VG97073

Integrated weed management, cover crop, mulch and rotation management in vegetable production systems

Craig Henderson
Queensland Horticulture Institute

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VG97073

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Queensland Fruit and Vegetable Growers

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Media summary

Society demands safe, inexpensive food, produced with minimum environmental impact. Within these legitimate constraints, vegetable producers still need to manage weeds, but because of commercial considerations amongst agribusiness, and the producers' declining profit margins, they have fewer tools at their disposal.

In our project we developed new herbicide strategies, by consulting industries and statutory bodies, and conducting efficacy and crop phytotoxicity evaluations (15 primary experiments). We focussed on reduced environmental chemical loads, improved weed management and profitability, e.g.:

- Oxyfluorfen (e.g. GOAL®) in onions, and brassica vegetables, has been widely adopted by producers. These uses reduce herbicide volumes and costs by 30-80%, improve weed management, and carry less risk of crop damage.
- Low-rate, sequential herbicide strategies in beetroot are now industry standard. They have reduced total herbicide volumes and crop damage by 30%, whilst improving weed control.
- We are concluding a data package for using clopyralid (LONTREL®) in brassicas.

Refer to product labels and permits, or Queensland Department of Primary Industries Prime Notes, for specific information on new uses.

Industries need best practice for herbicides described <u>before</u> new uses are legalised. Otherwise, adverse field experience may dissuade chemical companies from supporting Minor Use permits or label extensions. Industries must consider environmental impacts of new uses, as community expectations on this issue will become more rigorous.

In 18 collaborative demonstrations with producers, they recognised and acted on the importance of weed identification, herbicide selection and timing.

Viable killed-mulch systems, (where vegetables are planted directly into min-till killed cover crops), proved elusive. Vegetable yields were inconsistent, possibly due to natural chemicals released (or nutritional tie-up) as cover crop <u>roots</u> (not the surface residues) broke down. Forage sorghum was a good mulching crop when sown in rows (not broadcast), and then killed, and rolled (not cut) at six-eight weeks after planting. Around the world, seemingly viable killed-mulch systems have been developed, but not widely adopted. Understanding why may help guide future work.

Technical summary

Consumers and society demand safe, inexpensive food, produced with minimum environmental impact. Vegetable producers are confronting declining profit margins, falling commercial investment in herbicide development, whilst weeds require management. Our project expanded the herbicide options and use strategies available to producers, and reduced the associated environmental risks. We demonstrated principles of integrated weed management, as well as alternative weed management practices and vegetable production systems.

We developed new legal herbicide uses by consulting industries and statutory bodies, and conducting extensive efficacy and crop phytotoxicity evaluations (15 primary experiments). We focussed on strategies that reduced chemical loads on the environment, improved weed management, reduced risks of herbicide resistance, and maintained or improved producer economics. In a series of 18 experiments with collaborating producers, we demonstrated integrated weed management principles, current and potential weed management practices. We investigated alternative vegetable production systems, based on killed-mulch techniques (where vegetables are planted directly into min-till, killed cover crops), in nine experiments on Gatton Research Station.

New legal herbicide uses that we developed and refined, for oxyfluorfen (e.g. GOAL®) in onions, broccoli, cabbage and cauliflower, have been immediately and widely adopted by producers. These uses reduce herbicide volumes and costs by 30-80%, improve weed management, and have equivalent or less risk of crop damage. We developed a package of efficacy, phytotoxicity, and residual activity data on using clopyralid (LONTREL®) in brassicas. We are still negotiating with relevant companies and government agencies to legalise this use. Our low-rate, sequential herbicide strategies in beetroot are now industry standard, and have reduced total herbicide volumes and the risks of crop damage by 30%, whilst improving the reliability of weed control.

In our collaborative demonstrations, producers recognised the importance of weed identification, herbicide selection and timing, and acted accordingly. Interest in manipulating crop rotations, selective hand weeding and a program of seedbank depletion was more subdued.

Killed-mulch systems still require significant development before they will be attractive to industry. Vegetable yields are inconsistent. Reasons are not clear; possibly allelopathy or nutritional impacts as cover crop roots (not the surface residues) break down. Forage sorghum was a good cover crop for mulching. It must be sown in rows (not broadcast), killed, and rolled (not cut) at six-eight weeks after planting. Good contact between the vegetable transplant cell and soils is required. In our experiments, surface mulch improved crop performance, without increasing pests or diseases.

The margins between effective weed management and crop damage are very narrow for many herbicides used in vegetables. Industries need to have best practice for these herbicides described before new uses are legalised. Otherwise, adverse field experiences and subsequent litigation by growers will dissuade chemical companies from supporting new uses. Industries must consider environmental impacts of new uses, as community expectations will become more rigorous.

If industry believes an 'integrated weed management' approach, similar to IPM for insecticides, is desirable, then an improved understanding of 'barriers to adoption' in this issue will be required. Weed management is not viewed as a high priority by most producers, compared to other issues they are currently coping with.

A detailed review of alternative production systems, including research into killed-mulch type approaches, may be timely. Around the world, some very good and seemingly viable systems have been developed, but not widely adopted. Reasons why may be helpful in guiding future work.

Introduction

Managing weeds is becoming increasingly difficult for many vegetable producers. Problems arise with convergence of agronomic, environmental, economic, social and political issues.

Maintaining herbicide options

Certain weeds are becoming more resistant to a suite of herbicide types and modes of action. This resistance is increasing globally, with Australia having some of the most serious instances (Preston *et al.* 1999, Powles *et al.* 1997). Many Australian projects are currently addressing issues related to weed resistance management in agriculture (ARRIP 2000). Our current monoculture systems, with relatively inflexible rotations, also create weed spectrums difficult to control using conventional practices. Larger farms, less time for field detail, widespread movement of machinery and people, increased use of off-farm organic materials such as manures or composts (Tymms *et al.* 1999), enhances the probability of introducing new weed species or biotypes.

Economic, social and political pressures mean herbicide options available to producers have declined during the past five years, with de-registration, or withdrawal of products from the market.

Current products are withdrawn due to small market size (and thus profits), lack of incentive to generate new data to meet changing environmental or health guidelines, or incapacity of chemicals to comply with environmental or health standards. Examples of herbicidal compounds withdrawn from sale because of economic considerations include chlorthal di-methyl and methazole. Both products were still safe, still effective, still registered, and still widely used. Another example is the worldwide phase out of methyl bromide as a fumigant, because of atmospheric integrity considerations.

New registrations in vegetables are uncommon, primarily because of high costs and low returns to chemical companies. Macleod (1996) estimated it cost $250,000 to register a completely new product, and $100,000 for a new use of an existing product. He suggested chemical companies would need annual turnovers of $1,300,000 and $500,000 respectively to make registrations worthwhile. For example, a chemical manufacturer would need an assured return of $130 per annum for every hectare of lettuce planted in Australia, to justify adding that crop to an existing label. This problem can be partially overcome by adding several crops to a label at the same time to defray costs.

To maintain viability, Australian producers need to retain a diversity of chemical options. Our international competitors have access to a greater range of herbicides (eg. beetroot or onion herbicides in New Zealand). These chemicals must be safe and effective. As an adjunct to the standard registration system, an ongoing effective Minor Use Approval system would assist in meeting the needs of vegetable producers and the broader community.

Implementing Integrated Weed Management technologies and strategies

Our environmentally conscious global society is continually questioning the use of synthetic chemicals as the principal mechanism for managing pests. These concerns will inevitable lead to more stringent laws which producers must abide by. The ability to promote an environmental consciousness will be required by vegetable producers to maintain or enhance market share, both domestic and export. Most vegetable producers recognise these problems and are endeavouring to address them.

Implementing an Integrated Weed Management (IWM) program on farms means access to a diversity of weed control options (Henderson and Bishop 2000). Numerous Australian studies have shown the biological, environmental and economic benefits of adopting an integrated approach to weed management (Penfold and Miyan 1996, Medd and Jones 1996, Wallace and Bowran 1999, Whish *et al.* 1999). Emphasis is on diverse systems that reduce weed seedbanks over time (Walker *et al.* 1999). Almost invariably, these studies show higher levels of management and operational flexibility are required than are evident in conventional production systems.

Apart from conventional weed control practices, the diversity of considerations include selecting appropriate crop rotations, choosing effective strategies that don't restrict future flexibility, and managing cover crops and/or mulches for maximum agronomic and environmental benefit. Due to an over-reliance on simple weed control solutions, there has been little research, development, or extension effort on integrated weed management issues in vegetables.

Fortunately, simple strategies and principles that producers could immediately adopt are already available to reduce their weed problems. However, these need to be demonstrated as economically viable, and adaptable to individual producers' enterprises. There is a general recognition that more diverse farming systems, involving less repetitive chemical use, less cultivation and less monoculture cropping can bring agronomic, environmental, and economic benefits. These require incorporation into viable vegetable production systems.

Managing cover crops and mulches in vegetable production

The roles of cover crops, judicious selection of crop rotations, and development of new mulch management systems are the focus of new and innovative research throughout the world, including Australia. International examples include the Sustainable Agriculture Research and Education Program (SAREP) conducted by the University of California; living and killed mulch research for vegetable production in Florida and Maryland (e.g. Abdul-Baki *et al.* 1996), New York State (Lanfranconi *et al.* 1993), and California (Hutchinson and McGiffen Jr. 2000, Lanini *et al.* 1989).

In Australia, Stirzaker (1996) investigated vegetable production in various cover crop/mulch/tillage systems. Sherriff *et al.* (1999), Olsen (pers. comm.) and Rogers (pers. comm.) have looked at vegetable production in Tasmania, Queensland and New South Wales using killed mulch production systems.

Project objectives

This project sought to develop priority new minor uses and/or herbicide registrations in vegetables, to meet the needs previously described. We also supported the establishment of a system(s) for prioritising and actioning new legal uses. Such system(s) would be ongoing beyond the life of this project.

Secondly this project aimed to demonstrate integrated weed management principles to vegetable producers, evaluating their practicality, and capacity to fit within producers' priority activities.

The third and final component of the project was to investigate the potential and practicality of new vegetable production systems, with a focus on weed management. The key area of study was cover crop and mulch management prior to vegetable establishment.

Thus the overall concept of project outcome was threefold. Initially, specific and immediate benefit from expanded herbicide options. Secondly, the integrated approach to pest management (already widely adopted for insect pests) would be extended to encompass weeds. Thirdly, the project would assist vegetable industries determine the viability and implementation issues associated with innovative mulch management practices.

Materials and methods

Project activities comprised three main areas.

Firstly, we conducted experimental studies generating data enabling legalisation of new herbicide uses. We consulted with vegetable industry groups, representatives, and individuals to determine priority needs and potential solutions. We negotiated with chemical companies to determine levels of support, probabilities of successful outcomes, and ability to assist the process. We collaborated with other research and extension organisations to facilitate data generation and cross check results. On behalf of various vegetable industries, we submitted permit applications, advised regulatory authorities, and provided additional detail when requested. On many occasions we persisted in following up registration and minor use submissions, trying to overcome delays and blockages in the system.

Secondly, we undertook an array of experimental and extension activities to encourage adoption of integrated weed management strategies and practices amongst vegetable producing communities. This included Research Station demonstrations, individual on-farm demonstrations, displays, and posters at field events, seminars, and field days.

Thirdly, we investigated alternative production systems, with a focus on the practicality of killed mulch systems in producing vegetables such as lettuce, celery, broccoli, and pumpkin.

As would be anticipated, many activities covered several objectives, so the following segregation is somewhat arbitrary, and relates to the prime focus of the activity.

Developing new herbicide uses

Experimental activities

During this project period, we completed 15 experiments with primary foci of generating information to enable new legal herbicide uses in vegetables. The herbicides targeted in this component of the project are listed in Table 1.

Table 1. Herbicides investigated with a view to generating new legal uses in vegetables.

Product	Active	Active concentration in formulation	Resistance group Mode of action	Target vegetable uses
GOAL®	Oxyfluorfen	240 g/L	G diphenyl ether Inhibitor of protoporphyrinogen oxidase	Brassicas, alliums
LONTREL®	Clopyralid	300 g/L	I pyridine Disruptor of plant cell growth	Brassicas
RADIATE®	Clopyralid Picloram	225 g/L 150 g/L	I pyridine Disruptor of plant cell growth	Brassicas
LENTAGRAN®	Pyridate	450 g/kg	C phenyl-pyridazine Inhibitor of photosynthesis at PSII	Brassicas
BRODAL®	Diflufenican	500 g/L	F nicotinanalide Inhibitor of carotenoid biosynthesis	Lettuce
SPINNAKER®	Imazethapyr	240 g/L	B imidazolinone Inhibitor of acetolactate synthase	Lettuce
COMMAND®	Clomazone	480 g/L	F isoxazolidinine Inhibitor of carotenoid biosynthesis	Cucurbits, potatoes, beans
TITUS®	Rimsulfuron	250 g/kg	B sulfonylurea Inhibitor of acetolactate synthase	Potato
PERLKA®	Calcium cyanamide	Fertiliser	Not applicable	Transplanted vegetables

Other herbicides used in these experiments as comparisons, or in the demonstration experiments described in the next section, are listed in Table 2.

Table 2. Herbicides used in demonstrations or as experimental standards.

Product	Active	Active concentration in formulation	Resistance group Mode of action	Labelled vegetable crop uses
DUAL®	Metolachlor	720 g/L	K amide Multiple sites of action	Beans, brassicas, sweet corn, sweet potato
RAMROD®	Propachlor	480 g/L	K amide Multiple sites of action	Beetroot, brassicas, onion, sweet corn
STOMP®	Pendimethalin	330 g/L	D dinitroanaline Inhibitor of tubulin formation	Beans, brassicas, carrot, lettuce, processing peas
TREFLAN®	Trifluralin	400 g/L	D dinitroanaline Inhibitor of tubulin formation	Beans, brassicas, carrot, peas, tomato
KERB®	Propyzamide	500 g/kg	K amide Multiple sites of action	Lettuce
BETANAL®	Phenmedipham	157 g/L	K carbamate Multiple sites of action	Beets
PYRAMIN®	Chloridazon	650 g/kg	C pyridazinone Inhibitor of photosynthesis at PSII	Beets
TRAMAT®	Ethofumesate	500 g/L	K benzofuran Multiple sites of action	Beets
DACTHAL®	Chlorthal di-methyl	750 g/kg	D benzoic acid Inhibitor of tubulin formation	Beans, brassicas, carrot, garlic, onion, peas, potato, sweet potato, yam
TOTRIL®	Ioxynil	250 g/L	C nitrile Inhibitor of photosynthesis at PSII	Onion
TRIBUNIL®	Methabenzthiazuron	700 g/kg	C urea Inhibitor of photosynthesis at PSII	Onion
LEXONE DF®	Metribuzin	750 g/kg	C triazinone Inhibitor of photosynthesis at PSII	Asparagus, peas, potato, tomato
SENCOR®	Metribuzin	480 g/L	C triazinone Inhibitor of photosynthesis at PSII	Asparagus, peas, potato, tomato
GESAGARD®	Prometryn	500 g/L	C triazine Inhibitor of photosynthesis at PSII	Carrot, celery, potato
AFALON®	Linuron	450 g/L	C urea Inhibitor of photosynthesis at PSII	Carrot, onion, parsnip, potato, sweet corn
STARANE®	Fluroxypyr	300 g/L	I pyridine Disruptor of plant cell growth	Sweet corn

We have provided summary information for each herbicide experiment in Table 3. Generally, in each experiment we recorded: agronomic and treatment activities; weather details; crop growth and weed counts (whole plot or quadrats) at several stages during the growing period; final crop yield and quality; and final weed biomass. Results were analysed using relevant GENSTAT® statistical packages.

We have provided a Materials and Methods section from a sample experiment report in Appendix 1. For similar details on a specific experiment, contact the author.

Table 3. Experiment information for investigations with herbicide data generation as a prime focus.

Code	Short title	Crop	Location	Period	Herbicides
P1440.13	Evaluation of post-emergence herbicides in broccoli	Broccoli	Gatton RS	June 1997 to September 1997	LONTREL®, RADIATE®, LENTAGRAN®
P2087.08	Long-term weed management – broccoli	Broccoli	Gatton RS	April 1998 to July 1998	GOAL®, STOMP®, RAMROD®, DUAL®
P1440.14	Evaluation of post-emergence herbicides in cabbage	Cabbage	Gatton RS	June 1997 to September 1997	LONTREL®, RADIATE®, LENTAGRAN®
P1440.12	Evaluation of post-emergence herbicides in Chinese cabbage	Chinese cabbage	Gatton RS	June 1997 to September 1997	LONTREL®, RADIATE®, LENTAGRAN®
P2087.03	Agronomic effects of PERLKA® fertiliser – Chinese cabbage	Chinese cabbage	Granite Belt	November 1997 to December 1997	PERLKA®
P1440.15	Evaluation of post-emergence herbicides in cauliflower	Cauliflower	Gatton RS	June 1997 to September 1997	LONTREL®, RADIATE®, LENTAGRAN®
P2087.02	Demonstration of herbicide phytotoxicity in lettuce, broccoli and cabbage	Lettuce Broccoli Cabbage	Granite Belt	November 1997 to January 1998	GESAGARD®, SENCOR®, LENTAGRAN®, TRIFLURALIN®, STOMP®, GOAL®, LONTREL®, DUAL®, KERB®, RAMROD®
P1440.11	Long-term weed management – lettuce	Lettuce	Gatton RS	May 1997 to July 1997	SPINNAKER®
P2087.20	Phytotoxicity of LONTREL® and BRODAL® herbicides to transplanted lettuce	Lettuce	Granite Belt	January 1999 to April 1999	LONTREL®, BRODAL®
P2087.21	Phytotoxicity of LONTREL® herbicide to transplanted lettuce	Lettuce	Granite Belt	November 1998 to December 1998	LONTREL®
P2087.25	The use of COMMAND® and BRODAL® herbicides in transplanted lettuce	Lettuce	Gatton RS	March 1999 to May 1999	COMMAND®, BRODAL®
P2087.05	Agronomic effects of PERLKA® fertiliser – celery	Celery	Granite Belt	January 1998	PERLKA®
P2087.09	Long-term weed management in onion production	Onion	Gatton RS	April 1998 to September 1998	DACTHAL®, RAMROD®, TOTRIL®, GOAL®
P2087.26	Long-term weed management in onion production	Onion	Gatton RS	March 1999 to August 1999	RAMROD®, TOTRIL®, GOAL®
P1440.02	Long-term weed management – potatoes	Potato	Gatton RS	February 1997 to July 1997	LEXONE®, TITUS®

Other activities

- Collaborated with Rohm and Haas P/L to assist registration of GOAL® herbicide for use in brassicas and onions.
- Ongoing discussions with Dow AgroSciences on options for legalising the use of LONTREL® on brassica vegetables.
- Submitted Minor Use Permit applications for use of GOAL® herbicide in onions, and trifluralin in direct-sown broccoli and cauliflower.
- Minor role in assisting Serve-Ag P/L register and promote the use of COMMAND® herbicide in cucurbits, potatoes, and green beans.
- Provided expert advice to Queensland Fruit and Vegetable Growers, Department of Primary Industries, National Registration Authority, and Crop Protection Approvals on at least ten Minor Use Permit Applications.
- Provided comment in the lead up and establishment of the National Minor Use program in vegetables (currently via Crop Protection Approvals).
- Collaborated with industry groups prioritising their needs for new herbicide uses in vegetables.
- Provided industry wide advisory service to producers and agribusiness with queries on herbicide use in vegetables.

Adoption of integrated weed management strategies and practices

In the course of this project we completed 18 demonstrations of Integrated Weed Management (IWM) principles and practices, with most conducted on individual growers' properties. Generally, these demonstrations involved large plots (e.g. 16 m by 15 m), with four treatments replicated twice. The basic treatments included standard grower practice, best IWM practice, best future practice (often involving a potential new herbicide use), and a producer-interest option. Either the producer or we implemented the treatments, depending on complexity and suitability of equipment.

We have listed summary information for each of the demonstrations in Table 4. We conducted all the demonstrations, apart from those listed as Gatton RS, on the properties of collaborating producers. As in the detailed herbicide experiments described previously, we usually recorded: agronomic and treatment activities; weather details; crop growth and weed counts (whole plot or quadrats) at several stages during the growing period; final crop yield and quality; and final weed biomass. Results were analysed using relevant GENSTAT® statistical packages.

We have provided a Materials and Methods section from a sample demonstration report in Appendix 2. The collaborating producers all received copies of these reports. Collaborating producers were compensated for any crop losses associated with the demonstrations.

Table 4 Summary information for demonstrations of Integrated Weed Management principles and practices.

Code	Short title	Crop	Location	Period	Treatments
P2087.10	Split-rate application strategies in beetroot production	Beetroot	Upper Lockyer	February 1998 to June 1998	BETANAL®, TRAMAT®
P2087.23	Early and late split-rate herbicide application strategies in beetroot production	Beetroot	Upper Lockyer	April 1999 to September 1999	BETANAL®, PYRAMIN®, TRAMAT®, hand weeding
P2087.12	Weed management strategies in direct seeded broccoli production	Broccoli	Central Lockyer	May 1998 to September 1998	LONTREL®, LENTAGRAN®, hand weeding
P2087.14	Post-emergence weed management strategies in broccoli production	Broccoli	Upper Lockyer	June 1998 to August 1998	LONTREL®, LENTAGRAN®, hand weeding
P2087.27	Weed management strategies in direct seeded broccoli production	Broccoli	Central Lockyer	April 1999 to July 1999	TREFLAN®, LENTAGRAN®, LONTREL®, hand weeding
P2087.22	Weed management strategies in brassica production	Broccoli Cauliflower	Upper Lockyer	March 1999 to May 1999	DUAL®, STOMP®, RAMROD®, GOAL®, LONTREL®, LENTAGRAN®
P2087.11	Post-emergence weed management strategies in cauliflower and broccoli production	Broccoli Cauliflower	Lower Lockyer	May 1998 to August 1998	LONTREL®, cultivation, hand weeding
P2087.15	Weed management strategies in cabbage production	Cabbage	Lower Lockyer	February 1999 to May 1999	STOMP®, RAMROD®, GOAL®, LONTREL®, LENTAGRAN®
P2087.17	Weed management strategies in brassica production	Cabbage Cauliflower	Lower Lockyer	March 1999 to June 1999	STOMP®, RAMROD®, GOAL®, LONTREL®
P2087.01	Long-term weed management – Chinese cabbage	Chinese cabbage	Granite Belt	November 1997 to December 1997	LONTREL®, stale seedbed, flaming
P2087.16	Strategies for managing weeds in lettuce production	Lettuce	Granite Belt	November 1998 to December 1998	STOMP®, RAMROD®, deep ripping, straw mulching
P2087.16A	Deep ploughing and weed distributions	Lettuce	Granite Belt	October 1998 to December 1998	Deep cultivation
P2087.24	Weed management strategies in lettuce production	Lettuce	Lower Lockyer	May 1999 to August 1999	STOMP®, KERB®, hand weeding
P2087.07	Long-term weed management – celery	Celery	Granite Belt	January 1998 to April 1998	LONTREL®, stale seedbed
P2087.29	Long-term weed management strategies in onion production	Onion	Lower Lockyer	May 1999 to October 1999	GOAL®, TOTRIL®, TRIBUNIL®
P2087.13	Weed management strategies in pumpkin production	Pumpkin	Upper Lockyer	August 1998 to December 1998	COMMAND®, cultivation, hand weeding, straw mulching
P2087.04	Long-term weed management – sweet corn	Sweet corn	Gatton RS	December 1997 to March 1998	DUAL®, cultivation, hand weeding
P2087.18	Weed management strategies in sweet corn production	Sweet corn	Central Lockyer	August 1998 to December 1998	AFALON®, STARANE®, hand weeding

Other activities
We conducted field walks at several of the sites during the project (see Technology Transfer), to ascertain producer opinions on the concepts and practicalities demonstrated, and to obtain feedback for future activities.

Investigations of alternative production systems
The experiments completed in this project followed on directly from activities conducted under a previous project, VG406 'Integrated weed management in vegetables'. We re-analysed the results of those experiments in detail during this current project; therefore their summary information is included in this project, even though the physical activity predated its commencement. We carried out an additional three detailed experiments in this area of study. In addition, several demonstration experiments also involved killed-mulches as a treatment.

In this section we investigated the practical difficulties of growing vegetables in a killed mulch system, and attempted to analyse the predominant causes of poor performance. These main experiments were all carried out on Gatton Research Station. They generally involved planting a cover crop such as forage sorghum, and manipulating it (by slashing, spraying with herbicide, ploughing in, flattening, rolling, or removing), once it had grown for six to ten weeks. We planted vegetable crops into the managed mulches, and monitored their performance, as well as weed emergence and growth.

We have listed summary information for each of the investigations in Table 5. As in the experiments described previously, we recorded: agronomic and treatment activities; weather details; crop growth and weed counts (whole plot or quadrats) at several stages during the growing period; final crop yield and quality; and final weed biomass. Results were analysed using relevant GENSTAT® statistical packages.

We have provided the Materials and Methods section in the last, most detailed experiment, in Appendix 3. For similar details on a specific experiment, contact the author.

Table 5. Summary information for investigations of killed mulch systems.

Code	Short title	Crop	Period	Treatments
P1440.03	Management of cover crops in lettuce production	Lettuce	June 1996 to August 1996	STOMP®, RAMROD®, hand weeding, nitrogen, mulching, tillage
P1440.04	Management of cover crops in broccoli production	Broccoli	June 1996 to August 1996	DUAL®, GOAL®, hand weeding, nitrogen, mulching, tillage
P1440.05	Management of cover crops in celery production	Celery	June 1996 to August 1996	STOMP®, PROMETRYNE®, hand weeding, nitrogen, mulching, tillage
P1440.08	Growing lettuce in killed cover crops	Lettuce	December 1996 to May 1997	STOMP®, RAMROD®, hand weeding, nitrogen, mulching, tillage
P1440.09	Growing broccoli in killed cover crops	Broccoli	December 1996 to May 1997	DUAL®, GOAL®, hand weeding, nitrogen, mulching, tillage
P1440.10	Growing celery in killed cover crops	Celery	December 1996 to May 1997	STOMP®, PROMETRYNE®, hand weeding, nitrogen, mulching, tillage
P2080.01	Cover crops affect weed growth in vegetable production	None	February 1998 to June 1998	Various cover crops
P2080.02	Killed mulches in lettuce production	Lettuce	February 1999 to June 1999	STOMP®, mulches, hand weeding
P2080.03	Mulch and soil management in broccoli production	Broccoli	March 2000 to July 2000	Fallowing, cover crops, tillage, mulching

Other activities

We liaised with other scientists and producers also investigating killed mulch systems, principally Dr Jason Olsen (DPI Bundaberg – HRDC project VG97021), Dr Gordon Rogers (Applied Horticulture Research P/L), and Ian Macleod, Phil Frost and Matt Sheriff (Serve-Ag P/L). We modified some of our research directions and techniques on the basis of these discussions.

Results

Developing new herbicide uses

Brassicas

1. Oxyfluorfen

Outcomes

After many years of research, liaison with industry, chemical companies, representative organisations and the National Registration Authority, oxyfluorfen (GOAL®) herbicide finally became registered for pre-emergence use in broccoli, cabbage and cauliflower in April 2000. Applied 4-7 days prior to transplanting at 1.5-2 L/ha to a weed free seedbed, this herbicide prevents weed emergence for most of the growing period, meaning other weed management practices are rarely required. From a different herbicide resistance group (G), relative to the other herbicides registered in brassica vegetables, oxyfluorfen enhances the ability to manage the risk of developing herbicide resistance. There are no detectable herbicide residues present in the harvested product, and under normal seasonal conditions, no implications for following crops in the rotation.

Our research shows reduced risk of crop damage and a wider spectrum of weeds controlled than achieved with other registered herbicides.

The registered label indicates the following weeds are controlled by this pre-emergence application:

Table 6. Weeds controlled pre-emergence in brassicas by oxyfluorfen herbicide.

Common name	Scientific name	Common name	Scientific name
Amsinckia	*Amsinckia spp.*	Prickly lettuce	*Lactuca spp.*
Barley grass	*Hordeum leporinum*	Red Natal grass	*Rhynchelytrum repens*
Barnyard grass	*Echinochloa spp.*	Redshank	*Amaranthus cruentus*
Blackberry nightshade	*Solanum nigrum*	Ryegrass	*Lolium spp.*
Bladder ketmia	*Hibiscus trionum*	Sesbania pea	*Sesbania cannabina*
Burrgrass	*Cenchrus australis*	Shepherd's purse	*Capsella bursa-pastoris*
Caltrop	*Tribulus terrestris*	Small flowered mallow	*Malva parviflora*
Capeweed	*Arctotheca calendula*	Soursob	*Oxalis pes-caprae*
Chickweed	*Stellaria media*	Sowthistle	*Sonchus oleraceus*
Crowsfoot grass	*Eleusine indica*	Starburr	*Acanthospermum hispidum*
Deadnettle	*Lamium amplexicaule*	Stinkgrass	*Eragrostis cilianensis*
Fat hen	*Chenopodium album*	Summer grass	*Digitaria spp.*
Giant pigweed	*Trianthema portulacastrum*	Thornapple	*Datura stramonium*
Liverseed grass	*Urachloa panicoides*	White eye	*Richardia brasiliensis*
Lovegrass	*Eragrostis spp.*	Wild Mustard	*Sisymbrium spp.*
Pigeon grass	*Setaria spp.*	Wild radish	*Raphanus raphanistrum*
Pigweed	*Portulaca oleracea*	Wireweed	*Polygonum aviculare*

For additional or update information, refer to the product label.

Project research supporting outcome

Experiment P2087.02

Pre-plant application of 2.5 L/ha GOAL® did not affect cabbage, but produced very minor plant stunting in broccoli.

Post-planting application of 0.4 L/ha GOAL® caused severe necrotic spotting of sprayed cabbage and broccoli leaves, and twisting of necrotic leaf margins, which would be commercially unacceptable.

ExperimentP2087.08

Compared to the industry standard of 3.5 L/ha of DUAL® immediately after transplanting, a STOMP®/RAMROD® combination produced similar broccoli yields, whilst controlling a slightly different weed spectrum. However, GOAL® sprayed before transplanting resulted in higher broccoli yields, and controlled all the weeds present (Table 7).

Table 7. Comparison of oxyfluorfen with other registered herbicides in brassicas.

Herbicide	**3.5 L/ha DUAL®**	**2.5 L/ha STOMP® + 9 L/ha RAMROD®**	**1.5 L/ha GOAL®**
Broccoli yield (t/ha)	7.7	7.7	10.7
Crop notes	Minor phyto	Minor phyto	No phyto
Final weed biomass (g m^{-2})	17	8	2
Weed notes	• Controlled bittercress • Suppressed sowthistle • Nil effect on small flowered mallow • Nil effect on burr medic	• Suppressed bittercress • Controlled sowthistle • Controlled small flowered mallow • Nil effect on burr medic	• Controlled bittercress • Controlled sowthistle • Controlled small flowered mallow • Controlled burr medic

Experiment P2087.15

Application of 1.5 L/ha of GOAL® before transplanting cabbage did not result in any crop phytotoxicity. Compared to spraying 9 L/ha of RAMROD®, or 9 L/ha of RAMROD® mixed with 2 L/ha of STOMP®, GOAL® gave the best control of fat hen, potato weed, small flowered mallow, and sowthistle.

Experiment P2087.17

Application of 1.5 L/ha of GOAL® before transplanting sugarloaf cabbage caused some necrotic spotting of leaves, and minor yield reductions (about 10%) compared to a hand-weeded control. Although similar initial symptoms were observed in cauliflower, there was no subsequent yield reduction.

Experiment P2087.22

Of the three pre-emergence herbicide strategies used in an experiment with broccoli and cabbage, GOAL® controlled the widest spectrum of weeds (Table 8).

Table 8. Comparison of oxyfluorfen with other registered herbicides in brassicas.

Herbicide	3.5 L/ha DUAL®	2 L/ha STOMP® + 9 L/ha RAMROD®	1.5 L/ha GOAL®
Broccoli and cauliflower crop notes	Transient initial phyto symptoms which disappeared as the crops developed	Transient initial phyto symptoms which disappeared as the crops developed	Transient initial phyto symptoms which disappeared as the crops developed
Weed notes	• Controlled pigweed • Controlled sowthistle • Suppressed green fat hen • Suppressed giant pigweed	• Controlled pigweed • Suppressed sowthistle • Suppressed green fat hen • Suppressed giant pigweed	• Controlled pigweed • Controlled sowthistle • Controlled green fat hen • Suppressed giant pigweed

2. Clopyralid

<u>Outcomes</u>

Our research has demonstrated that clopyralid (LONTREL®) is a very useful herbicide for post-emergence use in brassica vegetables. There are no herbicides currently registered for post-emergence broadleaf weed control in the brassica vegetable crops. Although LONTREL® is only active against a limited weed spectrum, principally Asteraceae, Polygonaceae, Fabaceae and Solanaceae, many important weeds of brassica crops belong to these families. Examples are sowthistle and potato weed, blackberry nightshade, wireweed, medics, thornapples, and apple of Peru.

We showed that rates of 50-300 mL/ha managed several key weeds, and that there are no issues with this herbicide adversely affecting the crop. The biggest impediment to approval of a legal use is residual activity on following crops, particularly sensitive species such as lettuce. Although clopyralid residues can remain in the soil for extended periods, we believe our research shows that in many production areas within Australia, this issue can be well managed. We did not detect any residual effects of LONTREL® on vegetable crops following treated brassicas, and in many instances did not observe phytotoxicity even when deliberately sprayed before transplanting a lettuce crop.

Further information on the residual activity of LONTREL® is contained in other sections of this report.

We are currently putting together an information package including efficacy, phytotoxicity and residual activity data, to present to the responsible company Dow AgroSciences, in an attempt to persuade them to allow the use of LONTREL® in brassica vegetables, either via registration, or issuing of a Minor Use Permit.

Project research supporting outcome

Experiments P1440.12-15
Spraying LONTREL® at rates of 200 or 300 mL/ha five weeks after direct sowing Chinese cabbage or broccoli, or transplanting cabbage or cauliflower, had no adverse effects on the crops. LONTREL® controlled sowthistle and burr medic, but as expected, did not affect deadnettle, shepherd's purse, or London rocket. Generally, the higher rates improved the levels of weed control.

Addition of picloram, in the formulation of RADIATE® herbicide, did not damage the crops, but gave some suppression of fat hen, which was not achieved where just LONTREL® was sprayed. However, because picloram also has significant residual longevity, and inclusion of a second active component would substantially extend the legalisation process, we decide to proceed in further research with LONTREL®, rather than the RADIATE® herbicide mixture.

Experiment P2087.01
Applying 300 mL/ha of LONTREL® to transplanted Chinese cabbage did not affect the crop, but eliminated potato weed. As expected, LONTREL® did not control stinging nettle or grasses.

Experiment P2087.11
Applying 300 mL/ha of LONTREL® to transplanted broccoli and cauliflower did not affect the crop, but suppressed sowthistle to commercially acceptable levels. As expected, LONTREL® did not control fat hen, or stinging nettle.

Experiment P2087.12
Applying 300 mL/ha of LONTREL® to direct sown broccoli did not affect the crop, but suppressed blackberry nightshade to commercially acceptable levels. As expected, LONTREL® did not control fat hen, stinging nettle, shepherd's purse or grass species.

Experiment P2087.14
Applying 300 mL/ha of LONTREL® to transplanted broccoli did not affect the crop, but suppressed sowthistle to commercially acceptable levels.

Experiment P2087.15
Applying 300 mL/ha of LONTREL® to transplanted cabbage did not affect the crop, but suppressed sowthistle and potato weed to commercially acceptable levels.

3. Pyridate

Outcomes

Similar to the rationale for investigating clopyralid, we have also looked at the potential for using pyridate as a post-emergence brassica herbicide. Pyridate (LENTAGRAN®, TOUGH®), is in a different resistance group (C) to LONTREL® (I), which would aid resistance management. It controls a different weed spectrum to clopyralid, which is also advantageous. Our research shows that the window of opportunity between rates of pyridate that control weeds and rates that cause crop damage is much smaller than with clopyralid. The ownership and distribution of herbicides containing pyridate in Australia is relatively fluid and imprecise at the current time. Thus development of data to enable a new legal use for pyridate was a lower priority than was clopyralid.

We demonstrated that rates of 1-1.5 kg/ha of LENTAGRAN® gave reasonable control of weeds such as sowthistle, fat hen, deadnettle and blackberry nightshade. Post-emergence spraying of LENTAGRAN® over brassica crops often resulted in transient symptoms of phytotoxicity, usually patterns of chlorotic spotting on sprayed leaves. Where higher rates were used, these chlorotic areas sometimes became necrotic lesions. Seldom did these transient symptoms of crop damage result in yield reductions.

Once we have completed the LONTREL® information package, we will develop a similar package for whoever retains the rights to herbicides containing pyridate in Australia.

Project research supporting outcome

Experiments P1440.12-15
Spraying LENTAGRAN® at rates of 1 kg/ha or 2 kg/ha five weeks after direct sowing Chinese cabbage or broccoli, or transplanting cabbage or cauliflower, caused transient damage to all the crops, particularly at the higher rate. There were very minor yield reductions in the case of the direct sown Chinese cabbage and transplanted cauliflower. LENTAGRAN® controlled fat hen and deadnettle and suppressed sowthistle, but as expected, did not affect burr medic, shepherd's purse or London rocket. Generally, the higher rates improved the level of weed control.

Experiment P2087.02
Spraying 4 kg/ha of LENTAGRAN® post-emergence caused obvious inter-venial chlorosis and necrosis in both broccoli and cabbage. Although probably mainly visual and transient, the levels of damage would be commercially unacceptable.

Experiment P2087.12
Applying 1 kg/ha of LENTAGRAN® to direct sown broccoli did not affect the crop, but suppressed blackberry nightshade and fat hen to commercially acceptable levels. As expected, LENTAGRAN® did not control stinging nettle, shepherd's purse, or grass species.

Experiment P2087.14
Applying 1.5 kg/ha of LENTAGRAN® to transplanted broccoli did not affect the crop, but suppressed sowthistle to commercially acceptable levels.

Experiment P2087.15
Applying 1.5 kg/ha of LENTAGRAN® to transplanted cabbage did not affect the crop, but suppressed sowthistle to commercially acceptable levels.

Experiment P2087.27
Applying 1.5 kg/ha of LENTAGRAN® to direct sown broccoli did not affect the crop, but controlled deadnettle and stinging nettle. Unexpectedly, in this experiment, LENTAGRAN® did not control fat hen.

Lettuce

1. Clomazone, diflufenican, imazethapyr

Outcomes

Clomazone (COMMAND®) is a newly registered herbicide used in beans, potatoes, and cucurbits, as well as a range of field crops. A pre-emergence product, it is active against grasses and a number of broadleaf weeds. Lettuce has very limited herbicide options, particularly for managing weeds in the Asteraceae family, such as potato weed and sowthistle. We determined there might be opportunities for COMMAND® to be used at low rates in transplanted lettuce, although the margins between weed control and crop safety are very narrow. We sent the relevant experiment outcomes to Serve-Ag P/L, who are researching and distributing this herbicide, for integration into their label expansion program.

We demonstrated that rates of up to 0.5 L/ha of COMMAND® gave reasonable control and only transient lettuce damage. Because clomazone is a moisture-activated pre-emergence herbicide that interacts strongly with soil clay and organic matter, considerable fine-tuning will be required before any industry use in lettuce should be contemplated. Symptoms of damage from clomazone are very obvious, with bleaching of affected tissues. These symptoms can appear and disappear, as the herbicide becomes more and less available within the soil complex.

Diflufenican (BRODAL®) is a good companion herbicide with COMMAND®, as it has controls a complementary weed spectrum, and has no mixing problems. The experiments we conducted did not test BRODAL®'s efficacy, as the appropriate weeds were not present. We did determine that BRODAL® could be safely used in lettuce at rates up to 0.15 L/ha, which are efficacious on the currently registered label for other crops. We forwarded the relevant information to Aventis P/L in case they wished to pursue this use.

Imazethapyr was too phytotoxic to lettuce for us to continue investigating that product beyond the initial experiment.

Project research supporting outcome

Experiment P1440.11

Spraying imazethapyr (SPINNAKER®) at 200-400 mL/ha before transplanting lettuce controlled sowthistle and suppressed deadnettle and London rocket. Unfortunately, these treatments also substantially suppressed lettuce yields compared to hand-weeded controls. Post-transplanting treatments were less damaging to the crop, but also were ineffective against the weeds that were present. There was no combination of pre and post-emergence applications that gave commercially acceptable weed control without significantly reducing lettuce yields. The lettuce cultivar Greenway was significantly more sensitive to imazethapyr than was the cultivar Crystal.

Experiment P2087.20

Spraying BRODAL® at up to 0.2 L/ha either fourteen days before transplanting or 21 days after transplanting lettuce did not cause any noticeable crop damage. BRODAL® did not affect either small flowered mallow or grasses.

Experiment P2087.25
Spraying COMMAND® at 0.5 L/ha before transplanting lettuce caused noticeable initial bleaching for the first few weeks following planting. However these symptoms disappeared before heart formation commenced, and yields of three lettuce cultivars (Fame, Seagreen and Oxford) were unaffected compared to hand weeded controls. This herbicide rate gave good control of giant pigweed, sowthistle, and various grasses. There were late weed germinations as the residual activity of the herbicide declined. However, these were commercially unimportant, as their biomass was insufficient to affect production, and they had not flowered by the time we harvested the lettuces.

COMMAND® rates greater than 0.5 L/ha caused unacceptable crop damage, and significant yield reductions.

Spraying BRODAL® at up to 0.15 L/ha before transplanting caused very minor and transient damage to the seedling leaves, and certainly had no effect on heart quality or yields. There was no apparent interaction between the herbicides (either synergism or antagonism) when BRODAL® and COMMAND® were applied in mixtures. BRODAL® did not affect giant pigweed, sowthistle, or grasses.

2. Clopyralid

<u>Outcomes</u>
As previously indicated, we were very interested in identifying the residual activity of LONTREL® in vegetable crops following the brassica crop in which it had been sprayed. As part of this investigation, we actually sprayed rates of LONTREL® immediately before planting the most sensitive vegetable crop, lettuce. We clearly demonstrated that in areas such as the Granite Belt and Lockyer Valley in Southern Queensland, the risks of residual LONTREL® activity affecting following crops is much less than conventional wisdom would suggest.

We successfully sprayed very low rates of LONTREL® (50-75 mL/ha) post-emergence to kill key weeds such as potato weed in brassica vegetables, which would pose virtually no risk to following sensitive vegetable crops. There may even be scope in the longer term to use LONTREL® as a pre-emergent at very low rates before transplanted lettuce, although this would require much more research and very careful management. These are very preliminary results, and further investigation may prove this idea impractical.

We are finalising analysis of a complex residue assessment experiment, which will be included in the package of information provided to Dow AgroSciences to enhance the opportunity for legalisation of the use of LONTREL® in vegetable production systems.

<u>Project research supporting outcome</u>
Experiment P2087.20
Applying LONTREL® at rates of up to 300 mL/ha 14 days before transplanting lettuce on a sandy soil in the Granite Belt had no adverse effect on the lettuce. Spraying up to 30 mL/ha of LONTREL® over the lettuce three weeks after transplanting did not cause any significant damage to the lettuce, however rates of 100 mL/ha were phytotoxic. As expected, LONTREL® controlled potato weed, but had no impact on small flowered mallow or grasses.

Experiment P2087.21
In this experiment, lettuce tolerated up to 30 mL/ha of LONTREL® sprayed pre-transplanting, or 100 mL/ha applied post-transplanting, with no significant crop yield reductions. Potato weed was controlled by 30 mL/ha pre-emergence, or rates as low as 10 mL/ha post-emergence.

Onion

Outcomes
As with the use in brassica vegetables, after many years of research, liaison with industry, chemical companies, representative organisations and the National Registration Authority, oxyfluorfen (GOAL®) herbicide finally became nationally registered for post-emergence use in onions in April 2000. It had previously been registered in Tasmania, under a different use pattern.

Following extensive negotiation with the NRA, a permit for use in onions was issued in November 1998. The use we promoted was for very low rates (50-100 mL/ha) at the hook leaf stage of the onions, which was much earlier than any other herbicide could be applied. The strategy gives good early control of very small weeds. Follow up, sequential applications at higher rates provide extended weed control into the growing period, and builds up pre-emergence activity as well. Because there is a narrow margin of safety, the spray application and management skills required to use oxyfluorfen successfully in onions is relatively high. Details of those requirements are included on the most recent herbicide label, and on the DPI Note *Guidelines for Using Oxyfluorfen Herbicide (e.g. GOAL®) in Onions*.

Widespread use of the strategy incorporating the use of oxyfluorfen in onions occurred in 1999 and 2000. Adoption of this strategy reduced the quantities of herbicides used, overall weed management costs, and generally resulted in excellent weed control. We did note a few instances of initial crop damage from early oxyfluorfen application. Damage is generally associated with conditions that increase herbicide uptake, such as high humidity, or 'soft' weather that reduces waxy cuticle development on the surface of the onion leaves.

As with brassica vegetables, using oxyfluorfen in onions improves management of herbicide resistance, as the other main post-emergence onion herbicides (TOTRIL®, TRIBUNIL®, linuron) are all Group C products. There are no detectable herbicide residues present in the harvested product, and under normal seasonal conditions, no implications for following crops in the rotation.

For additional or update information, refer to the product label.

Project research supporting outcome

Experiment P2087.26

In a March sowing of onions, a sequential GOAL® application strategy was compared with the previous conventional herbicide strategy (9 L/ha RAMROD® sprayed at sowing, followed by 2.8 L/ha of TOTRIL® four weeks after sowing). The sequential GOAL® applications involved 50 mL/ha when the onions were at the hook leaf stage, followed by 100 mL/ha four days later, and then 250 mL/ha, 300 mL/ha and 400 mL/ha one week apart.

The initial GOAL® application caused transitory necrosis where the herbicide droplets pooled in the crook of the leaf. The TOTRIL® application also resulted in phytotoxic symptom expression, which persisted for much longer into the cropping period than did the GOAL® symptoms (Table 9).

Table 9. Comparison of oxyfluorfen strategy with conventional herbicide strategy in onions.

Herbicide	GOAL®	RAMROD® TOTRIL®
Marketable fresh onion yield (t/ha)	60	56
Total onion yield (t/ha) (included doubles)	77	67
Crop notes	Minor, transient phyto	Minor, prolonged phyto
Final weed biomass (g m^{-2})	25	100
Weed notes	• Controlled bittercress • Controlled burr medic	• Suppressed bittercress • Suppressed burr medic
Total herbicide volume (L/ha)	1.1	11.8
Total herbicide cost ($/ha)	43	223

Experiment P2087.09

In an April sowing of onions, we compared a conventional herbicide strategy (12 L/ha DACTHAL® or 9 L/ha RAMROD® sprayed at sowing, followed by 1.5 L/ha of TOTRIL® four weeks after sowing and 2.8 L/ha of TOTRIL® nine weeks after sowing) with experimental strategies. In one experimental sequence, we altered the RAMROD®/TOTRIL® by including 0.3 L/ha LONTREL® with the second TOTRIL® application. In the other experimental strategy, we sprayed 0.1 L/ha GOAL at the hook leaf stage of the onions, followed by 0.3 L/ha of LONTREL® nine weeks after sowing.

The DACTHAL®/TOTRIL® combination gave poor weed control, and hence the lowest yields. Swapping RAMROD® for DACTHAL® in the pre-emergence component certainly improved the weed management result. The strategy involving GOAL® could have been more effective if sequential oxyfluorfen spraying had been undertaken (Table 10).

Table 10. Comparison of herbicide strategies in onions.

Herbicide	DACTHAL® TOTRIL®	RAMROD® TOTRIL®	RAMROD® TOTRIL® LONTREL®	GOAL® LONTREL®
Marketable fresh onion yield (t/ha)	32	60	50	65
Final weed biomass (g m^{-2})	1,400	700	350	400
Weed notes	Poor control	• Controlled fat hen • Poor impact on sowthistle • Controlled London rocket • Controlled burr medic	• Controlled fat hen • Controlled sowthistle • Controlled London rocket • Controlled burr medic	• Suppressed fat hen • Controlled sowthistle • Controlled London rocket • Controlled burr medic
Total herbicide volume (L/ha)	16.3	13.3	13.6	0.4
Total herbicide cost ($/ha)	520	256	277	34

Experiment P2087.29

In this experiment on a collaborating producer's property, onions were sown into a paddock that had a pre-emerged weed problem. By the time the first GOAL® application was sprayed, many weeds, particularly wild radish, were too large to be successfully controlled with this practice. Rain also caused delays in follow-up sprays, exacerbating the problem. An alternative herbicide strategy was required. We sprayed 1 L/ha of TOTRIL® mixed with 1 kg/ha of TRIBUNIL® at 64 days after sowing the onions, and repeated the application about one week later. Although causing some initial damage to the onions, this technique killed the very large weeds present, and salvaged the crop.

Miscellaneous crops

Outcomes

We investigated the potential of PERLKA® (calcium cyanamide) as both a nutritional source and a product with herbicidal properties in vegetable production. A preliminary experiment with Chinese cabbage showed reasonable crop safety and good weed control, where we broadcast 400 kg/ha of PERLKA® seven days before transplanting (and irrigated it in). However, a second experiment in celery did not demonstrate any benefit. Owing to the expensive nature of the practice, and the variable results, we did not pursue this line of research any further in the project.

We investigated whether the herbicide rimsulfuron (TITUS®), registered in processing tomatoes, provided an advantage for weed management over the principle herbicide currently used post-emergence in potatoes, metribuzin. There may be a herbicide resistance management benefit from alternating/mixing metribuzin with rimsulfuron, and potentially lower phytotoxicity risk in some potato cultivars. However, we did not perceive sufficient benefits to proceed with this activity beyond the initial investigation.

STARANE® herbicide is registered for use in sweet corn in NSW. Our investigation determined that post-emergence application of 0.3 L/ha carried a slight risk of phytotoxicity, but gave initial suppression of sowthistle. Increasing the rate to 0.5 L/ha extended the period of sowthistle control, however it also resulted in significant crop phytotoxicity. STARANE® had no activity against fat hen. Interestingly, in the same experiment, application of linuron at the registered rate killed the sweet corn outright.

The herbicide management system we developed for post-emergence weed management in beetroot was adopted by the entire beetroot industry during the life of this project. Sequential applications of 1.5-2.5 L/ha of BETANAL®, with or without an addition of 0.2 L/ha of TRAMAT®, provided excellent weed control, with substantially reduced risks of crop damage compared to the previously conventional practices. There seemed to be little additional benefit from using a pre-emergence herbicide in most situations.

Post-sowing, pre-emergence application of COMMAND® herbicide at 0.5 L/ha was a successful weed management practice in a preliminary pumpkin investigation. Although it caused some transient whitening of the seedling leaves, pumpkin growth and yield were not significantly affected. This herbicide gave good initial suppression of apple of Peru, potato weed, and various grasses.

Project research supporting outcome

Experiment P2087.03

We broadcast rates of PERLKA® in a Chinese cabbage crop, before, at or after transplanting. Because of a misunderstanding with the collaborating producer, some plots were harvested before we could record the data, hence some yield performance values are missing. Generally, crop damage increased (Table 11), and weed control declined (Table 12), as the application dates became later.

Table 11. Rate and timing of PERLKA® fertiliser application affects Chinese cabbage head size (kg), compared to a hand-weeded control head of 2.1 kg.

	Rate of application (kg/ha)		
Time of application	**100**	**200**	**400**
Seven days before transplanting	2.3		2.2
Immediately before transplanting	-	2.1	2.0
Seven days after transplanting	1.6	-	1.7

Table 12. Rate and timing of PERLKA® fertiliser application affects potato weed densities (plants m^{-2}) seven days after planting, compared to an unweeded control density of 180 plants m^{-2}.

	Rate of application (kg/ha)		
Time of application	**100**	**200**	**400**
Seven days before transplanting	100	25	8
Immediately before transplanting	20	18	2

Experiment P2087.05

Broadcasting PERLKA® at rates of up to 400 kg/ha two weeks before transplanting celery did not affect celery growth compared to an untreated control. However, the PERLKA® treatments also had no impact on potato weed densities, which were consistently 800-1000 plants m^{-2} across the experiment

Experiment P1440.02

We compared post-emergence applications of LEXONE® at 350 g/ha or 700 g/ha, with a mixture of 350 g/ha LEXONE® and 100 g/ha TITUS®. None of the herbicide treatments affected yields of Pontiac (45 t/ha) or Sebago (39 t/ha) potatoes. Both the high rate of LEXONE® and the herbicide mixture controlled all the weeds present, whilst the level of suppression from 350 g/ha LEXONE® was commercially acceptable (Table 13).

Table 13. Comparison of herbicide strategies in potatoes.

Herbicide	No weed control post-hilling	LEXONE® (low rate)	LEXONE® (low rate	LEXONE® + TITUS®
Final weed biomass (g m^{-2})	11	2	0.5	0.5
Weed notes	Poor control	• Controlled sowthistle • Controlled fat hen • Controlled small flower mallow • Suppressed burr medic • No impact on blackberry nightshade	• Controlled sowthistle • Controlled fat hen • Controlled small flower mallow • Controlled burr medic • Suppressed blackberry nightshade	• Controlled sowthistle • Controlled fat hen • Controlled small flower mallow • Controlled burr medic • Suppressed blackberry nightshade

Experiment P2087.10

The label recommendation of 5 L/ha of BETANAL® mixed with 2 L/ha TRAMAT®, sprayed 22 days after planting beetroot, reduced beetroot plant stand by nearly 50% compared to our split-rate sequential herbicide strategy. All treatments gave acceptable control of fat hen and amaranthus.

Experiment P2087.23

Applying split-rate sequential mixtures at the cotyledon stage of the beetroot gave good initial weed control, however later emerging wild radish escaped this treatment. Delaying the commencement of this strategy until the beetroot had two true leaves gave the same level of initial control, and also prevented the second weed flush from becoming a problem. Addition of a pre-emergence application of 7.5 kg/ha of PYRAMIN® to the strategy did not improve weed control.

Adoption of integrated weed management strategies and practices

Industry focus

Outcomes

Many vegetable growers readily accept and adopt Integrated Pest Management principles. There is also a trend in vegetable disease management to consider such things as disease forecasting systems, bio-control agents, crop rotations, biofumigation, and many other innovative practices.

In the course of this project, and in discussion with our collaborating growers, it was obvious that their main focus in weed management was new herbicide uses. Whether this was because they perceived there were few other viable practices is unclear.

At many of our field walks, there was little enthusiasm for the concepts of quarantine for weed prevention, weed management around borders or headlands, or the implementation of crop rotations for weed management. There was some acceptance of the benefits of killing weeds before flowering to reduce seed set.

Many producers held the view that some weeds could be tolerated, and even encouraged in the crop, as they acted as hosts/refuges for beneficial insects. There appeared to be little hard evidence for this, however it cannot be dismissed outright. We would argue that it is probably more efficient to plant specific, high efficiency refuges, rather than rely on whatever weeds are fortuitously present in a particular cropping system.

A positive outcome is that in some new 'certified' production systems, some cognisance is being given to adoption of Integrated Weed management principles.

Project research supporting outcome

During the project, of the thirty-one opportunities for additional weed management practices, only fifteen were not different herbicide uses. Of those fifteen, only six were not additional hand weeding or cultivation.

Enterprise/crop strategies

Outcomes

There is certainly scope for producers to fine-tune their herbicide selection and management strategies within an IWM context. For example, by understanding the weed histories of a paddock, they can select the most suitable pre-emergence herbicide for a particular situation. Producers can also put together a resistance management strategy without compromising their profitability. There are also many local soil type, weed spectrum and weather variables that influence the decision as to the most appropriate herbicide strategy.

Many pre-emergence herbicides have increased activity in sandy soils, hence rates need to be adjusted accordingly. For example, on the sandy soils of the Queensland Granite Belt, application of 3 L/ha of STOMP® caused some phytotoxicity to lettuce. In contrast, the optimum rate on the black earths of the Lockyer Valley was about 3.5 L/ha.

In circumstances where potato weed is a problem in lettuce, the ability to use RAMROD® in a pre-emergence mixture would be very welcome. (This use has been pursued by industry and under various projects for at least 14 years).

Many of the new herbicide strategies (e.g. GOAL® in onions, split rate applications in beetroot), require precise timings and application management, and cooperative weather conditions. Because we operate in fluid biological systems, producers require back up alternatives if the primary control systems fail. For example, mixtures of 1 L/ha of TOTRIL® with 1 kg/ha of TRIBUNIL® have proved effective at controlling larger weeds in onions. There may occasionally be some crop damage from this treatment, however this is usually acceptable when compared with the certainty of yield and quality loss from out of control weeds!

Experimental results confirmed that 3 L/ha of DUAL® was the optimum herbicide rate for sweet corn in the Lockyer Valley.

<u>Project research supporting outcome</u>

Experiment P2087.16

Application of STOMP® at 3 L/ha prior to transplanting lettuce on sandy soils in the Granite Belt district of Queensland, reduced yields by 4-6% compared to where only 2 L/ha was applied. Addition of 5 L/ha of RAMROD® into the post-emergence mixture improved the residual activity of the herbicides well into the cropping period, and also improved potato weed control.

P2087.24

Spraying 4 L/ha of STOMP® prior to transplanting lettuce in the Lockyer Valley improved weed control compared to spraying 3 L/ha of STOMP®, but also resulted in some transient phytotoxicity symptoms (chlorosis and initial stunting). Both STOMP® treatments were more active against the weed spectrum present at the site than was KERB® herbicide, although neither product was effective against potato weed or amaranthus.

P2087.29

Early GOAL® applications of 50-100 mL/ha at the hook leaf stage of onions were only effective against small bladder ketmia and bell vine that emerged with the crop. Larger wild radish that were already several centimetres in diameter when the crop was planted were barely affected by this herbicide strategy. Rain also delayed the later GOAL® applications, exacerbating the situation. Spraying a mixture of 1 L/ha TOTRIL® and 1 kg/ha TRIBUNIL® 64 days after planting and again 74 days after planting knocked the onion crop around, but controlled wild radish, deadnettle and wireweed that were up to 30 cm in diameter. The crop eventually recovered to provide a reasonable yield that would otherwise have been completely lost. Note that this treatment was not particularly effective against large sowthistle in this instance.

<u>*Alternative practices*</u>

During this component of the project we did investigate other weed management practices such as flaming, deep cultivation, and spreading straw as mulch. These were only minor experimental components, however we did identify the following outcomes.

<u>Flaming</u>

Done properly, flaming can certainly kill emerged broadleaf weeds. It is not particularly effective against grasses, which tend to re-shoot from below ground level. Flaming can be used in crop, either as shielded or spot application, however this is difficult, and still leaves weeds within the crop row (similar to inter-row cultivation). We had mixed success in using flaming to kill weed seeds present on the soil surface and thus reduce subsequent weed emergence. In one experiment, pre-transplant flaming reduced potato weed emergence (30 plants m^{-2}) compared to the unweeded control (160 plants m^{-2}). There were certainly no adverse effects on pre-plant flaming on the following crop.

Deep cultivation

As with flaming, our experimental evidence as to the weed management benefits of deep cultivation was mixed. In one experiment, deep cultivation markedly reduced the emerged population of potato weed (although there was no impact on stinging nettle densities), whilst in another experiment it had no effect. Borrowing from the experimental conclusions 'Deep ploughing may be a viable option where it is known that large weed seedbanks exist on the surface. It should only be used occasionally, as it will otherwise distribute seeds throughout a broad soil horizon, reducing the efficacy of strategies for seedbank depletion. The impact of deep ploughing on seedbank dynamics will depend on the relative survival of surface versus deep-buried seed for each species.'

Spreading straw

These treatments simulated some of the in-crop impacts of the killed mulch strategies discussed later. In diverse experiments with lettuce, sweet corn, and pumpkin, we found yields equivalent to or superior to hand-weeded, bare plot controls. The spread straw always gave good early weed control, but there were generally sufficient later-emerging weeds to cause seed set problems. Spreading straw mulches is obviously not a viable practice in commercial horticulture (except possibly in high value organic production), however the positive yield benefits and partial weed control did point to some potential for *in-situ* mulch systems.

Investigations of killed mulch production systems

Selection of appropriate cover crops

In a killed mulch system, the cover crop needs to be relatively easily grown, with low inputs. It needs to rapidly produce biomass, to provide the most rapid weed suppressive effect. The killed mulch should persist well into the growing period of the following vegetable crop. The mulch should be easily managed, be easy to kill, and cause minimal agronomic problems in the vegetable cropping phase.

In an experiment where we evaluated a range of potential mulches (Table 14), very few proved suitable. Of the legumes, only the vetches and *Centrosema* spp. provided sufficient ground cover in the time frame required to generate useful mulches. Both *Sorghum* spp. and Indian bluegrass also developed useful mulch coverage. Only the vetches were easily killed by a single application of glyphosate; the centro, sorghums, and bluegrass required follow up management.

The Indian blue grass formed a very dense and well knitted mat that would be extremely difficult to plant through without extensive disturbance, which would in turn reduce the efficacy of the mulch.

Table 14. Performance of February planted cover crops.

Common name	Scientific name	Cultivar	Proportional ground cover 10 weeks after sowing (%)	Ground cover persisting 17 weeks after sowing (%)	Regrowth rating 0=nil 9=extensive
American jointvetch	*Aeschynomene americana*	Lee	65	70	0
American jointvetch	*Aeschynomene americana*	Glenn	85	65	0.5
Villose jointvetch	*Aeschynomene villosa*	Reid	35	50	0
Villose jointvetch	*Aeschynomene villosa*	Kretschmer	70	60	0.5
White clover	*Trifolium repens*	Haifa	25	65*	7
Subterranean clover	*Trifolium subterraneum*	Clare	15	60*	0
Centurion	*Centrosema pascuorum*	Cavalcade	55	85	2
Centurion	*Centrosema pascuorum*	Bundy	85	80	3
Siratro	*Macroptilium atropurpureum*	Aztec atro	30	75*	4
Carribbean stylo	*Stylosanthes hamata*	Verano	20	65*	0
Dalrymple vigna	*Vigna luteola*	-	10	55*	0
Roundleaf cassia	*Cassia rotundifolia*	Wynn cassia	70	75*	0.5
Lotus	*Lotus pendunculatus*	Maku	10	45*	0
Lablab	*Lablab purpureus*	Highworth	75	75	1
Lotononis	*Lotononis bainesii*	Miles	45	70*	0
Butterfly pea	*Clitorea ternatea*	Milgarra	45	70*	1
Leucaena	*Leucaena leucocephela*	Cunningham	30	75*	1
Finger grass	*Digitaria milanjiana*	Sorafi	60	65	0.5
Sudan grass	*Sorghum sudanense*	-	80	95	1
Indian bluegrass	*Bothriochloa pertusa*	Bowen	90	100	3
Oats	*Avena sativa*	-	0	65*	0
Forage sorghum	*Sorghum bicolor*	Jumbo	70	90	5
Japanese millet	*Echinochloa utilis*	-	40	65*	0
Pearl millet	*Pennisetum glaucum*	-	55	60	0

* Principally comprising dead weed residues rather than killed cover crop

In additional experiments, centro proved too slow to develop biomass, and was out-competed in mixtures with forage sorghum. Because centro is also a nematode host, which may limit its usefulness in many vegetable production areas, we confined our detailed killed mulch experimentation to using forage sorghum as the cover crop in the latter stages of the project.

Managing mulches before planting vegetables
Using forage sorghum as the model cover crop, there were a number of management issues associated with generating suitable mulch.
The sorghum needs to be planted in rows, allowing sufficient space for planting the vegetable crop without interference from sorghum crowns or roots. Broadcasting the forage crop creates a seedbed that is very difficult to plant into without major disturbance and planter blockages.

The sorghum needs to be killed before the stems become too thick or woody, or the root systems too extensive and bulky. In Southern Queensland, this is around six to eight weeks after planting. After killing with a herbicide, the mulch should be left to stand and dry for one to two weeks, and then rolled, not cut. By rolling the mulch flat in the direction of vegetable crop planting, but still having the sorghum stems and leaves anchored to the root system, planters can 'comb' through the mulch with many fewer blockages. Cut mulch tends to move across the seedbed and pin around planting equipment.

Managing the vegetable crop
Six experiments demonstrated inconsistent performance of vegetable crops (lettuce, broccoli, and celery) in killed mulch systems, where forage sorghum was used as the prior cover crop. Lettuce consistently gave equivalent yields in comparisons with a conventional production system, broccoli consistently performed worse, whilst comparative celery yields were variable (Table 15).

It was unclear whether poorer performance in the killed mulches was due to nitrogen tie up by the degrading mulches, as there was no consistent relationship between lower yields and greater nitrogen response in the mulched treatments.

The mulches had minimal effect on weed distributions in 1996, but did reduce the efficacy of pre-emergence herbicides. Conversely, in 1997 the mulches did reduce emergence of pigweed and giant pigweed, and suppressed emergence of sowthistle. Sowthistle is documented as a weed that is favoured by the minimum tillage conditions present under a killed mulch system.

Allelopathy from the breakdown products exuded by sorghum roots and stubble as it decays may also be a cause of poorer performance in the killed mulch system.

The lower yields may be due to poor plant establishment in the minimum tilled soils, because of higher soil strength, and interference with seedling-soil contact by root and stubble residues from the forage sorghum.

Table 15. Performance of vegetable crops in a killed mulch system, compared to performance under conventional fallow preparation.

		Yield response (%)	Nitrogen response	Impact of mulch on weed densities	Impacts of mulch on herbicide efficacy
Lettuce	1996	+8	No change in response	• No impact on fat hen • No impact on sowthistle	Reduced pre-emergence herbicide efficacy
	1997	+3	Greater in mulched crop	• No impact on sowthistle	No impact on pre-emergence herbicide efficacy
Broccoli	1996	-22	Greater in mulched crop	• No impact on fat hen • No impact on sowthistle	Reduced pre-emergence herbicide efficacy
	1997	-16	Less in mulched crop	• Controlled pigweed • Controlled giant pigweed • Suppressed sowthistle	No impact on pre-emergence herbicide efficacy
Celery	1996	+6	No change in response	• No impact on fat hen • No impact on sowthistle	Reduced pre-emergence herbicide efficacy
	1997	-23	Greater in mulched crop	• Controlled pigweed • Controlled giant pigweed • No impact on sowthistle	No impact on pre-emergence herbicide efficacy

A detailed experiment to examine the barriers to performance of killed mulch systems is outlined in Appendix 3. We used broccoli as the test crop; a vegetable that had consistently performed poorly in previous killed mulch experiments.

A summary from that experiment follows.

Detailed killed mulch experiment summary

Our previous research showed some vegetable crops did not grow or yield as well under a killed mulch system, compared to conventional production. Killed mulch systems involve transplanting vegetable seedlings into undisturbed beds, in which a cover crop such as forage sorghum was previously grown for six to seven weeks, killed with herbicide, and flattened to form a protective mulch layer. This experiment sought to isolate which components of killed mulch systems were limiting crop performance. We investigated cover crop, tillage, and residue management combinations in broccoli production at Gatton Research Station between February and July 2000. Treatments included growing conventional fallow and cover crops, conventional and zero tillage, and mulch incorporation, retention or addition, in a series of treatment combinations.

Jumbo forage sorghum produced 15 t/ha of dry matter, forming a good cover, either as an in situ killed mulch, or transported mulch, hand laid. Planting broccoli through mulch was much easier where the mulch was still anchored to its root structure in defined rows. Where mulch was loose on the surface, straw pinned around the tines of planting equipment, causing blockages.

Broccoli grew slightly slower in ground that was cover cropped prior to planting. Slower growth could be due to either nutritional tie up or release of allelopathic chemicals as the sorghum roots degraded. The surface component of sorghum residues, i.e. surface straw, did not affect broccoli growth, either by locking up nutrients or increasing disease incidence. Neither pre-plant tillage, nor removal of surface residues, ameliorated reduced broccoli growth after cover cropping.

There were positive yield benefits from having a surface mulch of sorghum straw present, either grown in situ, or transported in. Hypotheses include; improved soil temperature (slightly cooler), improved surface soil water relations (slightly moister), or a combination, giving a better surface soil microenvironment and hence surface root growth.

There were no responses in broccoli growth to tillage treatments. This absence suggests that in our structured, black earth soils, a recently disturbed seedbed is not essential for acceptable vegetable performance, provided we achieve reasonable initial transplant-to-soil contact.

Our experiment confirmed that conditions leading to good establishment, early growth and high yields, are associated with earlier and more synchronous head development, reducing the need for extended, multiple harvests.

In the absence of herbicide applications, surface mulches reduced weed establishment. The reduction in hand weeding times using a mulched, no till strategy, (such as in the killed mulch system compared to the conventional strategy), would be an important commercial consideration in the absence of herbicidal weed management. In a low chemical or organic system, this would be a significant management factor. However, a mechanism for killing the tall, vigorous forage sorghum would be an interesting difficulty in the latter. In vegetables, such as brassicas produced with chemical management options, where there are some effective herbicide choices, and hence minimal hand weeding, the weed management from mulches is not as important.

Apart from factors not considered in this experiment (such as build up of nematodes and soil borne diseases), the important points in implementing a killed mulch system are:

1. *The cover crop must be sown and managed to provide clear rows, into which the vegetable crop can then be planted.*
2. *Good contact between the transplant cell and soil is required for acceptable vegetable growth and yield, however full soil disturbance is not.*
3. *There are benefits from the presence of surface mulches that may compensate for disadvantages of cover cropping prior to planting.*
4. *Improved crop nutrition may be a solution to poorer growth following a cover crop, however pre-planting tillage is not.*

Discussion

The most concise way to discuss the project outcomes is in the context of those agreed to in the original HRDC project submission.

Reduced risks of weeds becoming resistant to herbicides

Herbicide resistance is managed by increasing the weed management options available to producers, and reducing the reliance on one or two herbicides. It also means introducing concepts such as farm hygiene, prevention of weed seed set, and use of non-chemical management practices.

As noted elsewhere in this report, during this project we assisted in several new legal herbicide uses. The new use of oxyfluorfen in brassicas and onions means a herbicide from a separate herbicide resistance group is now available in those crops. Trifluralin is now available for direct-sown brassica vegetables. Many producers are also implementing appropriate herbicide rotations to cope with changing weed spectrums. If clopyralid becomes available to brassica growers, that will also be another invaluable resistance management tool. The non-herbicide, alternative practices outlined in this report enhance resistance management.

Reduced environmental hazard from inefficient use of herbicides

The new herbicide uses and refinement of existing practices has markedly reduced volumes of herbicides used in several vegetable crops. In brassicas, the switch to oxyfluorfen reduces herbicide use by 2/3, whilst in onions it is up to 85%. Although oxyfluorfen is a Dangerous Poison (due to the xylene carrier, rather than the active ingredient), proper use means the environmental hazard is minimal. For example, oxyfluorfen is not a leaching risk, and there are no detectable residues in the harvested food product. The project also clearly demonstrated the importance of not wasting herbicide by spraying for weeds that the herbicide does not control, or applying them in environmental or weed situations where they have little chance of working. We also demonstrated systems for reducing the amounts of chemical applied, whilst still achieving the same or superior crop performance (e.g. beetroot split-rate strategy).

Reduced weed management costs in vegetable production

Many of the strategies detailed in the report clearly reduce weed management costs compared to previous systems. For example, the herbicide costs in brassicas were reduced by 30-50%, in onions by 80%, and beetroot by 40-70% (variation due to whether and what pre-emergence herbicides were previously used). Reducing weed populations by effective herbicide use, adopting minimal seed set strategies, and a planned approach to weed management, all mean that density-dependent hand weeding, which is very expensive, can also be markedly reduced. (Density-dependent means that the cost of the control practice is proportional to the weeds present. For example, hand weeding time is proportional to the number of weeds there are to remove. In contrast, mechanical cultivation and herbicide application are generally density-independent, at least in the range of populations likely to be encountered in commercial production).

More effective long-term weed management outcomes

Although in this project we certainly developed and demonstrated long-term weed management principles, it would be fair to conclude that this was not a component that attracted a lot of industry interest or emphasis. Although producers expressed concern about the long-term impacts of weed management practices, the approach to weed management generally had a relatively short-term focus. Most concern was in managing a weed problem here and now, rather than putting in place a management plan to reduce populations over time. As previously discussed, this was probably allied to theories that tolerance of weed populations was OK, and that there were other more pressing issues that demanded attention during the cropping period.

Higher vegetable yields through better weed management and less crop damage

Our results clearly demonstrate the potential for the new strategies to give superior weed control with less risk of crop damage – as noted in the summary results presented for brassicas, onions, beetroot, and to a lesser extent, lettuce.

Enhanced product image, marketability and hence higher prices

We currently have a number of producers and producer groups developing marketing systems based on 'environmentally friendly' production concepts. These developments are in their infancy, however at least one of the groups is conscious of including weed management issues and management as part of its certification process. The two main components are a weed problem definition protocol (including weed mapping, species recognition and planned approaches), combined with environmentally acceptable management practices. As an example, the use of low-rate, sequential applications of oxyfluorfen in onions, or split applications in beetroot, neatly fit the certification guidelines. The work in killed mulches, if able to be developed into viable commercial production systems, could also lead to this outcome.

Innovative production systems, with less adverse environmental impacts

Many of the alternative weed management practices, such as flaming, transported mulches, or killed mulches, probably have little commercial application to general vegetable production at this time. More conventional production systems are much more reliable, easier to manage, less costly, and their environmental impact is rapidly being diminished as we become more adept at fine-tuning the systems. Some of the alternative practices may have niche applications in systems such as organic agriculture, or in circumstances where conventional options become unavailable, for example due to the development of herbicide resistance, preclusions on the use of polyethylene plastic mulches, or legislative constraints on chemical use due to political perceptions.

This project has provided some base data that may assist in the future development of these innovative systems if required.

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Technology transfer

Throughout the project we emphasised the need to work with industry and industry groups, agribusiness, chemical companies, the National Registration Authority, and various government and semi-government agencies, to ensure a two-way flow of knowledge. Apart from personal contact, we also committed to extensive publication in the rural media to promote awareness of relevant activities and outcomes.

New herbicide uses that are practical and effective are readily adopted, and in fact are generally demanded and well recognised long before they become a legal use. The biggest issue is the fine-tuning of these uses for particular environments and situations. Longer-term issues, which require in-depth consideration (and frequently discussion and questioning), really require more personal contact. They appear to have a longer gestation time, and may take over a decade to become part of the system. This is an ongoing process which we have undertaken over the last ten or so years. Because of a shift in industry focus and funding, although we will still be involved in weed management issues, it will be a much smaller component of our work once this project is finalised.

During the project, we published four major weed management chapters (in a weed reference book and three Agrilink books), twenty-three industry journal, DPI note, and newspaper articles, and five research summaries for research bulletins. We also completed 42 individual experimental reports (an example included in Appendix 3), which were sent to the collaborating producer, and made available to requesting groups or organisations on a negotiated basis.

We presented (and most cases organised) project information at 17 field walks or field days, gave nine seminars to industry groups, attended one National Weeds Conference and visited three interstate production districts. We gave four radio interviews relating to the project, and had regular contact with local and interstate consultants. We attended two workshops developing Minor Use procedures, and provided comment as the national Minor Use system was being developed.

We have a forthcoming article in Onions Australia, commitments to updating current Agrilinks and providing the weed information for the new brassica Agrilink. We have several scientific papers under development, and commitments to herbicide packages for Dow AgroSciences, and a final project article for Good Fruit and Vegetables.

A detailed list of technology transfer activities is provided in Appendix 4.

Recommendations

Industry will rapidly adopt useful new herbicide uses. Many producers have been involved with the initial discovery that a use is effective, either by experience in other production regions of the world, transfer from similar crops, actual experimentation and screening, or logical deduction based on chemistry and efficacy patterns.

The danger with many herbicide products is that the margins between effective weed control and crop damage are often narrow. They may also have specific environmental constraints to, and operational requirements for, effective implementation.

The Australian vegetable industry has committed to a national pesticide Minor Use program, with the charter for facilitating and coordinating industry pesticide priorities, investigating legal requirements and obtaining a legal use.

Although one argument says that producers can work out the best application strategies through trial and error, there is a problem with chemical company liability for problems. Many companies are currently reluctant to allow a new use (and their support is a requirement), because they are being sued for poor performance or crop damage for uses which have no commercial relevance to them. Until that circumstance changes, and the liability no longer exists, it is very important that pesticide application strategies (and particularly herbicides) are optimised <u>before</u> the use is legalised.

Alternatively, producers need to be aware that litigation against chemical companies for problems with minor uses has implications for those companies' support for the whole system.

Environmental impacts of food production are clearly becoming more important in the marketing of products, and on the operating conditions under which such production takes place. In developing new herbicide uses, either through the full registration or Minor Use processes, environmental impacts of these new uses need to be considered.

It may be useful to look at standardising an impact assessment process whereby all current and new uses can be objectively measured and compared. There have already been several studies throughout the world on such 'Environmental Indices', however I am not aware of any current standard process. I believe it is inevitable that industry will be asked to justify its production systems using such objective criteria in the not too distant future.

As noted in our report, whilst industry readily adopts effective new herbicide practices, they are much slower to embrace and particularly to act upon integrated weed management principles. This is probably because in the vegetable industry there is currently no 'weed crisis' (e.g. widespread herbicide resistance) and many of our current practices do a reasonable job. It is obvious that there are price, marketing, and other economic crisis that rightfully take precedence in the producers' precious thinking time. It is probably an industry decision to determine whether they will wait until a crisis leads to a change in mindset (such as insecticide resistance leading to IPM) before they address the need for a longer-term approach to weed management.

One of the aspects alluded to earlier in our report was the perception by producers that weeds around or in the crop could be a good thing, particularly with reference to sheltering beneficial insect. Without disputing this view, the scientific literature offers little support, as most weed species are poor nectar producers, and are seldom recorded as preferred hosts of beneficial species. It is often more likely that they are hosts of pest species (which may help build up beneficials in a circuitous route). As this perception of 'useful weeds' is a clear barrier to adoption of some weed management principles, it is probably a required avenue for investigation if the 'barrier' is to be circumvented.

Over the past five to eight years there has been considerable effort into killed mulch systems around the world, and in Australia. I am not aware of any commercial adoption, even though some of the systems in the USA have been demonstrated as very viable and competitive with conventional production. Perhaps a detailed review of what are the barriers/impediments to commercial application would be timely, including a comprehensive review of all the research to date. It is my view that we have a great deal of empirical evidence of a range of different systems, but not a very clear understanding of the factors determining those outcomes. The trial and error process to date has not led to a commercial outcome yet, so perhaps a different approach is required.

Appendix 1. Materials and Methods section from Experiment P1440.13

The experiment was conducted on a black earth soil (*Ug5.15*) at Gatton Research Station (lat. 27°33'S, long. 152°20'E). The experimental design was a randomised complete block, with each plot 10 m long and 1.5 m wide. There were 4 replicates of 8 treatments.

The soil was prepared as per standard practice for a broccoli crop. The cultivar *Greenbelt* was direct sown on the 3 June 1997. The broccoli had intra- and inter-row spacings of 33 cm and 75 cm respectively. A compound fertiliser containing 12% N, 5.2% P, 14.1% K, 4% S, 5% Ca and 1.2% Mg was incorporated into the beds at 400 kg/ha, 3 weeks before planting. Urea fertiliser was broadcast at 60 kgN/ha across the entire experiment 52 days after sowing (DAS), and incorporated with irrigation. Micronutrient solutions containing 2 L/ha of BORTRAC® and 0.15 L/ha of MOLYTRAC® were sprayed one day earlier.

Diseases were controlled with 2.2 kg/ha of BLUE SHIELD® (copper hydroxide) sprayed 16, 36, 51 and 77 DAS. Lepidopteran insects were managed with 2 L/ha of LANNATE® (methomyl) sprayed 16, and 36 DAS; 700 mL/ha of LORSBAN® (chlorpyrifos) at 21 DAS; 1.5 L/ha of TOKUTHION® (prothiofos) 36, 51, 64 and 77 DAS; and 0.8 L/ha of NITOFOL® (methamidophos) at 64 DAS. Aphid management involved spraying 750 mL/ha of ROGOR® (dimethoate) at 16, 36, 58, and 77 DAS.

Irrigation

After planting, the broccoli were irrigated by lines of solid-set sprinklers running longitudinally down both blocks. Irrigations were scheduled, based on data from tensiometer stations installed in the crop six weeks after sowing. The tensiometers were installed 15 cm and 60 cm below ground level in the hand-weeded treatments. Loctronic® tensiometers were used, which consist of a standard ceramic tip and tube, but no vacuum gauge. To obtain readings, a hollow syringe is forced through the rubber septum at the top of the tensiometer, and an electronic vacuum gauge senses the vacuum in the small air gap below the septum. Tensiometer readings were recorded around 8-9 am daily.

Weed management strategies

The herbicides used in this experiment were:

LONTREL® (300 g/L clopyralid) registered for broadleaf weed control in a range of crops at 0.1-0.3 L/ha. LONTREL® is effective against Asteraceae, Fabaceae, and Polygonaceae, but does not affect brassica species (weeds or crops). Commercial application rates in crops (canola in Australia, and horticultural brassicas overseas), are generally in the order of 0.3 L/ha.
RADIATE® (225 g/L clopyralid and 150 g/L picloram) is registered in New Zealand for broadleaf weed control in forests and fodder brassicas. The picloram component gives an expanded weed spectrum and longer residual weed control. Use in the latter crops is at around 0.3-0.35 L/ha.
LENTAGRAN® (450 g/kg pyridate) is a post-emergence broadleaf herbicide registered for use overseas in horticultural brassica crops. Use rates vary between 1-4 kg/ha, depending on target weed species.

The 8 weed management strategies compared in this experiment are detailed below.

1. LONTREL® applied as a post-emergence herbicide at 200 mL/ha or 300 mL/ha on 7 July 1997 (34 DAS).
2. RADIATE® applied as a post-emergence herbicide at 100 mL/ha on 7 July 1997 (34 DAS), or 200 mL/ha on 8 July 1997 (35 DAS).
3. LENTAGRAN® applied as a post-emergence herbicide at 1 kg/ha or 2 kg/ha on 8 July 1997 (35 DAS).
4. Hand-weeded. All weeds controlled by hand-weeding 44 DAS and 87 DAS; no herbicides used.
5. Unweeded control. No weed control methods used.

The herbicides were sprayed using a motorised knapsack sprayer with a 1.5 m hand held boom operating at 200 kPa and applying 300 L/ha of spray solution.

The weather on each day of spraying is shown in Table 1.

Table 1. Weather conditions when herbicide treatments were sprayed

Date	Time	Temperature (°C)	Wind (km/hr)	Relative humidity (%)
7 July 1997	7:30-9:00 am	13	5-10	84
8 July 1997	8:00-9:15 am	14	5	87

Measurements

Growth of weeds was monitored throughout the experiment. On 30 June 1997 (27 DAS), weeds in 5 randomly placed 0.2 m^2 plots were counted. On 22 August 1997 (80 DAS), the total number of weeds in each plot were counted. The time taken to hand-weed the control treatments was recorded on each occasion. On the 11 September 1997 (100 DAS), weeds were removed from all treatments, sorted into species, counted and weighed.

Marketable broccoli heads were harvested from each plot on the 5 September 1997 (94 DAS), 8 September 1997 (97 DAS), and 10 September 1997 (99 DAS). Total numbers and weights of heads harvested were recorded.

Data analyses

All broccoli yield variables were analysed using standard analysis of variance. Owing to the nature of their distributions, weed counts and biomass were log-transformed before analysis. Conversion of the data to its original form took place before presentation.

Appendix 2. Materials and Methods section from Experiment P2087.16

We conducted the experiment on a loamy sand soil on Harslett farms, on the Granite Belt in southern Queensland. The experimental design was a randomised complete block design, with four treatments replicated twice in a total of eight plots. The total experiment comprised a strip approximately 120 m long and 16 m wide. Each plot was 16 m wide and 15 m long.

The soil was prepared as per standard practice for lettuce production, except for the additional cultivations in one of the experimental treatments (see below). Alec and Denise Harslett, the collaborating producers, conducted all the normal agronomic treatments such as irrigation, nutrition, disease, and insect management. Lettuce cultivar *Mustang* was transplanted on the 9-10 November 1998 into rows 0.50 m apart, with an intra-row spacing of 0.33 m.

Experimental strategies

Farm staff implemented general weed management practices across the whole site, which included:

- Cultivated, rotary hoed and levelled the area one week before transplanting.
- Hand weeded the area to remove residual weeds on 8 November 1998, 28 days after transplanting (DAP).
- Sprayed the area with 1 L/ha of FUSILADE (fluazifop-p, butyl) 17 DAP.

The experiment involved four weed management strategies that included the following additional practices.

Herbicide strategy

Farm staff sprayed this treatment with 2 L/ha of STOMP® (pendimethalin) and 5 L/ha of RAMROD® (propachlor) four days before transplanting and watered in the herbicides with 10 mm of irrigation.

Hand weeding strategy

Farm staff sprayed the treatment with 3 L/ha of STOMP® four days before transplanting and watered in the herbicide with 10 mm of irrigation.

Stale-seedbed strategy

Farm staff deep ripped this treatment to a depth of 0.5 m 4 weeks before transplanting, and cultivated this area two days later. The intention was to not cultivate again prior to planting, and to spray out any weeds with a knockdown herbicide just before planting. However, these plots were cultivated at the same time as the others one week before transplanting, which obviated the need for the knockdown herbicide. Farm staff sprayed the treatment with 3 L/ha of STOMP® four days before transplanting and watered in the herbicide with 10 mm of irrigation.

Alternative strategy

Farm staff sprayed the treatment with 3 L/ha of STOMP® four days before transplanting and watered in the herbicide with 10 mm of irrigation. Immediately after transplanting, wheat straw was spread across the plots at a rate of 4 t/ha. Straw was moved from around lettuce seedlings, repeated 1 week later.

Measurements

We photographed the mulched plots on 17 November 1998 (7 DAP) and 26 November 1998 (16 DAP). We recorded the widths of 40 randomly selected lettuces per plot on 26 November 1998 (16 DAP). We harvested the lettuces on 23 December 1998 (43 DAP). In each plot, we counted all the marketable heads in six 12 m rows, then harvested and weighed 12 marketable lettuces from each row.

We counted the weeds in all plots on 17 November 1998 (7 DAP), at which time the weeds present were at the cotyledon stage. We counted weeds again on the 7 December 1998 (27 DAP), just before farm staff weeded the entire experimental area.

Data analyses

We analysed lettuce growth and yield using standard analysis of variance procedures. Because of weed distributions, we log-transformed all the weed counts prior to standard AOV, and then re-transformed the data back to conventional units before presentation.

Appendix 3. Mulch and soil management in broccoli production

by Craig Henderson, Angelina Gilbert and Greg Finlay, QDPI Gatton Research Station.

Summary

Our previous research showed some vegetable crops did not grow or yield as well under a killed mulch system, compared to conventional production. Killed mulch systems involve transplanting vegetable seedlings into undisturbed beds, in which a cover crop such as forage sorghum was previously grown for six to seven weeks, killed with herbicide, and flattened to form a protective mulch layer. This experiment sought to isolate which components of killed mulch systems were limiting crop performance. We investigated cover crop, tillage, and residue management combinations in broccoli production at Gatton Research Station between February and July 2000. Treatments included growing conventional fallow and cover crops, conventional and zero tillage, and mulch incorporation, retention or addition, in a series of treatment combinations.

Jumbo forage sorghum produced 15 t/ha of dry matter, forming a good cover, either as an in situ killed mulch, or transported mulch, hand laid. Planting broccoli through mulch was much easier where the mulch was still anchored to its root structure in defined rows. Where mulch was loose on the surface, straw pinned around the tines of planting equipment, causing blockages.

Broccoli grew slightly slower in ground that was cover cropped prior to planting. Slower growth could be due to either nutritional tie up or release of allelopathic chemicals as the sorghum roots degraded. The surface component of sorghum residues, i.e. surface straw, did not affect broccoli growth, either by locking up nutrients or increasing disease incidence. Neither pre-plant tillage, nor removal of surface residues, ameliorated reduced broccoli growth after cover cropping.

There were positive yield benefits from having a surface mulch of sorghum straw present, either grown in situ, or transported in. Hypotheses include; improved soil temperature (slightly cooler), improved surface soil water relations (slightly moister), or a combination, giving a better surface soil microenvironment and hence surface root growth.

There were no responses in broccoli growth to tillage treatments. This absence suggests that in our structured, black earth soils, a recently disturbed seedbed is not essential for acceptable vegetable performance, provided we achieve reasonable initial transplant-to-soil contact.

Our experiment confirmed that conditions leading to good establishment, early growth and high yields, are associated with earlier and more synchronous head development, reducing the need for extended, multiple harvests.

In the absence of herbicide applications, surface mulches reduced weed establishment. The reduction in hand weeding times using a mulched, no till strategy, (such as in the killed mulch system compared to the conventional strategy), would be an important commercial consideration in the absence of herbicidal weed management. In a low chemical or organic system, this would be a significant management factor. However, a mechanism for killing the tall, vigorous forage sorghum would be an interesting difficulty in the latter. In vegetables, such as brassicas produced with chemical management options, where there are some effective herbicide choices, and hence minimal hand weeding, the weed management from mulches is not as important.

Apart from factors not considered in this experiment (such as build up of nematodes and soil borne diseases), the important points in implementing a killed mulch system are:

5. *The cover crop must be sown and managed to provide clear rows, into which the vegetable crop can then be planted.*
6. *Good contact between the transplant cell and soil is required for acceptable vegetable growth and yield, however full soil disturbance is not.*
7. *There are benefits from the presence of surface mulches that may compensate for disadvantages of cover cropping prior to planting.*
8. *Improved crop nutrition may be a solution to poorer growth following a cover crop, however pre-planting tillage is not.*

Relevance to industry

Organic mulches are an innovative method for managing weeds in vegetable production. Killing cover crops and then planting through them has been investigated in vegetable production in other parts of the world and in southern states of Australia. This experiment established a series of cover-crop management plots, following which we imposed tillage and residue management treatments.

Objectives

- To determine which components of a killed mulch system cause problems with broccoli crop performance and yield.
- To observe the practical difficulties of using a killed mulch system, and suggest methods for ameliorating those problems.

Materials and methods

We conducted the experiment on a black earth soil (*Ug5.15*) at Gatton Research Station (lat. 27°33'S, long. 152°20'E). We used a randomised complete block experiment, with eight treatments replicated four times in blocks. Our total experiment comprised a strip approximately 100 m long and 10 m wide, arranged in thirty-two 3.0 m wide plots running east-west across the width of the main strip. Our eight treatments involved two cover cropping practices, two tillage practices, and two residue handling practices, as outlined Table 1.

Table 1. Killed mulch system evaluation treatments.

Treat no.	Pre-crop activities to form the mulch treatment	Tillage treatment	Additional activity
1	Conventional fallow	Tilled	
2	Conventional fallow	No till	
3	Conventional fallow	Tilled	Sorghum tops transported in
4	Conventional fallow	No till	Sorghum tops transported in
5	Sorghum cover crop grown, then tops cut at soil level and removed	Tilled	
6	Sorghum cover crop grown, then tops cut at soil level and removed	No till	
7	Sorghum cover crop grown, then sprayed with glyphosate and allowed to lodge to form a mulch	Tilled	
8	Sorghum cover crop grown, then sprayed with glyphosate and allowed to lodge to form a mulch	No till	

Research Station staff ripped the site before preparing the ground for planting using conventional cultivation. On 8 February 2000, they sowed *Jumbo* forage sorghum at 50 kg/ha into the designated plots, leaving 12 cm wide gaps for broccoli planting. After a few weeds emerged, we removed them by hand on 22 February, and again on 7 March. After 7 weeks, we sprayed the experimental area with 4 L/ha of ROUNDUP® herbicide, to kill the forage sorghum and any late emerging weeds.

On 10 April (62 days after planting the sorghum), we cut off the dried forage sorghum at ground level from the designated plots (Treatments 5, 6), and removed the straw beyond the ends of the plots. We rotary hoed all the tilled treatments (Treatments 1, 3, 5, 7). After we completed the tillage, we replaced the cut sorghum onto the designated plots (Treatments 3, 4), and flattened the sorghum on Treatment 8.

As a consequence of these practices, we had a conventionally prepared treatment (1), and the following comparisons:

Whether absence of soil disturbance affected broccoli growth (1 vs 2)
Whether the presence of surface mulch affected broccoli growth (1 vs 3)
Whether growing a cover crop previously affected broccoli growth (1 vs 5)
Whether incorporating killed, dry sorghum tops into the root zone affected broccoli growth (1 vs7)
Whether a killed mulch system affected broccoli growth (1 vs 8).
Whether the presence of cover crop roots in a killed mulch system affected broccoli growth (4 vs 8).
Whether the absence of soil disturbance in a killed mulch system affected broccoli growth (3 vs 4).

We transplanted broccoli cv. Greenbelt into the experimental area two days after the residue manipulation and tillage, on 12 April 2000, with inter-row spacing of 0.75 m and an intra-row spacing of 0.33 m. Farm staff spread the compound fertiliser CK77S on 13 April at a rate of 400 kg/ha. Only one side dressing of 25 kgN/ha as urea was broadcast over the experimental area on 19 April, 7 days after transplanting (DAP).

We hand weeded the broccoli crop on one occasion, five weeks after transplanting, and recorded the time taken in each of plot.

Chemicals applied to the broccoli throughout the growing period were;
Insecticides
- 0.75 L/ha of PIRIMOR® (pirimicarb) 29 DAP
- 0.25 mL/ha of REGENT® (fipronil) 29, and 36 DAP
- 2.1 L/ha of LANNATE® (methomyl) 37, and 72 DAP

Fungicides
- nil

Herbicides
- nil

Irrigation

We irrigated the broccoli with lines of solid-set sprinklers running down the long edges of the block. We installed tensiometer stations in the forage sorghum crop 4 weeks after planting, and in the broccoli crop 8 weeks after transplanting. The tensiometers were installed 15 cm and 60 cm below ground level in one plot of each block. We used Soilspec tensiometers, which consist of a standard ceramic tip and tube, but no vacuum gauge. To obtain readings, a hollow syringe is forced through the rubber septum at the top of the tensiometer, and an electronic vacuum gauge senses the vacuum in the small air gap below the septum. Tensiometer readings were recorded around 8-9 am daily.

Measurements

Forage sorghum cover crop

We counted the weeds present in each plot (30 m^2) on 22 February (14 days after sowing), just before the initial hand weeding. On 28 March (49 days after sowing), we again counted the weeds present in each plot, and cut two 0.2 m^2 quadrats of forage sorghum per plot. We weighed these sorghum samples, and then dried sub-samples to enable conversion of the data to a dry weight basis.

Broccoli

One week after transplanting, we removed two 0.2 m^2 quadrats of forage sorghum residues from the respective plots, weighed these samples, and dried sub-samples to enable conversion of the data to a dry weight basis. We undertook a final measurement of remaining sorghum residues biomass on 4 July (83 DAP), using the same procedure as above.

We measured the widths of 20 randomly selected broccoli plants from each plot on 4 May (22 DAP), and photographed representative plots. At the same time, we counted the weeds present in eight 0.2 m^2 quadrats per plot, prior to hand weeding the whole area. We rated plots for general health, using a 1-4 scale, on 25 May (43 DAP). We counted the numbers of broccoli heads greater than 5 cm diameter in each plot on 22 June (71 DAP).

We harvested mature broccoli heads on 29 June (78 DAP), 3 July (82 DAP), 6 July (85 DAP), and conducted a final clean-up harvest on 19 July (98 DAP). At each harvest, we counted the heads and recorded the total weight per plot. On 13 July, we counted any weeds that had emerged over the whole plots, cut the weeds off at ground level and recorded their fresh weights.

Data analyses

We analysed all plant growth and yield variables using standard analysis of variance. Owing to the nature of their distributions, we log-transformed weed counts and biomass before analysis. We converted the data back to its original form prior to presentation in this report.

Results and discussion

Irrigation

A total of 36 mm of rain fell during the cover cropping phase, with a further 94 mm during the broccoli growing period (Fig 1). Because of significant soil water storage, the cover crop was able to grow without supplementary irrigation. By the time we implemented the cover crop treatments, most of the water had been extracted from the crop root zones, with deep cracks in the cover-cropped plots.

We applied 237 mm of irrigation during the broccoli cropping period, following an additional 30 mm irrigation two days before transplanting. As we did not install the tensiometers until late in the cropping period, we can only estimate the water status of the crop during the vegetative and early reproductive phases. The irrigation frequency suggests that there should have been sufficient water to prevent any significant water stress. There may have been a 5-7 day period around 11 weeks after transplanting when the broccoli was slightly stressed, indicated by shallow tensiometer values greater than 40 kPa, and extraction of moisture from deeper in the soil profile. This slight stress did not appear to affect yield or head quality.

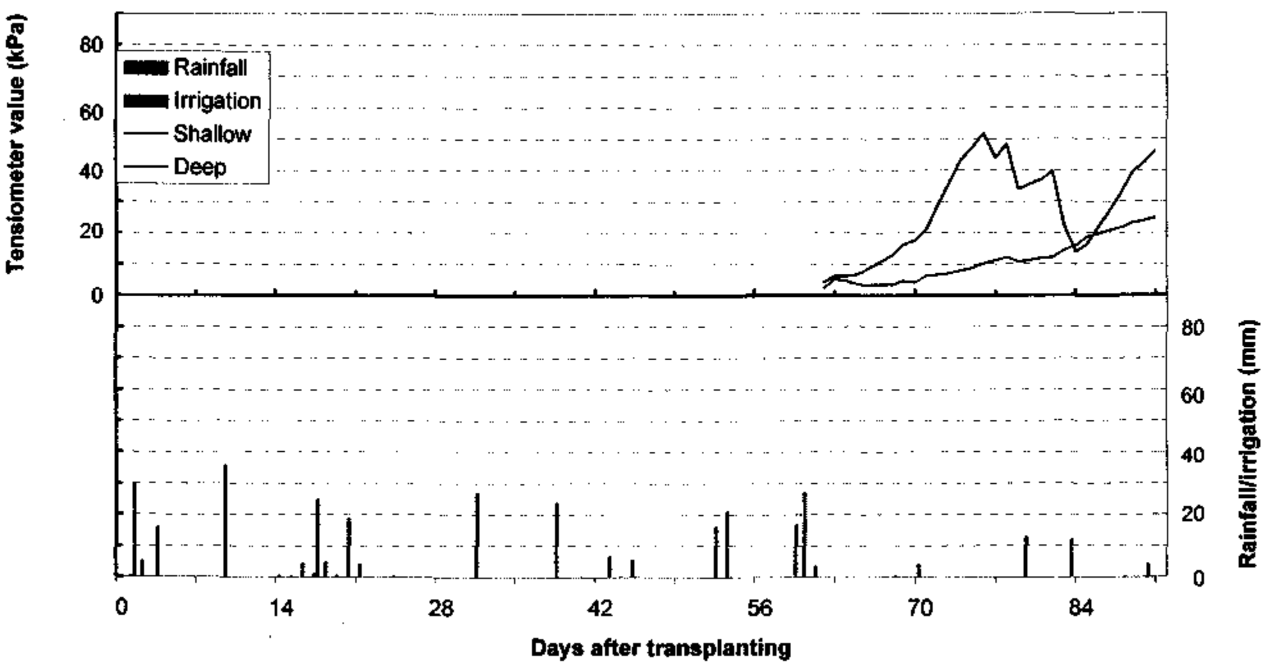

Figure 1. Fluctuation in tensiometer values with rainfall and irrigation during the broccoli growing period.

Forage sorghum cover crop

Weed incidence

There were few weeds present two weeks after planting the forage crop (Fig. 2). There were significantly more weeds in the uncropped areas, compared to those plots where the forage sorghum was growing. Sowthistle (*Sonchus oleraceus*) and giant pigweed (*Trianthema portulacastrum*) were the species most obviously suppressed by the forage sorghum.

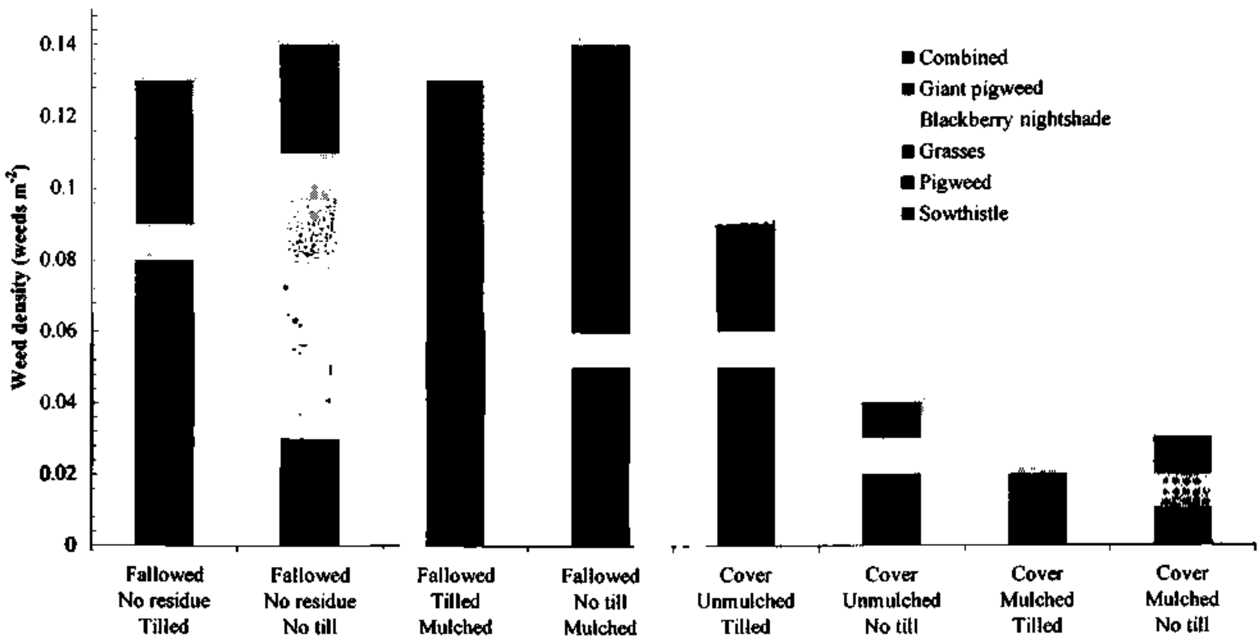

Figure 2. Forage sorghum reduces the presence of weed species two weeks after sowing.

After seven weeks growth, the forage sorghum had produced 14.1 t/ha of dry matter, evenly across all the cover crop treatment plots. The presence of the sorghum had basically eliminated any further weed emergence, whilst there were some new weeds in the uncropped plots (Fig. 3), predominantly sowthistle and pigweed (*Portulaca oleracea*), with a few residual giant pigweed.

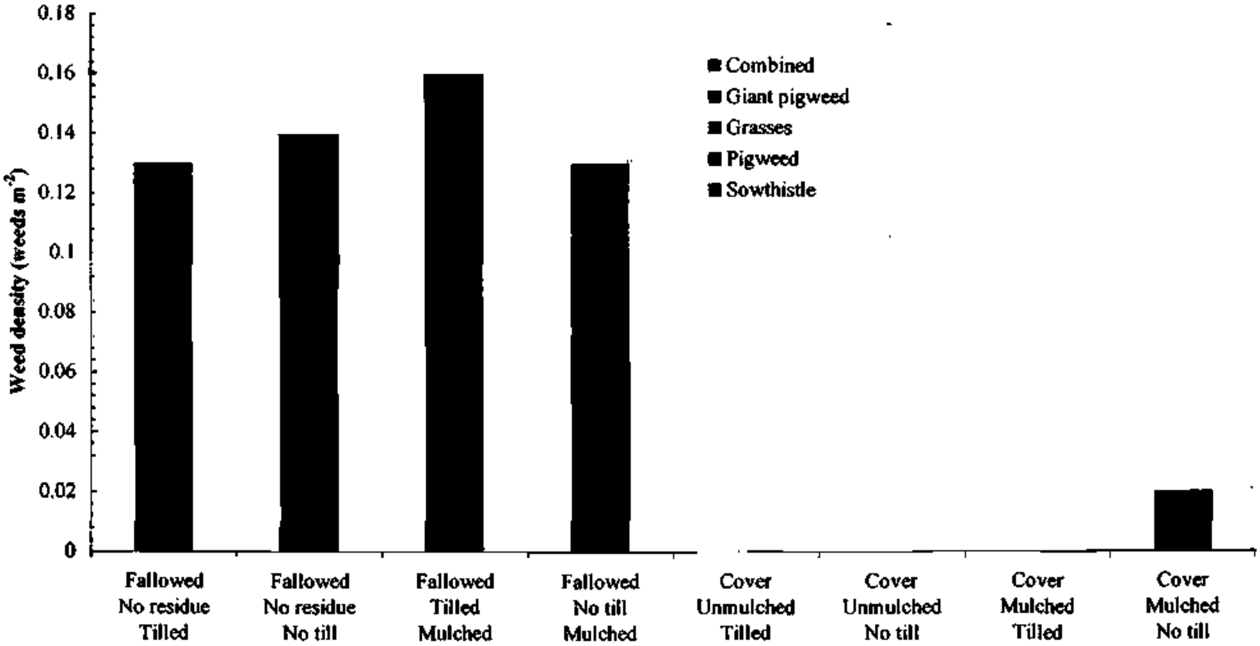

Figure 3. Forage sorghum reduces the presence of weed species seven weeks after sowing.

Broccoli growth and yield

Where residues were present during broccoli transplanting, the planting was much more difficult where the residue was not anchored between the planting tines (e.g. Treatment 7), as it tended to pin around the tines. In the standard killed mulch treatment (8), where the sorghum was sprayed and then flattened, the transplanting proceeded relatively smoothly, with only occasional disruption.

One week after transplanting the broccoli, about 15.0 t/ha dry weight of sorghum stubble remained on the surface mulched treatments (3, 4, 8), with 2.9 t/ha of surface residue on Treatment 7, where we incorporated the sorghum cover crop with a rotary hoe before broccoli transplanting.

Three weeks after planting, none of the cover crop, tillage, or residue retention treatments (Fig. 4) consistently affected the widths of broccoli plants, even though there were some significant differences between the individual treatment combinations.

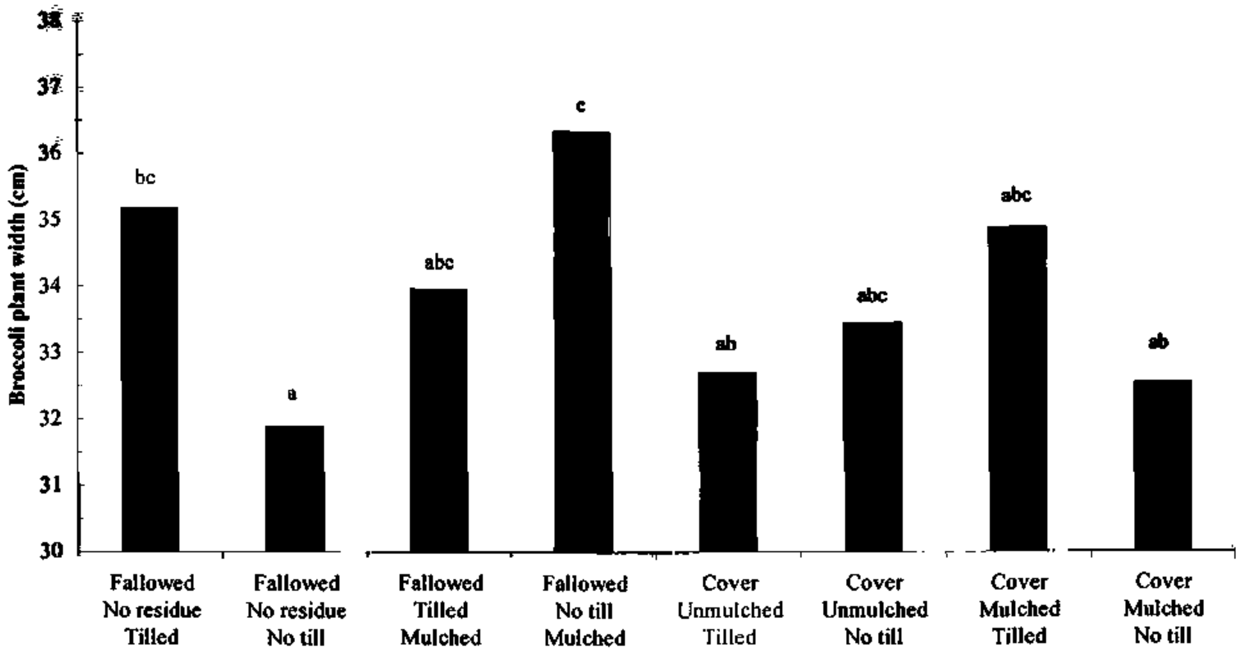

Figure 4. Soil and cover crop residue management marginally affected broccoli plant widths three weeks after transplanting.

The photographs in the Appendix provide an impression of the broccoli crops, sorghum residue status and weed management impacts around three to four weeks after transplanting.

Six weeks after transplanting, the broccoli plants in plots which had been previously fallowed appeared more vigorous than plants growing in cover cropped soil (Fig. 5). The worst performed treatment was the killed mulch practice (8), where the broccoli was transplanted into undisturbed sorghum residue. Similarly, broccoli head development appeared slightly more advanced in the treatments with a fallow preparation, compared to the cover cropped areas, although this was not consistent (Fig. 6). The killed mulch treatment (8) had the fewest developed heads, whilst its companion treatment, where the sorghum was simply turned into the soil (7), had the most.

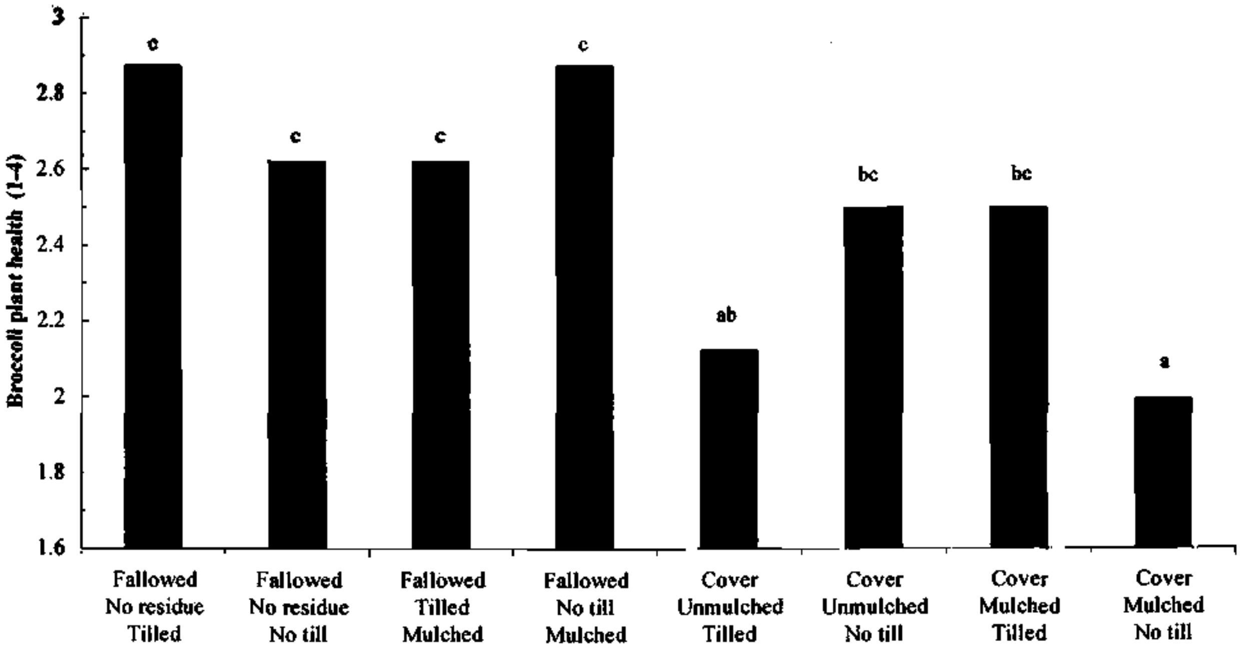

Figure 5. Soil and cover crop residue management affected broccoli plant vigour seven weeks after transplanting.

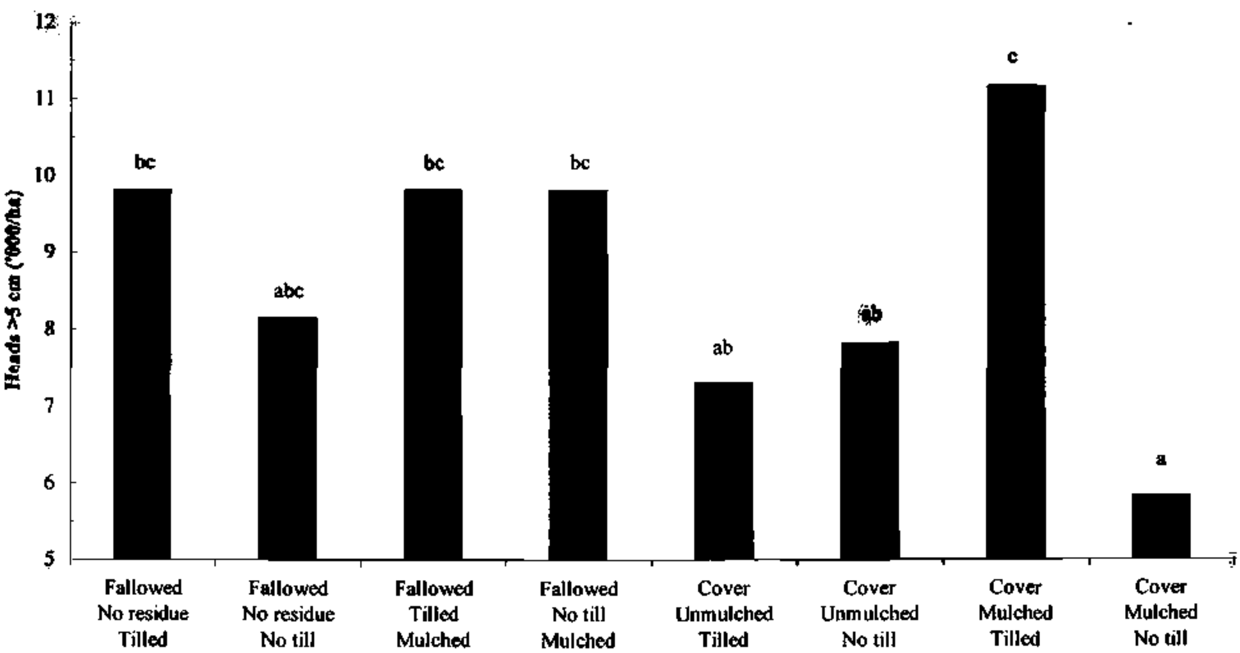

Figure 6. Soil and cover crop residue management affected broccoli plant head development ten weeks after transplanting.

There was surprisingly little difference in total broccoli yields across the experiment (Fig. 7). There was a trend for slightly greater yields in the treatments with a fallow preparation, compared to the cover cropped areas. There was also a trend for slightly greater broccoli yields in treatments with a surface sorghum residue presence (3, 4, 7, 8), than where there was no mulch on the surface. The best performed treatments were those where the sorghum residue was manually spread over plots with a fallow preparation (3, 4). Interestingly, any improvement in yield from disturbing the soil (i.e. till vs no till) was only marginal. Higher yields were associated with treatments where the bulk of the crop was cut in the first two harvests.

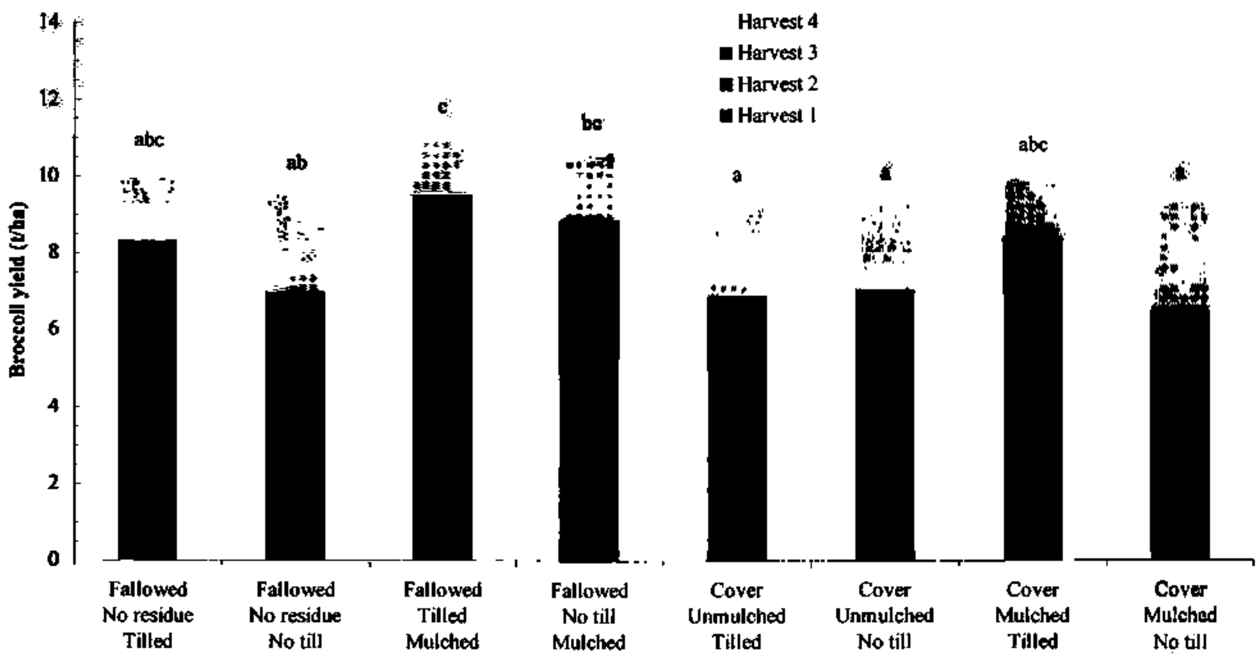

Figure 7. Soil and crop residue management affected broccoli yields.

We consistently cut 36,100 heads/ha (90%) across the experiment, with little variation amongst the treatments (Fig. 8). The data also confirmed the earlier head maturity in the higher yielding plots.

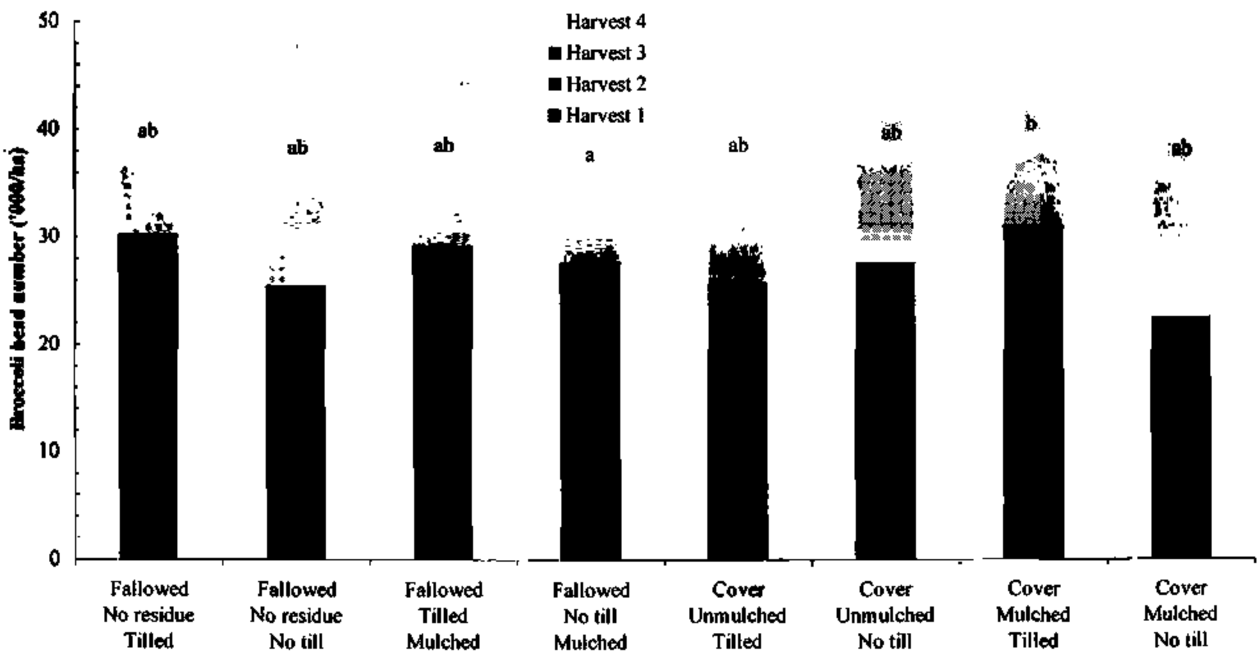

Figure 8. Soil and crop residue management did not affect total heads harvested, but did affect time of head maturity.

Broccoli areas with a fallow preparation, followed by manual mulching of transported sorghum straw (Treatments 3, 4), had consistently heavier heads than the other broccoli plots (Fig. 9).

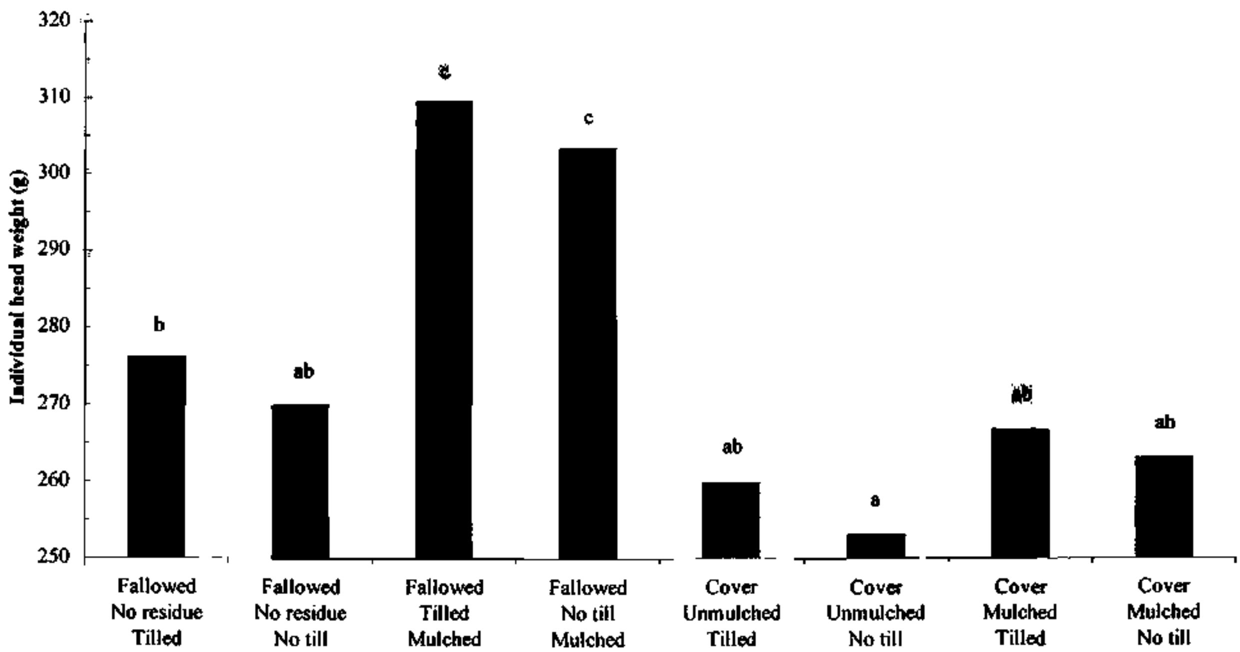

Figure 9. Soil and crop residue management affected individual broccoli head weights.

Weed management
Once we transplanted the broccoli, the main weeds present in the experimental area included sowthistle (*Sonchus oleraceus*), pigweed (*Portulaca oleracea*), various grasses, blackberry nightshade (*Solanum nigrum*), deadnettle (*Lamium amplexicaule*), London rocket (*Sisymbrium irio*), shepherd's purse (*Capsella bursa-pastoris*), with a few other species sporadically present.

Three weeks after transplanting, total weed populations were reduced in the presence of surface mulch residues (Fig. 10), indicated by Treatments 3, 4, and 8. Individual species showed the same trends. The populations of sowthistle, pigweed, and grasses were also reduced by the no tillage practice, whilst this effect was not significant with blackberry nightshade, deadnettle, or the two brassica species.

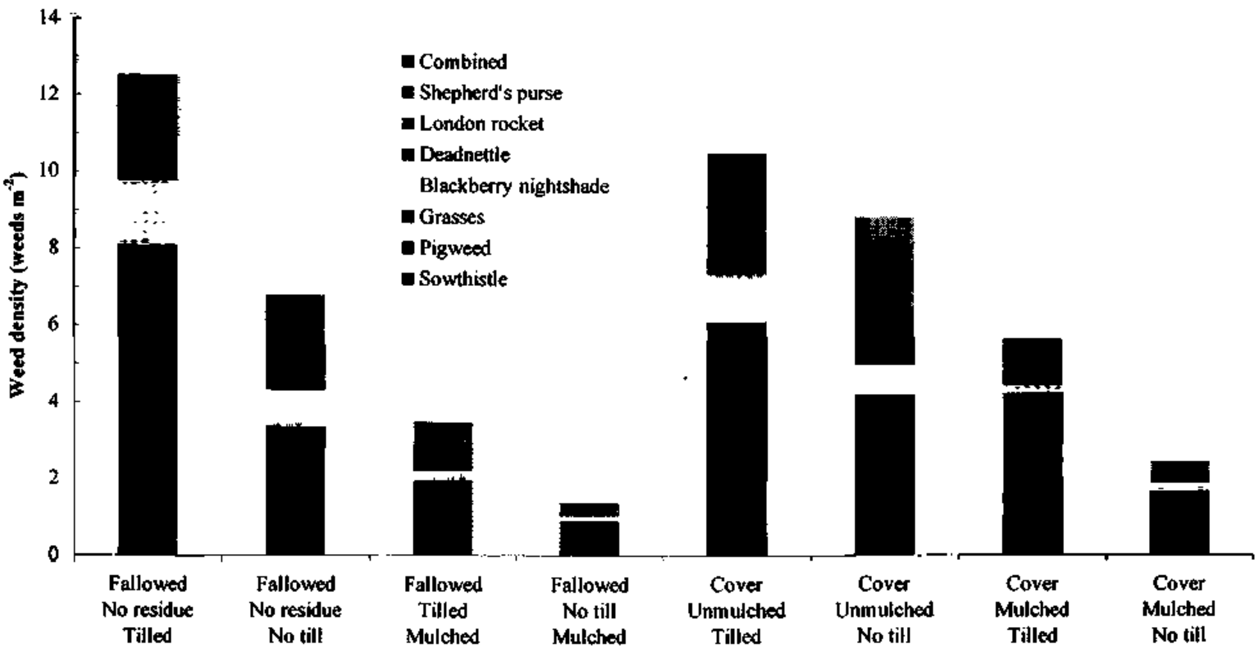

Figure 10. Tillage and the presence of surface mulch reduced the populations of weed species three weeks after transplanting.

The time taken to hand weed the various treatments reflected weed abundance (Fig. 11). An equivalent of 55 hours/ha was needed to weed the tilled plots with no surface residue (Treatments 1, 5). Implementing a no till practice reduced that time to about 38 hours/ha, whilst mulching the tilled treatments reduced weeding time to about 32 hours/ha. The least weeding was needed on no till, mulched plots (26 hours/ha).

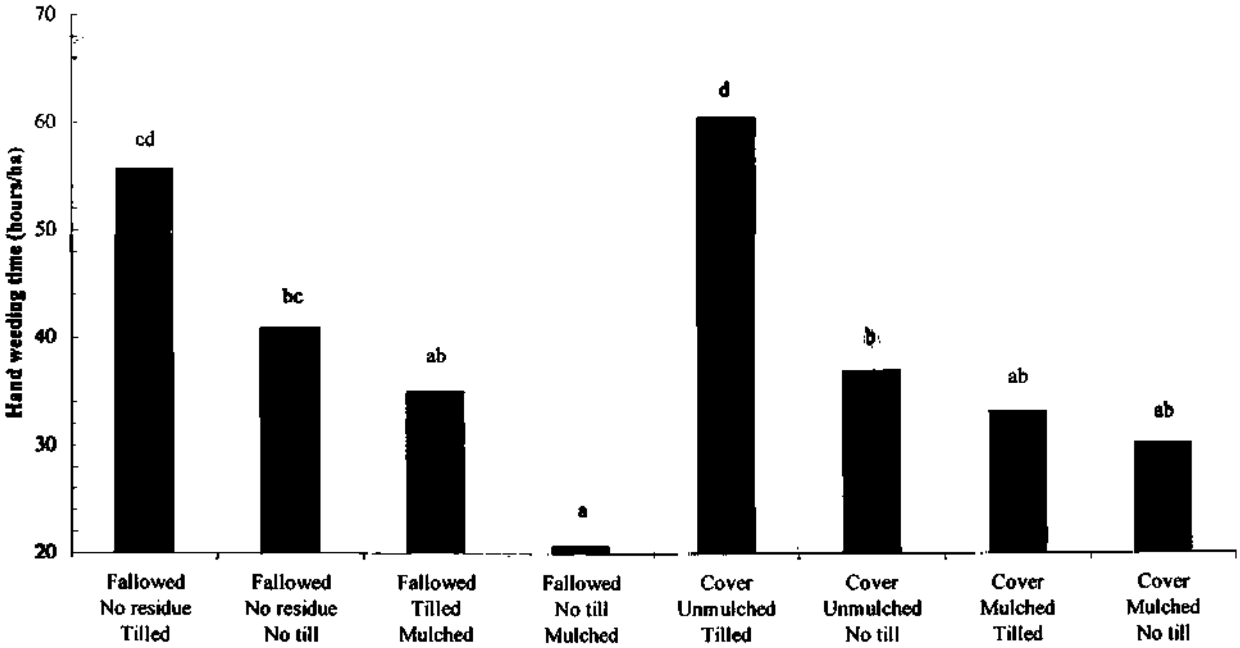

Figure 11. Tillage and the presence of surface mulch reduced hand weeding times three weeks after transplanting.

As the broccoli was being harvested, there was still about 9.2 t/ha dry weight of sorghum residues remaining on the surface of the mulched treatments (3, 4, 8), and 2.0 t/ha of mulch where the sorghum had been incorporated with the rotary hoe (Treatment 7).

Late emergence of sowthistle was substantially lower in those treatments that were cover cropped prior to planting broccoli, compared to treatments with a fallow preparation (Fig. 12, 13). The overall weed presence was very low (less than one weed every 5 m^2), so this is not a particularly meaningful result in a commercial context.

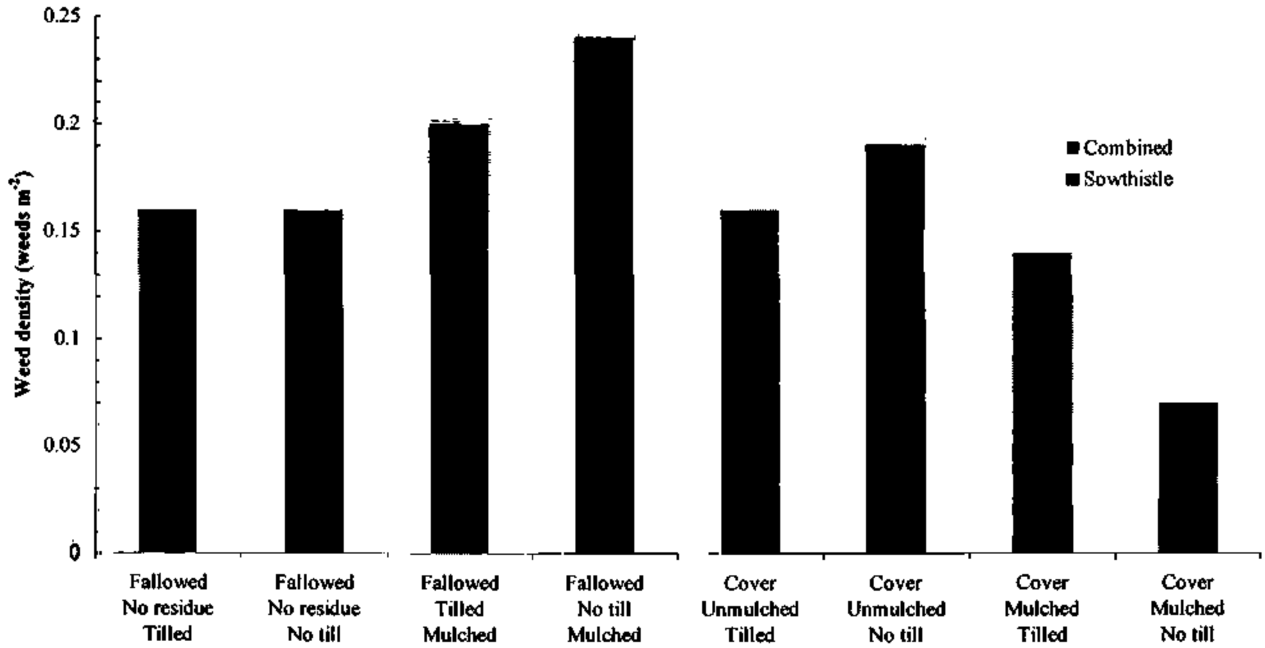

Figure 12. Cover cropping prior to broccoli transplanting reduced late sowthistle emergence.

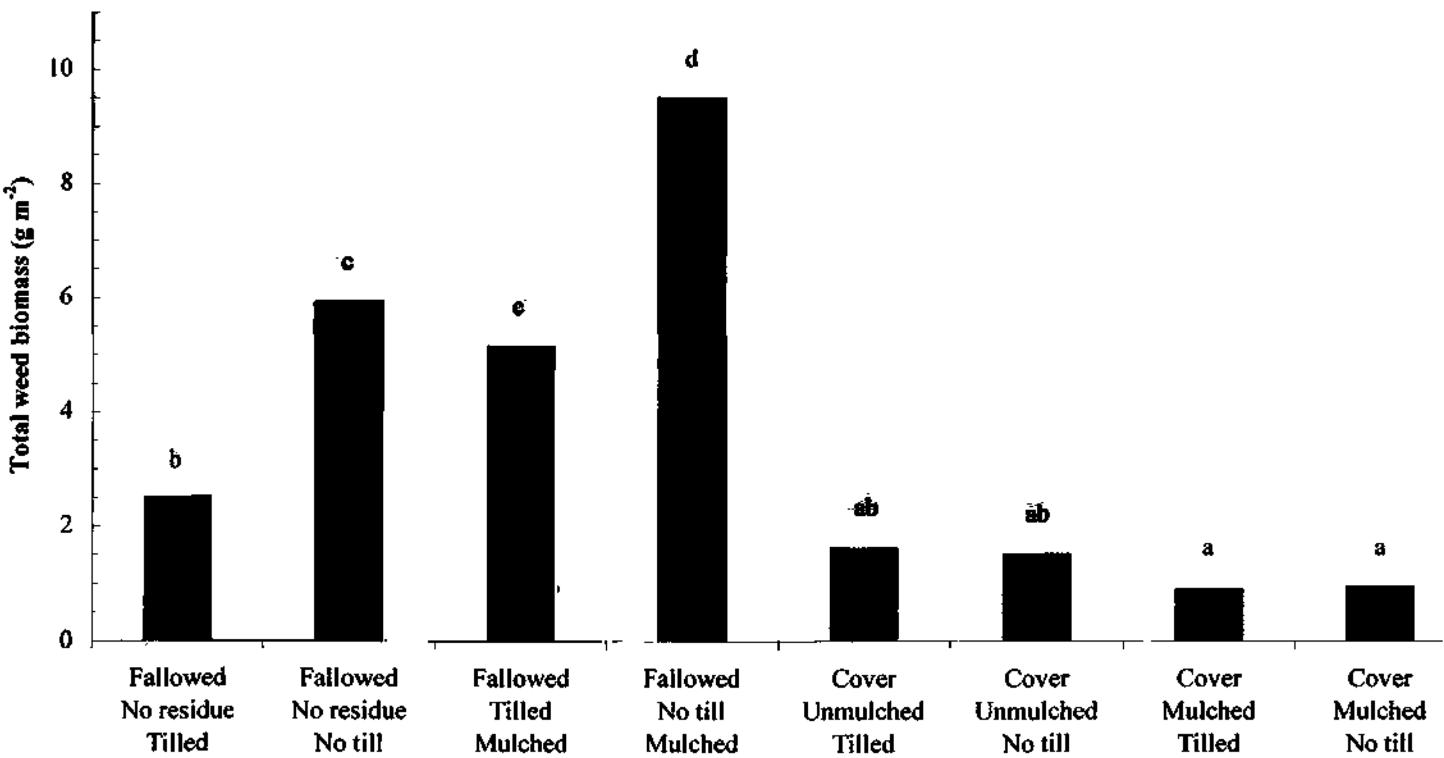

Figure 13. Cover cropping prior to broccoli transplanting reduced late weed biomass development.

Conclusions

As expected, growing a cover crop suppressed weed emergence and growth prior to planting the broccoli. The volume of mulch produced by the forage sorghum (15 t/ha of dry matter), was sufficient to form a good surface cover, either as an *in situ* (Treatment 8) or transported mulch (Treatments 3, 4). Even where we incorporated the mulch with a rotary hoe, there was still 2-3 t/ha of mulch remaining on the surface.

Planting through the mulch was much easier where there were clearly defined rows and the mulch was still anchored to its root structure. This confirms that in planting and managing the killed mulch:

1. The mulch should be sown in defined rows, with sufficient inter-row spacing to enable the transplanter to plant vegetables between mulch rows.
2. Once killed, the mulch should be rolled rather than chopped up and spread.
3. Any cultivation required for the planting operation should be confined to the planting row.

There may be some slight reduction in initial vegetable crop performance associated with the presence of a cover crop prior to planting (Fig. 4-6). This may be a nutritional effect, from the cover crop tying up elements such as nitrogen, which are not released back into the soil sufficiently quickly once the vegetable crop is planted. Alternatively, it may be due to the presence of sorghum root residues having an allelopathic impact as they break down. Whatever the cause, tillage immediately before transplanting the broccoli did not ameliorate that slight disadvantage.

There was no adverse impact on early vegetable growth from having surface mulch of sorghum residues. There was no evidence of nutrient tie up, or increased disease.

The slight reduction in broccoli performance associated with growing a prior crop of forage sorghum continued through to yield, and could not be ameliorated by removing the surface mulch, or tilling the root zone (Fig. 7). The disadvantage of adopting the killed mulch system (Treatment 8) compared to the conventional system (Treatment 1) was only about 8% in this experiment, much less than in previous investigations. This may indicate we achieved better planting performance with the improved design of the sorghum mulch rows. The obvious benefits of having a surface mulch cover (seen when comparing the best Treatments 3 and 4 with Treatments 1 and 2) may also compensate for the disadvantages associated with cover cropping.

The reasons for improved yields where surface mulch was present are unclear. Three hypotheses are; improved soil temperature (slightly cooler), improved surface soil water relations (slightly moister), or a combination giving better surface soil microenvironment and hence surface root growth. It does indicate that there are positive benefits from a system that retains surface residues.

The absence of any significant tillage responses suggests that in the structured, black earth soils, a recently disturbed seedbed is not essential for acceptable vegetable performance, provided reasonable initial transplant-to-soil contact can be achieved.

This experiment confirmed that conditions leading to good establishment, early growth and high yields, are associated with earlier and more synchronous head development, reducing the need for later, and multiple harvests.

In the absence of herbicide applications, the presence of surface mulch is obviously very beneficial in reducing weed establishment (Fig. 10). The reduction in weed emergence in a no till system is often recorded, although frequently it is also associated with a shift in weed spectrum. Interestingly, in this experiment, populations of sowthistle were reduced both by adopting no till and mulching strategies. In previous investigations, sowthistle was one species that was more resistant to those practices than other weeds. Perhaps the proportion of reduction was less than other species in this instance as well.

The halving of hand weeding times using a mulched, no till strategy, such as in the killed mulch system, compared to the conventional strategy, would be an important commercial consideration in the absence of herbicidal weed management. In a low chemical or organic system, this would be a significant management factor, however a mechanism for killing the tall, vigorous forage sorghum would be an interesting difficulty in the latter. In vegetables, such as brassicas produced with chemical management options, where there are some effective herbicide choices, and hence minimal hand weeding, this implication is not as important.

Apart from factors not considered in this experiment (such as the build up of nematodes and soil borne diseases), the important points in relation to implementing a killed mulch system are:

1. The cover crop must be sown and managed to provide clear rows into which the vegetable crop can be planted.
2. Good contact between the transplant cell and soil is required for acceptable vegetable growth and yield, however full soil disturbance is not.
3. There are benefits from the presence of surface mulch that may compensate for disadvantages of cover cropping prior to planting.
4. Improved crop nutrition may be a solution to poorer growth following a cover crop, however pre-planting tillage is not.

Appendix 4. Detailed technology transfer publications and activities

Publications

Scientific papers, book chapters, conference papers (reviewed)

Henderson CWL and A Bishop (2000). Vegetable Weed Management Systems pp 355-72, *In* 'Australian Weed Management Systems', (B. Sindel Ed.) RG and FJ Richardson Melbourne. A new reference and tertiary education textbook.

DPI Agrilink Packages

Weed management components for Lettuce Agrilink	February 1998
Weed management components for Onion Agrilink	August 1997
Weed management components for Potato Agrilink	July 1997

Industry journal papers, magazine, and newspaper articles

Henderson CWL (2000). Environmentally friendly mulches? *EXPO 16 poster*

Henderson CWL (2000). New herbicide options help growers, consumers and the environment *EXPO 16 poster*

Henderson CWL (2000). Mulching alternatives for vegetable growers. *Gatton Star newspaper*, 17 May 2000

Henderson CWL (2000). Herbicide research pays off for growers and consumers. *Gatton Star newspaper*, 17 May 2000

Henderson CWL (2000 update). Weed management in lettuce. DPINote Agdex 252/640

Tonia Loughrey and Henderson CWL (2000 update). Integrated weed management components in vegetable crops. DPINote Agdex 250/640

Gilbert A (2000). New lease of life for GOAL. *Good Fruit and vegetables ???*,

Gilbert A (2000). New lease of life for GOAL. *Gatton Star newspaper*, 5 April 2000

Gilbert A (2000). Onion research demonstrates good early weed control is possible. *Burnett Fruit and Vegetable Grower*, Summer 1999-2000

Gilbert A (1999). New brassica herbicide use. *Gatton Star newspaper*, 20 October 1999

Gilbert A (1999). Onion research demonstrates good early weed control is possible. *Gatton Star newspaper*, 1 September 1999

Gilbert A and Henderson CWL (1999). New herbicide helps Queensland onion growers. *Onions Australia*, **16**, 31-2.

Gilbert A (1999). Onion research demonstrates good early weed control is possible. *Gatton Star newspaper*, 1 September 1999

Henderson CWL (1999). Oxyfluorfen guidelines for QLD onion growers. *Queensland Fruit and Vegetable News*, 25 March 1999

Henderson CWL (1999). A new herbicide for onion growers. *Good Fruit and Vegetables* **9 (9)**, 6.

Henderson CWL (1999). Guidelines for using oxyfluorfen (eg. Goal®) in Queensland onions. DPINote Agdex 256/682

Tonia Loughrey and Henderson CWL (1999). Integrated weed management components in vegetable crops. DPINote Agdex 250/640

Henderson CWL (1999 update). Weed management in lettuce. DPINote Agdex 252/640

Henderson CWL (1999). QFVG gains new herbicide for onion growers. *Queensland Fruit and Vegetable News* 28 January 1999

Henderson CWL (1998). New onion herbicide. *Gatton Star newspaper*. 23 December 1998.

Henderson CWL (1998). Rooting out weeds. *Gatton Star newspaper*. 14 October 1998.

Henderson CWL (1997). Future weed problems in onions.? *Onions Australia* **14**, 39.

Henderson CWL (1997). Improving profits by better weed management in beetroot production. *Good Fruit & Vegetables* 7 **(12)**, 43.

Articles contained in Annual QFVG Research Summaries

Henderson CWL (1999). Integrated weed management in vegetables
Henderson CWL (1997). Integrated weed management in vegetables

Field walk and seminar notes

Brassica field walk notes.	11 June 1998.
Integrated weed management in onions.	8 November 1997.

Detailed experimental reports

A total of 42 experimental reports have been compiled and sent to collaborating growers or research staff since June 1997.

Activities

Field walks/days

Note: most field walks are advertised by announcement on local radio, articles in local papers, flyers in local businesses, and by issuing individual invitations. At all field walks, and on almost all extension material, our addresses and phone numbers are presented.

- *Environmentally friendly mulches?* EXPO 16 (+ poster) — 17-18 March 2000
- *New herbicide options help growers, consumers and the environment*, EXPO 16 (+ poster) — 17-18 March 2000
- *Weed management update in onions*, GRS — 24 November 1999
- *Weed management in onions*, GRS — 12 May 1999
- *Weed management in vegetables*, Boonah District High School tour — 15 March 1999
- *Weed management in brassicas*, Vege Fresh experimental site — 8 April 1999
- *Weed management in onions*, GRS — 26 November 1998
- *Weed management in pumpkins*, Merv Hodges property, Thornton — 15 October 1998
- *Weed management in brassicas*, GRS (+handout) — 11 June 1998
- *Weed management in vegetables*, Gatton College students — 26 May 1998
- *Weed management in vegetables*, EXPO 15 (+posters) — 21-22 May 1998
- *Herbicide strategies in beetroot*, Murray Hughes property, Mulgowie — 3 April 1998
- *Alternative mulches in tomatoes*, Peter Macintosh property, Helidon — 3 April 1998
- *Alternative mulches in vegetables*, Bundaberg Research Station — 17 March 1998
- *Weed management in vegetables*, Lockyer District High School tour — 16 March 1998
- *Integrated weed management in onions*, International Alliums Conference Tour (+handout) — 8 November 1997
- *Weed management in vegetables*, GRS Opening — 14 August 1997

General seminars to producers, agribusiness and producer groups

Note: most seminars are advertised by announcement on local radio, articles in local papers, flyers in local businesses, and in frequently by issuing individual invitations.

- *Weed management in vegetables* Leafy Vegetable workshop, Bribie — 2 December 1999
- *QHI weeds RDE activities (to UNE Brian Sindel and post-graduates)* — 7-8 December 1998
- *QHI weeds RDE activities (to DPI,E&W staff, Tasmania)* — 2 December 1998
- *QHI weeds RDE activities (to Serve-Ag P/L staff, Tasmania)* — 1 December 1998
- *Minor use pesticide priorities, GRS (to BIG)* — 10 September 1998
- *Interactions in managing insects and weeds,* GRS (to GRS staff) — 17 June 1998
- *Herbicide update in brassicas*, GRS (to BIG) — 12 March 1998
- *Weed management in brassicas*, GRS — 26 February 1998
- *Weed management in brassicas*, Applethorpe — 25 February 1998

<u>*Conferences*</u>

- *12th Australian Weeds Conference, Hobart* — 13-17 September 1999

<u>*Study Tours*</u>

- *Serve-Ag update and field walks, Devonport* — 19 January 2000
- *Weed studies at UNE* — 7-8 December 1998
- *Weed research and management in Tasmania* — 1-3 December 1998

<u>*Courses and Workshops*</u>

- *Off label permits for pesticides in horticulture (National Project, Knoxfield Victoria)* — 23-24 March 1998
- *Off label permits for pesticides in horticulture (QFVG)* — 19 March 1998

<u>*Media interviews*</u>

Commercial Radio 4WK	Use of oxyfluorfen in onions	7 September 1999
ABC Rural Radio 4QS	Use of oxyfluorfen in onions	21 December 1998
ABC Rural Radio 4QS	Weed management in pumpkins	16 October 1998
ABC Rural Radio 4QS	Current weed management issues in vegetable production	11 June 1998

<u>*Consultants*</u>

- Local consultants (David Carey, John Rochecouste, Graeme Thomas, Julian Winch)
- Other Australian consultants (Ian Macleod, Matt Sherriff, Phil Frost, Serve-Ag P/L Tasmania; Neil Delroy, ARM, Western Australia)
- Other Australian scientists and extension officers