VG304
Investigating vegetable production systems in the United States of America

Craig Henderson
Queensland Department of Primary Industries

Know-how for Horticulture™

VG304

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Level 6
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Telephone: (02) 9418 2200
Fax: (02) 9418 1352

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Final Report **Study Tour** **Project No. VG304**

Investigating vegetable production systems in the United States of America

Craig Henderson
Senior Horticulturist

DPI Gatton Research Station

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Queensland Fruit and Vegetable Growers

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Craig Henderson

Summary.

Background.

As in the rest of the world, Queensland horticultural industries are under community and market pressure to reduce pesticide use and avoid chemical contamination of both surface and groundwater resources. Environmental and economic concerns are forcing vegetable producers to more efficiently use water, fertilisers and pesticides.

Funded by QFVG/HRDC, the study-tour investigated new vegetable production systems (research and commercial production) in California and the north-eastern states of the USA. It focused on reduced pesticide use and 'ecologically sustainable' approaches to vegetable production, including pest and disease management strategies, innovative methods of weed control, use of cover crops and mulches. As well as meeting scientists from University of California (Davis), Cornell University, University of Massachusetts and the United States Department of Agriculture, I also met local extension personnel and commercial growers, discussing those issues mentioned previously.

Results.

Reduced pesticide use. There were 3 main areas of weed management research; i) modified equipment for in-row cultivation and non-chemical weed control; ii) equipment/systems for using less herbicide; iii) use of organic mulches to smother weeds. I saw working equipment (both prototypes and commercially available models) cultivating between and even within rows of young seedling vegetables. The operating principles were very diverse, including simple vertical or horizontal spring tines, rotating spoked wheels or synthetic brushes. Each piece of equipment seemed best suited to different vegetable/weed/soil combinations. I have video and slide pictures of this machinery, as well as scientific comparisons and producer experiences. Many innovative growers and local engineering firms would be able modify their existing machinery once the operating principles are understood. Although flame/steam weeders were used on some organic vegetable farms, the philosophical basis for burning non-renewable propane, compared to a relatively safe herbicide like glyphosate, is arguable.

Spray equipment capable of applying reduced amounts of herbicides (frequently in bands behind seeders and transplanters) were being used in both research and commercial production. The equipment is very simple; more difficult is developing vegetable growing systems to manage weeds in unsprayed areas.

In California, Maryland and New York State, there was substantial research into using cover crops to suppress weeds. Cover crops were grown, then either sprayed or allowed to die naturally, with the vegetable crops sown directly into the dead or dying mulch. The mulch provided short-medium term weed suppression, reducing the need for chemical or mechanical weed control. These mulch systems required approaches to vegetable production different from those traditionally practised. A highlight of my tour was the quantity and quality of information on selection and management of optimum mulch species, and practical methods of

establishing vegetables in relatively undisturbed mulch. As we currently have a research program investigating such systems for Queensland, ideas and practical hints acquired during my tour will certainly save us preliminary research that would otherwise have been necessary.

As in Queensland, IPM is being used to reduce pesticide use, minimise the build-up of pesticide-resistant insects and diseases, and address the marketing and environmental concerns of the wider community. I saw many systems with direct relevance to Queensland horticulture, and obtained research and extension literature describing the systems and how they work. One example of an IPM system is the prediction and management of *Sclerotinia* in green beans, a major disease in Queensland production. By monitoring soil moisture at flowering time, and scouting for the presence of the disease, the need to apply sprays can be substantially reduced. The importance of field-based demonstration and extension of IPM systems cannot be over-emphasised.

Crop nutrition, fertiliser use, and water pollution. During my study tour, the problem of pollution of groundwater by both pesticides and fertilisers was a recurring issue. In Queensland, contamination of water resources by fertilisers (particularly nitrogen), is also an emerging environmental concern. Scientists in the USA are investigating this problem, finding it particularly complex and not readily overcome by simple solutions. For example, they initially thought that supplying nitrogen by 'green-manure' cover crops, ploughed in before the main crop, would give less nitrate pollution than chemical fertilisers. However, with soils in poor condition (particularly low organic matter), the green-manure crops broke down very quickly, releasing their nitrogen before the crop plants could use it. This 'organic' nitrogen then leached into the groundwater as readily as that from fertilisers. During my study tour, the need to consider major changes in production system and practices, to build up the soil and achieve better management of nutrients such as nitrogen, became more apparent.

Other issues. The development and practical use of buried drip irrigation was notable in California. The buried drip system is particularly useful in reduced-tillage production systems, aimed at improving soil condition and managing weed and pest populations.

Other areas I encountered that had obvious relevance to Queensland were: operation of extension services in various States; the use of computer-based information systems; the packaging of research information for practical extension; and the relative importance/significance of the 'organic-farming' movement.

Use of study-tour findings. During the tour, I acquired videos, slides, literature and notes on all aspects previously mentioned. The visual material is being edited and organised into packages for presentation to producers. A program of seminars to producers in the Lockyer Valley, Granite Belt, Bundaberg, Bowen/Burdekin and Atherton Tableland vegetable production areas is planned. A detailed study-tour report will be available from QFVG or QDPI. Information from the study-tour will be incorporated in future QDPI research programs. A network of contacts with people in the United States has been established; I will continue to interact with them, discussing and implementing useful R & D findings for the improvement of Australian vegetable industries.

Recommendations.

1. *By utilising targeted in-crop tillage, reduced-rate herbicide applications and strip spraying, there is scope for reducing herbicide use in Australian vegetable production. Specific developmental research is required for particular crop/weed/environmental situations.*

2. For successful adoption of reduced pesticide use strategies, producers need to closely monitor paddock situations on a regular basis, to prevent rapid escalation of problems. *Extension advice and information should emphasise that reduced pesticide inputs means greater management inputs.*

3. *Australian vegetable growers and cultivation equipment manufacturers could readily develop successful production practices and equipment, provided they incorporate the principles outlined in this report.*

4. Organic mulch systems have the potential to reduce the need for black plastic mulches in many vegetable producing enterprises in Australia. Such systems are still in the developmental stage in the USA. If considered a priority by Australian horticultural industries, research in Australia should build on the USA research findings. *Investigations into organic mulches in Australia should concentrate on the agronomy of legume/cereal mixtures, initially for production of large-seeded or transplanted vegetables (e.g. sweet corn, brassicas, tomatoes, potatoes).*

5. Pollution of water resources with nutrients, particularly nitrates, is an emerging issue for Australian horticulture. We should learn from overseas experience, and be investigating strategies for more accurately matching fertiliser use with crop demand. Quick, cost-effective soil and plant nutrient monitoring methods, correlated to plant performance should be an industry priority. Strategies for improving the soil's ability to retain nutrients in the root-zone, e.g. increasing soil organic matter content, use of cover crops, slow release nutrient sources, and water management to reduce drainage are also required. *The Australian horticultural industries need to be aware of the importance of the nutrient pollution issue, and to be pro-active in addressing it; because pressure from the wider community will inevitably evolve and escalate during the coming decade.*

6. The technical base for Integrated Pest Management (IPM) systems against many insect, disease and weed problems already exists. Adoption requires synthesis into packages and presentation of the packages in a format useable by producers in the real world. Successful adoption of IPM in the USA has generally required intensive, field-based demonstration to individual producers, as well as group extension. This involves commitment by the information agency of staff and time to the field demonstration process. *Australian horticultural industries and servicing agencies need to recognise the importance of this step in technology transfer, particularly for complex, management-intensive practices with ill-defined cost/benefit balances.*

Study Tour Review and Implications for Australian Horticulture.

Introduction.

Apart from the inevitable cost-price squeeze, the other major issue impacting on vegetable industries is a community requirement for reduced pesticide use and 'more sustainable' production. There will be substantial pressure over the coming decade for vegetable production systems to reduce overall pesticide use, and to be seen to be less exploitive of natural resources such as soil and water. Growers and horticulturists are already responding to these issues, by funding and conducting research into modifying vegetable production systems, to meet changing requirements and expectations.

Both horticulturists and growers recognise that we can no longer depend on the simple chemical 'quick-fix' to our pest management problems. With regards weed control, a shift to different weed spectrums and resistant weed ecotypes is an inevitable result of relying on a few simple methods of control. Integrated pest management systems are as important in long-term control of weeds as in the more publicised sphere of insect control. Around the world, scientists and growers are investigating new ways of managing weeds in vegetables, including new herbicide combinations, cultivation practices, mulch techniques and crop rotations. Apart from being effective in their own right, these new practices must also fit into the overall production system used by the grower. Synthesising these new systems is one of the more complicated and important challenges facing both research and production horticulturists.

Several areas in the USA, particularly California, are recognised as centres where research and practice of 'sustainable' horticultural production systems are well advanced. The aim of the study tour was to visit several such centres, to review the work being conducted and establish contact with scientists and growers involved in similar fields. Primary focus was research and practical application of new vegetable production systems that reduce pesticide (particularly herbicide) use, conserving soil and water resources whilst maintaining the productivity and profitability of producers. Findings from this tour would assist in developing vegetable production systems that look after our water and soil resources, while enhancing marketability of our 'clean-green' production image. I sought to avoid unnecessary duplication of effort in our research program, as well as indicate avenues of investigation of which we may otherwise be unaware.

The study tour sought to address the following vegetable industry goals, as outlined by the Horticultural Research and Development Corporation (HRDC).

To develop better holistic soil management practices to ensure environmentally and economically sustainable vegetable production.

To develop IPM techniques for the vegetable industry in order that the market continues to be supplied with safe and nutritious fresh and processed vegetables.

To have well communicated and adopted technology transfer to optimise productivity and quality through a coordinated approach to satisfy market needs.

As shown in the Detailed Itinerary, the study tour took place during over 2 weeks of early June 1994. I visited scientists at the University of California (Davis), USDA Beltsville Research Station in Maryland, Cornell University in upper New York State, and the University of Massachusetts in Amherst. I also visited extension workers and producers in the Salinas and San Joaquin Valleys in California, New York State and Massachusetts.

During this study tour the primary focus was on weeds, however insect and disease management, in the context of Integrated Pest Management (IPM) systems, were also frequently encountered. This reinforces the systems approach to Research, Development and Extension (R, D & E) necessary for modern horticultural enterprises.

Study Tour Findings and Discussion.

The following discussion synthesises information gleaned from the whole of the study tour, rather than each individual component. Detailed information with regard any specific location visited can be obtained by contacting the author of this report, and referring to the literature and contact addresses mentioned in the relevant sections.

Reduced pesticide use.

With relatively low prices of fuel and migrant labour, there is an historic tradition of cultural weed control in American horticulture. With increasing concern about the hazards of agricultural chemicals, there has been a renewed emphasis on non-chemical methods for weed management. Legislative trends, particularly in California, are also impacting on the current and future availability of herbicides. It is probable that such trends will also occur in Australia.

I studied 3 main areas of weed management research; i) modified equipment for in-row cultivation and non-chemical weed control; ii) equipment/systems for using less herbicide; iii) use of organic mulches to smother weeds

Cultivation equipment.

During my visit I encountered a large number of different cultivators for managing weeds in vegetable production. These ranged from prototypes to commercially available units, with various degrees of success, acceptance and utilisation by vegetable producers. Each type of machine appeared to be best suited to different vegetable/weed/soil combinations. Despite the variety of designs and operating principles, there were a number of common elements with each system.

A key issue is to have relatively flat paddocks, with well-shaped beds (not necessarily flat). This is because most systems require precise guidance of the cultivating tools, in order to:

(a) cultivate as close as possible to vegetable row, without damaging crop plants;

(b) optimise depth control of the cultivating tools, to maximise destruction of emerged/emerging weeds while burying the fewest weed seeds (minimising following germination flushes).

The most common guidance system uses a sled runner to support the cultivating frame. The runner travels along the base of the furrow beside the bed. Other guidance systems include inward angled guidance wheels that also run in the furrows either side of the bed (eg Fig. 1a), or disc coulters acting similar to a ship's rudder. At the University of California (Davis), they are developing a video guidance system (linked via computer to cultivating tools), that accurately determines where the crop row is and positions the cultivating gear accordingly.

To maximise the efficiency of the simpler guidance systems, such as the sled or angled wheel methods, it is desirable to use the same guidance systems for both planting and cultivating, and to travel in the same pattern when cultivating as when planting.

There is research in Australia investigating computer-aided tractor guidance systems, mainly in broadacre agriculture, particularly cotton. The points about guidance systems and planting patterns are directly transferable to Australian horticulture.

Systems need cultivation tools that completely destroy weeds in the inter-row. These can be virtually any design, including tines, sweeps, discs, rotary hoes, side knives etc. They should minimise the burial of new weed seeds, and not impact on the crop row. Examples include the *McDonnell* coulter/tine (Fig. 1b) and *Lucas* rotating hoe/tine (Fig. 1c) inter-row cultivators.

The most difficult part is removal of weeds close to and within the crop row. Tools that I saw for this operation included:

(a) *Buddingh* 'spider' weeders (Fig. 1d) - these consist of bent and staggered wire fingers attached to a ground-driven hub rotating in a vertical plane. The wheel travels at an angle to the direction of travel and 'plucks' or loosens weeds from beside or within the crop row. The more angled the tool to the direction of travel, the more aggressive its action. This tool generally precedes the more aggressive inter-row cultivating tools, which then tend to drag the loosened weeds from within the row. It can cause difficulties with mechanical harvesting, as it tends to create ridges in the vegetable bed

(b) *Bezzerides* 'torsion' weeder (Fig. 1e) - consists of lightly sprung horizontal tines angling in at a narrow angle either side of the crop row. They have a square profile with about a 10 mm edge, and travel just beneath the soil surface, with soil just flowing over the top of the tine. They can be set to operate very close to the crop row, with the action loosening small, just emerged weeds. The greater the angle between the tines and the direction of travel, the more vigorous the soil disturbance.

(c) *RabeWerk* (Fig. 1f) and *Einbock* (Fig. 2a) flexi-tine weeders - these are very lightly sprung arrays of tines, which can be operated close to, or even over, planting rows. The former has a mechanism where tines directly over the planting row can be lifted to a raised, non-operating position. Both these cultivators work best on tiny weeds; i.e. prior to full expansion of cotyledons. They can be effectively used post-planting, but before crops emerge, to kill emerging weeds but not harm the emerging crops. This latter technique has been successfully used in green beans and brassicas.

(d) *Barschti Brush-Hoe* (Fig. 2b,c) - consisting of PTO-driven rotating synthetic bristles, with spaced clearances for minimal damage to the planting row. These require precision guidance to avoid severe crop damage; currently achieved by a separate operator steering the cultivator. This cultivator can kill larger weeds than the other systems, but may cause substantial crop injury. In experiments in New York State, a single use of this implement gave broccoli and bean yields equivalent to those achieved with herbicide applications.

Some of these machines may be able to be imported into Australia, however a more sensible approach would be for innovative Australian producers or machinery manufacturers to adopt the principles, and adapt them to the Australian environment and vegetable production systems.

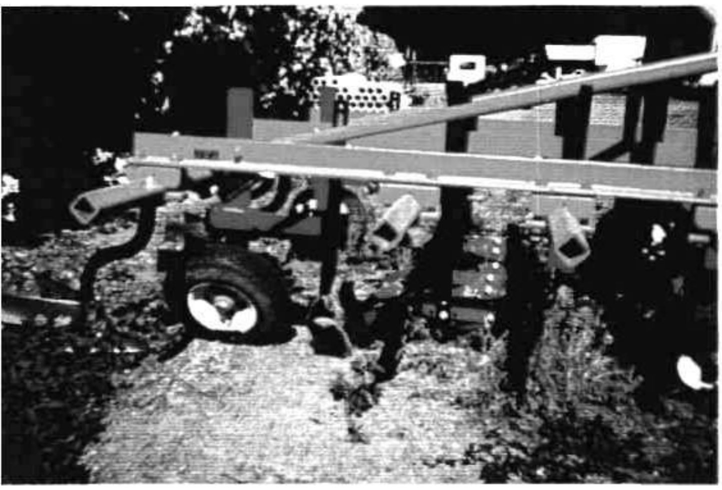
As in all aspects of weed management, successful use of these types of cultivating machinery requires a total package of weed control. Different examples illustrate this point.

One vegetable producer, has installed a buried-drip irrigation system (discussed later), which obviously limits the use of deep cultivation. His bed preparation involves reduced soil disturbance. Stalk and root residues from the previous crop are removed with a series of discs that grab and lift residues from the bed. The bed is then cultivated open and reformed with a further set of discs; all these operations are achieved with a single pass of machinery.

Professor Tom Lanini at U.C. Davis has a prototype cultivation system that scrapes soil away from beside rows of young vegetable seedlings soon after transplanting or establishment. At a later cultivation stage, when the crop plants are more robust, another pass of the cultivator throws the soil back over the plant row, burying weeds that have emerged within the row. Weeds between crop rows are managed by more conventional inter-row cultivators.

Phil Foster, an organic grower at Hollister in California, flails residues from the previous crop and rips the furrows between beds. A tractor with chisel bars on the front and a 'Go-Devil' (an implement with large sweeps and disc bed-formers, as shown in Fig. 2d) behind then makes the vegetable bed in one pass. A flame weeder (Fig. 2e) is used to control weeds prior to, and in some cases at the same time as, crop emergence.

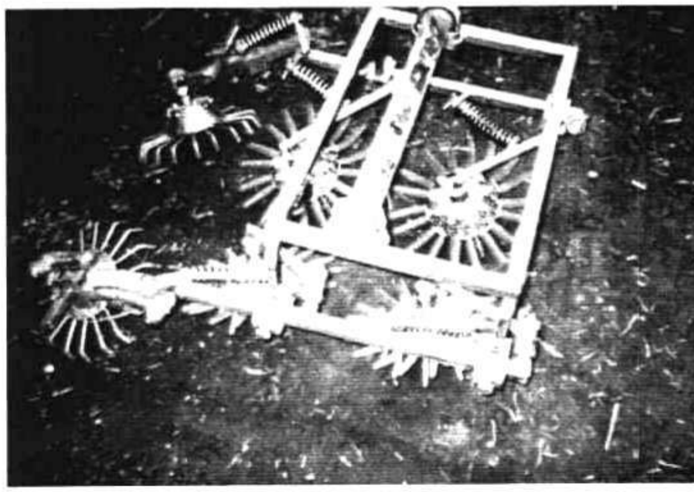
One system involved forming flat beds, then pre-irrigating to get an initial flush of weeds prior to planting. These weeds were then killed using a cultivator that only disturbed the top few centimetres of the bed. The cultivators had either very shallow sweeps, or vertical 'egg-beater' type rotary knives. The objective was to kill the emerged weeds without burying dormant



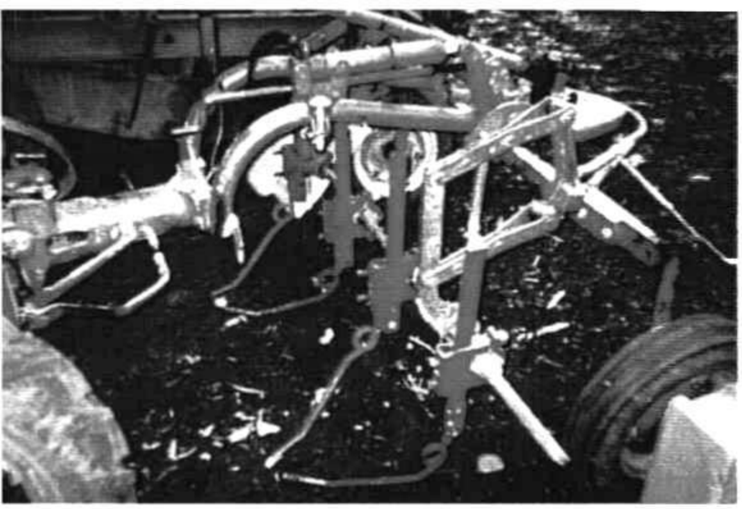
(a). Bed cultivator with angled guidance wheels

(b). McDonnell inter-row cultivator

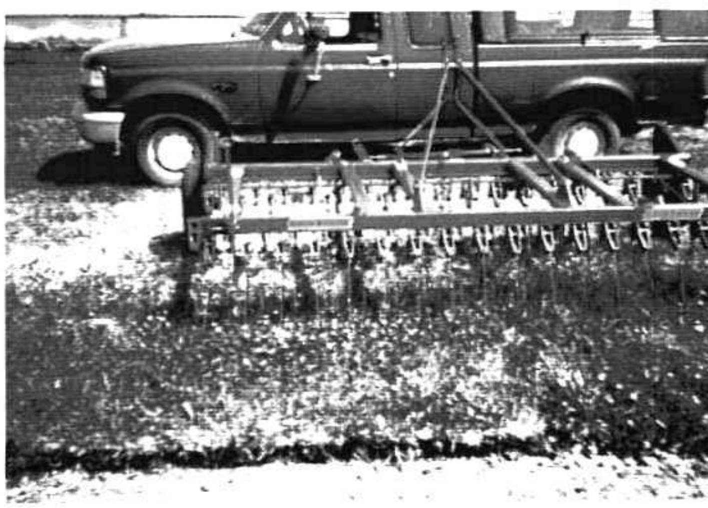
(c). Lucas inter-row cultivator



(d). Buddingh 'finger' weeder

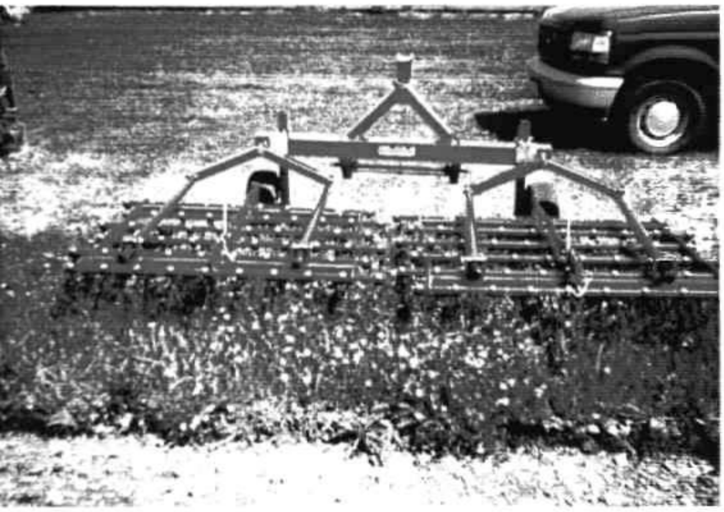


(e). Bezzerides torsion weeder

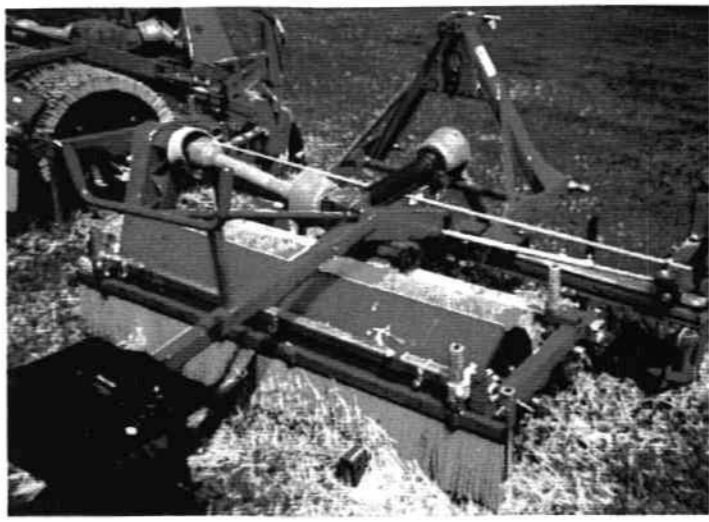


(f). Rabe-Werk flex-tine cultivator

Figure 1. Cultivation machinery for reduced-herbicide vegetable cropping.



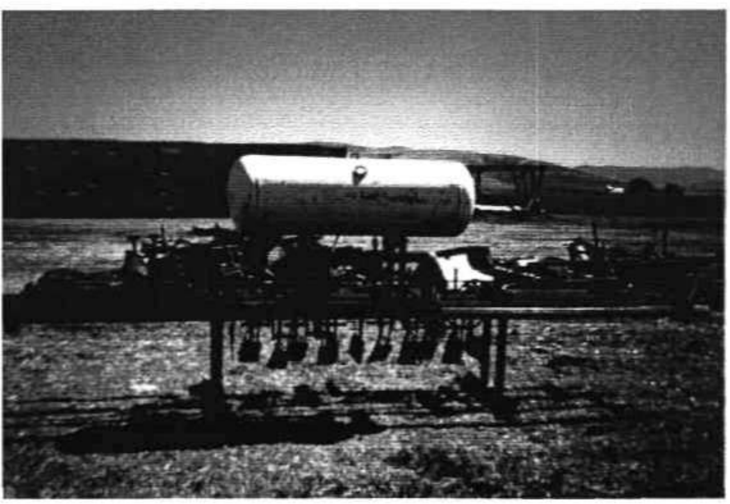
(a). Einbock flex-tine cultivator



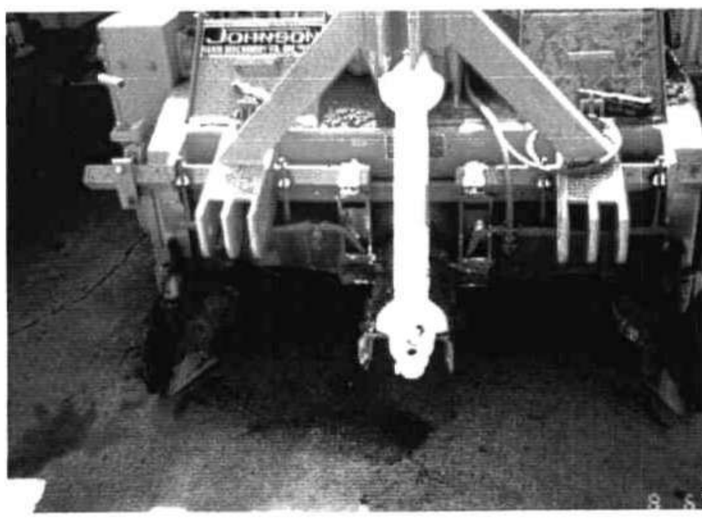
(b). Barschti brush-hoe

(c). Brush-hoe operating in broccoli

(d). `Go-Devil' chisels and disc bed-formers



(e). Propane gas flame weeder



(f). Unit for cultivating, applying and incorporating herbicid

Figure 2. Weed management equipment used in reduced-herbicide vegetable production

weed seeds. Many growers also desired to create a 'dust-mulch'; a fine, dry soil layer that inhibited further weed seed germination. Immediately following this cultivation, vegetable seeds were sown into moist soil below the 'dust-mulch' layer, relying on this residual moisture to establish the crop.

Application of the dust-mulch principle is probably not appropriate to Australian horticulture, due to our humid environment and more frequent rain events. It is probably also undesirable from a wind erosion perspective.

Flame weeders generally employ liquid propane gas as the fuel, and are commonly non-selective, although some crops e.g. onions can survive flaming just after emergence. This implement is mainly used on organic farms to kill young, emerged weeds after the crop has been sown but prior to crop emergence. The flame disrupts cell membranes within the leaf and stem tissues of young weeds. Weed species with a waxy cuticle, such as common pigweed (*Portulaca oleracea*), and grasses, are more difficult to kill by flaming. Other variants on this system use hot water or steam to achieve the same result (these are generally more costly to both purchase and operate). Use of flame weeders is generally restricted to organic farms, (based on philosophical considerations), although this equipment is sometimes found in enterprises that utilise synthetic chemicals. Control of emerged weeds prior to crop emergence can be more easily and economically achieved using knockdown herbicides such as glyphosate or paraquat/diquat combinations. Even on a philosophical basis, there is some argument that applying low concentrations of glyphosate is more environmentally acceptable and sustainable than using large amounts of a non-renewable fossil fuel such as propane.

Some vegetables are more suited to weed management using mechanical cultivation only. Generally those types that grow rapidly, and are relatively competitive, are more amenable to such systems. For example, scientists at Cornell University in New York State found green beans and transplanted broccoli were sufficiently fast-growing and competitive to give maximum yields with only a single mechanical cultivation early in the life of the crop. In contrast, sweet corn grew too slowly, and suffered yield suppression from later-germinating weeds.

In terms of overall weed management, Professor Robin Bellinder from Cornell University commented that while conventional tillage may increase yields by reducing early in-row weed competition, it may also prolong the long-term seedbank in the soil by enforcing dormancy on deeply buried weed seeds. A reduced-tillage system in potatoes relies on effective cultural weed control prior to hilling, as post-hilling herbicides did not seem to control early germinating weeds (which may have already reduced potato yields through early competition).

A critical component of successful weed management with cultivation implements is selection of the appropriate implement for the soil type, vegetable crop and stage of growth of both weeds and crop. For example, the flexi-tine type cultivators are best suited to loamy or clay soils, and will not reliably kill weeds that have developed true leaves. An interesting point discussed with scientists from Cornell was the observation that weed management with cultivation is often more successful when cultivation is conducted in the dark. Many weed seeds require light to germinate, but this light requirement may only be a few milli-seconds exposure. Cultivating in daylight, as soil is thrown into the air and then buried by the implement, can give sufficient light exposure to seeds to promote germination, even though they are again buried after cultivation. The value of cultivating in the dark, to minimise this light exposure, is being investigated both at Cornell University and in Europe.

Reduced herbicide systems.

In both California and the north-eastern United States, the use of banded application of herbicides immediately above the planting row is common, particularly in vegetables such as sweet corn and beets. Weeds between crop rows are controlled by standard mechanical inter-row cultivation. The equipment is very simple; more difficult is developing vegetable growing systems to manage weeds in the unsprayed areas, particularly late emerging weeds. From a crop competition point of view, these weeds may not affect yields. However, if they are allowed to set seed, they may provide a weed seedbank, creating problems for future crops. Much of the mulch and inter-seeding work discussed later is an attempt to address these issues of inter-row weed management, particularly as the crop canopy develops and inter-row cultivation without damaging the vegetables becomes more difficult.

Professor Tom Lanini at U.C. Davis is investigating a reduced-herbicide system in tomatoes. Rather than broadcast application uniformly across the bed, or band-spraying above the crop row, Tom sprays a variable rate of trifluralin (TREFLAN) across the bed. Directly above the planting row receives no pre-emergence herbicide; across the top of the bed 1/3-1/2 normal rate; with 2/3 - full rate in the irrigation furrow. The concept requires that the planting operation kills weeds in the crop row, while the developing crop canopy shades the planting bed and compensates for the reduced residual activity of the lower rates of herbicide. This system appeared to be working effectively when I viewed a tomato crop whose canopy covered 2/3 of the planting bed. Tom uses a cultivator/sprayer unit (Fig. 2f) that applies the trifluralin and incorporates the herbicide using a rotary cultivator in a single pass. Note the shielding that protects the crop row from herbicide application.

At the USDA Research Station in Beltsville, Maryland, Dr John Teasdale is looking at planting arrangements of sweet corn, halving normal inter-row spacings (75 cm)to 38 cm, in order to enhance the development of the crop canopy, to shade and inhibit weed emergence. Crops on this narrow row spacing are planted using a modified planter, however they can be harvested with standard mechanical equipment (2 rows feed in where a single row is normally accommodated).

All the equipment and production systems discussed previously could be readily incorporated into Australian vegetable production strategies. Many would require only minor adjustments to current practices; the real need is to evaluate their suitability to the Australian environment.

Organic mulches.

A highlight of the tour was reviewing research into the establishment and production of vegetables in reduced-tillage / organic mulch systems. This is differentiated from the use of cover crops before planting vegetables, which is discussed in a later section. Although some mulch work was being conducted in California, the bulk of the sites where I saw this concept in operation were at the USDA Beltsville Research Station (with Dr John Teasdale) in Maryland, and with Professor Robin Bellinder at Cornell University in upper New York State.

John Teasdale has been working with reduced tillage cropping into mulches for several years. The preliminary work started with field crops, notably maize, however it has since expanded into a number of vegetables, including sweet corn, green beans, rockmelons, and substantial research with tomatoes.

Although there are several variants, a common mulch system involves sowing a legume (e.g. hairy vetch) in autumn, which germinates and establishes, then lies dormant over the winter period. As the weather warms in spring, the legume grows rapidly to form a dense cover, which then naturally senesces in early-mid summer. For early summer vegetable crops, the vetch is killed by either mowing or spraying with a knockdown herbicide after flowering. The dead vetch then forms a dense mat of vegetation, that inhibits weed germination, as well as releasing nitrogen for utilisation by the vegetable crop. An example of a tomato crop transplanted into a hairy vetch mulch, in comparison with a standard commercial black plastic mulch, is shown in Fig. 3a,b.

During the tour I obtained substantial amounts of information about many aspects of plant mulches in vegetable production. What follows is a brief synopsis of that information.

Performance of different mulch crops.

Mulches can be divided into 2 basic groups; legumes and non-legumes. The most commonly used legume species in vegetable systems are various vetches, with hairy vetch (*Vicia villosa*) being the most popular. A typical use pattern is planting the vetch in the autumn; the crop establishes but then lies dormant through the winter, growing vigorously as the weather warms up in early spring. This vetch species is very winter hardy, surviving under severe snow conditions. Hairy vetch naturally senesces in mid-summer; for early summer vegetable crops it can be killed by mowing just after flowering, or by application of knockdown herbicides.

Other legumes evaluated by John include crimson clover (*Trifolium incarnatum*) which helps add bulk and structure to the mulch, with a superior final weed control mat. Fig. 3c shows tomatoes growing in a crimson clover mulch that has been mown too close to the top of the bed. Sub-clover (*Trifolium subterranean*) has also been tried; this species has the advantage of self regeneration on an annual basis. Unfortunately, sub-clover does not persist very well during severe winters, when snow is a common occurrence. In overall studies at Beltsville, hairy vetch, bigflower vetch (*Vicia grandiflora*) and crimson clover gave the best crop growth and weed suppression of the legume mulches tested. In general, legume mulches (e.g. vetch) break down more rapidly than non-leguminous mulches such as rye.

Of the mulches investigated at Beltsville, cereal rye (Fig. 3d) provides the most effective weed control, however it is also the mulch most likely to adversely affect crop growth. Whether this is due to tie-up of nitrogen, or the release of allelopathic compounds, is still unclear. Mixtures of hairy vetch and crimson clover are more successful than with either alone (Fig. 3e). However, incorporation of small amounts of rye in an hairy vetch mulch (Fig. 3f) appears a very effective system, increasing the overall bulk and structure of the mulch, with a better carbon:nitrogen ratio in the residue.

Weed emergence is generally greater under a killed vetch mulch compared to killed rye, possibly due to promotion of weed germination by nitrates leached from the vetch mulch, or inhibition of germination by allelopathic compounds leaching from the rye mulch. In dryland agriculture, natural levels of crop residues have generally been insufficient for effective weed control for the whole life of the ensuing crop.

John Teasdale has also just started investigating summer crops to provide mulches for winter vegetables. Mulch species being studied are forage soybeans, which grow to 1.5-2 m high ; closely planted grain millet; and buckwheat, which is low growing but spreads rapidly.

Mulch benefits and disadvantages.

Although many killed or living mulches let through sufficient light to allow germination of weed seed on the surface, they may reduce light penetration into the soil sufficiently to inhibit shallow buried seeds. Research has shown that inhibition of weed germination is not due to change in the wavelenths of light penetrating the mulches (germination of some weeds is affected by the ratio of red to far-red wavelength light). The effort of emerging through thick mulches may exhaust the energy reserves of weed seedlings, particularly small-seeded species. Mulches reduce soil temperature fluctuations, which can also inhibit the germination of some weeds. However, mulches can also increase soil moisture content, promoting establishment of weeds.

In studies of the effects of mulches on the micro-environment, John Teasdale observed more predatory animals under residues. In general, small-seeded or light-sensitive weed species are more likely to be suppressed by mulches, however the behaviour of individual species cannot be predicted by their germination requirements.

Hairy vetch mulches provide short-term weed control early in the growing season, but insufficient to prevent weed competition limiting growth and yields later in the growing period. Use of a killed vetch mulch did not improve the effectiveness of pre-emergence herbicides applied at either full rates or 1/4 rates. Mulch systems may be better suited to post-emergence weed control strategies.

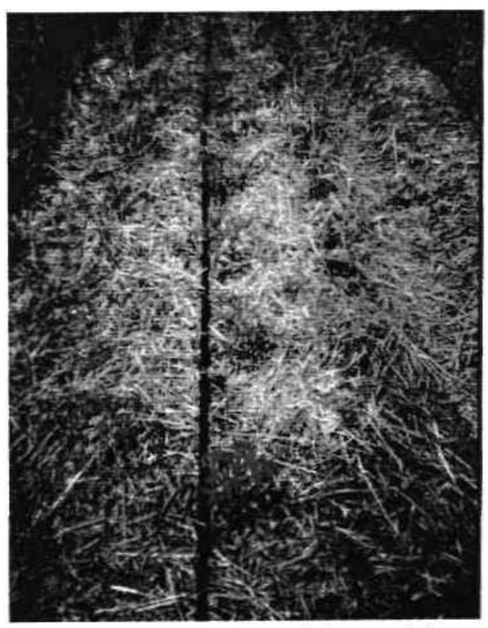
(a). Tomatoes in conventional plastic mulch

(b). Tomatoes in hairy vetch mulch

(c). Tomatoes in crimson clover mulch

(d). Tomatoes in rye mulch

(e). Tomatoes in clover/rye mulch



(f). Tomatoes in vetch/rye mulch

Figure 3. Killed mulch systems in tomato production

Research by Professor Robin Bellinder at Cornell University showed a killed rye mulch reduced emergence of redroot amaranth (*Amaranthus retroflexus*) and fat hen (*Chenopodium album*) but also suppressed potato yields, possibly due to the release of allelopathic chemicals by microbial breakdown of the rye mulch. Although later emerging weeds were partially suppressed by the canopy of the potato crop, her experience was that some form of herbicidal weed control was usually still required. Robin felt that rye mulches may assist in the use of lower herbicide rates, by providing a buffer for poor control of germinating weeds, however the mulch may also adversely affect the activity of some herbicide types.

Although the rye mulches reduced early weed germinations, Robin did not find improved control as the amount of mulch used was increased, until a level of 8 t/ha of residue was retained. Such quantities are unlikely to be present in normal agricultural situations.

The effectiveness of mulch systems was somewhat dependent on the weed species present. Rye mulch in potatoes worked relatively well when redroot amaranth or fat hen were the principle weeds, however the system was less effective when hairy galinsoga (*Galinsoga ciliata*) was the main species.

Management of killed mulch systems.

Using a vetch mulch - sweet corn production system as an example, the timing of killing the vetch in relation to planting the sweet corn can dramatically affect crop establishment, nitrogen nutrition and weed control. When the vetch is killed (by spraying with a knockdown herbicide) a few weeks before planting the sweet corn, the subsequent breakdown of the vetch gives a good release of N to the crop. However, little suppressive weed cover is left about 3 weeks after crop emergence, hence weeds become a problem. A second system involves using a no-till planter to sow sweet corn through the living vetch. The vetch is killed by mowing or spraying immediately. This leaves a good suppressive weed cover, while the sweet corn has no problem emerging through the mulch. Release of N to the emerging crop by mulch breakdown will depend on rainfall, irrigation and soil temperature. Alternatively, killing of the vetch can be delayed until after the sweet corn emerges, however depending on seasonal conditions, the vetch can be too competitive for the crop. In most situations, killing the vetch at sowing appears the system that gives the best results.

In managing a killed vetch mulch system, critical components are timing of vetch planting to target a specific senescence date, and managing the vetch mulch when planting or transplanting the crop. Modern no-till planters can easily plant through the living vetch mat with no clumping or blockages. When killing the vetch by mowing after flowering, the height of mowing is critical. The mower needs to be set sufficiently low to slash the residue as close to the ground as possible, without scalping the bed surface (note the scalping in Fig. 3c). With a pure vetch mulch, many of the stems are prostrate on the ground, making successful mowing difficult. This is one reason why a mixture with a more erect species (such as rye) may be advantageous; to lift the bulk of the mulch off the ground and make mowing easier.

Transplanted crops such as tomatoes can also be successfully planted through vetch mulches. Equipment with tines or coulters on the front are useful, provided bearings do not block with strands of vetch. More important is the use of relatively high pressure press wheels immediately behind the transplanting implement, to close up the soil around the seedling (as the vetch mat prevents soil automatically falling back into the planting row).

In initial studies, the relative performance of vegetable species under vetch mulch and conventional production varies. Sweet corn grown in vetch tends to lag behind conventional sweet corn for the first 4 weeks after sowing, however it catches up as the vetch breaks down (Fig. 4a,b). In contrast, green beans are also slower to germinate and emerge under vetch mulch, but seldom catch up to conventional beans (note the beans just emerging through the vetch mat in Fig. 4d).

Rockmelons grown in a black plastic mulch system perform better than those in vetch mulch, probably due to warmer conditions during the early growth stages (Fig. 4e,f). Similarly, tomatoes are also slower in vetch compared to black plastic, but the vetch tomatoes then outperform conventional crops during the second half of the growing period. In tomatoes, research has shown that hairy vetch used as a mulch (killed by mowing after flowering), produced yields equivalent to the use of black plastic mulch, with fewer fertiliser and pesticide inputs. The crop grown under the black plastic fruited earlier, due to warmer initial growth conditions. Experimental work shows tomatoes grown under a vetch system require less fertiliser N than conventional crops, provided the environment is kept sufficiently moist to enable breakdown of the vetch mulch.

One of the points made by John Teasdale was that evaluation of other components of the production system, such as insect management, or selection of cultivars, should be done under the killed mulch systems as well as conventional methods. Cultivars that are relatively superior under the vetch mulch system may be disadvantaged and discarded in a selection process which only evaluates under conventional systems. As an example, tomato processing companies are assisting John evaluate the relative performance of tomato cultivars under vetch and black plastic mulches.

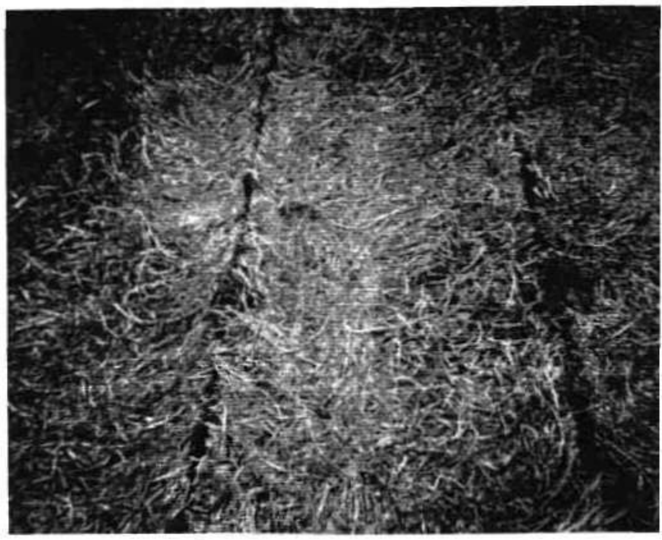
At Geneva, in upper New York, studies were being conducted on the effectiveness of trichoderma fungus (an organism that suppresses root diseases such as pythium, rhizoctonia and fusarium) under both conventional no-till and killed mulch systems. In this instance they are using a pure rye mulch, where the mulch is killed just prior to head emergence, and before the sweet corn is planted.

Use of a killed mulch system does not necessarily mean fewer herbicides. The vetch mulch may be able to delay weed emergence sufficiently to reduce herbicides, or to change from pre-emergence to post-emergence strategies. In conventional no-till sweet corn, a standard pre-emergence mixture may include paraquat (GRAMOXONE), atrazine, cyanazine (BLADEX), metolachlor (DUAL), followed by post-emergence spraying of dicamba, nicosulfuron or clopyralid (LONTREL). Given such a cocktail of herbicide use, it is not surprising that herbicide resistant weeds are a significant problem in parts of the USA (as shown in Fig. 7b).

(a). Conventional sweet corn

(b). Sweet corn in vetch mulch

(c). Conventional green beans



(d). Green beans in vetch mulch

(e). Conventional rockmelons

(f). Rockmelons in vetch mulch

Figure 4. Comparative performance of vegetables under conventional and killed mulch systems.

Much of the research information on killed mulch systems is directly transferable to areas of Australia where vegetable are grown during the spring - summer period, e.g. southern states; the Granite Belt; and summer vegetable enterprises of the Eastern Darling Downs and Lockyer Valley. There is less information available on summer-grown mulches for winter vegetable production, e.g. for the Lockyer Valley, Bundaberg, Bowen and Atherton Tableland districts in Queensland. Such work is just commencing in the USA; I will keep in touch with progress on a regular basis.

If organic mulches to replace black plastic becomes a priority research issue, then the first step will be evaluation of mulch species and production methods suited to Australian horticulture; knowing the final weed mat structure that is desired. Work such as the 'clever-clover' research by Dr Richard Stirzaker in NSW has already shown the potential of one such system in Australia.

Inter-seeding and living mulch systems.

Apart from killed mulch systems, the mulch crop can also be left to grow in the inter-row area during the life of the vegetables. Research at Geneva in upper New York State, was investigating the use of species such as perennial rye, salad burnett, rye-grass and white clover as inter-row mulches (Fig. 5). Transplanted cabbage appeared to fare much better under such a system than did green beans, which could not compete with the mulch crops. The weed suppression activity of mulches was very much allied to their growth habit; as would be expected, prostrate, mat-forming species were superior to clumping, erect types. An interesting observation was that insect infestation of the vegetables was significantly reduced where mulches were grown in the inter-row, even in small plot studies. This suggests a micro-climate effect, rather than benefits from build up of beneficials.

Where living mulches are sown at the same time as the vegetable crop, competition between the mulches and vegetables can have adversely affect crop yields. At Cornell University, Professor Robin Bellinder has found using cultivation management for early in-crop weed control, followed by later inter-sowing of the mulch species can be successful. An example of such a system in cabbage is the use of a flex-tine cultivator for early weed control, followed by sowing a legume such as Lana woolly-pod vetch about 4 weeks after transplanting. Where weeds escape this combination, post-emergence chemicals such as pyridate (TOUGH) and sethoxydim (SERTIN) can be used as salvage herbicides. Current research at Ithaca, New York, is comparing the benefits and problems associated with the use of various legumes such as woolly-pod vetch, hairy vetch and crimson clover in the living mulch production systems.

Nitrogen cycling, nitrate pollution and interactions with cover crops.

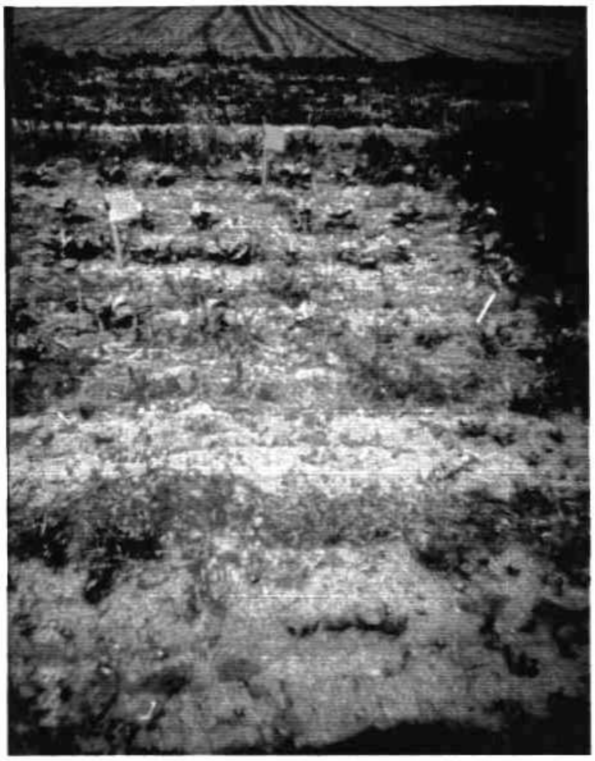
At intensive production areas such as the Salinas Valley in California (Fig. 6a), there are significant problems with nitrate contamination of both ground and surface water resources. Many of the areas that have been intensively farmed using conventional commercial practices have soils very depleted in organic matter; e.g. at Salinas, levels of 1% are common. The production system used for lettuce in the Salinas area enhances the risks of N leaching, as well as inefficient use of water resources. Many fields are furrow irrigated, with a minimum of 50 mm applied every 10 days. In such circumstances, lettuce are probably suffering stress between irrigations, with possible nutrient leaching when irrigated. There is some use of solid-set sprinklers, linear-move travelling irrigators, and buried drip systems (Fig. 6c), to attempt to improve water use efficiency. There is evidence that the timing of irrigation and fertiliser application, particularly pre-planting and close to harvest, may increase the risks of N leaching. Application of 150 kg/ha of N to a lettuce crop also seems excessive.

Professor Louise Jackson (U.C. Davis) and her staff at Salinas are investigating the cycling of nitrogen in lettuce production systems (fig. 6b), using models and radioactive tracer elements. Field verification has shown the EPIC model successfully simulates the movement of nitrate and development of lettuce crops during an annual production cycle. The aim is to use such models to evaluate potential changes in management practices, to reduce the leaching of nitrates while still maintaining lettuce yields and quality. Initial results suggest current practices probably over-fertilise, with too much early irrigation, particularly prior to planting.

Professor Jackson is also investigating the use of cover crops (such as rye) to scavenge for residual N remaining after the lettuce crop is harvested. 'Leachable' soil nitrate was reduced from 75-95 kg/ha in bare plots to 13-33 kg/ha in plots that were cover cropped and grown in a reduced-tillage system. The N content of cover crops has a very strong influence on the fate of applied fertiliser N, and hence the amount available for uptake by lettuce seedlings, during early growth stages. Cover crops with low N contents, such as mature cereals, tie up much more fertiliser N than a vetch crop incorporated at flowering. Studies by Louise Jackson have shown that when cover crops such as vetches are incorporated into the soil, there is a big boost in microbial activity for a few weeks, that then falls away. Given that the nitrogen demand by lettuce crops soon after planting is relatively low, it is possible that the rapidly mineralising organic N is available for leaching similar to fertiliser N.

Pollution of water resources with nitrates is also an emerging issue in Australia, particularly in intensively farmed horticultural areas. I suspect there will be strong community pressure in coming years to develop production systems that minimise the impacts of horticulture on this problem. In irrigated vegetable production in Australia, we need to (a) ensure vegetable producers are aware that the problem is serious, and that correct crop nutrition strategies for both optimum production and minimum pollution are becoming more essential, and (b) provide the research information and production practices that can enable these objectives to be met. Development of simple to use, quick, relatively cheap monitoring methods such as sap testing are probably going to become the essential tools used by producers to ensure they are only applying sufficient nutrients to optimise crop growth and produce quality. The nutrients need to be available when the crops need them, but sufficiently 'tied-into' the soil environment so as to minimise the leaching hazard.

In developing objective methods of making decisions on nitrogen fertilisation, Mr Tim Hartz (U.C. Davis) investigated relationships between nitrate levels in sap and N contents of plants for a range of vegetable crops including broccoli, celery, capsicums, tomatoes and water



(a). Conventional cabbage and green beans

(b). Cabbage in annual ryegrass/white clover

(c). Cabbage in perennial ryegrass/red clover

(d). Green beans in perennial ryegrass/red clover

Figure 5. Vegetable production with inter-row living mulches

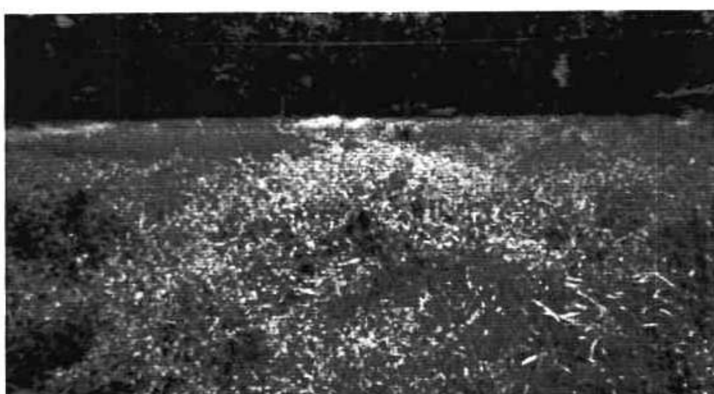
(a). Lettuce production at Salinas

(b). Researching irrigation and N management in lettuce

(c). Sub-surface irrigation in lettuce

(d). Monitoring N movement in sweet corn

(e). A white clover/annual ryegrass cover crop



(f). An hairy vetch/cereal rye cover crop

Figure 6. Nitrogen movement and environmental impact in vegetable production.

melons. The correlations were very high, although other workers suggested the relationship may be different for organic vs conventionally grown vegetables.

Tim Hartz had also developed a quick test for estimating soil nitrate levels, using a volumetric measurement of soil quantity and either colorimetric strips or a nitrate electrode to measure nitrate in the soil solution. This would be very useful for ongoing field assessment of soil nitrogen availability, prior to making decisions on fertiliser applications.

At Massachusetts University there is a strong emphasis on managing nitrogen in cropping systems (due to problems with contamination of surface and groundwater). The are seeking to understand inputs from soil organic matter, manures (depending on types and incorporation methods), legume and non-legume cover crops, composts and artificial fertilisers. They have developed a program of N fertilisation (both organic and chemical sources) for vegetables based on nitrogen balance and soil test calculations. The objective is to target applications to when the crop needs nitrogen, with particular emphasis on N soil tests prior to side-dressing. Currently this involves the use of conventional laboratory soil analysis procedures, however there may be scope for more widespread use of the simple soil nitrate test discussed previously.

In the shorter season growing areas of Massachusetts, there is a feeling that killed mulches have less application because of the limited growing period. There is more emphasis on the use of cover crops, cultivation techniques and crop rotations.

In determining appropriate N use patterns, it is important to understand the contributions made by previous rotational history, particularly where leguminous cover crops are employed. In Massachusetts, Frank Mangan is investigating N cycling after different cover crops, using soil water samplers and lysimeters, to measure nitrate movement at 30 cm intervals to 1.2 m below the soil surface (Fig. 6d). As would be expected, nitrate leaching was greatest where high N fertilisation followed a vetch cover crop, while least leaching occurred where no fertiliser was applied after a cereal rye cover. The growth and N contributions of various types of covers and mixtures, including hairy vetch, annual rye grass, red or crimson clover are being studied (Fig. 6e,f). In an experiment where cover crops were grown inter-row between capsicums under black plastic, the cover crops were too competitive with the vegetables, reducing yields.

Where vetch cover crops were grown, mineralisation of N was greater under conventional tillage systems compared to no-till establishment. Addition of fertiliser N to no-till plots increased yields to levels equivalent to or greater than those achieved with conventional tillage.

In Massachusetts, where cover crops consisting of hairy vetch / rye mixtures were grown and incorporated prior to planting sweet corn, the use of soil tests for N prior to side-dressings with N fertiliser reduced N applications by 50-150 kg/ha. Although incorporated cover crops may provide sufficient N for relatively short term crops such as melons or sweet corn, for longer-term crops such as capsicums additional fertiliser N may be required.

Investigations of cover crop and mulches in the N-E of the USA showed that in their environment, most mulches can be killed by mowing at flowering. Rye/vetch combinations proved more successful and manageable than vetch alone. In colder weather conditions, mobilisation of organic N sources may be sufficiently slow as not to meet crop requirements, particularly in no-till systems.

General cover crop information.

Cover crops can improve the soil by adding nitrogen, adding organic matter, improving soil structure, acting as a disease break and reducing nutrient leaching. They can either be incorporated into the soil before maturity (green manures), or left on the surface as a mulch. Cover crops can be used to capture nutrients below the normal root zone of vegetables; cover crops used for this purpose include grasses, brassicas, phaselia. They can be used to smother weeds, to act as living mulches in vegetable crops, or relay inter-cropped with vegetables. Cover crops can also act as an insectary for beneficial predators and parasites of crop pests.

Depending on the environment, leguminous cover crops can fix between 100-300 kg/ha of nitrogen. Cool season legumes commonly used as cover crops include species such as purple vetch, common vetch, hairy vetch, woolly pod vetch, clovers, medics, bell bean, and field peas. Warm season options include cow pea, hyacinth bean, sesbania and sunn hemp

With legume cover crops, it is essential to use the correct rhizobia inoculant with the appropriate legume species. With legumes, the timing of planting, seed bed management and nutrition are important to maximise growth and nitrogen fixation. Breakdown and hence mobilisation of N reserves is enhanced by incorporation, at least 7-10 days prior to sowing the cash crop. Incorporation of legumes at peak bloom generally maximises the amount of N returned to the soil. If left on the surface, up to 1/3 of the fixed N may volatilise. Even so, the retention of mulches on the soil surface in a no-till system may enhance weed control, earthworm activity and biological control of insects and diseases.

Common non-legume cover crops include cereals such as oats, barley and cereal rye, mustards and buckwheat. Non-legumes are used when the priorities are improvement in soil structure, capture of nutrients, or when slower breakdown is desired.

Mixtures of oats and vetch have the advantage that they can also be harvested for forage on an opportunity basis if the price is good.

The SAREP program has published a booklet (noted in the Bibliography), that summarises the experiences and knowledge of scientists and growers with cover crops in the USA. It is segmented into regional considerations, and details both leguminous and non-leguminous crops, providing information on optimum planting times, potential N benefits, weed control and agronomic requirements, and economics. It also outlines the use of cover crops in production systems for each region at all times of the year. The information is also included in a computerised database, of which I have a copy. This database can be queried by reference to any selected cover crop, production system, location etc. or combination of same.

Integrated pest management (IPM): Technology and extension.

Each of the States I visited produce publications containing guidelines for pest management and general agronomic production for a range of vegetable crops (see Bibliography). These are frequently in the form of databases, that can be updated and re-issued on a yearly basis, to include the latest changes in chemical registrations and extension information.

In New York, IPM programs are developed and extended on a whole crop basis, including management of weeds, insects and diseases. The New York State IPM research and extension program involves collaboration between Cornell University and the New York State Department of Agriculture and Markets. Apart from direct activities, the also have a catalogue of extension materials which includes videos, slide presentations, books, booklets and extension leaflets.

New York State has a series of publications that indicate methodology and threshold levels for IPM management of weeds, insects and diseases in a range of crops, including onions, sweet corn and tomatoes. As research proceeds, these publications are regularly updated every few years to include the latest recommendations. These are the Scouting Handbooks noted in the Bibliography.

A further example is a guide to Field Monitoring of Snap Beans, which includes details of systems for monitoring weeds, insects and diseases in beans, including predictive assays and management sequences for growing a bean crop. This booklet is also accompanied by a companion video as an extension package.

Useful segments with particular relevance to Queensland enterprises are segments on prediction of root-rots from soil assays and management of *Sclerotinia* using spore counts and assessments of soil moisture regimes at bean flowering. Control of root-rot in green beans was improved by incorporation of sudan grass prior to planting. Use of metalaxyl (APRON) and tolclofos-methyl (RIZOLEX) as seed coatings gave more effective root-rot control than in furrow treatment with metalaxyl (RIDOMIL). Scientists noted that control of *Sclerotinia* is improved when infected crops are incorporated into the soil immediately after harvesting, while many sclerotes are still immature and vulnerable to attack by soil micro organisms.

In other research, conventional, IPM present, IPM future and organic systems in growing cabbage were compared, in terms of economic and environmental costs and risks. The best system, in terms of economics and environmental aspects appears to be a combination of the IPM present and future production systems.

Onion blight and thrip IPM programs have been shown to reduce pesticide applications by 60% in dry years, with no adverse effects on onion yields or bulb quality. Notwithstanding these large reductions in pesticide use, with associated economic as well as environmental benefits, it is still requiring a relatively extensive extension program to facilitate adoption. This involves demonstrations and close interaction with cooperating producers, requiring a personal relationship between producers and the extension officer, rather than simply relying on sending out information for the producer to assimilate and act upon..

With sweet corn studies in New York, IPM did not significantly alter the amounts, timing or toxicity of insecticides used, nor were yields affected. There appears to be a need to look at scouting methodology to better detect small larvae on silks, and to provide superior control of insects in later stages. There is also considerable study of the use of Trichogramma for control of European Corn Borer in processing sweet corn.

In Massachusetts, research scientists and extension workers are investigating and demonstrating the viability of 'bio-intensive' production systems in crops such as sweet corn, using demonstrations on growers' properties as experimental units. They have found that practices such as banding of herbicides with inter-row cultivation, delayed herbicide application, provision of nitrogen by the use of hairy vetch cover crops, scouting for insects and the use of Bt-based pesticides, have provided yields and produce quality equivalent to more chemically-dependent, conventional production systems.

In Massachusetts, part of the package to accelerate adoption involves reference booklets providing information to help identify insects and beneficials, crop growth stages, the use of monitoring and control traps, IPM spraying technology and equipment. They are investigating setting an IPM standard certification system, by which growers can achieve levels of accreditation based on production practices. These can include issues such as monitoring and managing soil and plant nutrition , as well as insects, weeds and plant diseases. Each strategy is allocated points, with growers having to achieve a certain score to qualify for certification.

In the vegetable producing areas of the USA, there is an extensive amount of information available on IPM, and commitment by the various government, research and education agencies to its promulgation. The information is available in an array of formats as previously discussed. Nevertheless, a very striking point was that adoption, even by relatively educated and advanced sectors of the horticultural industry, still required a focused program of demonstration in the field, via interaction between individual researchers, consultants and producers. Simply presenting information, in whatever format, did not result in adoption. I suggest this an important issue, which all vested groups in Australia should take into account when making decisions on technology transfer strategies.

Environmental Impact Quotient.

As part of the effort in developing more environmentally friendly agriculture, scientists with the new York IPM program are developing a system to objectively measure the environmental effects of pesticides and total production systems. Their concept involves an Environmental Impact Quotient (EIQ), which is applied to individual pesticides, and thence a field use rating which can be used to evaluate single pesticide applications or whole production systems. The formula for deriving the initial EIQ for a pesticide includes risks to; the applicator, picker, general consumer, groundwater, aquatic animals, birds, bees, beneficials. These are used to formulate components for farm-worker, consumer and ecological risks, averaged to give an EIQ for the active ingredient of the pesticide.

A field-use rating is derived by multiplying the EIQ by the % active ingredient in the formulation, and then by the rate used in the field..

An example of its use in an Australian broccoli crop could be to evaluate alternatives for pre-emergence herbicide application. Application of 3.5 L/ha of DUAL has a field rating of 45; 2 L/ha of STOMP with 8 L/ha of RAMROD rates at 86, while 1.5 L/ha of GOAL has a rating of 17 (higher ratings indicate greater environmental impact). Thus, due to its lower application rate, GOAL has the lowest field rating, even though the EIQ for its active ingredient was the highest.

The use of systems such as the EIQ should not be used as the sole arbiter of the environmental impacts of pesticide applications, but rather as a component of more comprehensive evaluations, that take into account long-term effects, interactions with other crop rotations etc.

Farming systems.

California has a broad sweep of farming philosophies and systems, from small, family-run farms, to large, company owned, vertically integrated 'factory'-type enterprises. As an example, in some areas of California, particularly in the southern parts of San Joaquin Valley and in the Salinas Valley, there is extensive use of soil fumigants such as methyl bromide or metham-sodium. The latter fumigant is occasionally applied through sprinklers and watered in. In combination with 'dust-mulch' techniques, and the extensive nature of the paddocks, there is a real contrast with the smaller, less intensive and seemingly more environmentally friendly systems in areas around Hollister and in the eastern USA. My personal view is that Australian vegetable producers should be wary of heading down the large-scale, high chemical use, factory-farming approach, as it does not seem to be sustainable either economically or environmentally, even in the short-term.

Growers, scientists and extension workers are looking for new ways to produce crops and manage problems. For example, yellow nutsedge (*Cyprus esculentus*) is a significant problem in California, particularly where solanaceous crops such as tomatoes or capsicums are frequently grown in a short rotation. Jesus Valencia, an extension officer in Stanislaus County, is investigating the use of sweet potato as an inter-crop between the tomato rows (Fig. 7a); there is some evidence that the sweet potato can suppress and smother the weeds. This system appears fraught with problems, including establishment of the sweet potato, preventing excessive competition with the main crop, and harvesting and marketing the sweet potatoes.

In California, processing tomatoes are cropped in rotation with wheat, often in a year to year rotation. Because much of the vegetable land is leased from absentee landlords, there is a reduced 'land ethic' in terms of building up the soil resources, improving soil structure and nutrition, or long term pest management. Although in recent years processing tomatoes have been established by direct sowing because of cost considerations, there is a shift back to transplanting because of problems with disease and weed management. I saw several areas where problems with crop establishment were apparent. Some of these appeared to be due to herbicide damage from trifluralin (Fig. 7c), incorporated prior to transplanting. Note the formation of callus tissue around the stem at ground level (Fig. 7d), symptomatic of damage from the DNA herbicides. The transplanting process may place even more chemical around the root ball than a post-transplant application. Other problems seemed to be insufficient frequency of irrigation after transplanting, transplanting too deeply, and poor quality control by some seedling producers.

Tom Lanini at UC Davis is comparing production, economic and environmental consequences of different crop rotations and agronomic practices in vegetables (particularly tomatoes). He is investigating conventional rotations using synthetic fertilisers and pesticides, low input systems which utilise cover crops and IPM procedures, and certifiable organic systems. This work is still in the initial stages. Although cover crop systemsare less reliant on synthetic fertilisers, they do require more irrigation water (to grow the cover crops).

Composting.

In parts of California there is increasing interest and utilisation of compost as a source of nutrition, organic matter and general soil structure improvement. This is particularly the case with certified organic growers, but also with producers concerned about reducing synthetic pesticide and chemical use. Apart from specific recipes for making compost, including different sources of raw materials, use of inoculants and composting conditions, there is a deal of occasionally heated discussion about the philosophies behind composting and the proposed benefits (e.g. composting vs incorporating a cover crop). Apart from the producer end, there is also a deal of interest in using composting to cope with urban wastes, both traditional garden refuse, food and cellulose based products, but also the more difficult materials such as human sewage and factory effluents. Various levels of government and urban community groups are supporting investigations into the potential for such waste management systems. On the other hand, some producers are concerned that in the end they will be forced to act as the *de facto* refuse tips for urban communities, with little control over the nutritional quality and potentially polluting or toxic nature of composting materials.

Some growers such as Pat Herbert at Hollister are producing compost on a large scale, using earth moving machinery and hectares of land. Pat sources manure from feedlot dairies in the Central Valley (approx $12/t), adds straw, urban green waste and processing factory wastes. Moisture in the compost piles is gradually increased by 5% per day to the appropriate water content, then turned and watered every few days to keep hot and moist.

The mature compost is currently spread at about 5 t/ha,; eventually Pat hopes to increase this to 25 t/ha. As part of Pat's production philosophy, he has eliminated his use of pesticides for soil insect and weed control; the money he saves on pesticide application he uses to employ labourers to hand chip the vegetables and accepts occasional loss from soil insects.

(a). Sweet potato to suppress nut sedge

(b). Herbicide resistant weeds in corn

(c). Trifluralin damage in a tomato crop

(d). Callus formation in trifluralin damaged tomato

(e). Sub-surface drip irrigation in capsicums

(f). Home-made sub-surface drip installer

Figure 7. Miscellaneous production issues in American vegetable production.

Farming philosophies.

Successful organic and reduced pesticide producers appeared to have many things in common. It was imperative to keep good paddock records, noting crop sequences, inputs and particularly pest and disease problems. Paddocks also had to be closely monitored on a regular basis; problems can very quickly get out of control and the options for coping with them are more restricted. These enterprises all relied on cheap, plentiful labour, which had to be reliable. Many producers were prepared to plant vegetables to keep their labour employed, in the full realisation that they would probably not make any money on that particúlar crop. Many of their management decisions are much more influenced by social and philosophical considerations, as opposed to scientific and economic rationales, than are decisions made by more conventional producers.

Many organic growers use IPM systems; scouting their crops to determine pest pressures (albeit their options for killing the pests are more restricted). In many instances they have determined it is simply uneconomic to grow specific crops at certain times of the year, when pest pressures are too great to manage. This problem is not unique to organic growers, however it is less likely to be masked, in comparison with more conventional growers, who may resort to using large amounts of pesticides.

Many organic growers, and even conventional producers grow rows of insectary crops amongst their vegetables, to act as sources of beneficials. Companies are marketing proprietary mixtures of seeds for planting in these rows, although many growers actively select species for their particular environment/crop/pest combinations.

Irrigation management.

Irrigation scheduling.

Although irrigation scheduling is currently not widely practised in California (despite that state being the source of many manufactured irrigation scheduling tools). Interest in the concept is ongoing, particularly in areas where drip irrigation is becoming more common, or water shortages are more prevalent. Where irrigation scheduling is in operation in California, it is mostly based on ET estimates; there is currently little interest in complex technological equipment.

Investigations with drip systems in tomatoes showed yields and quality could be maximised using a climate based irrigation scheduling system. This involved computation of potential evapotranspiration using weather station data, which was then converted to actual evapotranspiration by using crop coefficient or percent groundcover methods. The percent groundcover method gave better results, because it took into account fluctuations in crop performance due to cultivar, nutrition, disease management and seasonal growing conditions. In conjunction with the local and state government authorities, the University of California is establishing a network of weather stations throughout the major irrigation areas of the state. The CIMIS (California Irrigation Management Information System) stations output daily weather, including daily reference potential evapotranspiration (roughly 75-80% of Class A Pan evaporation), which can then be used by irrigators to schedule watering. The CIMIS information can either be directly accessed by on-line computer, by fax from a central information station, or by listening to local radio which broadcast daily values.

Although such a system may be possible in Australian vegetable growing areas, our sub-tropical, humid climate, with variable and unevenly distributed rainfall would make it less reliable. This is particularly the case with shallow-rooted crops sensitive to water stress, such as lettuce, celery and broccoli, where produce quality is rapidly affected. I believe systems where some measure of soil or plant water status are directly measured (e.g. tensiometers or capacitance probes) are preferred in our environments.

In California, Tim Hartz (U.C. Davis) observed that a deficit irrigation strategy, where water applied at each irrigation was less than that required to fully wet the plant root zone, resulted in slightly lower vegetable yields on a sandy textured soil, but did not adversely affect production on soils with a higher clay content. There is probably scope for deficit irrigation in some vegetable crops in Australia, such as sweet corn and processing tomatoes, when grown on finer-textured soils.

Buried drip irrigation systems.

Tim Hartz commented that efficiency gains from drip systems, as compared with sprinklers largely depended on the management of the systems being compared. Yields and water use efficiencies under well run sprinkler systems were very close to those achieved using drip irrigation. In most instances, crops watered with buried drip systems are initially irrigated using overhead sprinklers during the establishment phase. In shallow-rooted crops such as lettuce (with little tolerance of water stress), there can be appreciable deep drainage from buried drip systems, despite their claimed water use efficiencies. This is because of the requirement to keep the surface layers of the soil relatively moist. Tim quoted values of 330 mm of irrigation applied, when only 250 mm was used by the lettuce crop.

In buried drip systems, the drip line is generally about 15-20 cm below the surface in shallow rooted crops such as lettuce, and 30 cm or deeper in crops such as tomatoes, with emitters every 20-30 cm within the row (Fig. 7e,f). A standard system would involve 1 drip line per 1 m wide bed, with one row of a crop such as tomatoes, or 2 rows of crops such as lettuce or broccoli, per bed.

In the loamy Central Valley soils of California, where different arrangements of beds and buried drip lines in lettuce production (with 1-2 m wide beds and 1-2 drip lines per bed) were compared, highest yields were obtained in beds 1.5-2 m wide, with 2 drip lines per bed.

Beds are generally retained for several years, and cultivated over the top using practices such as the 'Sundance' system, where sets of large disks that pluck residue (roots and all) from the bed, shallow work the bed and then re-form the bed, all in a single pass of a (large) tractor. Effective handling of crop and cover crop residues is vital, given that broadcast deep cultivation is no longer an option. In a semi-permanent buried drip irrigation system, the precise location of beds in relation to the buried drip lines year after year is also critical.

Where semi-permanent buried drip irrigation systems are used in semi-arid environments, build-up of salts in the bed over time can be an important issue which needs to be closely monitored.

Root penetration of the drip lines via emitters can be a problem, particularly in weedy situations. One approach being investigated is chemigating trifluralin through the irrigation system. This herbicide, which inhibits root growth, does not move readily through the soil, but remains relatively close to the emitters, thus preventing root entry into the drip line but not substantially affecting the crop root system.

Buried-drip systems probably have application in Australia, although proponents in this country probably over-emphasise potential improvements in water use efficiency (particularly in comparison to well-managed sprinkler systems). Buried-drip irrigation makes most sense in reduced-tillage, permanent-bed production systems. These are still uncommon in Australia, and probably require substantial R&D before they would be accepted by mainstream vegetable producers.

Dissemination of information.

The information obtained during the study tour will be incorporated into our current research, development and extension programs. Ideas on cultural methods of weed control, reduced herbicide applications (low rates, strip spraying), IPM systems for insect and disease management, and deficit irrigation management will be used in our project investigating production systems in green beans, beetroot and sweet corn. Information on integrated weed management (timing of weed control, use of mulches, seedbank management) will be used in our integrated weed management project. All the information will be used when developing new R, D & E projects in ensuing years.

Copies of this report will be sent to QFVG and HRDC. In ensuing weeks it will be redrafted and published as a QDPI Monograph, for circulation to other QDPI scientists, extension workers, as well as horticultural personnel in other government, producer and agri-business organisations.

Sections of information (e.g. killed mulch vegetable production), will be developed and published as extension articles in producer newsletters such as *Good Fruit and Vegetables* and *Fruit and Vegetable News*. Where relevant, the information will also be included in pertinent sections of the QDPI AgriLink series.

I intend to inform interested people of the availability of the collected material (videos, slides, books, booklets) noted in the Bibliography, which they are welcome to borrow (or copy where permissible).

Unfortunately, video footage that I took during the study tour is not readily useable, due to problems with the hired video camera. After significant editing, some useful footage may be obtained. I took over 200 slides during the visit, which have been catalogued and organised into packages for scientific and producer oriented seminars. It is possible that by combining the slides with the retrievable video footage, an audio-visual package highlighting the findings of the tour could be prepared.

A program of seminars to producers, professional organisations and QDPI personnel is being developed and will be implemented during 1995. These will include seminars in the Lockyer Valley, Granite Belt, Bundaberg, Bowen/Burdekin and Atherton Tableland vegetable production areas.

As a result of my tour, I have established a network of contacts with horticultural personnel in the USA. I will continue to interact with them in the coming years, discussing their ongoing results and implementing useful R, D & E findings for the improvement of Australian vegetable industries.

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Contacts.

Dr Tom Lanini (Weed Agronomist),
Weed Science Program, University of California,
DAVIS CALIFORNIA 95616 USA.

Dr Tim Hartz (Extension Vegetable Specialist),
Department of Vegetable Crops, University of California,
DAVIS CALIFORNIA 95616 USA.

Dr David Chaney (Analyst - Annual Cropping Systems),
Sustainable Agriculture Research and Education Program, University of California,
DAVIS CALIFORNIA 95616 USA.

Mr Richard Smith (Area Farm Adviser),
University of California Cooperative Extension
649-A San Benito St
HOLLISTER CALIFORNIA 95023 USA.

Professor Louise Jackson (Plant/Soil Scientist)
Salinas Vegetable Crops Laboratory, UC Davis
1636 East Alisal St
SALINAS CALIFORNIA 93905 USA.

Mr Paul Buxman (California Green Fruit Producer)
Sweet Home Ranch
4399 Avenue 400
DINUBA CALIFORNIA 93618 USA.

Mr Harold Kempen (Weed Management Consultant)
2707 Rio Vista Drive
BAKERSFIELD CALIFORNIA 93306 USA.

Dr John Teasdale (Weed Scientist and Plant Physiologist)
USDA-ARS Weed Science Laboratory
Beltsville Agricultural Research Centre
10300 Baltimore Avenue
BELTSVILLE MARYLAND 20705-2350 USA.

Professor Robin Bellinder (Weed Scientist)
Department of Fruit and Vegetable Science
134-A Plant Science Building
Cornell University
ITHACA NEW YORK 14853-0327 USA.

Professor Thomas Bjorkman (Crop Physiologist)
Department of Horticultural Sciences
Hendrick Hall
GENEVA NEW YORK 14456-0462 USA.

Ms Mary Jane Else (IPM Adviser)
Department of Plant and Soil Sciences
French Hall, University of Massachusetts
AMHERST MASSACHUSETTS 01003 USA

Mr Frank Mangan (Extension Specialist)
Department of Plant and Soil Sciences
Bowditch Hall, University of Massachusetts
AMHERST MASSACHUSETTS 01003-0910 USA.

Detailed itinerary.

Saturday, 4 June 1994.
Travelled from Gatton to San Francisco, California.

Sunday, 5 June 1994.
Travelled from San Francisco to Davis.

Monday, 6 June 1994.
Met with University of California Davis host Professor Tom Lanini, who accompanied me most of day; took me to meetings with University of California staff, including irrigation specialists Tim Hartz and Blaine Hanson, and Sustainable Agriculture Research and Education Program Coordinator David Chaney. Afternoon with David Chaney and staff at SAREP centre; also visited field sites with Gene Mayo at Yolo County.

Tuesday, 7 June 1994.
Travelled with Tom Lanini to Stanislaus County, met with adviser Jesus Valencia, looking at field sites in vegetable crops. Afternoon with Tom Lanini looking at research sites. Received literature and videos on weed control and cover cropping. Travelled to Hollister.

Wednesday, 8 June 1994.
Breakfast meeting with County Adviser Richard Smith and organic growers' group. Visited large-scale organic (Phil Foster) and composting (Pat Herbert) farms. Departed Hollister, drove to Salinas. Met Professor Louise Jackson, toured USDA Research Station and farm sites looking at nitrogen cycling. Overnight Hollister.

Thursday, 9 June 1994.
Travelled to Fresno, met with County Adviser Bill Fischer, discussing weed control in vegetables. Departed Fresno, drove to Dinuba. Met with organic grower Paul Buxman, toured research and production orchards. Paul hosted me overnight at his home.

Friday 10 June 1994.
Toured Paul Buxman's farm reviewing organic production and pest management strategies. Departed Dinuba, drove to Bakersfield. Met with agricultural consultant Harold Kempen, visited field sites and discussed weed control technologies.

Saturday 11 June 1994.
Free day. Travelled from Bakersfield to Los Angeles.

Sunday 12 June 1994.
Travelled from Los Angeles to Beltsville, Maryland, staying overnight with Dr John Teasdale, USDA weed scientist.

Monday 13 June 1994.
Travelled to USDA Research Laboratories Beltsville. Visited John Teasdale's research sites at Research Station all day. Overnight with John.

Tuesday 14 June 1994.
John drove me to Beltsville labs; met with other staff during morning, including Ben Coffman (research agronomist) and Research Manager Jim Anderson. Travelled from Beltsville to Syracuse, New York.

Wednesday 15 June 1994.
Travelled from Syracuse to Ithaca.). Drove to Ithaca Research Farm, met Professor Robin Bellinder (Cornell University) and staff; reviewed experimental sites and equipment. Hosted overnight at the home of Robin Bellinder in Ithaca

Thursday 16 June 1994.
Travelled to Geneva; visiting the New York State Research Farm and discussed IPM with staff, reviewing several research sites. Departed Geneva and travelled to Amherst in Massachusetts. Had dinner meeting with Mary Jane Else (University of Massachusetts IPM Adviser).

Friday, 17 June 1994.
Visited research sites and growers around Amherst with Frank Mangan (University of Massachusetts Extension Specialist), reviewing use of cover crops in vegetable production.

Saturday, 18 June 1994.
Travelled to Los Angeles via Boston. Departed from Los Angeles en route to Australia.

Sunday, 19 June 1994.
In-flight; crossed International Dateline.

Monday 20 June 1994.
Travelled from Sydney to Gatton.