Pesticide Residues in Hydroponic Lettuce

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FINAL REPORT

Review of pesticide residues in hydroponic lettuce

HAL Project VG07165

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HAL VG 07165

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The purpose of this project was to conduct a review of hydroponic systems and the practices associated with these in the production of hydroponic lettuce in Australia.

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MEDIA SUMMARY

In response to consumer preferences for clean produce, market specifications for hydroponic lettuce describe a product that is free from pests, pest damage and disease symptoms. Growers are able to use pesticides to reduce pests and diseases but for hydroponic lettuce in particular pesticide residues have been found to exceed the maximum residue limit (MRL) more frequently than for other targeted products. The reasons for this are not fully understood. In order to evaluate how hydroponic systems and associated practices might affect residues in lettuce, a current description of these systems and crop management practices is needed. Information for this purpose was gathered from literature (industry and scientific reports) and from interviews with growers and others associated with the industry.

Hydroponic lettuce production systems differ in comparison to other hydroponic production systems used in protected cropping. Most hydroponic lettuce systems are placed outdoors with about half having hail netting supported above the crop. Another key characteristic of hydroponic lettuce systems is the use of nutrient film technique (NFT). In this type of system nutrient solution is supplied from a tank to sloping channels supporting the growing plants. The solution flows in a thin film down the channel feeding roots and returns to the tank to continually recirculate through the system. The set up can vary considerably from farm to farm for example, in the number of channels and plants that are supplied by a typical 5000L nutrient tank.

A positive finding of the review is that there is strong evidence that this industry is reducing its reliance on pesticides for the control of key pests and diseases. A pesticide residue survey conducted over the previous three years has shown that the number of pesticide detections in hydroponic lettuce has halved in this time, reflecting a considerable reduction in use of pesticides. There is also a strong emphasis on integrated pest management (IPM), which reduces pesticide use, with about 20% of growers employing IPM. This includes for example, using sticky traps to monitor insect pests to ensure that pesticides are applied only when necessary. However, calendar spraying is still in use for a third of the industry so addressing this issue through current education and extension programs must continue.

This review has identified that because hydroponic lettuce systems are different to field based systems, pesticides may also move differently through these systems. Generating pesticide data using the hydroponic lettuce situation is one way of producing appropriate pesticide use patterns, and recently such work has commenced. However, this does not address the question of how pesticides move in a hydroponic lettuce system or for how long they persist. It is a key recommendation of this review that understanding the fate of pesticides through research is likely to lead to recommendations for growers that assist in eliminating residues from hydroponic lettuce systems.

TECHNICAL SUMMARY

Pesticide residues are a concern for the hydroponic lettuce industry. Recent results of the residue testing program Cleanfresh, based at the Sydney markets, highlight that pesticide residues in hydroponic lettuce exceed maximum residue limits (MRL) more frequently than the other three vegetables monitored in the survey (cucumber, buk choy and silverbeet). However, this pesticide survey also demonstrates that the industry is actively addressing this problem. Within the three year period of the survey, the number of detections of residues occurring in hydroponic lettuce halved, and violations were reduced, reflecting a strong trend of reduced use of pesticides by growers. The strong commitment of the industry to reducing pesticide use is also evidenced by the number of projects supported by the industry that address pesticide issues.

This review highlights that hydroponic lettuce systems can be described differently to other hydroponic production systems used in protected cropping such as those used for the greenhouse crops cucumber and tomato. Unlike these greenhouse crops, hydroponic lettuce is mostly produced outdoors with about half of these systems having hail netting installed above the crop. Some growers also use shade cloth. A key feature of these systems is the use of nutrient film technique (NFT), in contrast to the run-to-waste and media based systems often used for greenhouse crops. NFT is a system where recirculated nutrient solution is supplied from a holding tank to gently sloping PVC channels in which plant roots are supported, with about 4-8 channels grouped together on raised benches above the ground. Five thousand litre tanks are commonly used and this will supply about 30 benches of between 8-24 m long with planting holes at a distance of 15-30 cm. The number of plants supplied by one tank of this size can vary considerably from farm to farm. The more sophisticated systems have automated control of the nutrient solution concentration (electrical conductivity) and pH, and the use of water treatment in production with ozone, reverse osmosis, activated carbon filtration, iodine, hydrogen peroxide or flocking agents. Other features of more modern systems include a ground surface that minimises weed growth and uniformity in the type and length of channels used across the production area. Growers with these types of systems have generally larger than average production areas and high levels of management in regards to production, site cleanliness and pest and disease management.

The hydroponic lettuce industry is largest in NSW and Queensland with small numbers of growers in other states. The average area of production on each farm appears to have increased from about 0.8 ha in 1996 to 1.5 ha today, although verifying industry figures was outside the scope of this study. Leafy types of lettuce are mostly grown, and other leafy vegetables such as Asian vegetables and herbs are increasingly being produced using the hydroponic lettuce system. There is a trend of growers crossing over from field production systems to hydroponic systems.

The key pests for growers in the survey were thrips, especially western flower thrips (WFT) *Frankliniella occidentalis*, Rutherglen bug *Nysius vinitor*, currant lettuce aphid (CLA) *Nasonovia ribisnigri*, and the key diseases were the root diseases *Phytophthora* spp. and *Pythium* spp. Although the uptake of integrated pest management (IPM) practices by approximately 20% of the industry is encouraging, some outdated practices such as calendar spraying, used by a third of the industry, do not minimise pesticide use. Programs currently in place in education and training need to continue to focus on reducing such practices. What remains unclear, and is not yet being addressed, is the potential impact of the hydroponic lettuce system and its components on residues in produce growing in that system. For example, we do not know the potential for contamination of the nutrient solution with pesticide following a spray application to the crop. Persistence of pesticide in nutrient solution would potentially create problems of pesticide uptake by plants via the root system and pest and disease resistance to pesticides.

Issues concerning pesticide residues in hydroponic lettuce can be addressed using several approaches. Some issues, including access to pesticides and pesticide alternatives, and the reduction of pest and disease pressure, are already being addressed and it is recommended that these efforts continue. However, a current gap in information on the movement of pesticides in hydroponic lettuces systems exists, and therefore it is a *key recommendation* that this particular issue be addressed. In addition to looking at the movement of pesticides within growing systems, it is important to identify the practices that increase the risk of nutrient solution becoming contaminated with pesticides, to assess the risks associated with mixing the ages and types of lettuce on benches serviced by the same nutrient tank, and to evaluate calibration and spray coverage control of mistblowers and backpack sprayers for hydroponic lettuce production situations.

INTRODUCTION

Market specifications for hydroponic lettuce describe a product that is free from pests, pest damage and disease symptoms. Specifications described by some customers have an almost “zero tolerance” for these defects. This has created an industry environment where pest and disease management is viewed as a critical priority for growers. As such, chemical sprays are considered an essential management tool for the production of high quality hydroponic lettuce in these intensive and continuous monoculture cropping systems in Australia.

Anecdotal evidence suggests that pesticide residues persist longer in hydroponic lettuce systems. A case study, conducted as part of a 2 year scoping study looking at the persistence of pesticides in hydroponic lettuce (Parks and Badgery-Parker, 2005), investigated lettuce from a commercial and experimental hydroponic system and demonstrated that methomyl residues greater than the MRL can occur in lettuce, well after the minimum withholding period.

A report published by the Rural Industries Research and Development Corporation (RIRDC) in 2001 touched upon the issue of chemical use in hydroponic lettuce. The report stated that the Australian hydroponics industry is highly concerned with chemical minimisation. Hydroponic growing systems were also described as facilitating “the adoption of IPM and a reduction in agricultural chemical use” and that Australian hydroponic producers should be “well placed strategically to respond to consumer concerns regarding pesticide use”. In 2008, the hydroponic lettuce industry maintains the commitment to minimising both chemical use and the risk of pesticide residues exceeding prescribed MRLs. However, it will be difficult to provide long-term strategies to achieve this objective unless the movement and persistence of pesticides within hydroponic systems and produce is fully understood.

There is little hard evidence available in the scientific literature regarding pesticide uptake and/or persistence in hydroponic production systems. This may be, in part, due to the rapid development of the hydroponic industry in recent years and little awareness or assessment of the new risks these growing systems may carry. To identify how pesticide persistence and degradation may be affected by the type of growing system, studies are required to compare pesticide fate in field growing systems (which is well understood), and hydroponic growing systems (not well understood). Factors that potentially impact on pesticide persistence in field and hydroponic lettuce production are shown in Figure 1. This shows that the dissipation and degradation of pesticides is potentially limited by the hydroponic system and may persist for longer in comparison to the field system.

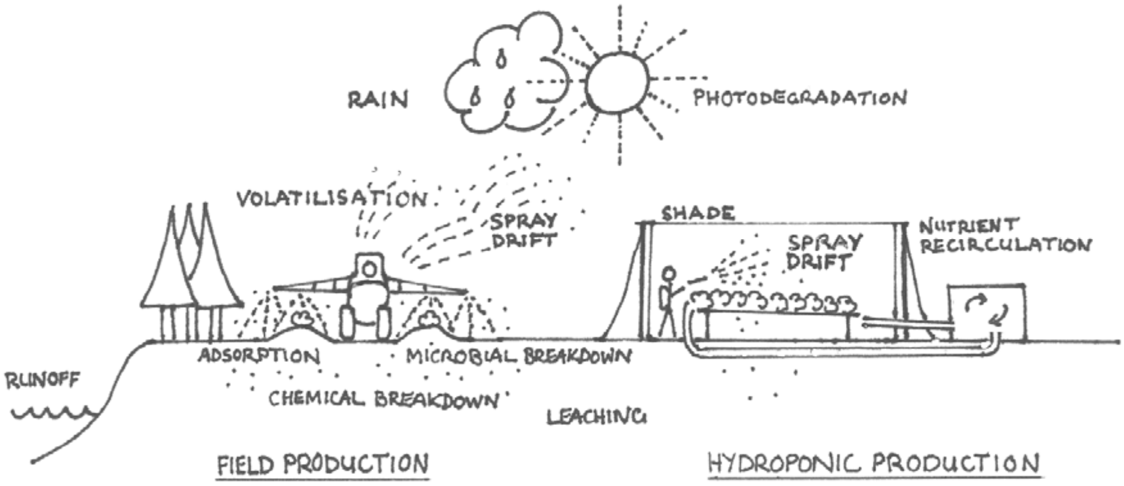

Figure 1. Factors that potentially impact on pesticide persistence in field and hydroponic lettuce production

Potential impacts on pesticide residues in hydroponic lettuce

1. Spray equipment

Pesticides are usually applied to field crops using boom sprayers, which are very accurate and efficient when used correctly. Due to the physical specifications of some hydroponic growing systems, the use of boom sprayers for pesticide application may not be as common as the use of other types of spray equipment that are not as accurate or efficient in their spray delivery. Generally, the closer that sprays are applied to ground level, the less spray drift can be expected. Stronger air currents at the height of hydroponic lettuce benches may increase the risk of spray drift. Inaccurate spray delivery, either as spray drift or over-application, may increase the risk of pesticide residues exceeding MRLs in hydroponically-grown lettuce.

2. Media (soil vs water)

In field-grown crops, pesticide run-off is deposited on soil between the plants. Pesticide degradation occurs at a rate determined by the individual chemical properties of each pesticide, but pesticides can be degraded more rapidly by naturally-occurring microorganisms found in soils. Exposure of pesticides to sunlight and heat can also increase the rate of degradation of pesticides present on the soil surface and pesticides can be leached from the soil by water, removing them from the crop's root-zone. These processes do not occur in hydroponic systems.

In hydroponic growing systems, pesticide run-off may potentially accumulate in re-circulated nutrient solutions, either by the pesticide spray entering solution through uncovered planting holes or run-off from sprayed leaves into the channels. Recently published studies have demonstrated that some pesticides are very persistent in re-circulating nutrient solutions and that pesticide residues in plants growing in pesticide-contaminated nutrient solutions can reach their maximum days after the initial application (Patakioutas *et al.*, 2007; Karras *et al.*, 2007a). Multiple applications of a spray to a single crop, especially if the pesticide has a short withholding period (WHP), could also lead to an accumulation of pesticides in nutrient solutions. However, some pesticides are not taken up by plant roots, and in these cases contamination of the nutrient solution is not a contributing factor to pesticide residues occurring in plants.

Research indicates that a proportion of applied pesticides may also be adsorbed to soil or dust on the plant surface, thereby reducing the amount of pesticide taken up through the leaves (Cabras *et al*., 1997; Krol *et al*., 2000). In general, plants grown in hydroponic production systems are raised off the ground and therefore are less exposed to soil or dust than plants grown in field production systems. Perhaps this situation permits higher exposure to pesticides, resulting in higher residues than would normally occur in field-grown plants.

3. Volatisation, photodegradation and wash-off

Some pesticides are readily degraded by volatilisation (passing off as vapour) and/or photodegradation (breakdown after exposure to sunlight), and rainfall or overhead watering systems can wash pesticides from the plants. Carbaryl residues in field-grown pak choy, for example, were higher in plants that had been covered compared to uncovered plants (Marutani and Edirveerasingam, 2003) and higher in plants exposed to basal irrigation compared to plants exposed to overhead irrigation (Marutani and Edirveerasingam, 2006). Similarly, Cabras *et al.* (1988) reported data that indicated pesticide residues on the outer leaves of field-grown crisphead and cos may be higher in plants irrigated with drippers than in plants irrigated with sprayers. The penetration of heat, solar and light radiation, and rainfall is not impeded in field-grown crops, but the presence of protected cropping structures used either for shading or other purposes (e.g shade cloth) in hydroponically-grown crops may slow the degradation of pesticides. In addition, recirculating nutrient solutions are distributed through tanks, pipes and channels, and are thereby mostly protected from sunlight and may not reach temperatures high enough to cause volatilisation of pesticides.

4. Lettuce types and varieties

Field-grown lettuce are predominately head-forming types such as *iceberg* or *cos* (romaine), whereas “fancy” or open head lettuce are more commonly grown in hydroponic systems. Ripley *et al.* (2003) reported that when pesticides were applied to a range of lettuce types with different leaf and head morphologies that the levels of pesticide residues varied. Generally, pesticide residues were highest in leafy (“fancy”) lettuce types, followed by endive, butterhead and cos types, and lowest in head lettuce types. This pattern follows the “openness” of the head and is probably a result of spray contact (pesticides contacting all leaves vs wrapper leaves only) and the ensuing dilution factors based on the surface area to volume ratio. These results also explain those of Sances *et al.* (1992), who found that most pesticide residues could be removed from head lettuce by the removal of the wrapper leaves.

5. Withholding periods and application rates

Few pesticide labels differentiate between application rates or WHPs for field-grown or hydroponically-grown lettuce and none show different application rates for different types of lettuce reflecting limited data generated for pesticide permits and registrations. Current application rates and WHPs for pesticides have been determined based on field-grown crops, and most field-grown lettuce are head or cos types. Applying the same rate of a pesticide to a field-grown crop and a hydroponically-grown crop could result in different levels of residues on a per plant basis. Further, hydroponic lettuce systems can contain plants that differ in stage of maturity or size and this may impact on residues when plants are sprayed at one rate of application.

6. Farm and crop management

Management strategies for pest and disease impact on pest and disease pressure and thus the need to use pesticides. This is relevant to all types of production systems and hydroponic production systems are no exception. For example, research clearly shows that poor farm and crop hygiene are strongly correlated with increased disease in hydroponic lettuce (Tesoriero, 2008). Consequently, the greater need to use pesticides increases the risk of residues occurring.

7. Season

Pest and disease pressure is seasonal with problems generally increasing with warmer temperatures. Root rot diseases increase in hydroponic lettuce with increased nutrient solution temperatures associated with warm weather (Tesoriero, 2008). Similarly, pest populations increase as temperatures increase in spring and summer and it is likely that the use of pesticides potentially increases at this time of year increasing the risk of residues occurring.

8. Pesticide properties

All pesticides are different in their chemical structure and carrier formulations. The structure and formulation will determine their behaviour with respect to water solubility, persistence, and their uptake and movement within the hydroponic system or the plant. These factors are important when considering whether residues can potentially accumulate in nutrient solutions or be taken up by the plant in high concentrations.

9. Plant properties

Pesticides that enter via the root system are more likely to accumulate in leaves compared with other plant parts. Karras *et al.* (2007b) showed that residues of metalaxyl accumulated in leaves more so than in flowers of gerbera and this was associated with the greater leaf stomatal density and higher transpiration rates of leaves. In the production scenario where pesticides are contaminating the hydroponic nutrient solution, leafy crops such as lettuce would be at risk of developing residues as a result of plant uptake through roots because the leaves are the edible part of the plant.

AIMS AND OBJECTIVES OF THE STUDY

The behaviour of pesticide residues in hydroponic lettuce growing systems may first be approached through a good understanding of the systems currently in use for production and the common management techniques being used by hydroponic lettuce growers.

The project aim was to assess information from people involved in various aspects of the hydroponic lettuce industry in Australia regarding the specifications of hydroponic systems currently used and the management practices of Australian hydroponic lettuce growers, particularly in relation to pesticide use and pesticide residue risk. This report will identify risk factors that may contribute to increased pesticide residues in hydroponic lettuce and summarise the industry as it stands in 2008. As a result of the review recommendations for reducing the risk of pesticides exceeding the maximum residue limit in hydroponic lettuce may also be revised.

SURVEY

SURVEY METHODOLOGY

Information was gathered from people involved with the hydroponic lettuce industry. Details of the project were announced at a number of grower workshops and field days, and some growers were directly recruited at these workshops to interview for the project. Workshops/field days included the Lettuce Field Day, Richmond, NSW, 28 November 2007, Hydroponic lettuce growers' meeting, Vineyard, NSW, 4 March, 2008, Seminis Fancy Lettuce Field Day, Vineyard, NSW, 7 March, 2008, the Chinese Growers Picnic Day, held at Gosford Horticultural Institute, 8 June 2008. A media article was placed in the Lettuce Leaf to promote awareness of the project and to seek participants for interview (Appendix 1). Participants were either:

- interviewed by means of a survey (Appendix 1); and/or
- volunteered relevant information pertinent to their role in the industry
- asked to comment on and contribute to draft reports.

Participants included growers, vegetable industry representatives, consultants, extension officers, research officers, education officers and regulatory agencies. Efforts were made to include input from participants in all states, although the information presented in this report was largely obtained from NSW, QLD, VIC and SA reflecting the presence and size of the hydroponic lettuce industries in these states Additional information was collected from current and recently completed projects in the area of hydroponic lettuce research.

RESULTS OF THE SURVEY

The results are presented in three sections:

1) Summary of grower interviews
2) Overview of hydroponic lettuce production systems and management
3) Key components of hydroponic lettuce systems and management

Summary of grower interviews

Fifteen growers agreed to be interviewed. They were asked a range of questions concerning the hydroponic systems that they used and questions on how they managed their crops in these systems with respect to pests and diseases (Appendix 1). The summary of systems used by these particular growers is shown in Table 1 and the summary of their management practices is shown in Table 2. Comments on these are provided in the following sections.

Table 1. A summary of the systems used by 15 growers interviewed in the survey. Note that the figures represent a small number of growers and may not reflect the industry generally. *Not all questions were answered by all respondents

Information on NFT growing systems	**Response***
Area under production	0.25 ha- 3.64 ha
Crops grown in addition to lettuce	60% respondents also grow Asian greens, herbs, spinach or rocket
System outdoors or semi-enclosed	87% outdoors, 13% semi-enclosed
Hail netting used	60% to at least part of farm
Ground covering under benches	80% soil, others: shale, plastic, road base, cement
Channel material	Predominately PVC
Channel shape and cross section dimensions	40% rectangular 100 x 50 mm, 20% semicircular 100 mm capped, others use a combination
Channel length	Varies from 8 m to 24 m, 20% used two lengths
Channel slope	Generally between 1-2^{o}
Nutrient tank size	67% 5,000 L, 20% 8,000-20,000 L
Number of tanks per farm	Varies from 1-14
Number of channels per bench	Generally between 4-8
Bench number per tank	28-35 mostly, 60-80 for 1 farm
Distance between plant holes	150 mm - 300 mm
Nutrition solution flow rate	1-2 L / min
Water treatment	47% of farms treat water including use of activated carbon filtration, flocking agents, iodine, reverse osmosis, hydrogen peroxide, ozone
Control of EC and pH	60% manual, 33% automatic, 7% no control

Table 2. A summary of some of the practices used by 15 growers interviewed in the survey. Note that the figures represent a small number of growers and may not reflect the industry generally. *Not all questions were answered by all respondents

Information on practices	**Response***
Dumping frequency of nutrient solution	30% never, 30% every 4 months or more, 15% less than every 4 months, 15% after every crop
Reasons for dumping nutrient solution	50% tipburn or disease, 30% system cleaning, 20% salinity
Frequency of cleaning systems	50% between crops, 20% between crops in summer only, 13% not undertaken, 17% other.
Those that use chlorine for cleaning	80%
Time the system is down between crops	27% less than 1 week, 20% 1 week, 20% more than 2 weeks, 20% more in summer, 13% never down
Those with plants of different ages supplied by same tank	60%
Those with plant holes left uncovered due to removal of plants	87%
Those that add fungicides to nutrient solution	33%
Those that calendar spray	27%
Equipment used	Boom (30%), blower (20%), backpack (15%), hand gun and tank, turbo mister, lance spray, fogger
Major pest and disease pressures	Thrips (80%), currant lettuce aphid (20%), rutherglen bug, (20%), diseases (20%) including pythium, fusarium, rhizoctonia, phytopthora, mildew, others including caterpillar, heliothis, fungus gnats
IPM tools used	NAS resistant varieties (26%), beneficials (13%), sticky traps for monitoring 1 grower

Overview of hydroponic lettuce production systems and management

1. Industry profile

Australia, with more than 240 ha under cultivation, is recognised as the largest hydroponic lettuce producer in the world (Rural Industries Research & Development Corporation, 2001). The increase in numbers of growers and areas under production between 1990 and 1996 serve to demonstrate the rapid rate of growth of the hydroponic lettuce industry in Australia (Table 3) and is one of the key reasons why there is a lack of knowledge regarding the fate of pesticides in hydroponic systems.

Table 3. Number of producers of hydroponic lettuce and total area of production in 1990 and 1996 (Rural Industries Research & Development Corporation, 2001).

	Number of growers		**Area (ha)**	
State	**1990**	**1996**	**1990**	**1996**
NSW	97	147	47.5	112.5
VIC	10	40	2.5	30.6
QLD	30	100	20.0	76.5
WA	2	15	0.4	11.5
TAS	N/A	5	N/A	3.8
SA	1	9	0.2	6.9
TOTAL	**140**	**316**	**70.6**	**241.8**

In 2008, based on anecdotal comments provided by industry representatives, the relative sizes of the hydroponic lettuce industries in each state appears to have remained similarly proportioned. A large number of hydroponic lettuce growers are in NSW, with smaller numbers of growers in Queensland, Victoria, WA, Tasmania and SA. However, verifying the actual numbers of growers and area under production was outside the scope of this report.

Hydroponic lettuce is commonly grown in peri-urban areas because of the close proximity to markets and this is reflected in the location of production areas in all states. NSW hydroponic lettuce is predominantly grown in the Sydney region (west and south-west suburbs), Central Coast and North Coast regions. Production areas in other states include South-East Queensland, the Werribee district west of Melbourne (Victoria), and the Virginia and North Adelaide Plains districts of Adelaide (SA).

The area under production on individual farms for growers interviewed in the survey ranges between 0.25-3.6 hectares, with the average farm having 1.5 ha of production area. Production areas in states other than NSW and QLD are often smaller. Hydroponic lettuce is not commonly grown in WA because the sandy soils in the south-west allow for successful cultivation of clean fancy lettuces in conventional field cropping systems.

Most hydroponic lettuce growers do not grow other crops, but those that do are growing hydroponic Asian vegetables or herbs. A few growers have greenhouses for tomato or cucumber production. The land neighbouring most hydroponic lettuce farms in all growing areas is residential or semi-rural land, often being used for vegetable production. Some properties are adjacent to bushland or vacant blocks. All properties have some road frontage, which may be weedy depending on how often councils slash roadsides.

2. Production systems

Nutrient film technique (NFT) is the only system being used for lettuce production and all systems use recirculating nutrient solutions as opposed to run-to-waste systems. Ebb-and-flow or overhead irrigation is more common for nursery stock. There is some evidence that a limited number of very small-scale producers are growing lettuce in boxes of soilless media (e.g. sawdust, vermiculite), using a run-to-waste system.

Hydroponic lettuce is generally grown outdoors as opposed to enclosed greenhouses or shade houses. Greater than half of the growers in the Sydney region have hail netting covering their crop and some have shade houses for the cultivation of seedling stock. No temperature or ventilation controls are typically installed, apart from the ability to roll up the ends to allow more air flow. Some growers in the southern states (SA and Victoria) grow their lettuce in plastic greenhouses or in shade houses, but this is generally because the greenhouses are pre-existing from another type of crop that they have grown in the past. These are usually low-tech without temperature or ventilation controls.

Growing benches are usually positioned on bare soil or on ground covered with either gravel or crushed roof tiles. While some growers strive to control weeds under and around benches using herbicides, growers tend to be less vigilant and these areas can become quite weedy, particularly if there are leaks in the system. Benches are generally comprised of four to eight channels (some up to 11 channels for seedlings or cut-salad production) constructed of PVC. Some older channels may be constructed from metal guttering with plastic covers. Some growers use lead-free, food-grade PVC for the construction of their channels, but this is not a technical requirement. Good Agricultural Practice guidelines specify that materials used for food production or processing be non-toxic and constructed to enable adequate cleaning and maintenance (Department of Agriculture Fisheries and Forestry, 2004).

Channels are 10-15 cm wide, usually with rectangular bases, though some may be semi-circular (PVC pipe halved lengthways). Open topped channels are fitted with plastic or rubber covers, and single-piece channels are either purpose-made, or constructed from PVC pipe with plant-holes drilled into the top. Channel lengths range from 8-24 m long, with plant-hole spacings of 25-30 cm. The planting holes themselves are usually 5cm in diameter. Channels used for seedlings have smaller plant-holes spaced at around 15 cm. The channels are erected on a marginal slope (about 1-2°) to allow nutrient flow back into the recirculation tank.

3. Water and nutrient solution management

The national industry food safety publication, Guidelines for On-Farm Food Safety for Fresh Produce (DAFF, 2004), provides specific recommendations in relation to water used in hydroponics. It recommends that NFT systems should use town water or a water sanitation treatment be introduced to ensure high quality water is used at the start and maintained for the life of the nutrient solution.

From the information sourced in this project, most growers use a town water supply for their systems. Those that use bore water, irrigation water or dam water apply a range of treatments, including:

- flocculation
- charcoal/sand filtration
- chlorination
- reverse osmosis

Depending on the size of the operation, the pH and EC of the nutrient solution is monitored manually by either the grower or a contractor, or controlled by automatic monitoring systems.

Temperature of the nutrient solutions is monitored by some growers during hot weather (particularly larger-scale growers), as temperatures in excess of 30°C are conducive to the growth of fungal organisms that cause root disease. This is not widespread practice as the cooling of nutrient solutions is logistically difficult and expensive. In systems based on high-tech equipment, nutrient solutions may be cooled by evaporative cooling towers. The problem of root diseases is treated mostly through the use of fungicides or sanitisers, rather than temperature control of solutions. Some producers in frost-prone areas (again, usually larger producers with high-tech systems) may heat their nutrient solutions during winter. As with cooling of solutions, this is expensive because of the high rate of heat transfer from the hydroponic system.

Nutrient tanks contain thousands of litres (4000-10000 L; average 8000 L) and each tank can supply any number of benches. In the survey, between 28 and 35 benches are usually supplied from each tank, but in other areas, the tanks may supply between 60 and 80 benches. In some particular cases, entire operations (in excess of 100 benches) are run off a single nutrient tank (example farm not included in the survey). The number of tanks varies per hectare and the topography of the growing area will affect how many tanks are needed.

There are advantages and disadvantages in running multiple tanks. Advantages include "spreading the risk", or ensuring that if there is a system failure or if the system needs to be stopped for any reason, that not all crops are at risk. Multiple tanks also allow better management of crop rotations, nutrient dumps and system maintenance and cleaning. Disadvantages include the maintenance of multiple solutions (nutrient, pH, EC) and higher equipment and capital costs.

The frequency with which nutrient solutions are replaced varies significantly between growers. It may range from fortnightly, monthly, between crop rotations to never. The reasons for nutrient dumps are generally the presence (or risk) of *Phytophthora* spp. or *Pythium* spp., which cause root diseases. Other reasons include nutrient imbalances, high sodium levels, pH problems and, to a lesser extent, to reduce the risk of residues. Some growers turn off water circulation at night or run an on/off circulation to save on electricity costs, but this practice is becoming less common since it has been linked with higher incidences of root disease.

Approximately 50% of growers clean their systems (including channels and tanks) between plantings, using either high-pressure water cleaners or a detergent/chlorine solution. This is more commonplace in summer, when the threat of root diseases is higher. Some growers with high-tech systems clean the entire system with iodine (2-3 ppm), then flush with water to ensure no iodine remains in the system (iodine can be phytotoxic), before renewing nutrient solutions. Channels are left empty for only short lengths of time before replanting. Plants are usually replaced within 24 hours to a week. Many growers also clean nursery areas and propagating equipment with chlorine-based cleaners on 3-6 monthly basis.

The flow rate of nutrient solution varies depending on:

- flow-rate of the pump
- size of the lettuce and roots in the channels (larger lettuce will slow the flow rate)
- pressure increase to the remaining benches if part of a system, some benches for example, is switched off.

There is usually a valve on each bench that allows the grower to adjust flow rates if required. The general rate used is 1-2 L/min., and growers will generally know through experience which flow rates work best for their system and growing conditions. Once the nutrient solution has flowed through the channels, it is returned to the nutrient tank for recirculation.

4. General system maintenance

General system maintenance includes sealing leaking pipes with silicone (although some growers don't repair leaks in a timely fashion) and pump maintenance. If blocked pipes occur, the system needs to be shut down to make repairs. As systems age, channels tend to sag and build up grime.

Movement of people and plant material

Growers will usually insist on prior arrangement for visitors to the farm and some may ask visitors to disinfest shoes or other equipment. A small number of growers maintain a visitors log but usually there are not any physical barriers to restricting entry. Growers only allow plant material from certified nurseries to enter their properties or use clean, certified seed.

5. Lettuce types and varieties

The most common lettuce types grown in hydroponic culture are red/green oak, red/green coral, red mignonette, salanova, butter, red/green baby cos and endive. Some growers have specialty varieties for selected customers, and some occasionally grow iceberg varieties. Many growers are now tending to select pest or disease resistant varieties, particularly if they have had specific problems in the past. Examples include the use of *Nas*-resistant varieties for currant lettuce aphid, and varieties with resistance to downy mildew, lettuce mosaic virus or root diseases. Although there are a number of *Nas*-resistant varieties of lettuce available, some growers have commented that many are not as good as some of the non-resistant varieties in terms of seasonality and physical characteristics. Seed company representatives and seedling producers surveyed for this report indicated that there was a definite trend of growers selecting varieties that are *Nas*-resistant and downy mildew resistant. With the exception of cos and mignionette varieties, there is a good range of resistant varieties available and, generally speaking, these varieties have quality characteristics comparable to non-resistant varieties.

Crops other than lettuce

There has been a recent trend in the take up of the NFT system for the production of herbs and Asian vegetables by field growers partly in response to demand for cleaner looking produce by buyers. Thus it is important that these crops are included in the response to pesticide residues in hydroponic lettuce.

6. Stock management

Growers stagger their plantings and tend to keep up continuous production throughout the year, so a new crop is planted on average every eight weeks. Some growers will have a break in production if they have problems with a particular pest on an annual basis, but if market demand is high (and therefore prices), growers will continue to produce lettuce. Other growers have a break in production during winter for recreational reasons. The time taken for lettuce to reach maturity varies depending on the season and growing region (Table 4).

Table 4. Time required for hydroponic lettuce to reach maturity in different growing regions of Australia during summer and winter.

Production area		Time to lettuce maturity	
Climate type	**Example regions**	**Summer**	**Winter**
Cool	Werribee (Vic)	5-8 weeks	8-14 weeks
Moderate	Sydney (NSW) Virginia (SA)	3-5 weeks	8-9 weeks
Warm	South-east QLD Northern NSW	19-25 days	5-6 weeks
Very warm	Northern Australia	Too warm and wet for production	Not grown

The majority of growers produce their own seedlings on site rather than purchase seedlings from nurseries. Producing their own seedlings gives them greater control over the availability of different varieties. Those that buy seedlings often do so to reduce their time and labour costs. Seedlings are usually raised in coco peat mixes, vermiculite or nursery potting mixes, rockwool is used as a medium very rarely. All growers use certified seed, which is often fungicide-treated and/or treat the media with fungicide prior to planting.

Growers that purchase seedlings do so from certified nurseries, many of which sterilise the growing media prior to use. Seedlings are treated with a fungicide drench/spray prior to planting and may receive insecticide sprays if required. Growers can specify that particular fungicide or insecticide treatments be applied to seedlings prior to purchase. Depending on the grower, seedlings are either planted into smaller channels with closely-spaced planting holes before being transferred to larger channels once they are established, or planted directly into the larger channels.

To simplify harvesting and management, plants on each bench are usually the same age and variety. Benches serviced by each nutrient tank are often a mixture of ages and varieties, ranging from newly transplanted to fully mature. A small percentage of growers ensure that benches serviced by each nutrient tank contain plants of the same age. This is because of concerns of pesticide residues being in nutrient solutions, and because it simplifies the timing of nutrient dumps, and system cleaning and maintenance. Unused planting holes are always left open and not plugged or covered. Most growers would not have unused plant holes except for where they may have removed diseased plants from the system, or plants have died.

7. Pest and disease management

The most problematic pests and diseases in hydroponic lettuce most commonly cited are:

- Thrips, particularly western flower thrips (WFT)
- Rutherglen bug
- Currant lettuce aphid (CLA)
- Root diseases (*Phytophthora*, *Pythium*)

The general perception among hydroponic lettuce growers is that the implementation of IPM practices is “too risky”. This is sometimes based on a poor understanding of IPM, including the perception that using IPM means not using pesticides at all. Some IPM practices are adopted by growers however as many growers now monitor crops for insect pests before applying pesticides, whereas a culture of “calendar spraying” was more common practice in the past. Even with monitoring crops for pests, timing of pesticide application is still governed by an individual grower’s perceived risk. For some growers, the presence of any insect pest would warrant pesticide application, whereas others may have a higher tolerance of insect pests before they apply pesticides. A number of growers still calendar spray, especially with fungicides, as most have a preventative action. Some growers also add fungicides or chlorinate the water/nutrient solution to reduce the risk of root diseases.

A number of people interviewed as part of the survey commented on the lack of chemicals registered for use in greenhouse or hydroponic cropping systems although the most problematic pests and diseases have limited chemical controls available in any cropping system. For example, Rutherglen bugs are hard to contact with sprays because they infest the heart of the lettuce.

It appears that the development of pesticide resistance is an issue not well understood by growers. This lack of awareness, in the Sydney Basin in particular, may well have contributed to strong resistance by WFT populations to spinosad in this region. Targeted information will assist in discouraging practices that lead to pesticide resistance.

Weed management has persistently been a problem area, but education regarding the role of weeds as alternate hosts of pests and diseases has started to have an impact with weed control becoming a higher priority for many growers. As a part of the CleanFresh project a current list of chemical registrations for lettuce has been created and updated that should assist growers with pesticide selection.

The recent work that has shown that high nutrient temperature is associated with disease expression highlights that adequately cooling nutrient solution is a technical challenge in an NFT system making root disease management difficult, particularly in summer (Tesoriero, 2008). Changes to the system that may assist in cooling the nutrient solution such as providing shade or overhead irrigation to reduce plant stress are recommended, but growers may be reluctant to pay for these.

8. Spray equipment

Pesticides are generally applied to lettuce using boom sprayers and mistblower (cannon) sprayers. Growers who use boom sprayers tend to have fewer problems with pests and diseases compared to those that use cannon sprayers, due to improved coverage. The type of spray unit used is limited by the height of the benches and tractor access, as the spacing of the benches (often around one metre between benches) and/or the design of the plumbing components of the system can inhibit machinery movement. Herbicides are generally applied under and around growing benches using a backpack sprayer or boom spray.

Although it is recommended that spray equipment be calibrated on a regular basis, it is unclear exactly how often equipment is calibrated, but probably varies considerably. Equipment maintenance is also an area governed by necessity (i.e. when equipment is not working) rather than routine inspection and servicing. There are a proportion of growers who are very meticulous with calibration and maintenance of spray equipment. For growers who use knapsack sprayers to apply chemicals there is the perception that calibration is difficult. If this perception is widespread then it is likely that pesticides are being applied at the wrong rates. As a part of the CleanFresh project, a horticulture spray diary is currently being developed and will assist growers to keep appropriate spray records as an alternative to agricultural crop diaries.

Many respondents raised the issue that converting chemical label rates for use in hydroponic systems was difficult, particularly for those pesticides where application rates were described in litres per hectare, highlighting again the need for pesticide data in hydroponic systems. In addition, the idea of specifying different spray rates for plants at different growth stages was also raised by some respondents.

9. Crop hygiene

Good crop hygiene is important to reducing disease pressure and hence the need to use pesticides. "Roguing", or the removal of diseased or unthrifty plants from the growing area, is a principle based on reducing the spread of disease (particularly viral diseases). Although many growers are aware of the threat of diseased plants, roguing is not commonplace. If plants are removed from the growing system, they will often be thrown onto the ground under the benches, thereby not removing the disease from the growing area. After harvesting, many growers will clean up the growing area and remove plant waste, either dumping it onto heaps nearby the growing area, bury the waste on-site or into skip bins which are later removed from site. Livestock are sometimes fed refuse from the harvested crops. A reasonable proportion of growers still throw plant waste under benches, where it remains. These practices, among other IPM strategies, are being examined under the auspices of VG07003 (Development of IPM strategies and tools for western flower thrips (*Frankliniella occidentalis*) in hydroponic lettuce) and it is hoped that with greater evidence more growers will practice the first effective step in reducing the need for pesticide applications.

10. Postharvest practices

Lettuce may be washed by spraying with a hose/ pressure washer before or just after harvest, mostly to remove dust or dead insects. This practice may assist in removing pesticide residues. Lettuce contracted to supermarkets are put into plastic sleeves for sale and then packed into boxes (roots on). Effort is made to transfer harvested lettuce to cool-rooms as quickly as possible and to maintain the cool-chain during transport. Producers of cut-salad mixes will put the lettuce through full processing and washing procedures in accordance with Hazard Analysis and Critical Control Points **(**HACCP**).**

11. Pesticide use

An indication of pesticide use in the hydroponic lettuce industry can be gained from the NSW CleanFresh pesticide monitoring program (Waterson, 2008). This program focused on 6 horticultural commodity groups including 4 vegetables and 2 fruits from NSW. Vegetables included buk choy, hydroponic lettuce, Lebanese cucumber and silverbeet and fruit included nectarines and strawberries. Samples of these 6 commodities were purchased from the Sydney Markets, retailers and at the farm gate between March 2005 and April 2008. These samples were analysed for the residues of up to 132 pesticides. A total of 312 hydroponic lettuce samples were measured. Eighty two percent of samples were sourced from Sydney Basin farms, and thus the results are not necessarily representative of the wider industry.

The samples were analysed for residues of a number of pesticides including organochlorines (OC), organophosphates (OP), synthetic pyrethroids, fungicides, acaricides, dithiocarbamates, herbicides and other pesticides. For the 312 lettuce samples, there were a total of 611 detections made, including 79 detections greater than the MRL. The pesticides subject of these violations, the target pest or disease that the pesticide was used for, and the reason for the breach, is presented in table 5. The most common violations, accounting for 38% of breaches, concerned dithiocarbamates (fungicides) and the insecticides chlorpyrifos and methamidophos.

Spray drift was one of the reasons for violations concerning chlorpyrifos and chlorothalonil. More information was not available about the circumstances of these violations. However, these incidents raise the point that spray drift is more likely to be an issue in a system that includes plantings of different ages that are not easily cordoned off. Also, violations occurred for seven different pesticides when the pesticide had been applied according to the label. This highlights that perhaps hydroponic systems prolong the persistence of these pesticides; it certainly warrants further investigation of this matter.

Total detections of pesticides reduced approximately by half from 312 detections per 115 samples in the first year, to 152 detections per 104 samples in the second year and remained at a similar level for the third year. Similarly, violations have dropped considerably over the duration of the survey with about 60% of total violations occurring within the first year and the rest over the subsequent two years. A specific example of this concerns carbendazim. This fungicide was suspended in early 2007 due to occupational health concerns for users. In the year prior to this there were 21 detections and 4 violations, but in the two years following the withdrawal there were no detections or violations. This probably reflects greater awareness of pesticide residue issues within the industry and consequent reduced pesticide usage. In response to initial results of the CleanFresh program, agencies worked together to provide a number of production based hydroponic lettuce grower meetings. These were well attended by concerned growers. An added positive outcome was that hydroponic lettuce growers formed a sub-branch of NSW Farmers Association, giving themselves a greater political voice.

Table 5. Pesticides found in excess of MRL in hydroponic lettuce, target pests and diseases and the reasons for the violation.

[UR]pesticide unregistered for use on lettuce; [P]permit available; [EP]permit now expired. WFT: western flower thrips. GVB: green vegetable bug.

Reasons for breach: [1]unregistered product; [2]label breach; [3]spray drift; [4]use as per label; [5]other reason; [6]no reply from Department of Environment and Climate Change (DECC).

Pesticide	**Pesticide group**	**Trade names**	**Target Pest/Disease**	**Reasons for breach**
Endosulfan[UR] (should not be used in protected cropping systems)	Organochlorine Group 2A Insecticide	Endosan Thiodan Thionex	<u>Possibly:</u> Aphids Thrips Jassids GVB	5
Chlorpyrifos	Organophosphate Group 1B Insecticide	Chlorfos Lorsban	Mites Thrips (including WFT) Vegetable weevil	3, 4, 5
Dimethoate	Organophosphate Group 1B Insecticide	Rogor	Thrips Aphids Mites (including spider mite, tomato mite) Bugs (including GVB) Leafmining fly	6
Methamidaphos[EP]	Organophosphate Group 1B Insecticide	Monitor Nitofol	<u>Possibly:</u> Caterpillars Aphids Thrips (including WFT)	2, 5, 6
Methomyl	Carbamate Group 1A Insecticide	Lannate	Heliothis Cluster caterpillar	4
Pirimicarb	Carbamate Group 1A Insecticide	Pirimor	Aphids	2
Cypermethrin	Group 3A	Cypermethrin,	<u>Possibly:</u>	5

	Insecticide	Scud, Sonic, Decis, Forte, Fastac	Thrips	
Chlorfenapyr[UR]	Group 13A Insecticide	Secure	Possibly: Caterpillars Mites WFT	5?
Fipronil[UR]	Phenyl pyrazole Group 2C Insecticide	Regent	Possibly: Caterpillars Thrips	1
Diuron	Group C Herbicide	Diuron	Weeds	5
Carbendazim[UR]	Group A Fungicide	Carbendazim	Possibly: *Erysiphe* sp. (powdery mildew)	2, 4?
Thiabendazole[UR]	Group A Fungicide	Storite	Possibly: *Erysiphe* sp. (powdery mildew)	5
Chlorothalonil[UR]	Group Y Fungicide	Echo	Possibly: *Bremia* sp. (downy mildew) *Colletotrichum* sp. (anthracnose)	2, 3, 4?
Metalaxyl-M[EP] (not for use in hydroponic or protected cropping systems)	Group D Fungicide	Metalaxyl M	*Pythium* sp. *Phytopthora* sp. (damping off)	2
Metalaxyl (in combination with mancozeb)	Group D/Y Fungicide	Axiom MZ	*Colletotrichum* sp. (anthracnose) *Septoria* sp. (leaf spot) *Bremia* sp. (downy mildew)	2
Procymidone[UR]	Group B Fungicide	Fortress	*Botrytis* sp. (grey mould) *Sclerotinia* sp. (rot)	4?
Quintozene (soil treatment)	Group Y Fungicide	Terraclor	Possibly: *Rhizoctonia* sp. (bottom rot)	4?
Pyrimethanil[UR]	Anilinopyrimidine Group I Fungicide	Scala Pyrus Vision	Possibly: *Sclerotinia* sp. (rot) *Botrytis* sp. (grey mould)	5
Azoxystrobin[UR]	Strobilurin Group K fungicide	Amistar	Possibly: *Sclerotinia* sp. (rot) *Erysiphe* sp.	5
Trifloxystrobin[UR]	Strobilurin Group K Fungicide	Flint	Possibly: *Sclerotinia* sp. (rot) *Erysiphe* sp. (powdery mildew)	1
Dithiocarbamates (Mancozeb not to be used in hydroponic or protected cropping systems)	Group Y Fungicides	Various	*Bremia* sp. (downy mildew) *Colletotrichum* sp. (anthracnose) *Septoria* sp. (spot)	2, 4

Key components of hydroponic lettuce systems and crop management

Hydroponic lettuce production systems, which can also be used for the production of other leafy vegetables and herbs, differ in a number of ways from other hydroponic production systems used in protected cropping for products such as tomato and cucumber. Hydroponic lettuce production systems as determined from information gathered in this survey can be characterised in part by the following:

- A production area of between 0.5-3.5 ha, average 1.5ha.
- The use of nutrient film technique (NFT). Recirculated nutrient solution is supplied from a tank to gently sloping PVC channels that are supporting the plants, with about 4-8 channels grouped together on raised benches. 5000L tanks are commonly chosen and one supplies about 30 benches that are between 8-24 m long with planting holes at a distance of 15-30 cm.
- The use of hail netting above the crop for about half of farms and the limited use of enclosed structures.
- The use of water treatment in production by about half the industry.
- The production of open leafy crops.
- Plantings of different ages supplied by the one nutrient tank are common practice for about half the industry.
- Calender spraying is common practice for about one third of the industry.
- A range of equipment is used to apply pesticides.
- IPM that includes the use of sticky traps and/or practices that encourage beneficial insects used by approximately 20% of the industry.
- All farms are affected by insect pests, mainly thrips, and 20% are affected by root diseases.

The more sophisticated systems have automated control of the nutrient solution concentration (electrical conductivity) and pH, and the use of water treatment in production. Other features of more modern systems include a ground surface that minimises weed growth and uniformity in the type and length of channels used across the production area. Growers with these types of systems have generally larger than average production areas and high levels of management in regards to production, site cleanliness and pest and disease management.

DISCUSSION

It is encouraging that 20% of the industry currently recognises and employs IPM as a means of reducing pest and disease pressure and that in the last few years pesticide use has reduced considerably. Certainly, the industry has invested considerably in projects and programs that assist this aim (Table 6). What remains unclear and is not addressed by current projects is the impact that some features of the hydroponic lettuce system might have on residues in produce. For example, we do not know the extent and impact of nutrient solution becoming contaminated with pesticides. This is undesirable as the persistence of pesticides in the hydroponic system may not only result in pesticides being taken up by plants via the root system. The resistance of pests and diseases to and the reduced efficacy of these pesticides is also a possibility. Currently, guidelines recommend dumping of nutrient solution following pesticide application for this reason (Appendix 2) but we do not have any information beyond the anecdotal evidence that nutrient solution can become contaminated indirectly (Badgery-Parker and Parks, 2005), or directly by growers who put fungicides into nutrient solution to prevent root diseases. The practice of having a crop that combines plants of different ages or different types would complicate this issue. If plants of different age are in close proximity, or supplied by the same nutrient tank, then there is potentially the risk of residues from spray drift or the nutrient solution, and clearly younger and smaller plants are not favoured by this situation.

It is evident that there is potential for greater uptake of IPM in hydroponic lettuce operations that includes the well-managed use of some pesticides. The uptake of classical or conservation biological control is more difficult because of the short growth period of the lettuce, although there is scope to develop greater opportunities for inundative biological control where beneficial insects are applied as you would a pesticide treatment. There are some alternatives to chemical control available eg. ViVUS for Heliothis, DiPel for caterpillars, and spinosad permitted in organic production. Pesticidal soaps and oils are also available but the use of these can be restricted by environmental factors, particularly high temperatures.

Ideally, tailoring pesticide use patterns for hydroponic production will be achieved by generating data from research conducted on hydroponic crops. A recently completed project *Generating pesticide residue data in various vegetables under protected cropping* (VG06111) evaluated five key pesticides for fancy lettuce production in hydroponic systems is likely to lead to new use patterns for at least some of these products. Data generated from such research will provide greater clarity in the directions for use of pesticides on hydroponic crops, as directions on labels must reflect the cropping situation in which the data was generated. The Australian Hydroponic and Greenhouse Association (AHGA) and the Australian Pesticides and Veterinary Medicines Authority (APVMA) have recognised that there is confusion about the definition of terms such as *greenhouse* and are working towards consistency in definitions and a glossary of terms.

Research that investigates the fate of pesticides in hydroponic systems will further assist the development of refined guidelines for the use of pesticides in these systems. Such research could consider other issues not considered in this review including pesticide use and farmer occupational health and safety. Information gathered for the review highlighted that pesticide movement in a hydroponic production system is a complex issue. Current guidelines for minimising pesticide residues in greenhouse and hydroponic crops remain relevant and have not been modified as a consequence of this review (Appendix 2). Many resources concerning pesticide use, IPM, pests and diseases and general information are currently available to growers that should be having an impact on minimising residues (Appendix 3) combined with relevant project activities (Table 6). What has emerged from this project, and the project *Nutrient management of Asian vegetables* (VG07153), is a gap in information available for setting up new hydroponic NFT systems, particularly for small producers moving across from field production. In response, the hydroponics expert Rick Donnan provided an introduction to hydroponics at a Chinese grower's workshop in December 2007 as part of *The Vegetable Industry Development* project (VG07140). Also, an introduction to hydroponics has been prepared (Appendix 4) and was produced as a handout at the Chinese Growers Picnic Day, held at Gosford Horticultural Institute, 8 June 2008. This document will be further developed as a NSW DPI Primefact. It is important that growers new to hydroponics do not build systems that compromise plant health increasing pest and disease pressure.

Table 6. Recent and current projects (largely NSW based), and their associated activities and outputs that contribute to addressing the issue of residues in hydroponic lettuce

Project Title	**End date**	**Project Leader**	**Research Activities**	**Extension Activities**	**Extension Outputs**
VG03098: Regional extension strategy for managing western flower thrips and tomato spotted wilt virus in the Sydney Region	2009	Leigh Pilkington		• Identify industry network and needs • Develop commercialisation process • Transfer of technology	• Training and extension resources for industry, including development of commercial service • IPM guide for growers • Interactive CD ROM
VG04012: Effective management of root diseases in hydroponic lettuce	2007	Len Tesoriero	• Understanding of root diseases of lettuce and their economic importance • Evaluation of available control strategies	• Evaluating and understanding grower patterns and practices • Demonstrating economic benefits of effective control of root diseases	• New control methodologies and management options for root diseases of lettuce • Fact sheet for growers
VG04032: Improved management of insect pests and diseases for Asian vegetables	2008	Len Tesoriero	• Identifying pests and diseases of Asian vegetables • Development of IPM strategies	• Developing grower awareness of monitoring techniques • Pest and disease identification and management options	• New control methodologies and management options for pests and diseases of Asian vegetables • Publication of multimedia resources • CD image library of pests and diseases of Asian vegetables
VG05044: Incorporating lettuce aphid into lettuce integrated pest management (IPM)	2007	Sandra McDougall	• Develop IPM strategies for Currant Lettuce Aphid (CLA) and other lettuce pests • Identify regional barriers to IPM adoption, preferred weed hosts and beneficial insects	• Information for crop consultants/growers • Training for IPM implementation	• Reduced pesticide usage • New IPM strategy for lettuce incorporating CLA control • Training programs for consultants and growers
VG05084: Integrated management of greenhouse vegetable diseases: Development of microbial biocontrols, biorational chemical and cultural strategies	2009	Len Tesoriero	• Understanding the biology of root diseases of cucumber • Evaluating alternative strategies for disease control, including microbial control	• Developing good hygiene practices within grower groups • Enhancing grower awareness of disease and hygiene practices	• New biological controls and IPM strategies for cucumber root diseases • Best-practices guide for growing cucumber • Demonstrations/field days • Reduced pesticide usage • Reduced pathogen pesticide resistance

Project Title	End date	Project Leader	Research Activities	Extension Activities	Extension Outputs
VG05086: Development of *Hippodamia variegata* and *Micromus tasmaniae* biocontrol agents for use in *Brassica* and other vegetable crops	2010	Leigh Pilkington	• Develop an understanding of the biology of the biocontrol agents and their interaction with the target pest and other beneficials • Development of an IPM strategy		• New biocontrol agents • Better IPM strategies • Researchers trained in biological control development and implementation
VG05093: Integrated pest management (IPM) for greenhouse vegetables – research to industry	2009	Leigh Pilkington	• Identify and develop new biocontrol agents for whitefly, thrips and spider mite • Investigate compatibility with reduced-risk chemicals	Information in the form of factsheets, media publications and presentations	• New biocontrol agents • Better/new IPM strategies • New uses of reduced-risk chemicals
VG06010: The sustainable use of pesticides (especially spinosad) against western flower thrips in vegetables	2009	Grant Herron	• Determine the mechanism of spinosad resistance in WFT using bioassay, biochemical and molecular techniques • Determine frequency of spinosad resistance	Understanding of spinosad-resistant populations of WFT	• Information regarding pesticide resistance in WFT • Tool for testing WFT for resistance to spinosad • More efficient use of spinosad in IPM programs
VG06111: Generating pesticide residue data in various vegetables grown under protected cropping	2008	Peter Dal Santo	• Data generation with five pesticides for hydro lettuce		
VG07003: Development of IPM strategies and tools for Western Flower Thrips (*Frankliniella occidentalis*) in hydroponic lettuce	2010	Leigh Pilkington	• Development of new biorational pesticides for use on lettuce and other leafy vegetables • Discovery and development of new biological control agent	Presentation of project results to industry *via* publications, presentations and demonstrations	New control methodologies and management options for WFT
VG07118: Build capacity of greenhouse growers to reduce crop loss through adoption of preventative disease management practices	2009	Jeremy Badgery-Parker		• Sanitation, quarantine and monitoring practices workshops	• Guide to preventing pest and disease for greenhouse and hydroponic growers
VG07076: IPM for lettuce extension	2010	Sandra McDougall		• IPM field demonstrations (WA, QLD) • State workshops	• Quarterly newsletter continued
VG: 08018: Implementing a national greenhouse business and productivity analysis and benchmarking system	2011	Jeremy Badgery-Parker		• Workshops	• Business and productivity analysis tool for growers
NSW Government: Clean Fresh	2008	Darren Waterson and Lawrence Ullio	Monitoring of pesticide residues in buk choy, silverbeet, hydroponic lettuce and Lebanese cucumbers		• Horticulture spray diary • Lettuce pest and disease poster • Pesticide use poster (four languages) • Updated list of pesticides registered in lettuce
NSW Government: Bilingual officers for vegetable farmers (Arabic, Cambodian, Chinese)	2007	Virginia Brunton	• Collection of statistics • Communication processes NESB farmers	• On-farm advice on chemical use • Chemical training	• Better use of pesticides and adoption of IPM strategies • Translated materials • Better network for NESB growers

RECOMMENDATIONS

Issues concerning pesticide residues in hydroponic lettuce can be addressed using several approaches. Some issues including access to pesticides and pesticide alternatives, and the reduction of pest and disease pressure, are already being addressed and it is recommended that these efforts continue. However, a current gap in information on the movement of pesticides in hydroponic lettuce systems exists, and therefore it is a *key recommendation* that this particular issue be addressed.

1. *Determine the movement of pesticides in hydroponic lettuce production*

The fate of pesticides in hydroponic production systems remains largely unknown. There is circumstantial evidence that the nutrient solution can be contaminated with pesticides and good evidence that pesticides can enter the root system via pesticide-contaminated nutrient solution. Thus it is a recommendation of this study that experimental research be conducted to elucidate the movement of pesticides within hydroponic growing systems. This is important considering that vegetables other than lettuce such as Asian vegetables are increasingly being produced in hydroponics. Information provided by this report provides baseline information on hydroponic production systems and will help define the parameters of the research. This knowledge may ultimately result in recommendations, which may include changing structural aspects of hydroponic lettuce systems, the methods and equipment used to apply chemicals, or general management practices to mitigate residues.

Recommendations:

- Conduct experimental research on pesticides used and their movement within growing systems. Take into consideration the components of the production system summarised in this report for example the presence of shading, number of tanks and volume of solution recirculated, ventilation around the crop, size of planting hole, and density of plantings.
- Identify and assess practices that increase the risk of particular pesticides accumulating in nutrient solutions and being absorbed through plant roots.
- Assess risks associated with mixing the ages of lettuce on benches serviced by the same nutrient tank. Sprays or drenches of chemicals like mancozeb (WHP = 2 weeks) for example, applied to young seedlings could potentially be taken up by mature plants in the same system.
- Evaluate calibration and spray coverage control of mistblowers and backpack sprayers for hydroponic lettuce production situations, and observe corresponding pesticide residues.
- Novel research may include the investigation of microbial additives for nutrient solutions that may help to degrade particularly "high risk" pesticides. For example, Yu *et al.* (2006) used a foliar spray based on cell-free extracts of a fungus capable of degrading chlorpyrifos to reduce chlorpyrifos residues on crop plants.

2. *Provide access to a range of pesticides*

A range of pesticides is important to provide to growers to ensure that any one pesticide is not over-relied upon. Some projects are investigating resistance of pest populations to specific pesticides and assist in maintaining the efficacy of these pesticides. The recent project *Generating pesticide residue data in various vegetables under protected cropping*

(VG06111) has started to address the great need for data on pesticide residues in the hydroponic cropping situation. It is important that this type of work receives continued support, particularly as more vegetable types are being produced in hydroponic lettuce systems.

Recommendations:

- Continued support for research that ensures the efficacy of available pesticides.
- Continued support for research that generates residue data for a range of crops in hydroponic and protected production situations.

3. *Develop pesticide alternatives*

A considerable effort is currently being made and builds on previous work to make biocontrol agents available to target the key pests and diseases in hydroponic crops. For example, a strain of *Bacillus subtilis* has been identified as a suppressor of root disease and is being developed for registration as a biopesticide on hydroponic lettuce (Tesoriero, 2008).

Recommendation:

- Continued support for research on new biological control agents and the development of alternative pesticide measures for problem pests and root diseases, particularly as new pests and diseases emerge, and as more leafy crops are grown using hydroponic lettuce systems.

4. *Reduce pest and disease pressure*

Management of pests and diseases in hydroponic lettuce has been a strong focus of a number of projects that already demonstrate that there are simple strategies growers can currently use to reduce pest and disease pressure and the reliance on the use of pesticides. Example topics include correct pesticide application, pest monitoring, improving hygiene, controlling weeds, and use of insect netting and shading. Growers planning to build a hydroponics system also need to be made aware of the system requirements that prevent any compromise to plant health.

Recommendations:

- Continued promotion of reduced pesticide use through IPM including continued farm and crop hygiene education (promoting weed control and maintaining a "clean" farm), and promotion and use of lettuce varieties with resistance to specific pests and diseases.
- Targeted promotion of the range of resources currently available to hydroponic lettuce growers at workshops and conferences, for example at the AHGA conference in July 2009.
- Information targeted to growers on the development of pesticide resistance in pests and diseases that also highlights the poor practices that lead to pesticide resistance.
- Promoting the uptake of business planning tools that allow growers to determine the long term economic value of investing in infrastructure such as insect netting. The current project *Implementing a national greenhouse business and productivity analysis and benchmarking system* (VG08018) will assist in addressing this issue.
- Development and promotion of a Primefact information sheet on an introduction to hydroponic systems for new growers.

REFERENCES

Badgery-Parker J and Parks S (2005). *Final report: - Evaluation of pesticide persistence in hydroponic lettuce* HAL project VG02017.

Cabras P, Meloni M, Manca MRA, Pirisi FM, Cabitza F, Cubeddu M (1988). Pesticide residues in lettuce. 1. Influence of the cultivar. *Journal of Agricultural and Food Chemistry* 36: 92-95.

Cabras P, Angioni A, Garau VL, Melis M, Pirisi FM, Karim M, Minelli EV (1997). Persistence of insecticide residues in olives and olive oil. *Journal of Agricultural and Food Chemistry* 45: 2244-2247.

Department of Agriculture Fisheries and Forestry (2004). *Guidelines for on-farm food safety for fresh produce* 2nd Edition, Canberra ACT.

Karras G, Savvas, D, Patakioutas G, Pomonis P, Albanis T (2007a). Fate of cyromazine applied in nutrient solution to a gerbera (*Gerbera jamesonii*) crop grown in a closed hydroponic system. *Crop Protection* 26: 721-728.

Karras G, Savvas D, Patakioutas G, Pomonis T, Albanis T, Pomonis P (2007b). Modelling the transport of metalaxyl in gerbera plants grown in a closed-loop hydroponic system. *Biosystems Engineering* 96: 279-292.

Krol WJ, Arsenault TL, Pylypiw, Jr HM, Incorvia Mattina MJ (2000). Reduction of pesticide residues in produce by rinsing. *Journal of Agricultural and Food Chemistry* 48: 4666-4670.

Marutani M, Edirveerasingam V (2003). Shadecovers affect degradation of carbaryl on field-grown pakchoi. *HortTechnology* 13: 637-640.

Marutani M, Edirveerasingam V (2006). Influence of irrigation methods and an adjuvant on the persistence of carbaryl on pakchoi. *Journal of Environmental Quality* 35: 1994-1998.

Patakioutas G, Savvas, D, Matakoulis C, Sakellarides T, Albanis T (2007). Application and fate of cyromazine in a closed-cycle hydroponic cultivation of bean (*Phaseolus vulgaris* L.). *Journal of Agricultural and Food Chemistry* 55:9928-9935.

Ripley BD, Ritcey GM, Harris CR, Denommé MA, Lissemore LI (2003). Comparitive persistence of pesticides on selected cultivars of specialty vegetables. *Journal of Agricultural and Food Chemistry* 51: 1328-1335.

Rural Industries Research & Development Corporation (2001). *Hydroponics as an Agricultural Production System.* Barton, ACT.

Sances FV, Toscano NC, Gaston LK (1992). Minimization of pesticide residues on head lettuce: within-head residue distribution of selected insecticides. *Journal of Economic Entomology* 85:202-207.

Tesoriero L (2008). *Final Report – Effective management of root diseases in hydroponic lettuce*, HAL project VG04012.

Waterson D (2008) *Final report – CleanFresh monitoring pesticide residues in fresh fruit and vegetables 2005-2008*. NSWDPI.

Yu YL, Fang H, Wang X, Wu XM, Shan M, Yu JQ (2006). Characterisation of a fungal strain capable of degrading chlorpyrifos and its use in detoxification of the insecticide on vegetables. *Biodegradation* 17: 487-494.

APPENDIX 1

Article in Lettuce Leaf

Issue 31, December 2007
NEW HYDROPONIC LETTUCE PROJECT UNDERWAY

A new hydroponic lettuce project was recently approved for funding by Horticulture Australia Limited. Sophie Parks and Katina Lindhout from NSW Department of Primary Industries' Gosford Horticultural Institute are conducting the six-month long project titled: VG07165 Review of pesticide residues in hydroponic lettuce.

The aim of this project is to produce a report that summarises the hydroponic lettuce industry in terms of management practices and the physical specifications of hydroponic systems currently used by Australian growers. Information for the report is being sourced from all states and from a range of people involved in the hydroponic lettuce industry. The final document will be a source of information on current industry trends and may help identify factors that could increase the potential risk of pesticide residues exceeding specified maximum residue limits. Current recommendations regarding the ways in which pesticide residue risks can be minimised will be updated and new areas for research may be identified.

We are calling on input from growers and industry representatives in all states, either through the completion of a survey or the provision of general information. All individual responses will be kept confidential. If you are interested in participating in this project or obtaining more information, please contact Katina Lindhout by phone: (02) 4348 1900; or email: Katina.Lindhout@dpi.nsw.gov.au.

Survey questions used to detail responses from interviews with growers

1. Operations:

- **a)** where is your farm?
- **b)** what is the area of lettuce production?
- **c)** other crops grown

2. Growing structures:

- **a)** lettuce is grown: outdoors / in an enclosed structure
- **b)** any coverings, including nursery areas
- **c)** any temperature or ventilation controls

3. Growing area:

- **a)** benches are on: bare ground / other surfaces, like gravel, weed mat etc
  if benches are on bare ground, description of vegetation under benches
- **b)** if benches are on surface other than bare ground, description of material
- **c)** description of land use, including vegetation, surrounding the growing areas

4. Channels:

- **a)** total number of benches
- **b)** number of channels per bench
- **c)** length of channels
- **d)** slope of channels
- **e)** material channels are fabricated from
- **f)** dimensions and shape of channels
- **g)** plant hole spacings

5. Nutrient solution:

- **a)** source of water
- **b)** treatments applied to water before use
- **c)** treatments applied to nutrient solution
- **d)** temperature management of nutrient solution

e) number of benches serviced by each nutrient tank
f) size of nutrient tanks
g) frequency of nutrient solution dumps
h) reasons for nutrient solution dumps
i) control of pH and EC: automatic / manual
j) flow rate of solution through channels

6. Production:

a) varieties/cultivars of lettuce grown
b) months of production or continuous
c) time to maturity in different seasons
d) plants in each bench are of: the same age / different ages
e) plants serviced by each nutrient tank are of: the same age / different ages
f) unused planting holes are: covered or plugged / left open
g) type of growing media used for seedlings
h) plants are: bought as seedlings / grown from seed on site
i) seedling treatments or practices pre-planting
j) pest and disease management: IPM / chemical sprays only
k) chemical sprays applied according to: calendar sprays / monitoring of insect pests
l) types of spray equipment used (including those for herbicides)
m) regularity of calibration of spray equipment
n) maintenance of spray equipment (eg nozzle replacement)
o) other notes on pest and disease management, including the most problematic pests

7. Hygiene during and between crop production:

a) removal of diseased or unthrifty plants from growing area: yes / no
b) disposal of crop waste
c) postharvest techniques
d) washing of system between plantings, with or without disinfectant
e) notes on general system maintenance
f) period of time before channels are reused
g) control of entry or movement of plant material and people on property, e.g. visitors log, open to public, sanitising footwear, equipment

10. Other information:

APPENDIX 2
Spraysense fact sheet

This article is available on line at http://www.dpi.nsw.gov.au/ data/assets/pdf file/0003/186384/minimising-pesticide-residue.pdf

i n f o r m a t i o n on **pesticide** issues

Spray sense

Minimising pesticide residues in greenhouse and hydroponic crops

Pesticide residues in food crops are a problem if the residue level is above the legal limit (maximum residue limit or MRL) at harvest. Persistent low levels of pesticide residues are also a problem as they can result in pest and disease resistance to the chemical being used. Pesticide residues can behave differently in some hydroponic and greenhouse systems compared with field grown crops. This can result in residue levels above the MRL even when the label withholding period is followed.

The potential for pesticide residues in crops grown in greenhouse and hydroponic systems can occur in two ways.

1. Hail netting, shade cloth or greenhouse covers can reduce the rate of pesticide residue breakdown from sunlight, wind and rain.

Research has shown that the crop environment will affect the degradation rate of pesticides. Crop covers can slow degradation of some pesticides compared with exposure to full sun, wind and rain. Pesticide degradation will also be reduced in the shorter daylight hours of winter compared to other seasons.

2. In some hydroponic systems the nutrient solution can become contaminated with pesticides and then taken up by plants.

Hydroponic systems are soil less with nutrients being delivered to roots in the irrigation water (nutrient solution). In some hydroponic systems the nutrient solution is delivered to plant roots then collected and reapplied on a continual basis (recirculating system). The same batch of nutrient solution can be recirculated for several months or longer until it is discarded. If the recirculated solution is contaminated with pesticides, these are also being continuously applied to plant roots. This can lead to uptake of pesticides resulting in residues which could persist in the crop for some time. The MRL could be exceeded and there is a risk of pest and disease resistance to the pesticide.

Nutrient film technique (NFT) is one hydroponic system where the nutrient solution is recirculated. The plants grow in sloped channels and the roots are bathed in the recirculating solution. Research has shown that spraying mature lettuce in an NFT system according to label directions can result in contamination of the nutrient solution and residues in the lettuce.

Management strategies to minimise pesticide residues

Growers need to take into account their own greenhouse or hydroponic production system in order to develop the most appropriate pest and disease management plan for their crop. There are a number of strategies which can be used to minimise pest and disease problems and avoid pesticide residues in hydroponic crops.

• ***Keep the farm clean***

A clean farm usually has fewer pest and disease problems. Keep the farm free of weeds and carefully dispose of diseased plants and old plant matter. These can be buried, composted with animal manures, or if the material has a high water content (e.g. lettuce) plants can be placed in black plastic bags, sealed and placed in the sun. After the plant matter has broken down it can be used as mulch.

• ***Avoid calendar spraying***

Calendar spraying is when pesticides are applied on a schedule without considering the actual presence or extent of pests and diseases in the crop. This practice can result in pesticides being applied when they are not needed, can increase pest and disease resistance and be a waste of time and money.

• ***Monitor pests and diseases***

Regularly check your crop for pests and diseases by carefully checking plants with a magnifying glass or hand lens for the presence of pests and disease. Sticky traps can also be used to check for the presence of specific pests. Regular monitoring ensures problems are found early, making control easier and saving you time and money. Additionally, monitoring records will allow you to evaluate the effectiveness of control methods and identify the time of the year for particular pest and disease issues.

• ***Use pest and disease thresholds***

The presence of a pest or disease does not automatically mean financial loss. In some situations, the cost of applying pesticides may be greater than the loss if no action was taken.

The point at which a control measure is needed to prevent economic loss is called the action threshold. For example, if you checked 50 plants and found one grub then you’d be more likely to squash it than make up a spray to kill it. On the other hand, if you checked 50 plants and found 200 grubs you may spray to control them. So, somewhere between these two situations there is a period where the crop can tolerate having pests in them before you need to spray. Action thresholds for certain pests and diseases are available for some crops. If there is no recommended action threshold then you need to use your own experience to develop them and make decisions. By using action thresholds you can more accurately time pesticide applications and may even reduce the number of applications made. This can also reduce the risk of pesticide residues.

• ***Choose the right control measure***

Use a combination of measures to control pests and diseases, including cultural, biological and chemical measures. There are a wide range of beneficial insects commercially available to control pests. They can be used in conjunction with pesticides but the choice of pesticide is critical to ensuring that these natural enemies survive. Where possible, choose pesticides that have a low impact on beneficial insects.

• ***Use separate production systems***

Set up the production site using multiple separate ground tanks and systems. Although this increases the initial set up cost it allows you to manage batches of plants separately. This is particularly valuable in managing root diseases especially when planting out new transplants. Transplanting young plants into a system containing older plants already infected with root diseases almost always results in high mortality of the younger plants and significantly affects growth rates. Similarly, if the nutrient solution becomes contaminated with pesticides the problem is confined to only one section of of the system. Sections can also be shut down seperately for cleaning and maintenance, without disrupting overall production.

• ***Prevent spray drift***

Preventing spray drift between young and old plants and different crops is also critical in reducing the risk of pesticide residues. Make sure there is adequate protection (i.e. screens and windbreaks) between production areas to reduce spray drift onto non-target plants from within the site and from any neighbouring farms.

• ***Increase the withholding period (WHP)***

Increasing the recommended withholding period is one way hydroponic and greenhouse growers can reduce the risk of pesticide residues. You need to be confident that your produce does not exceed the MRL for the chemicals you use. Testing your produce for residues will help you determine if the recommended withholding period needs to be increased for your method of production.

• ***Dump the nutrient solution***

Dumping the nutrient solution following the application of some pesticides is another strategy to ensure pesticides do not get into or remain in the nutrient solution. In order to reduce environmental contamination, dumped nutrient solutions need to be cleaned using artificial wetlands. Alternatively they can be collected by a waste disposal contractor.

More information

More information on using farm chemicals is available from the series *Spray Sense – safe and effective use of farm chemicals*. The series is available on the NSW DPI website at www.dpi.nsw.gov.au.

For more information on this series, contact Sandra Hardy, NSW Department of Primary Industries, Locked Bag 26, Gosford, NSW, 2250. Phone 02 4348 1900.

This information was correct at time of printing. December 2005.

ALWAYS READ THE LABEL

Users of agricultural chemical products must always read the label and any Permit, before using the product, and strictly comply with the directions on the label and the conditions of any Permit. Users are not absolved from compliance with the directions on the label or Permit by reason of any statement made or omitted to be made in this publication.

Authors: Sophie Parks, Sandra Hardy and Jeremy Badgery-Parker
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APPENDIX 3

Currently available extension resources

General

- Regular newsletters: Vegiebites; Vegetable IPM, Lettuce Leaf, Soilless, Vegetables Australia, NSW Vegelink, NSW Vegetable IPM Newsletter, Practical Hydroponics and Greenhouses
- Best Practice Guidelines for Growing Vegetables

Pesticide Use

- SpraySense articles:
    - How to calibrate hand operated sprayers
    - Testing for chemical residues
    - How to calibrate air blast sprayers
    - Preventing and treating pesticide poisoning
    - Storing pesticides safely on the farm
    - Using fungicides correctly
    - Safe disposal of empty pesticide containers
    - The role of DEC officers
    - Reading and understanding pesticide labels
    - Transporting farm chemicals
    - Spray water quality
    - Calibrating boom sprayers
    - Managing chemical spills
    - Choosing the right pressure gauge
    - What pesticides can I use?
    - Keeping pesticide records

    - Assessing spray coverage with water sensitive spray cards
    - Minimising pesticide residues in greenhouse and hydroponic crops
- Chemical Risk Management Reference Manual
- Western Flower Thrips (WFT) insecticide resistance management plan
- Primefact: Dithiocarbamate fungicides
- Agnote: Endosulfan regulations for horticultural crops
- Agnote: Reducing herbicide spray drift

Integrated Pest Management

- Primefact: Lettuce IPM
- Primefact: Plant bugs
- The Good Bug Book
- Pest Sense – a pest management card game
- Integrated Pest Management in Lettuce: Information guide
- Lettuce integrated pest management (IPM) survey 2006

Specific pests and Diseases

- Primefact: Currant lettuce aphid
- Primefact: Western flower thrips and tomato spotted wilt virus
- Pests, Beneficials, Diseases and Disorders in Lettuce: Field Identification Guide.
- Common pests of lettuce
- Common diseases of lettuce
- Key to aphids (Hemiptera:Aphididae) on lettuce in Australia
- Which thrips is that? A guide to the key species transmitting tomato spotted wilt virus in NSW

Other Resources

- Freshwise: Food safety from training to audit (DVD training resource)
- InfoPest CDROM (QDPI&F)
- Safe Use of Pesticides DVD and Use Pesticides Safely poster (DECC) (in English, Khmer, Vietnamese, Arabic, Cantonese and Mandarin)
- Guidelines for On-Farm Food Safety for Fresh Produce
- Freshcare Food Safety Workbook and Manual
- Freshcare Environmental Workbook and Manual

APPENDIX 4

An introduction to hydroponics

AN INTRODUCTION TO HYDROPONIC SYSTEMS AND THEIR MANAGEMENT

Sophie Parks

A range of hydroponic systems are used for commercial production of vegetables. Essentially hydroponic systems supply nutrients to crop roots as a solution with the irrigation water. Roots are suspended in a still or flowing solution or the solution is fed through drippers to the plant supported in contained substrate. Soil is not used. Some different types of hydroponic systems are described below. All hydroponic systems need to provide plant roots with enough nutrients, water and oxygen for good growth.

TYPES OF HYDROPONIC SYSTEMS

Tank culture

Tank culture is the simplest form of hydroponics. Plants are suspended by a cover over a tank of complete nutrient solution. Some tank systems require aeration of the nutrient solution (Figure 1).

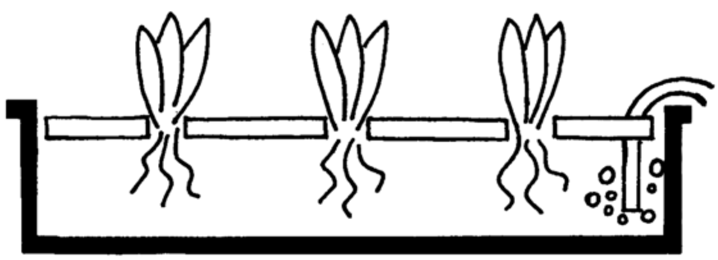

Figure 1. Aerated tank culture

In one type of system described by Kratky (2004) the solution is still and plants are supported by substrate within a small netted or perforated pot (Figure 2). 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. The crop is then harvested or terminated.

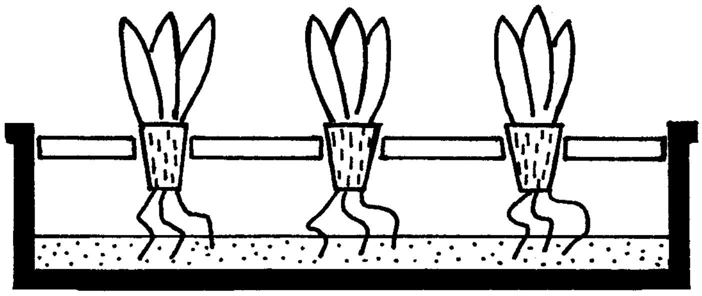

Figure 2. Still tank culture

Four main concepts encapsulate still tank culture:

- Exposure to air and high relative humidity is important for the upper part of the root system
- Drying out of roots must be avoided
- The lower part of the root system should gather water and nutrients
- The nutrient solution level can either be maintained or lowered but cannot be raised (otherwise aeration of roots is reduced)

Advantages of tank culture:

- Simple to set up and manage
- No pumps or electricity required
- Very efficient in water and nutrient use
- Only an initial application of nutrient solution is required

Disadvantages of tank culture:

- Not as suitable for long crops
- High quality water is needed, as the salts increase in concentration, as the solution is used
- Still nutrient solution can allow mosquitoes to breed

Flowing culture
In flowing culture plants are supported in a sloping shallow gully and the roots are suspended in a flowing stream of nutrient solution (Figure 3). This is also called the nutrient film technique (NFT). 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. 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 also needs to be avoided. To maintain adequate aeration 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.

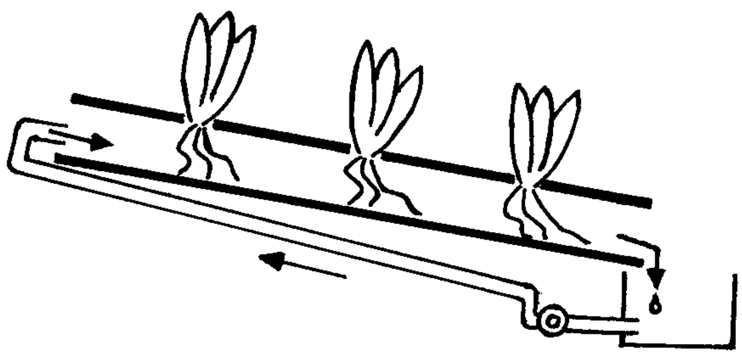

Figure 3. Flowing culture

Substrate culture
In substrate culture plants are grown in a soilless substrate held within a container (Figure 4). The substrate does not have any nutrient value for plant growth. The substrate needs to have enough water holding capacity to maintain moisture around roots and also must provide enough aeration to prevent waterlogging. Examples of substrates include gravel, peat, coir, perlite, vermiculite, rockwool, scoria and sawdust. Mixes of different products are also used. Water and nutrients are fed through a line supplying plants and the solution is allowed to drain through the substrate and openings at the base of the container. Enough nutrient solution is applied so that 10-20% drains from the pot. This prevents build up of salts in the substrate and maintains the solution around the root zone. The drainage solution (runoff) can be collected and continuously recycled through the system. This can be done manually. For example, a bucket could be used to collect runoff from a simple gravity fed system and returned to the raised solution feed bucket, or in larger systems, pumps can be used to return water to feed tanks. When this drainage is not recycled the system is known as a ‘run-to-waste’ system.

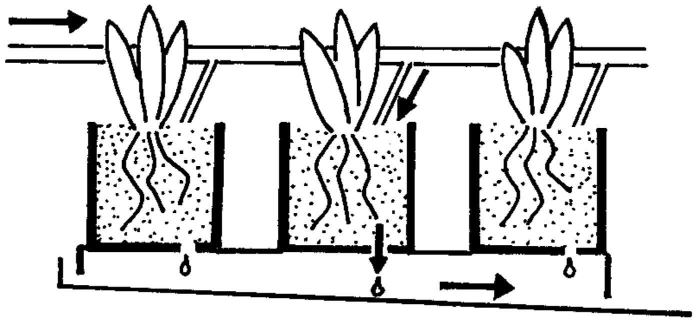

Figure 4. Substrate culture

Advantages of flowing and substrate culture:

- Suitable for long crops
- Lower quality water can be used if a run-to-waste system is used, or if nutrient solution is changed frequently
- Root zone solution can be fine tuned

Disadvantages of flowing and substrate culture:

- Setup can be expensive and require a continuous supply of electricity
- These systems can be inefficient in water and nutrient use when nutrient solution is not reused.
- Waste nutrient solution is produced
- A high level of technical knowledge is required

NUTRIENT MANAGEMENT OF HYDROPONIC SYSTEMS

It is important to have at least a basic understanding of the nutritional requirements of plants, and of chemistry, in order to make up and manage hydroponic nutrient solutions. Plants require large amounts of the macronutrients: nitrogen (N), potassium (K), calcium (Ca), magnesium (Mg), phosphorus (P) and sulphur (S); in comparison to 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 typical hydroponic nutrient solutions.

Preparing the nutrient solution

For those new to hydroponics an easy option is to buy and use a prepared hydroponic fertiliser. Alternatively, a fertiliser mix can be made up with individual chemical compounds, according to a nutrient recipe. The nutrient solution is made to the concentration required for immediate use by the crop, or it is made up into two concentrated stock solutions for convenience.

If buying a prepared hydroponic fertiliser, it is important to ensure that it contains sufficient calcium and magnesium. The hydroponic solution specialist Rick Donnan recommends that the content of calcium should be as much as, or up to 30% less than, the amount of nitrogen present. Magnesium needs to be at a content of about 20-30% of the amount of calcium present. Additionally he recommends avoiding fertilisers that contain urea, or those that have over 10% of total nitrogen in the ammonium form.

It is often practical for commercial hydroponic 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 needed 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 precipitation. Most nutrient solution recipes in use commercially are generally similar in composition. An example of a nutrient recipe is the “Huett” lettuce formulation which is also suitable for tomatoes (Table 1).

Table 1. Standard ‘Huett’ lettuce formulation. Recommended starting and to-up solutions are the same. Equal volumes of A and B stock solution are to be used. For 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	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

*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.

Managing irrigation and the nutrient solution

Still tank culture, as described by Kratky (2004), is designed to require only simple nutrient solution management. Once the solution has been made up to the desired concentration, which depends on the tank size and crop type, enough is added to the tank to last for the duration of the crop.

In flowing and substrate culture, nutrient management becomes more complex, particularly when solutions are recirculated. A crop will perform best when the grower aims to keep conditions constant around the plant roots.

There are some simple tools available that can be used to assist in the management of water and nutrients around the plant roots. These include monitoring of runoff volume in substrate systems, and testing the solution for acidity/alkalinity (pH), nutrient concentration (electrical conductivity or EC) and nitrate concentration. In NFT systems you can simply monitor the recirculating solution. In substrate systems, the runoff/drainage solution from plant substrates is collected over a 24 hour period for monitoring purposes. If measurements are made on a daily basis, these factors can be viewed over time along with the crop performance history, to help the grower make crop management decisions.

Percentage runoff
Percentage runoff is useful for tailoring irrigation to the conditions as it provides an indication of plant water use. You will need to know the volume of water being delivered to each plant (water input) in this time to calculate the percentage runoff. To measure percentage runoff, collect the runoff from several plants in a container over a 24 hour period. You will need to know the volume of water being delivered to each plant (water input) in the 24 hour period to calculate the percentage runoff. Percentage runoff should be below about 20%. Use the following equation to calculate percentage runoff.

$$\text{Percentage (\%) runoff} = \frac{\text{water input volume}}{\text{runoff volume}} \times 100$$

As a system is managed more efficiently the percentage runoff is reduced. Efficient systems produce less than 5% runoff.

Maintaining pH and EC levels
The acidity or alkalinity (pH) of a feed solution generally needs to be between 5.5 and 6.5. The requirements may vary depending on the crop being grown. Chemicals can be used to adjust the pH of the solution being delivered to the crop. To reduce the pH phosphoric acid or nitric acid is used and to increase the pH potassium hydroxide is used. As plants take up nutrients and water from the solution the pH may drift around the root zone. Monitoring the runoff solution over 24 hours, particularly from substrate systems, provides an indication of the pH in the root zone. The pH of runoff solution should be about 6.0-7.0. If this drifts, the ratio of ammonium and nitrate nitrogen in the feed solution can be adjusted to correct the root zone pH.

The target EC of a nutrient solution can vary according to the crop being grown, stage of growth and climatic conditions. The most common unit of measurement for EC is milliSiemens per centimetre (mS/cm). First, water quality needs to be assessed before being used for hydroponic solution. Water can contain dissolved ions such as sodium, chloride, calcium, magnesium and bicarbonate increasing the EC. Species differ in their tolerance of higher solution EC (salinity). For example, tomatoes are considered tolerant, cucumbers moderately tolerant and capsicums sensitive to high solution EC. At an EC of 4.5 mS/cm tomatoes may not experience reduced growth but capsicums may suffer a 25% reduction in growth. Lettuces are grown at a lower EC range of between 0.5-2.5 mS/cm. In substrate systems the EC of runoff solution is an indication of the root zone EC. When a plant is fruiting or experiencing hot and windy conditions more water is taken up by the plant than nutrients, increasing the EC of the root zone solution. In this situation damaging levels of EC in the root zone can be avoided by lowering the EC of the feed solution or by increasing the amount of runoff (i.e. increase volume of feed solution).

Treatment of waste nutrient solution or runoff

Waste nutrient solution can become a serious environmental problem if it is not treated appropriately. A substrate system that does not recirculate drainage produces more waste nutrient solution than other types of systems. Systems that do recirculate nutrient solution require periodic nutrient solution replacement and so still produce some waste solution. A simple and effective treatment of runoff waste water can be achieved using a constructed reed bed or a wetland system. The waste water enters the reed bed or wetland system and the waste nutrients are removed through filtration and by vegetation. The wetland system itself can produce crops such as kang kong.

References and resources:

Badgery-Parker, J. 2003. *Managing waste water with a wetland*, NSW Agriculture, Orange, Australia

Casper Publications web site: http://www.hydroponics.com.au

Dirou, J., Headley, T., Huett, D., Stovold, G. and Davison, L. 2003. *Constructing a reed bed to treat runoff water – a guide for nurseries* NSW Agriculture, Orange, Australia.

Huett, D. 1993. *Managing nutrient solutions in hydroponics*. NSW Agriculture, Orange.

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

Mason, J. 2005. *Commercial Hydroponics*. 2nd Ed. Kangaroo Press, Sydney Australia.

Morgan, L. 2003. *Hydroponic Lettuce Production, A comprehensive, Practical and Scientific Guide to Commercial Hydroponic Lettuce Production*. Casper Publications, Sydney, Australia.