegetable varieties has shown that leaf petioles, usually used for monitoring of plant nitrate, are not always suitable. Monitoring the nitrate concentration of sap from petioles is a tool used in several vegetable crops including pumpkin, potato, lettuce, and capsicum (Huett and White, 1992a; Huett and White, 1992b; Olsen and Lyons, 1994; Studstill et al., 2003). However, this may only be a suitable tool for some leafy Asian vegetables.

The nitrate concentration of coriander petiole sap is sensitive to the nitrate supply in hydroponic solution which makes it a good candidate as an index tissue. However, for en choy, leaf petioles are very small and impractical to collect, so sap from the main stem (apex) was investigated as a potential index tissue for nitrate. In its favour, the concentration of nitrate in stem sap was sensitive to the nitrate supply in hydroponic solution. However, the sap is not easily extracted from fresh stems on-farm, without freezing and thawing the stems first. Fortunately, investigations showed that the freezing and thawing process does not affect the sap nitrate concentration, or the concentrations of potassium and phosphorus, two additional nutrients that could potentially be measured in sap using quick tests.

The sap of pak choy petioles is not at all sensitive to the supply of nitrate in the hydroponic solution. Unfortunately, this means it cannot provide any indication of the sufficiency of nitrate within the plant. Regardless of the concentration in solution, petiolar nitrate in pak choy was shown to be fairly static between 3000-4000 mg/L nitrate. This is in contrast to the large range of nitrate concentrations in coriander petiole sap (7000-11000 mg/L) and en choy stem sap (2000-10000 mg/L), when grown under the same conditions as pak choy. Determining a suitable plant part for sampling in pak choy will require further work.

Other research required to make nutrient monitoring simple to conduct on-farm includes evaluating the suitability of a number of portable instruments for measuring nutrients. This is necessary because nutrients other than the one targeted for measurement in the plant sap or hydroponic solution may interfere with the accuracy of the reading of these instruments. For example, this project has highlighted the suitability of some reactive test strips for nitrate measurements in hydroponic vegetable production, but also the potential interference by chloride and plant organic compounds in plant sap, when measuring nitrate with a portable ion-selective electrode (Milham and Parks, 2009).

5.4 Kang kong grows well in a still tank system which mitigates the potential escape of this species as a weed in natural water ways.

Kang Kong or water spinach, *Ipomoea aquatica*, is a vegetable used widely in Asian cuisine and is a major Asian vegetable grown in Australia. In the USA it is a noxious weed, and has become an established weed in several southern states. There is however a permit system in America for the legal growth and sale in some areas. In Australia, there are problems with this plant invading waterways in the Darwin area but this plant has not been declared noxious. In temperate areas, production of this plant is limited by in winter temperatures, frost prone areas and fungal diseases. However, undesirable hybridisation with Morning Glory, *Ipomoea purpurea*, could potentially lead to a plant, able to withstand temperate winters, with a similarly invasive nature as Morning Glory.

Hydroponic production permits the growth of this plant in a contained system limiting the risk to the natural waterways, and to hybridisation with other species. Production in NFT was tested in this project but it was unsuccessful due to the prolific growth of roots in the hydroponic channel, which impeded the flow of nutrient solution down the channels. However, hydroponic production of this species in a still tank was successful, and is ideal because it requires little maintenance, and can be isolated from areas where it can be a potential weed problem. It can also be produced in a greenhouse which is able to provide the conditions for a longer season, particularly in cooler areas. A modified Huett's lettuce solution, containing nitrate-N at 50 mg/L, was sufficient for growth without excessive uptake of nitrate by the plants.

5.5 Visual symptoms, although an indication of extreme nutrient disorders, are a poor guide to nutrient management of Asian leafy vegetables.

This project has provided a guide to some nutrient disorders in some leafy Asian vegetables. However, in conducting the trial work, the difficulty of using a visual diagnosis for nutrient disorders was highlighted. The response of enchoy, pak choy Sumo, pak choy Miyako and tatsoi plants to the elimination of nitrogen, phosphorus, potassium, sulphur, calcium, magnesium or iron from their nutrient supply were not always the same among the varieties evaluated. The responses common to these vegetables were severe stunting from nitrogen deficiency, and moderate stunting from phosphorus deficiency. This shows the importance of nitrogen and phosphorus in growth. However, symptoms of potassium deficiency, for example, were not consistent among the vegetable types, with only tatsoi exhibiting the typical symptoms of deficiency of scorching on old leaves. This serves as a reminder that the prevention of nutrient disorders, through monitoring and management of nutrients, is the best approach to obtaining high yields and high quality produce.

6. Technology Transfer

Several approaches have been used to facilitate technology transfer during this project (see Appendix):

- News articles
- The guide to Leafy Asian vegetables and their nutrition in hydroponics will be available on-line and as a booklet.
- Scientific paper submitted to The Journal of Plant Nutrition

Additionally, information from the project was provided at workshops:

- Australian Hydroponic and Greenhouse Association National Conference, 19-22 July, 2009, Sydney: Grower workshop on Asian vegetables in NFT, demonstration of nutrient analysis on-farm at conference field trip
- Leafy vegetables Think Tank, Adelaide, 30/11/2009
- Asian vegetables field day, National Centre for Greenhouse Horticulture, Gosford, 12/01/2011

7. Recommendations

This project has provided a greater understanding of the responses of leafy Asian vegetables to fertilisers, and of their nutrient requirements in production. The following recommendations are made to ensure that individual growers are able to efficiently manage the nutrition of their Asian vegetable crop, and that the industry, as a whole, strives towards greater efficiency in the use of nutrient resources in production.

7.1 Industry

The industry must prioritise creating greater awareness amongst growers of the benefit of improving the management of Asian vegetable nutrition, and of the tools available for achieving this. Current channels for extension will be suitable for this purpose.

7.2 Scientific

1. Through scientific research, the suitability of the ion-selective electrodes that are commercially available (including nitrate, potassium and sodium), must be fully evaluated for quick testing of nutrient concentrations in plant sap and hydroponic nutrient solution. This is necessary because nutrients other than the one targeted for measurement in sap or hydroponic solution may interfere with the accuracy of the reading.
2. This project has determined the nitrogen requirements for some leafy Asian vegetables, but also that the common approach of using leaf petioles for testing plant nitrate is not suitable for some vegetable types. Further investigation of plant parts for on-farm sampling is recommended to give growers access to a range of tools for nutrition management of these crops.
3. Future research should additionally focus on determining the critical requirements for nutrients at different stages of plant development. This will permit fertiliser management using a plant-based approach, suitable for both soil and hydroponic production systems.

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9. Appendix

News articles

Asian Foods Newsletter Issue 108, July/August 2008

Leafy Asian Vegetables in Nutrient Film Technique Hydroponics

A number of growers are adopting the hydroponic Nutrient Film Technique (NFT) for the production of Asian vegetables.

Research Trials of Pak Choy in a NFT System

In a hydroponic system all the nutrients required for plant growth are supplied to crop roots in a nutrient solution. In the NFT system the plants are supported in a gently sloping gully with the roots suspended in a flowing shallow stream of nutrient solution. After passing down the gully, the nutrient solution is collected in a tank and pumped back to the top of the gully to continuously recycle the nutrient solution.

Before constructing a hydroponic system it is wise do some research to ensure that the system works effectively and does not potentially limit plant production. The type of gully and the way it is installed is very important to the success of the system. If the gullies are not constructed correctly, reduced oxygen and nutrient levels can occur, particularly towards the end of the gullies, resulting in poor growth and a greater risk of disease. The gullies need to be large enough to support the root system of the crop, and constructed to provide a constant flow rate of solution down each gully. Pooling of the nutrient solution along the gully should be avoided. To maintain adequate aeration and nutrition along the gully, the length ideally should be less than 30 metres and the slope steep enough to allow a good flow rate of solution. As the gully length increases, a steeper slope is required. Other important features include a tank large enough for efficient management of the nutrient solution, appropriate pumps and a well designed system layout.

Currently we do not have good information available for ideal nutrient management of Asian vegetables in hydroponics. One aim for the new three year project *Nutrient Management of Leafy Asian Vegetables* is to provide guidelines on suitable nutrient recipes and nutrient management recommendations for leafy Asian vegetables growing in hydroponics. The work will determine the optimum yield and quality for a range of species. In doing this, recommendations will be developed to ensure that production takes place efficiently, without wasting costly nutrients, and to prevent undesirably high nitrate levels building up in the shoots.

Mizuna on Display in a NFT System

Some excellent advice on constructing NFT systems and their management can be found in the books: *Hydroponic Lettuce Production* (2007) by Dr Lynette Morgan, and *The ABC of NFT* (1996) by Dr Allen Cooper, both available through Casper Publications.

Article *Agriculture Today* August, 2009

Reduce nitrate uptake

ASIAN vegetables are being put on a weight loss program to improve their quality, extend their shelf life and reduce their growing costs.

Research at Gosford Horticultural Institute aims to reduce the nitrate concentration of a range of vegetables grown in Australia.

"There is not much information available about appropriate fertiliser strategies for Asian vegetables grown in soil or in hydroponics," Gosford plant physiologist, Dr Sophie Parks, said.

"We know that about half of the leafy Asian vegetables purchased in the market place have an undesirably high nitrate concentration.

"This is likely to be due to the naturally high uptake of nitrate by Brassica vegetables, to which most Asian leafy vegetables belong, combined with excessive use of fertilisers in the production of these vegetables.

"Excessive application of nitrogen fertilisers to horticultural crops is a demonstrated problem in Australia where high losses of nitrate have been recorded from market gardens."

NSW Department of Primary Industries is undertaking the project, with $215,000 funding from Horticulture Australia and Ausveg over three-years.

Dr Parks has begun work with several greenhouse trials of plants, feeding them various nitrate levels.

Not that you would know which is which, as the plants are still thriving regardless of which tucker mix they are receiving.

"Efficient nutrient management in the production of leafy Asian vegetables is important to minimise production costs, prevent nutrient runoff and to ensure that the produce is of a high quality," Dr Parks said.

"Excessive nutrients can reduce vegetable quality, for example, lower the vitamin C concentration and increase the risk of soft rots.

"Vegetable quality is also compromised as increasing application rates of nitrogen-content fertilisers can increase the incidence and severity of bacterial soft-rot."

The nutritional requirements for a range of species will be determined through experiments.

Consultation with commercial laboratories will also assist in the development of protocols for plant analysis.

"Protocols for simple on-farm leaf tests will be developed using existing nitrate tools on the market," she said.

Farmers and agronomists will be trained in simple test protocols and on interpreting test results to improve crop nutritional management.

"If we can reduce the amount of nitrate input we will end up with a healthier product at a cheaper cost to the grower," Dr Parks said.

Dr Parks said the European Community had limits on fresh nitrate concentrations in some leafy vegetables such as spinach and lettuce, but there were no limits yet in Australia.

"Food Standards Australia and New Zealand (FSANZ) will soon publish a dietary exposure assessment and risk characterisation of nitrate and nitrite in foods in Australia and this may affect the introduction of any regulations," Dr Parks said.

"Therefore the vegetable industry's action on nitrates in vegetables with this project is timely."

■ Contact Sophie Parks, Gosford, (02) 4348 1914.

Plant physiologist Dr Sophie Parks has begun work with several greenhouse trials at Gosford Horticultural Institute, aiming to reduce the nitrate concentration of a range of vegetables grown in Australia.

Article *Agriculture Today* October, 2009

On-farm rapid measuring nitrate in leafy vegetables

OPTIMISING nitrogen application in intensive vegetable production relies on being able to adjust N supply during crop growth, so monitoring needs to be quick, cheap, accurate.

Monitoring would best be done on-farm and three Industry and Investment NSW researchers are trialling a field test that uses the sap to measure N circulating in the plant.

The sap can be obtained using something as simple as a garlic press.

Whichever way nitrogen is applied, such as in urea or animal manures, plants take up most of the N as nitrate.

Excess nitrate can accumulate in leafy vegetable crops, a potential concern for human health, and now being recognised internationally as a negative food quality factor.

Other undesirable consequences include contamination of water bodies and the emission of greenhouse gas into the atmosphere.

This is driving farmers to optimise N inputs and minimise unwanted effects from excessive applications.

"Optimisation is not simple," said Dr Sophie Parks, a plant physiologist with Industry and Investment NSW, based at the Gosford Primary Industries Institute.

"Although the amount of nitrogen removed by a crop is readily calculated, the calculated amount is an underestimate of the amount of fertiliser needed to grow the crop."

"This discrepancy can be large, and occurs because various factors affect how efficiently the applied nitrogen is taken up."

Dr Parks and her colleagues, Donald Irving at Yanco and Paul Milham at Richmond, are focusing on the fact that the nitrate content of sap squeezed from leaf stems or leaves is a well established index of nitrogen supply.

The nitrate is readily measured in the laboratory, however the lab methods are unsuited for use on-farm.

The methods tested most widely to optimise N supply on-farm are ion-selective electrodes and test strips.

Reviewing available literature, the researchers found the most pertinent studies compared the results of measuring nitrate in the field using test strips and/or an ion-selective electrode with results obtained in the laboratory.

Test strips consistently gave accurate measurements, whereas ion-selective electrodes tended to give high results.

The difference between the results from the on-farm electrode and laboratory methods varied between studies and was large in some, possibly due to the effects of organics and chloride in the sap.

The researchers aim initially to quantify the interference by chloride and so increase the accuracy of the nitrate measurement.

■ Contact Sophie Parks, Gosford, (02) 4348 1914, sophie.parks@dpi.nsw.gov.au

Visiting the Gosford Primary Industries Institute from France, student, Marine Sanouiller, uses test strips with a reflectometer to measure nitrate from leafy vegetables in solution.

Australian Hydroponic and Greenhouse Association National Conference, 19-22 July, 2009, Sydney. Conference proceedings pages 108-111.

Improving nutrient management through using on-farm meters and interpreting nutrient analysis: Crop nutrition from the point of view of the plant Sophie Parks

Nutrient uptake by plants
In brief, nutrients arrive at the root surface driven by transpiration 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.

Plant management of plant nutrition
Achieving balance in water and nutrient uptake is a regulatory challenge for plants so they have developed strategies to manage their nutrition. For example, during rapid transpiration roots can fail to take up enough nutrients, particularly in a weak nutrient solution. In this situation water uptake is gradually restricted or nutrient influx rates increase or, where root reserves are sufficient, nutrients are released from reserves into the transpiration stream. Evidently the ability of plants to manage their situation is limited. For example, in a strong nutrient solution, damage to roots can occur when transpiration is so rapid that nutrients build up at the root surface causing water to move out of roots. This is known as ‘osmotic drought’.

People management of plant nutrition
Several strategies can help to efficiently manage crop nutrition in hydroponic systems. These include:

- Avoiding rapid changes in the nutrient solution

Hydroponic systems do not have the buffering capacity of soil systems and are more susceptible to rapid changes occurring in the root zone. It is important to be aware of the sensitivity of plants to changes in nutrient concentrations around roots and the resulting consequences. Phosphorus is used here as an example. Suppose the level of phosphorus is very low in a recirculating solution but then the solution is replaced with one having a high phosphorus level. The plant having being starved of phosphorus responds by increasing the influx of phosphorus, using energy dependent membrane transporters, into roots. For a short time (a few hours) phosphorus is moved rapidly into shoots until shoot levels are elevated. Because of the rapid movement of phosphorus into shoots the levels in the roots may not increase. As a result, feedback from the shoots to roots of the raised shoot levels can take several days. Phosphorus toxicity can result.

- Managing the nutrient solution for the conditions

Be aware of the climatic conditions and the effect that these will have on plants and their nutrition. If it is an unusually hot or windy day the crop will be focussed on water uptake. Give the crop a drink by lowering the EC. Under these conditions the crop has a higher requirement for water than nutrients, so doing nothing risks increasing the EC of the nutrient solution, and nutrient toxicity. Make sure too that you keep a record of weather conditions to help you monitor how your crop responds under a range of conditions.

- Monitoring crop and nutrient solution to guide solution modification or replacement

Certain nutrients are useful to monitor in either the hydroponic crop or in the nutrient solution including sodium, potassium and nitrate. This will assist in deciding when to modify or replace nutrient solution.

Sodium (Na) is important to monitor in the recirculating nutrient solution particularly for those dealing with poor quality water, and for a sensitive crop like lettuce, it should not be allowed to exceed 30 mg/L. Sodium is rapidly taken up by sensitive crops and is associated with a decline in potassium uptake. This is important considering that in recirculating systems potassium can drop to a level below that required for optimum growth. A few sodium meters are available on the market and range in cost. Nutrients other than sodium in the recirculating system may interfere with the accuracy of the reading. When buying a sodium meter, make sure you ask about this and the suitability of the instrument for hydroponics solutions. Go for the one with the greatest accuracy, that is, the one least likely to suffer from interfering ions.

Potassium (K) can be easily measured in plant sap. The guide for potassium in lettuce petiole (leaf stem or main vein) sap is approximately 700-1300 mg/L in young expanding leaves and 1900-2600 mg/L in mature leaves. This guide could also be used as the rough requirement for other leafy crops. Whilst potassium is maintained at these concentrations you can expect that the plant is growing optimally, assuming that all other nutrients are also at optimal levels. Potassium can be measured with an ion specific electrode meter or with colormetric test strips that are dipped into the sap extract and read by eye next to a colour scale or read quantitatively with a reflectometer instrument. The cheapest method is to use colormetric test strips and estimate the concentration with a colour scale. These are approximately $1 per test. Diluting the sap with distilled water might be required to bring the potassium concentration within the range of the test.

Accumulated nitrate in leafy vegetables is undesirable because it can reduce vegetable quality and it is a potential food safety issue. A high concentration of nitrate in lettuce reduces the concentration of vitamin C, and Chinese cabbages grown with an excessive nitrate supply are more likely to develop bacterial soft rots. In some regions, for example the EU, maximum limits on lettuce nitrate concentration have been imposed, partly due to the concern that there is an association between dietary nitrate and some cancers despite there being no demonstrated link between nitrate derived from vegetables and cancers. There are no such limits imposed in Australia but it is wise to try and prevent nitrate accumulation if only to increase vegetable quality and to save money on fertilisers. Guidelines for nitrate levels in lettuce petiole sap are shown in table 1.

Table 1. Guidelines for nitrate-N concentration in lettuce petiole sap (mg/L) (Huett and White, 1992)

	Weeks after transplanting					
Plant part	1	2	3	5	7	8
YFEL*	500	300	500	800	950	900
OL**	400	700	1600	1200	900	1000

*YFEL – youngest fully expanded leaf **OL-oldest green leaf

Guidelines for nitrate in lettuce are not appropriate for all leafy vegetables. Asian leafy vegetables in the Brassicaceae family appear to have a higher nitrate requirement. These requirements are being determined for a range of Asian leafy vegetables in the current Horticulture Australia Ltd project (VG07153): Nutrient management of leafy Asian vegetables.

General guidelines for plant sampling and analysis

A good guide to sampling and testing plant petioles for nutrient analysis produced by the University of Florida is available on the internet (Hochmuth 1994). Essentially you need to consider the following:

- Take samples in the morning and at the same time for every sampling occasion
- Avoid diseased or damaged plants
- Choose the correct index leaf or plant part for the vegetable you are testing. If you cannot find out any information on this use the petiole of the youngest fully expanded leaf otherwise known as the most recently matured leaf
- Pick enough samples to represent the crop, and enough for a sap test (about 3 millilitres). You can pick 20 per hectare as a rough guide
- Keep the petiole samples cool and measure them as soon as possible (within a few hours). Alternatively you can freeze the petioles overnight before measuring. Do not wash petioles; simply wipe them with paper towel if needed.
- Conduct measurements at room temperature. Samples must also be at room temperature and measured immediately after extracting sap with a garlic press or similar instrument. Ensure the measuring equipment is used in the conditions as recommended by the manufacturer.
- Be aware of nitrate units. Nitrate, (NO_3^-), and nitrate-N, (NO_3-N) are both used and you may need to convert from one to the other. For example, if you have measured *nitrate* (NO_3^-) in sap using test strips but you are looking up guidelines for your crop which are expressed as nitrate-N then you need to divide your result by 4.43 to find the nitrate-N value.

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A critical evaluation of on-farm rapid tests for measuring nitrate in leafy vegetables

Paul Milham and Sophie Parks, NSW Department of Primary Industries

A source of nitrogen that is readily taken up by plants is necessary for intensive vegetable production. The nitrogen (N) can be applied in various forms, such as urea or animal manures, but whatever the chemical form, plants take up most of the N as nitrate. An excess supply of nitrate does not usually affect crop production or health; however, it has undesirable consequences which include contamination of water bodies and the atmosphere. In addition, excess nitrate can accumulate in the leaves, which is a concern for human health.

Internationally, excess nitrate in leafy vegetables is being recognised as a negative food quality factor. This recognition is driving a trend for farmers to optimise N inputs to satisfy crop needs and minimise the unwanted effects associated with excessive applications. Optimisation is not simple, because although the amount of N removed by a crop is readily calculated, the calculated amount is an underestimate of the amount of fertiliser N needed to grow the crop. This discrepancy can be large, and occurs because various factors affect how efficiently the applied N is taken up. Consequently, optimising the N application relies on being able to monitor and adjust the N supply during crop growth. For this purpose, this monitoring needs to be quick, cheap and effective. In addition, the monitoring would best be done on-farm.

NSW DPI researchers Sophie Parks, Donald E. Irving and Paul J. Milham are reviewing the literature on potential methods of on-farm monitoring of nitrate in leafy vegetables. This is the first step towards optimising N fertiliser use in intensive vegetable production.

The nitrate content of sap squeezed from leaf stems or leaves is well established as an index of N supply to vegetables. The sap can be obtained using something as simple as a garlic press. The nitrate is readily measured in the laboratory; however, the laboratory methods are unsuited for use on-farm. The methods tested most widely to optimise N-supply on-farm are ion-selective electrodes and test strips.

There is information in the scientific literature on the use of ion-selective electrodes and test strips for the estimation of nitrate in plant sap. For this review, the most pertinent studies were those that compared the results of measuring nitrate in the field using test strips and/or an ion-selective electrode with results obtained in the laboratory using "standard" methods. These studies indicate that the test strips consistently give accurate measurements, whereas ion-selective electrodes tend to give high results. The difference between the results from the electrode and the "standard" laboratory methods varied between studies and was large in some studies, possibly due to the effects of organics and chloride in the sap.

As a result of this review the authors are themselves interested in evaluating the performance of an on-farm model of the ion-selective electrode. They aim initially to quantify the potential interference by chloride with the accuracy of the nitrate measurement. Future work may also lead to a suitable buffer solution that could be combined with samples to allow users to easily and accurately test plant sap for nitrate.

For more information contact:
Sophie Parks
NSW Department of Primary Industries
sophie.parks@dpi.nsw.gov.au

Abstract of paper submitted to The Journal of Plant Nutrition

Sap nitrate in frozen-thawed and refrigerated stems of *Amaranthus tricolor* is indicative of nitrogen fertilizer supply

S. E. Parks and L. J. Spohr

Gosford Primary Industries Institute, Industry and Investment NSW, Gosford, NSW, Australia.

Address correspondence to: S. E. Parks, Gosford Primary Industries Institute, Industry and Investment NSW, Gosford, NSW 2250, Australia. E-mail: sophie.parks@industry.nsw.gov.au

Amaranthus tricolor is a potential accumulator of nitrate but nutrient sufficiency guidelines have not been developed for this vegetable. We investigated whether the shoot stem of *A. tricolor* is a suitable index for crop nitrate status, and whether freezing the stem, which aids sap extraction, would render it unsuitable for the analysis of nitrate and other nutrients. We grew *A. tricolor* at two nitrate rates (100 and 200 mg/L N) and established that sap nitrate from both fresh and frozen-thawed stems did not differ but was significantly increased by additional nitrate fertilizer. Shoot growth was correspondingly higher with additional nitrate. Therefore, the stem is a suitable index for crop nitrate. B, Ca, Fe, Mg, Mn, Mo, Na and S were significantly affected by frozen storage but K, P and Zn were not. A single sufficiency guideline is possible for these nutrients, for use with both fresh and frozen-thawed stem sap.

Grower guidelines – excerpt

LEAFY ASIAN VEGETABLES AND THEIR NUTRITION IN HYDROPONICS

Dr Sophie Parks (Research Horticulturist)
Ms Carly Murray (Technical Officer)
Gosford Primary Industries Institute

NSW GOVERNMENT Industry & Investment

AUSVEG HAL Know-how for Horticulture™ Australian Government Australian Centre for International Agricultural Research

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, or have solution analysed by a laboratory, and 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, or have solution analysed by a laboratory, and replace or modify solution if needed.
Nutrient solution strength is too low.	Increase solution strength (EC) or replace solution more frequently.

Figure 1. Potassium deficiency in tat soi. Scorching of old leaves at the edges and between leaf veins.