VG406

Integrated weed management in vegetable production

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Know-how for Horticulture™

VG406

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Craig Henderson

Industry and technical summary

We studied 2 weeds important in vegetable crops; potato weed (*Galinsoga parviflora*) and sowthistle (*Sonchus oleraceus*), investigating development stages and seed production under ambient, controlled-environment and on-farm conditions. We compared new herbicide uses with current strategies, evaluating their fit with vegetable production systems. In building weed management packages, we demonstrated philosophies ranging from short-term, single crop considerations, to long-term strategies and weed eradication. We had a preliminary look at alternative vegetable production systems involving killed mulch techniques.

Potato weed can set viable seed within 45 days of germination under summer growing conditions. The species has low seed dormancy, with freshly shed seed able to germinate immediately after shedding. It relies on producing large numbers of seeds to maintain populations. There were no differences in growth habit nor development timing between potato weed biotypes we collected. In contrast, sowthistle seed had substantial dormancy, and produced more robust seedlings, able to cope with dry/cold conditions. Granite Belt sowthistles were less vigorous and slightly slower growing than Lockyer Valley biotypes.

We developed methods for predicting time to seed maturity for potato weed and sowthistle at different growth stages at times of year. Vegetable growers can use this information to decide whether additional weed control efforts in-crop (usually by hand-weeding) is necessary to reduce weed seed set, or whether weed seed set will not occur until after the crop is harvested. For example, potato weed with 4 true leaves in September will shed mature seed in around 24 days, whereas sowthistle at the same growth stage will take 42 days. With both species, effective management requires control both in cropping areas and surrounds (eg. drainage and irrigation lines, headlands, roadways).

We investigated herbicide options in lettuce, brassicas, onions, beetroot, potatoes, sweet corn and celery. Based on our results, we will be pursuing registrations/approvals for GOAL® (oxyfluorfen) in brassicas and onions; LONTREL® in brassicas (possibly onions and other crops); low rates of BETANAL® (phenmedipham) and TRAMAT® (ethofumesate) in beetroot; as well as preparing herbicide application notes for each of the crops mentioned.

Our long-term sites demonstrated successful on-going weed management could be achieved by: (a) knowing what weeds were present and selecting herbicides accordingly; (b) rotating crops with different weed control needs and practices; (c) expending a little extra weed control effort in a current crop for the benefit of future crops; (d) using practices whose cost is virtually independent of weed populations (such as cultivation or herbicides) primary weed control tools, and restricting population-dependent practices (eg. hand-weeding or spot spraying) to 'mop-up' operations.

Initial studies using forage sorghum and millets as killed mulches (retained on the soil surface) in lettuce, broccoli and celery, maintained or increased yields compared to conventional systems. Improved mulch management practices and ways of establishing crops through the mulch need to be developed before the systems can be promoted commercially. Research programs to develop these systems are ongoing.

Vegetable producers have been made aware of this project via talks at field days, group meetings, and press releases. Results are included in various QDPI information packages.

Introduction

While conducting previous vegetable research, it was evident that certain weed/crop combinations substantially affected production costs and risks. Specific examples included: *Galinsoga parviflora* (potato weed, yellow weed) in lettuce, brassicas, celery and onions. This weed is particularly severe on the sandy soils of the Granite Belt region of Queensland, as well as other areas of southern Queensland and horticultural areas of New South Wales. *Sonchus oleraceus* (common sowthistle) is an important weed of vegetable production on loamy and clay soils used for vegetable production in Queensland and New South Wales. Other examples of difficult weed/crop combinations include *Chenopodium album* (fat hen) in brassicas and beetroot, and *Apium leptophyllum* (slender celery) in celery.

In a continent wide survey, Schroeder *et al* (1993) found potato weed and corn sowthistle (related to common sowthistle) were in the top ten most important weeds in vegetable production in Europe. Although similar surveys have not been conducted in Australia, discussions with growers and personal observations confirm the status of potato weed and sowthistle as important weeds in Australian vegetable production.

In some instances herbicides are registered for the particular weed/crop combinations. In others, such as potato weed in lettuce, no products are currently registered. Even where herbicides are available, practical problems such as high costs, risks of crop damage, rotation restrictions, lack of fine-tuning for different soil types and climates are still issues. Expensive hand-weeding is often necessary.

Continued use of the same herbicide can lead to development of resistant weeds or uncontrolled weed spectrums. A biotype of sowthistle resistant to several herbicide groups has recently been recorded in Queensland and northern New South Wales. There is a strong community desire for reduced pesticide use. Vegetable growers need to be seen to be taking positive action in this regard.

Integrated weed management

Scientists and practical horticulturists throughout the world are realising that simple 'quick-fix' solutions to pest control, whilst they may have worked to some degree in the past, may no longer be appropriate, nor acceptable to society. Weed control is no exception; the focus must be changed from the traditional single-solution in a monoculture situation, to a more integrated and 'holistic' approach (Putnam 1990, Morgan 1992, Radosevich and Ghersa 1992, Swanton and Weise 1992).

Because of shifting weed spectrums, concerns about pesticide use and the development of herbicide resistance, we must become more conscious of alternative weed management techniques. Whilst herbicide resistance in Australia has largely been confined to grass weeds, in Europe and North America numerous broadleaf species have also become resistant to a range of herbicides (Schroeder *et al* 1993). In the Goondiwindi area of Queensland, a biotype of sowthistle has become resistant to several types of herbicides (Boutsalis and Powles 1993).

Studies of weed population dynamics can be used to determine the critical events that lead to a build up in weed numbers, as well as those parts of the life-cycle where the weed population (as opposed to the individual plant) is most vulnerable (eg. Cheam 1986, Wilson and

Lawson 1992). In an integrated weed control program, management of various points of the life-cycle must be addressed. Weed populations may be more sensitive at particular points in their life-cycle, eg. a simulation study showed weed numbers were more sensitive to the efficiency of cultivation in killing weed seedlings, than to the numbers of seeds set per mature plant (Jordan 1993).

Weed management options

Manipulating plant spacings both between and within rows is one method of managing weeds. Reducing row widths and increasing the overall population of crop plants can reduce weed biomass in particular. This manipulation of plant spacing, whilst it may inhibit weed growth, will generally not completely eliminate adverse effects of weed competition on crop yield (eg. Malik *et al* 1993).

Selection of crop cultivars that rapidly establish expansive leaf areas may aid in the suppression of weeds. This is more likely to reduce the development of weed biomass, rather than overall weed numbers (Malik *et al* 1993).

Mulch management

Living mulch systems have been shown to reduce weed populations to non-competitive levels, maintaining vegetable yields equivalent to those achieved in traditional horticulture (Stirzaker *et al* 1992a). Utilising living mulches in vegetables can be very difficult, requiring careful management of the mulch to compromise between weed and crop suppression, while obtaining good crop establishment through the mulch (Lanini *et al* 1989).

Mulches have been shown to improve the physical condition of the soil compared to bare surfaces. Stirzaker *et al* (1993b) found that lettuce growth and yields in beds following a sub-clover mulch were equivalent to those from traditionally tilled beds, and greater than those in bare-surfaced no-till plots. This was thought to be due to moister, more porous soil conditions after the sub-clover mulch, compared to the bare, uncultivated beds.

Reductions in weed biomass by mulches may be due to light restriction, lower temperatures, physical impedance or allelopathy (Teasdale 1993). Different weed species are affected to different degrees by the presence of mulches; some are completely suppressed, while others remain unaffected (Teasdale 1993).

On the down side, living mulches can reduce crop yields through competition, provide insufficient weed control, or shift the weed spectrum to biennial or perennial weeds (Nicholson and Wien 1983, Mohler 1991). Living mulches need not be competitive with the crop, particularly if killed in strips directly above the planted row. This is particularly true of mulches which die and regenerate each year from a seedbank (eg. Kumwenda *et al* 1993).

The amounts of mulch residues required to inhibit weed establishment (in the absence of herbicides) may be several times that available in a natural field situation (Lanfranconi *et al* 1993, Mohler and Teasdale 1993, Teasdale 1993). Rye residues appear to last longer in the field than leguminous residues (such as hairy vetch). It may be that there are some toxins leaching from rye residues that inhibit weed germination. The relative effectiveness of mulches on the establishment of various weed species does not seem to be well correlated with any easily identified trait such as seed size (Mohler and Teasdale 1993).

In Australia, Young and Hingston (1993) found rye residues suppressed weed growth in transplanted broccoli sufficiently to maintain yields only slightly less than hand-weeded plots. Rye residues were more effective than barley residues. Overcoming problems with sowing through residues was a significant problem in establishing both sweet corn and onions from seed.

Project objectives

This project sought to develop Integrated Weed Management (IWM) systems in vegetable crops, initially concentrating on potato weed and sowthistle in lettuce, celery, brassicas and onions. In collaboration with the University of QLD, we attempted to study the biologies of these two weeds, searching for vulnerable points in their life-cycle. We will also evaluated how alternative weed management and crop production techniques affected weed populations and the economics of growing vegetables. The long-term benefits to producers that we were seeking were (a) more cost-effective, reliable weed control, (b) reduced risk of herbicide resistance,(c) less dependence on herbicides and (d) enhanced images of environmentally friendly production and safe produce.

Materials and methods

Literature review of biologies of potato weed and sowthistle

We searched the world literature by using CAB Abstracts, Current Contents and the DIALOG database. We back-searched for earlier references by checking for relevant materials references in the reference lists of more recent papers.

Ambient temperature studies of development phenology of potato weed and sowthistle

Development rates of potato weed and sowthistle were observed in plants grown in pots under ambient external environmental conditions between August 1995 and February 1997. Mature seed collected from potato weed and sowthistle plants growing in the Granite Belt or Lockyer Valley were used as the sources of genetic diversity for the 2 weed species. At the beginning of each month the following procedures were carried out.

For each of the biotypes of each weed species, around 20 seeds were sown in 10 cm diameter pots containing potting mix and complete slow-release fertiliser. There were 5 replicate pots for each biotype/species combination, giving a total of 20 pots per sowing. Once the weed seedlings were established with 3-4 true leaves, they were thinned to one plant per pot. Plants were watered regularly to maintain maximum growth under the prevailing conditions.

The growth stages of each plant were recorded every 2 days, using the number of leaves on the main stem, and the floral stages of the first buds to appear, as the development indices. Once flowering commenced, the numbers of buds, flowers and maturing seedheads were counted. Seeds were collected from the plants as the seedheads matured, prior to actual seed shedding where possible. Measurements only ceased once the plants started to senesce.

Controlled temperature studies of development phenology of potato weed and sowthistle

In conjunction with a 4th Year student at the University of Queensland, Gatton College, we studied the growth and development of potato weed and sowthistle under controlled environment conditions. The same combinations of biotype/species as used in ambient experiments described above were used as the source seed materials. The plants were sown in pots as previously, and germinated in ambient conditions in late March 1997. Once the weeds had reached the cotyledon stage, the pots were placed in one of three fluctuating temperature treatments (10°C/20°C, 15°C/25°C, 20°C/30°C). Inside the growth cabinets, the plants were subject to 12 hr light at the maximum temperature, followed by 12 hr dark at the minimum temperature. Development stages were recorded by the student using the procedures outlined for the previous experiment. Plant heights were regularly measured, as well as weed biomass after 4 months, at the conclusion of the growing period.

Farm weed observations

In summer/autumn 1995, populations of weeds in vegetable growers crops were monitored from planting through to the stage that vegetables were harvested. This work was principally conducted in the Granite Belt district of southern Queensland. The emergence of weed cohorts; their density and growth stages through time were recorded on a weekly basis. Particular importance was placed on the relative development rates of the weeds vs. their host

crops. This work was discontinued after June 1995, as we felt the effort involved in collecting the information could be more effectively used in other targeted research.

Targeted herbicide evaluation experiments

As part of this project, we collaborated with several Granite Belt growers in implementing and/or monitoring small herbicide evaluation experiments, as well as larger experiments at Gatton Research Station (Table 1). Summary details for each experiment are given below in point form. For more specific information, readers should contact the Author.

Table 1. Agronomic details for 7 targeted herbicide evaluation experiments.

Code	Location	Crop	Herbicides evaluated	Planting date	Harvest date
CHIN1	Bapaume	Chinese cabbage	Post-emergence	20-10-94	10-12-94
LETT1	Amiens	Lettuce	Pre-emergence	01-03-95	03-05-95
LETT2	Amiens	Lettuce	Pre-emergence	17-03-95	16-05-95
LETT3	Applethorpe	Lettuce	Pre-emergence	12-12-96	05-02-97
BEET1	GRS	Beetroot	Post-emergence	30-03-95	21-06-95
BEET2	GRS	Beetroot	Post-emergence	22-04-96	15-08-96
BROC1	GRS	Broccoli	Post-emergence	05-06-96	26-08-96
CABB1	Stanthorpe	Cabbage	Pre and post-emergence	23-01-97	15-04-97

The experiments on the Granite belt were conducted on a sandy surfaced soils typical of the region, whilst those at Gatton Research Station were on black earth soils. Apart from the treatment details given below, crops were grown using agronomic practices standard in commercial production (eg. plant spacings, crop nutrition, irrigation practices, pest management). Pertinent details for experiments in each of the crops are given below in point form.

CHIN1

Experiment design - Randomised complete block, sprinkler irrigated

Treatments - 7 post-emergence herbicide applications

a) Control treatment - no post-emergence herbicide
b) GOAL® sprayed at 50 mL/ha (crop 4 true leaves, weeds 1 pair true leaves)
c) GOAL® sprayed at 100 mL/ha as above
d) GOAL® sprayed at 200 mL/ha as above
e) GOAL® sprayed at 17 mL/ha (crop 8 true leaves, weeds 2 pair true leaves)
f) GOAL® sprayed at 33 mL/ha as above
g) GOAL® sprayed at 50 mL/ha as above

Measurements

- Crop damage symptoms
- Weed control ratings
- Crop marketability

LETT1

Experiment design - Randomised complete block, sprinkler irrigated

Treatments - 6 pre-emergence herbicide applications

a) KERB® sprayed at 4.5 kg/ha immediately after transplanting
b) STOMP® sprayed at 4 L/ha 7 days before transplanting
c) STOMP® sprayed at 8 L/ha as above
d) STOMP® at 4 L/ha plus DUAL® at 2.5 L/ha as above
e) STOMP® at 4 L/ha plus RAMROD® at 2 L/ha as above
f) RAMROD® at 3.3 L/ha as above

Measurements

- Crop damage symptoms
- Weed control ratings
- Crop marketability

LETT2

Experiment design - Randomised complete block, sprinkler irrigated

Treatments - 5 pre-emergence herbicide applications

a) Control treatment - no herbicide
b) RAMROD® sprayed at 3.3 L/ha 3 days after transplanting
c) RAMROD® sprayed at 5 L/ha as above
d) RAMROD® sprayed at 10 L/ha as above
e) RAMROD® at 3.3 L/ha plus DACTHAL® at 10 kg/ha as above

Measurements

- Crop damage symptoms
- Weed control ratings
- Crop marketability

LETT3

Experiment design - Randomised complete block, sprinkler irrigated

Treatments - 5 pre-emergence herbicide applications

a) KERB® sprayed at 4.5 kg/ha immediately after transplanting
b) STOMP® sprayed at 3 L/ha 7 days before transplanting
c) STOMP® sprayed at 4 L/ha as above
d) STOMP® at 3 L/ha plus RAMROD® at 3.5 L/ha sprayed 7 days before transplanting
e) STOMP® at 3 L/ha sprayed 7 days before transplanting plus RAMROD® at 3.5 L/ha sprayed immediately after transplanting

Measurements

- All cultural operations
- Crop damage symptoms and growth assessments
- Weed counts and final weed biomass
- Crop yields and quality assessments

BEET1

Experiment design - Randomised complete block, all irrigated with sprinklers

Main plot treatments - 9 weed management treatments

a) Very low rates of BETANAL® herbicide sprayed at the cotyledon stage of the beetroot and again one week later
b) Low rates of BETANAL® herbicide sprayed at the cotyledon stage of the beetroot and again one week later
c) Moderate rates of BETANAL® herbicide sprayed at the cotyledon stage of the beetroot and again one week later
d) Low rates of BETANAL® herbicide sprayed at the 2 true leaf stage of the beetroot and again one week later
e) Moderate rates of BETANAL® herbicide sprayed at the 2 true leaf stage of the beetroot and again one week later
f) Low rates of BETANAL® and TRAMAT® herbicides sprayed at the 2 true leaf stage of the beetroot and again one week later
g) Commercial rates of BETANAL® herbicide sprayed at the 4 true leaf stage of the beetroot
h) Commercial rates of BETANAL® and TRAMAT® herbicides sprayed at the 4 true leaf stage of the beetroot
i) Weeds removed by hand as they emerged

Measurements

- Standard weather data (rainfall, pan evaporation, max and min temperatures) - daily
- Tensiometer values - daily
- Irrigation - as applied
- All fertiliser and pesticide applications - as applied
- Beetroot plant heights just before the baby beet stage
- Beetroot yields
- Beetroot quality (size grades)
- Weed counts during the growing period
- Weed counts and biomass at beetroot harvest

BEET2

Experiment design - Randomised complete block, all irrigated with sprinklers

Main plot treatments - 5 weed management treatments

a) Low rates of BETANAL® and TRAMAT® herbicides sprayed at the 4 true leaf stage of the beetroot
b) Moderate rates of BETANAL® herbicide sprayed at the 4 true leaf stage of the beetroot and again one week later
c) Low rates of BETANAL® and TRAMAT® herbicides sprayed at the 4 true leaf stage of the beetroot and again one week later
d) Commercial rates of BETANAL® and TRAMAT® herbicides sprayed at the 4-6 true leaf stage of the beetroot
e) Weeds removed by hand as they emerged

Measurements

- Standard weather data (rainfall, pan evaporation, max and min temperatures) - daily
- Tensiometer values - daily
- Irrigation - as applied
- All fertiliser and pesticide applications - as applied
- Beetroot plant widths just before the baby beet stage
- Beetroot yields
- Beetroot quality (size grades)
- Weed counts during the growing period
- Weed counts and biomass at beetroot harvest

BROC1

Experiment design - Split-plot, sprinkler irrigated

Main plot treatments - Time of post-emergence herbicide application

a) Herbicide treatments sprayed 9 days after transplanting
b) Herbicide treatments sprayed 37 days after transplanting

Sub plot treatments - Herbicide products and rates

a) No herbicide applied; weeds removed by hand
b) LONTREL® sprayed at 0.15 L/ha
c) LONTREL® sprayed at 0.30 L/ha
d) LONTREL® sprayed at 0.60 L/ha
e) LENTAGRAN® sprayed at 2 kg/ha
f) LENTAGRAN® sprayed at 4 kg/ha
g) LENTAGRAN® sprayed at 8 kg/ha

Measurements

- All cultural operations
- Crop damage symptoms and growth assessments
- Weed counts and final weed biomass
- Crop yields and quality assessments

CABB1

Experiment design - Randomised complete block, sprinkler irrigated

Treatments - 12 pre and post-emergence herbicide applications

a) DUAL® sprayed at 2.5 L/ha immediately after transplanting
b) DUAL® sprayed at 2.5 L/ha as above
c) RAMROD® sprayed at 8 L/ha as above
d) RAMROD® sprayed at 12 L/ha as above
e) GOAL® sprayed at 0.2 L/ha 20 days after transplanting
f) GOAL® sprayed at 0.4 L/ha as above
g) LONTREL® sprayed at 0.2 L/ha as above
h) LONTREL® sprayed at 0.4 L/ha as above
i) LENTAGRAN® sprayed at 1 kg/ha as above
j) LENTAGRAN® sprayed at 2 kg/ha as above
k) No herbicides applied, weeds removed by hand
l) No herbicides applied, weeds left in plot

Measurements

- All cultural operations
- Crop damage symptoms and growth assessments
- Weed counts and final weed biomass
- Crop yields and quality assessments

Long-term weed management strategies

Underlying philosophies influence weed management strategies. Focussing on weed eradication, long term suppression or short term economic management require different production systems and result in different economic and ecosystem development. In 1995, we established 2 sites at Gatton Research Station, each approximately 100 m * 25 m, to demonstrate these philosophies and investigate their economic and environmental ramifications. One site was targeted at heavy vegetable type enterprises, whilst the other concentrated on salad and heading vegetables. Within each site, plots were 12 m long and 11 m wide, with 8 plots per bay and 2 bays per site.

The 4 weed management strategies comprised:

1. **Short-term** Best weed management practice determined on a single-crop economic consideration. This involves implementing the most cost-effective weed management practice for the individual crop, ignoring the consequences of allowing seed-set for following crops. In practice, it generally means ignoring isolated outbreaks of weeds, as well as late germinating weeds that will not economically reduce the yield of the companion crop. This is a strategy commonly adopted by vegetable producers.

2. **Long-term** Best weed management practice aimed at long-term weed suppression. This requires the use of measures less economic in the short term, but that is directed at reducing weed seedbanks, and thus the long term costs of weed control. It will generally involve the use of more expensive herbicides, use of post-emergence herbicides, or more cultivation and hand-weeding. It may also mean selection of different rotations and more concern with weed management in cover crops.

3. **Eradication** Best practice aimed at total weed eradication. This simply requires the prevention of weed seed-set by the most cost-effective method. This is generally a combination of herbicides, cultivation and hand-weeding, conducted at all times during the year.

4. **Future** Best weed management practice utilising unproven methods or unregistered herbicides. In these experiments, this means the use of herbicides not yet registered (but with potential), different crop rotations and agronomic practices.

Actual practices for each system varied, depending on the vegetable grown and prevailing environmental conditions. These were flexible within the crop and involved responses to actual weed populations, but possible programs were outlined before vegetables were planted. Crop sequences at each site are outlined in Table 2.

Table 2 Agronomic details for 2 long-term weed management evaluation sites at Gatton Research Station

Code	Crop	Cultivar	Planting date	Harvest date
Site 1				
LETT4	Lettuce	Boxhill Oxford	15-08-95	16-10-95
ONIN1	Onions	Golden Brown	04-04-96	15-10-96
POTO1	Potato	Sebago Pontiac	24-02-97	22-07-97
Site 2				
CABB2	Cabbage	Green Coronet Kameron	16-08-95	29-11-95
BROC2	Broccoli	Greenbelt	03-04-96	27-06-96
CORN1	Sweet corn	Pacific H5 Golden Sweet	19-09-96	02-01-96
LETT5	Lettuce	Greenway	25-02-97	11-04-97

In each individual experiment, all cultural operations, including nutrition, irrigation, cultivation, pesticide application and hand-weeding were noted and costed. Crop growth, yields and produce quality were assessed. Weed populations and biomass production were recorded. The actual weed management practices adopted under each strategy are detailed in Table 3.

Table 3 Weed management practices for each long-term experiment, allocated to the 4 different strategies.

Code	Short-term strategy	Long-term strategy	Eradication strategy	Future strategy
Site 1				
LETT4	3 L/ha STOMP® at 1 DBP*	3 L/ha STOMP® at 1 DBP	4 L/ha STOMP® at 1 DBP + I HW*	3 L/ha STOMP® at 1 DBP + 4.5 L/ha RAMROD® at 5 DAP*
ONIN1	2.8 L/ha TOTRIL® at 36 DAP* + 1 CN	2.8 L/ha TOTRIL® at 36 DAP* + 2.1 L/ha TOTRIL® at 91 DAP + 1 CN* + 1 HW	2.8 L/ha TOTRIL® at 36 DAP* + 2.1 L/ha TOTRIL® at 91 DAP + 1 CN* + 3 HW	0.1 L/ha GOAL® at 15 DAP + 0.2 L/ha GOAL® at 22 DAP + 0.5 L/ha GOAL® at 91 DAP + 1 CN* + 3 HW
POTO1	No weed management after cultivation and hilling	0.35 kg/ha LEXONE DF® at 31 DAP	0.7 kg/ha LEXONE DF® at 31 DAP	0.7 kg/ha LEXONE DF® + 100 g/ha TITUS® at 31 DAP
Site 2				
CABB2	3.5 L/ha DUAL® at 1 DAP + 1 HW	2 L/ha STOMP® at 1 DBP + 7 L/ha RAMROD® at 1 DAP + 1 HW	3 L/ha STOMP® at 1 DBP + 9 L/ha RAMROD® at 1 DAP + 1 HW	1.5 L/ha GOAL® at 1 DBP + 1 HW
BROC2	3.5 L/ha DUAL® at transplanting + 2 cultivations + 1 HW	2.5 L/ha STOMP® + 9 L/ha RAMROD® at 2 DBP + 2 cultivations + 1 HW	2.5 L/ha STOMP® + 9 L/ha RAMROD® at 2 DBP + 2 cultivations + 2 HW	1.5 L/ha GOAL® at 2 DBP + 2 cultivations + 1 HW
CORN1	3 L/ha DUAL® at 1 DAP	4 L/ha DUAL® at 1 DAP	4 L/ha DUAL® at 1 DAP + 2 HW	3 L/ha DUAL® at 1 DAP + 0.7 L/ha STARANE® at 34 DAP + 1 HW
LETT5	4.5 kg/ha KERB® at transplanting	3 L/ha STOMP® 4 DBP	4 L/ha STOMP® 4 DBP	3 L/ha STOMP® 4 DBP + 4.5 L/ha RAMROD® at transplanting

DBP* days before planting
DAP days after planting
CN mechanical cultivation
HW hand-weeding

Killed-mulch experimentation

The use of organic mulches is one suggested method for managing weeds in vegetable production. Killing cover crops and then planting through them has been successfully demonstrated in vegetable production in other parts of the world and in experimental plots in southern Australia. The experiments described below established a series of cover-crop management areas, over which were imposed herbicide and nitrogen fertiliser treatments during the vegetable cropping phase. The same experiment was conducted on lettuce (LETT6), broccoli (BROC3) and celery (CELE1) crops.

The 5 main cover crop management treatments were:

1. FALLOW Maintained as a continuous fallow by shallow cultivation from mid-February until vegetables were transplanted in early June.

2. SORGHUM INCORPORATED A forage sorghum cover crop was planted in mid-February, and maintained until late-May. At that time it was slashed, mulched and incorporated into the soil using a rotary hoe. Beds were reformed prior to vegetable transplanting in early June.

3. SORGHUM MULCHED A forage sorghum cover crop was planted in mid-February, and maintained until late-May. At that time it was slashed, mulched on the surface, and left as a surface layer on the tops of the beds. Vegetables were transplanted through the mulch in early June.

4. MILLET INCORPORATED A French millet cover crop was planted in mid-February, and maintained until late-May. At that time it was slashed, mulched and incorporated into the soil using a rotary hoe. Beds were reformed prior to vegetable transplanting in early June.

5. MILLET MULCHED A French millet cover crop was planted in mid-February, and maintained until late-May. At that time it was slashed, mulched on the surface, and left as a surface layer on the tops of the beds. Vegetables were transplanted through the mulch in early June.

Within each of these main plots was imposed a factorial set of treatments, comprising three weed management strategies and two nitrogen nutrition strategies (either standard nitrogen rates, or additional side-dressings to compensate for uptake by decaying mulches). The weed management treatments for each vegetable are detailed below.

1. No herbicides used; all weeds controlled by hand-weeding.
2. Use of the optimum registered herbicide strategy.

Lettuce	4 L/ha of STOMP® herbicide applied before transplanting the lettuce.
Broccoli	3.5 L/ha of DUAL® herbicide applied after transplanting the broccoli.
Celery	2.2 L/ha of GESAGARD® herbicide applied after 23 DAP the celery.

3. Use of the best experimental strategy, including unregistered herbicides where appropriate.

Lettuce	4 L/ha of STOMP® applied before transplanting the lettuce, and 4.5 L/ha of RAMROD® sprayed immediately after transplanting.
Broccoli	1.5 L/ha of GOAL® herbicide applied before transplanting the broccoli.
Celery	4 L/ha of STOMP® herbicide applied before transplanting the celery.

In each individual experiment, all cultural operations, including nutrition, irrigation, cultivation, pesticide application and hand-weeding were noted and costed. Crop growth, yields and produce quality were assessed. Weed populations and biomass production were recorded.

Results and discussion

Review of literature on the biologies of potato weed and sowthistle

Introduction

Potato weed (*Galinsoga parviflora*) and sowthistle (*Sonchus oleraceus*) and are two common weed pests of the Australian vegetable industry, and are plants of economic importance world wide (Holm *et al* 1977). Potato weed is alternately known as yellow weed, chick weed, quick weed, gallant soldier, galinsoga and small-flowered galinsoga. *Sonchus oleraceus* is also referred to as common sowthistle, annual sowthistle, annual milkthistle and milkthistle. In vegetable production, both weeds are commonly found in lettuce, celery, cabbage, Chinese cabbage, broccoli and potato crops. The also readily occur in disturbed areas such as roadway edges, headlands, irrigation and drainage channels, fallowed lands, and disused land. Members of the Asteraceae family, *G. parviflora* and *S. oleraceus* are related to important vegetables such as lettuce, artichokes and endives. As a result of these relationships, selective herbicides options that control the weeds and are safe to the crop are limited.

Viruses such as cucumber mosaic, tobacco mosaic, tomato aspermy and spotted wilt are associated with potato weed. This weed also acts as an alternate host for *Melodogyne spp* and *Heterodera schachtii* nematodes (Holm *et al* 1977). Sowthistle is an alternate host for a number of plant pathogens and insects. For example, sowthistle is the principal host for Lettuce Necrotic Yellows Virus and the main aphid vector (Martin 1983). Many other viruses, pathogens and nematodes are also found on sowthistle plants (Holm *et al* 1977; Hutchinson *et al* 1984).

Understanding weed life cycles or biologies is important in determining control measures that will most benefit vegetable growers. If we understand when and where to target the weed, (eg. flowering or seed production), then control measures may be more effective. An example may be killing sowthistle populations just before lettuce leaves develop a full canopy, shading the soil. This shade may suppress weed germination for the remainder of the cropping period, as sowthistle requires high light for germination and growth (Martin 1983).

Botanical descriptions:-

Galinsoga parviflora

Potato weed is a small, erect, multi-branched annual herb, growing to an average height of 10-90 cm. The potato weed 'flower' consists of many flowers grouped together, giving the appearance of a single organ. Ray florets are white, while disc florets are yellow. Seeds have a pappus attached, which aids dispersal. Each flower head contains an average of 24 viable seeds with little evidence of dormancy. Most seeds are capable of germinating immediately upon contact with warm, moist soil. A single potato weed plant 8-9 weeks old is capable of producing 300 flower heads and over 7,000 viable seeds (Ivany and Sweet 1973; Holm 1977). Potato weed is a day neutral plant with regard flowering (Baskin and Baskin 1981; Ivany and Sweet, 1973), and continues to flower throughout the summer until killed by frost in early winter. Flowers are both self-pollinated or cross-pollinated (Baskin and Baskin 1981). Holm (1977) suggested the plant could complete its life cycle (germination to shedding seed) in as little as 50 days. Although Hopen (1983) states that "Plants can produce flowers in as little as

50 days", he was studying potato weed growing under an Illinios climate. Potato weed populations have been estimated to produce as many as 300 million seeds per hectare. Furthermore, potato weed shoots cut during hoeing or cultivation can re-root rapidly, even in semi-moist soils.

Sonchus oleraceus

Sowthistle is an annual or occasionally biennial herb, varying from 0.2-1.5 m in height (Holm *et al* 1977, Hutchinson *et al* 1984). Each seed-head (capitulum) contains 25-150 bisexual yellow florets. Achenes (seeds) are 1.5 mm long and 0.5 mm wide; most are brown but those of the outermost whorl are paler (Holm *et al* 1977). The pappus of sowthistle are numerous unbranched white bristles, 8 mm long, with the inner whorl rigid and spiny. These pappi help wind and water dispersal of seed (Holm *et al* 1977).

Other than light, sowthistle doesn't seem to have any specific environmental requirements for germination. Fresh seeds have a high percentage of dormancy, and can remain viable for 8 years or more, although a proportion will germinate readily when recently shed (Holm *et al* 1977). Sowthistle can produce seed almost all year round in Southern Queensland. Plants can grow in a wide range of soil pH and is moderately salt tolerant. Sowthistle can survive as a rosette to persist through mowing, grazing or cold periods (Martin 1983).

Environmental aspects that affect plant development

Photoperiod/Light

Galinsoga parviflora

Potato weed is very responsive to light, with high germination rates in the presence of light, and poor germination in its absence (Baskin and Baskin 1981). This species is basically day neutral, with flowering occurring once the 7th node has developed, usually equating to 4-8 weeks after germination (Ivany and Sweet 1973, Holm *et al* 1977)

Sonchus oleraceus

Red and far-red light ratios and absolute intensities seems to affect germination percentage of sowthistle seeds (Hutchinson, Colosi & Lewin 1984). Sowthistle requires reasonable light exposure to maintain adequate levels of plant development (Zollinger and Kells 1991). Martin (1983) found that the percentage of plants in a field reflected the light intensity, with fewer plants found in shaded areas than in full sunlight.

Temperature on Germination/Dormancy/Viability

Galinsoga parviflora

Freshly shed seeds are not dormant and can germinate in the field from early spring until the first frosts. Ivany and Sweet (1973) found the rate of germination, but not the final total percentage was stimulated by alternating temperatures. They also found best germination occurred at 30°C day and 20°C night temperatures, with 16 hour illumination at 11,000 lux. Potato weed can however germinate well at temperatures between 10°C and 30°C, particularly where temperatures alternate diurnally.

Potato weed can remain ungerminated and viable within the seed bank for several years. Low winter temperatures does not induce dormancy nor significantly reduce viability (Baskin and Baskin 1981).

Sonchus oleraceus

Holm (1984) found germination rates of sowthistle improved as temperatures increased from 10°C to 25°C, particularly when temperatures alternated, rather than remained constant. Although germination is optimal in this range, the plant still germinates fairly readily where minimums are >7°C and maximums<35°C.

Hutchinson *et al* (1984) showed most fresh sowthistle seeds have a period of dormancy before germination takes place. The seed has been found to remain viable for up to 8 years (Holm *et al* 1977), although Hutchinson *et al* (1984) noted seed viability in dry storage of only 2-3 years, with seeds in the seed bank remaining viable for little more than 1 year under constant cultivation.

Temperature on growth and development

Galinsoga parviflora

Higher temperatures promote the rate of node development, and hence reduce the time to flowering and seed set.

Sonchus oleraceus

Growth of common sowthistle is usually restricted in cooler periods. Winter plants may have elongated stems bearing flowers, however many of the population may remain as non-flowering, frost-resistant rosettes until temperatures increase. The vegetative rosette form persists longest during cool months with short day lengths (Martin 1983; Hutchinson *et al* 1984). Zollinger and Kells (1991) found that sowthistle plants grown under day/night temperature regimes of 20°C/15°C grew more rapidly than the plants grown under 35°C/25°C, or 10°C/5°C.

Studies of development phenology of potato weed and sowthistle biotypes

Potato weed

Our experiments confirmed potato weed seed has little inherent dormancy; mature seeds can germinate immediately after shedding. Potato weed seed required light for germination.

There were no differences in phenology nor growth between the potato weed biotypes collected from the Lockyer Valley and the Granite Belt. The following information thus applies across both biotypes.

Our ambient temperature and controlled temperature growth cabinet studies showed the period from planting to fully expanded cotyledons decreased from 18 days at mid-winter temperatures to 10 days in early summer conditions. First flowers appear on the main shoot after 7 sets of true leaves have emerged. Appearance of the first flower buds takes about 7 weeks after sowing in winter, decreasing to 5 weeks after sowing in early summer.

The most important practical application of this phenology data is to enable growers to predict how long weeds they observe in the field will take to produce viable seed. For example, a grower may note potato weeds with 2 sets of true leaves in his lettuce crop, with the lettuce heads due to be harvested in 3 weeks time. He knows that although the weeds will not affect this year's yields, if they set seed it will create a major problem for following crops. Should he expend resources to control those weeds, or will his crop be harvested before the potato weeds produce viable seed?

By putting together all the information from our pot studies, we have developed general models that can be used to predict how long it will take potato weed to produce viable seed, given it is at a certain growth stage at a certain time of the year. A graphical representation of this model is shown in Figure 1. The use of this chart is best demonstrated by examples.

Assume that a grower observes potato weed with fully expanded cotyledons in his Chinese cabbage crop in mid-February. His crop is scheduled to be harvested in 4 weeks. From the chart we can determine that the potato weed will not produce viable seed for another 40 days. If the grower is confident that he can cultivate or spray the crop with a knockdown herbicide soon after harvesting, then he does not need to worry about controlling the weed in crop, as it will not have produced viable seed by the time the Chinese cabbage are cut. If however in the same crop the potato weed had 4 sets of true leaves, then it is highly likely that the weeds will set viable seeds, and some control measures may be warranted.

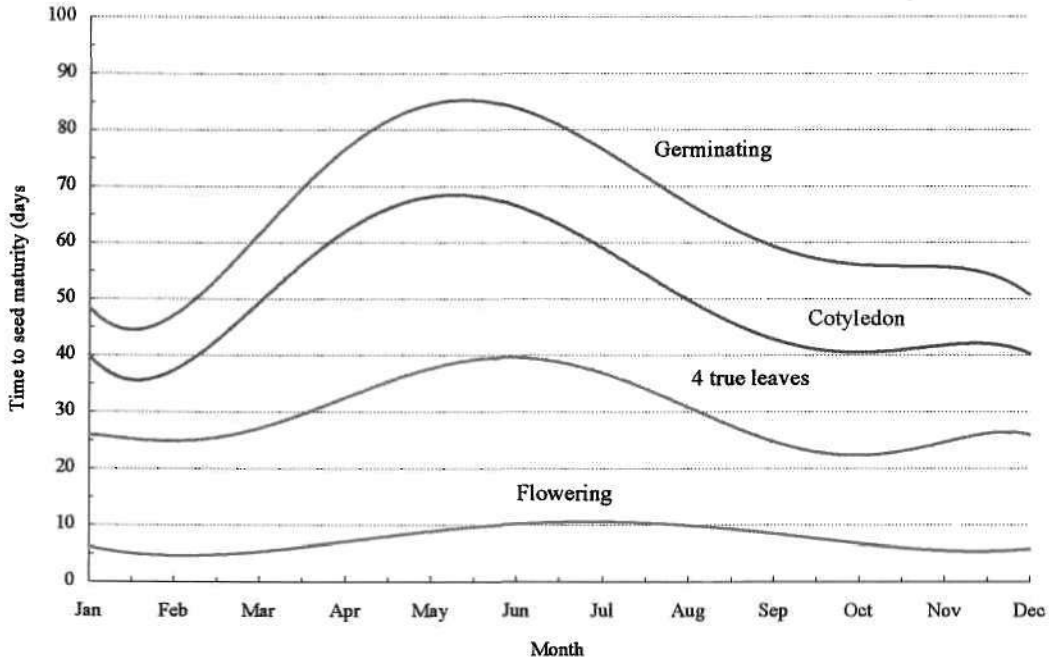


Figure 1. Time from selected potato weed growth stage to seed maturity at various periods of the year in Southern Queensland.

From the chart we can see that from germination to mature seed takes less than 7 weeks in mid-summer, to over 12 weeks in mid-winter. The values indicated by the graphics were developed for southern Queensland. From observations at several growers' properties in the Granite belt and Lockyer Valley, these values were relatively accurate (generally ± 4 days). By reviewing the data we may be able to develop models based on temperatures and day-degree concepts, applicable to other vegetable growing regions of Australia.

Potato weed continues to produce flowers and seeds until killed by drought, frost or human activity. Once the first flowers set seed, the number of buds emerging and setting seeds increase exponentially. For example, in an October planting at GRS, an average potato weed plant supported 200 visible flowers when the first flower was setting seed. All these flowers shed their seed over the following 3 weeks.

From the growth cabinet studies, temperature substantially affected the growth habit and seed production of potato weed. Under warmer growing conditions, the weeds were taller but more spindly, with less total biomass (Fig. 2). Although higher temperatures reduced biomass production, the plants shifted resource expenditure to more rapid reproductive effort, resulting in much greater average seed production over a given time period (Fig. 3). This suggests that potato weed developing under warmer conditions is more capable of replenishing and enhancing its soil seedbank. This may be why potato weed is a more significant problem on the Granite Belt (with a focus on summer production), than in the Lockyer Valley, a cooler season production area.

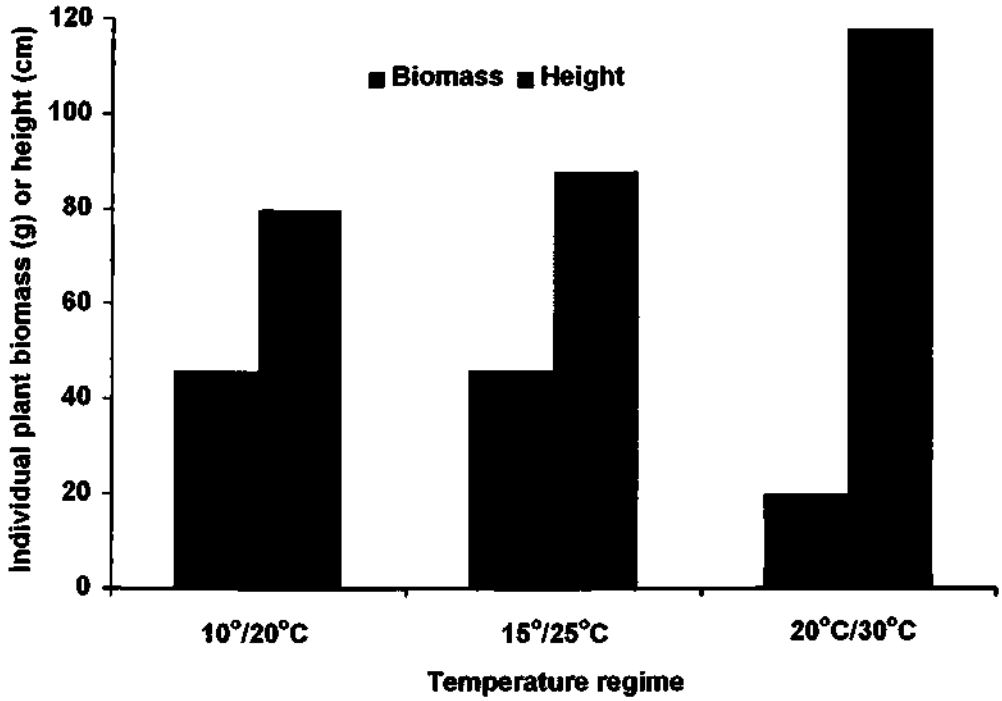


Figure 2. Temperature regime affects biomass and height of potato weed plants harvested 16 weeks after sowing.

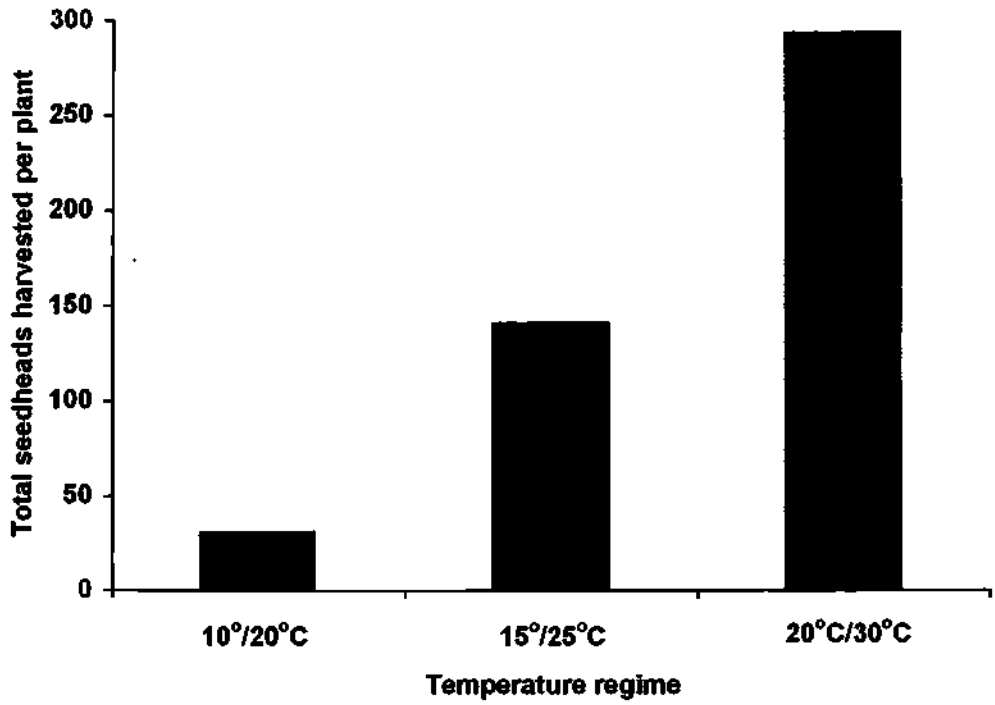


Figure 3. Temperature regime affects total seedhead production of potato weed plants during a 16 weeks period after sowing.

Sowthistle

In contrast to potato weed, sowthistle seeds require ripening after shedding before most will germinate. Germination requirements appear more stringent than potato weed, particularly moisture and light. However, sowthistle seedlings are robust, able to cope with adverse moisture and temperature.

In our pot studies, planting to fully expanded cotyledons decreased from 15 days in winter to 7 days in early summer. There does not seem to be a set leaf number before flower buds appear (at least 17-20 true leaves). Although our initial observations suggested different development rates between sowthistle biotypes collected from the Lockyer Valley compared to biotypes collected from the Granite Belt, once all the data was reviewed, these differences were not consistent. In constructing the phenology chart (Fig. 4), we used mean values for the 2 biotypes, however a general observation was that the Granite Belt biotype was 7-10 days slower to develop flower buds than the Lockyer Valley biotype. The sowthistle results were more variable than for potato weed. The conjunction of the 'germination' and 'cotyledon' lines in Fig. 4 is a statistical consequence of this variability, rather than an indication of a very rapid germination phase at that time of year. Germination to mature seed was about 10 weeks in summer, increasing to over 16 weeks in mid-winter.

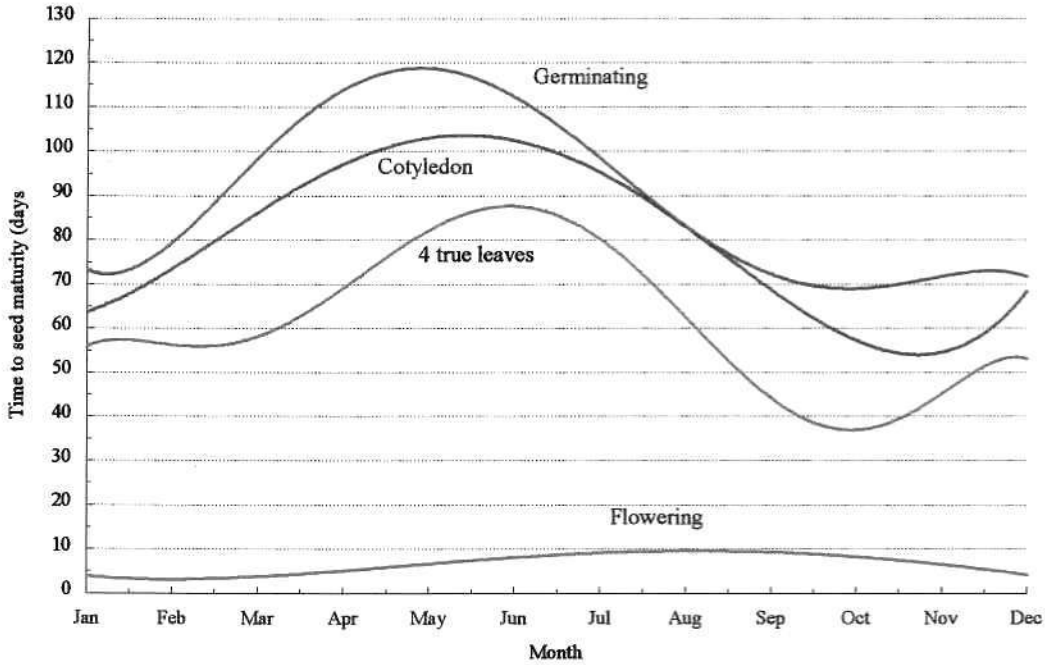


Figure 4. Time from selected sowthistle growth stage to seed maturity at various period of the year in Southern Queensland.

Under warmer growing conditions, sowthistle plants increased in height but had less total biomass (Fig. 5), and possibly less overall seed production, particularly the Lockyer Valley biotype. Interestingly, at all temperatures the Granite Belt biotype were slightly shorter, but certainly produced fewer seedheads than the Lockyer biotype (Fig. 6). Sowthistle is a much less significant weed on the Granite Belt; whether this reflects a 'less fit' naturalised biotype, or a shorter suitable growing season, is not obvious.

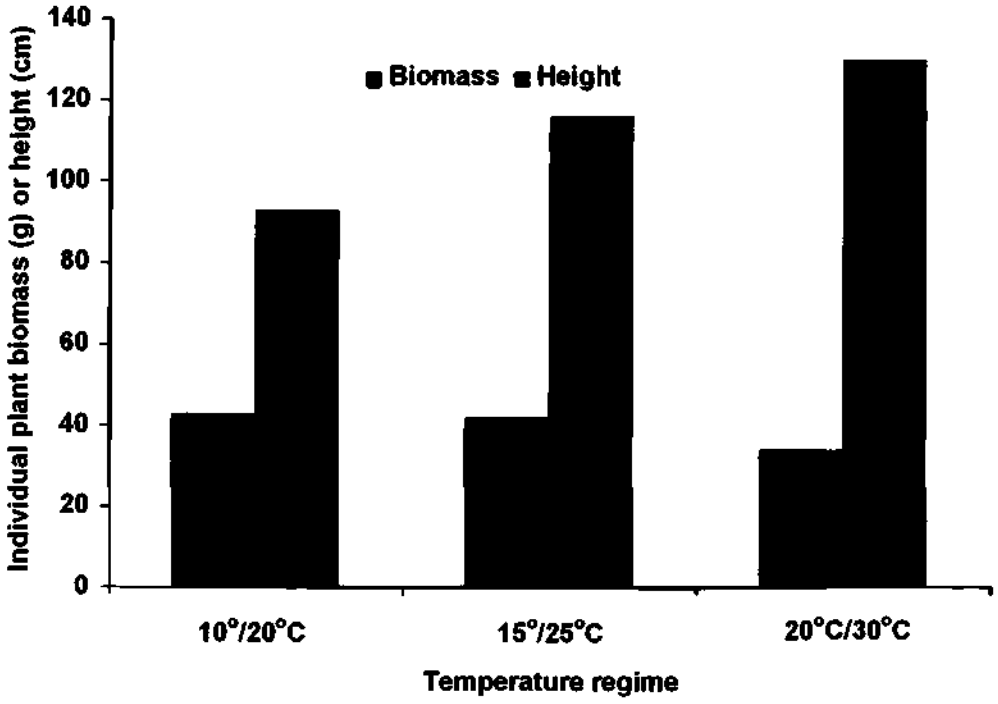


Figure 5. Temperature regime affects biomass and height of sowthistle plants harvested 16 weeks after sowing.

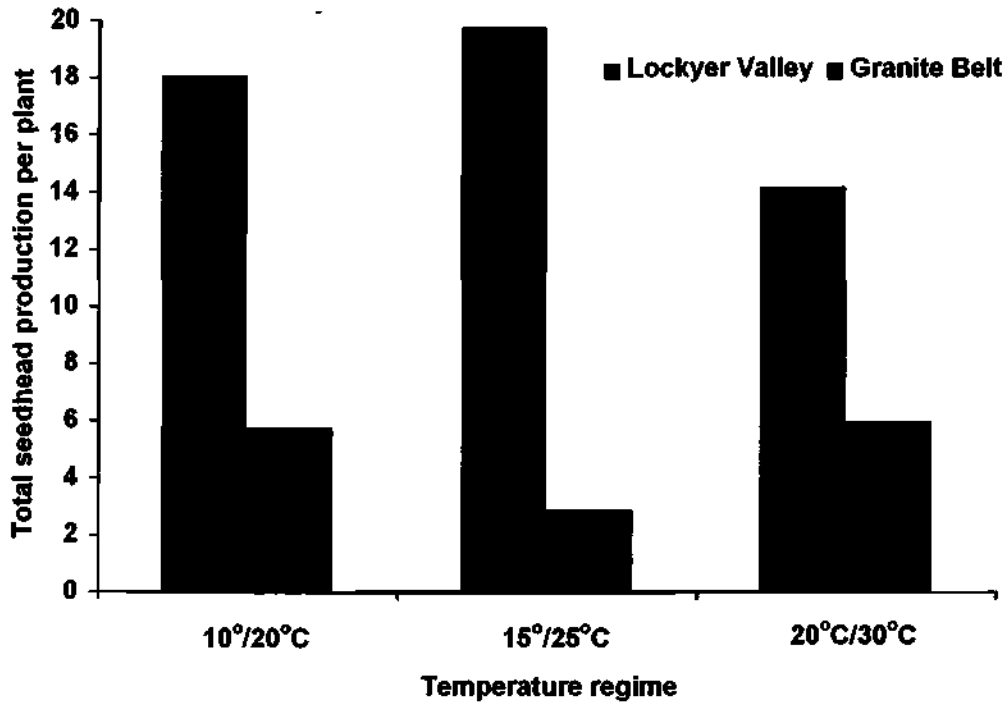


Figure 6. Temperature regime marginally affects total seedhead production of sowthistle biotypes during a 16 weeks period after sowing.

Implications of weed biology studies and farm observations for weed management

Potato weed

During summer/autumn 1995, we monitored potato weed populations in lettuce, celery, cabbage and Chinese cabbage in the Granite Belt. Within crop beds, pre-emergence herbicides and hand-weeding were used to control early germinations of potato weed. With emergence prevented for 3-4 weeks after transplanting, later cohorts of potato weed were not able to set viable seed before crop harvest. It is essential weeds are destroyed before mature seed can be exported to the soil seedbank. Potato weeds adjacent to irrigation lines were larger and matured earlier than plants within the crop beds. This was probably due to wetter soil conditions and problems with mechanical weed control, with less effective management of early germinating cohorts. Although weeds within crop beds often did not set viable seed, on many farms large numbers of potato weeds in roadways, headlands, irrigation and drainage lines shed seed throughout the cropping cycle. Managing these off-site weed seed sources is a very important issue in any IWM program (refer to later discussion).

Except in very short-term crops, potato weed can produce large numbers of seeds to carry over into following crops. Maximum kill of early germinations is needed. Potato weed is easiest to kill when small; larger plants require more herbicide and are readily transplanted by ineffective mechanical cultivations. Particular vigilance is needed along fences or irrigation lines, where controls are less effective and plants more vigorous and earlier maturing, acting as seed sources for future problems. Potato weed is favoured by bare, open,

not where there is competition from crops, pastures or native bush. Problems occur when small colonising populations are left unchecked, creating a seedbank for following crops. Although seed is dispersed by wind, this does not seem to be the major source of problems within a crop, but rather the mechanism by which initial colonising plants arrive. An integrated management program with this species has a good chance of success. Because of low inherent dormancy, a concerted approach to weed eradication should lead to rapid depletion of the soil seedbank. Selection of crops where control of potato weed is easier is one strategy.

Sowthistle

Sowthistle seeds are readily wind transported, with more seed dormancy than potato weed. Sowthistles can cope with extended dry weather; they are common in fallow paddocks or neglected/abandoned crops. Growers of some crops, eg. potatoes are often unconcerned about sowthistle present at harvest. Sowthistles can grow in pastures, disturbed native habitat, road reserves, etc. These situations lead to reserves of sowthistle seeds readily spread to otherwise 'clean' vegetable paddocks. Sowthistle is killed by a range of herbicides and mechanical cultivation. Managing sowthistle populations is difficult, involving long-term control both within paddocks and surrounding areas.

Herbicides in vegetable crops

Rather than deal with experiments individually, the following discussions reflect overall findings for herbicide treatments as they relate to specific crops. Apart from dealing with herbicide/crop combinations, there is also some consideration of the implications of particular herbicide strategies to other components of the enterprise, especially following crop rotations.

Lettuce

The herbicides we used in lettuce experiments included KERB® (propyzamide), and STOMP® (pendimethalin), both of which are registered for use in lettuce, and RAMROD® (propachlor) which is not.

KERB®

In none of the experiments or observations did KERB® used at the registered rate (4.5 kg/ha) cause crop damage. Unfortunately, KERB® was also ineffective at controlling many weed species, particularly potato weed (eg. Fig. 7). Although KERB® has been an effective herbicide in lettuce for many years, its cost ($450/ha) and poor control of Asteraceae weeds, means use in long-term lettuce growing areas is more problematic. At the very least, alternatives for use in rotation are required to reduce build up of non-susceptible weed populations.

STOMP®

As a result of previous herbicide work funded by QFVG/HRDC, STOMP® became registered in lettuce and a number of other vegetable crops. Sprayed at 3 L/ha before transplanting, we did not note crop damage in any experiments nor grower observations. Increasing the rate to 4 L/ha caused minor yield suppression (about 5%) in 20% of experiments; this level would probably go unnoticed in a commercial situation.

In most instances STOMP® gave good control of diverse weed spectrums (Figs 7 and 8). In experimental work undertaken in this project, STOMP® managed species such as London rocket (*Sysimbrium irio*), fat hen (*Chenopodium album*), bittercress (*Coronopus didymus*), giant pigweed (*Trianthema portulacastrum*) and sowthistle. Interestingly, on the sandy soils at Applethorpe, it also partially suppressed potato weed, although the level of control would not be commercially acceptable on its own account.

RAMROD®

The margin between acceptable weed control and crop damage with this herbicide is very small. When sprayed at 3.5 L/ha, RAMROD® caused transient crop damage in 20% of experiments. Increasing the application rate to 4.5 L/ha caused slight yield reductions (circa 10%) and delayed maturity in 50% of cases. In most instances RAMROD® was applied in conjunction with STOMP®, as RAMROD® by itself at these rates does not give acceptable weed control.

Given the potential phytotoxicity problems, the use of RAMROD® as a herbicide in lettuce could only be justified where a known problem with weeds (eg. potato weed) resistant to the other herbicides such as STOMP® are present. A good demonstration is where RAMROD is well justified at the site shown in Fig. 7, but not required at the site shown in Fig. 8.

OTHER

DACTHAL® (chlorthal di-methyl) achieved reasonable weed control in lettuce, however its spectrum was not dissimilar to STOMP®, with the latter much more cost effective. DUAL (metolachlor) caused unacceptable crop damage, in the form of stunting, chlorosis and poor head formation.

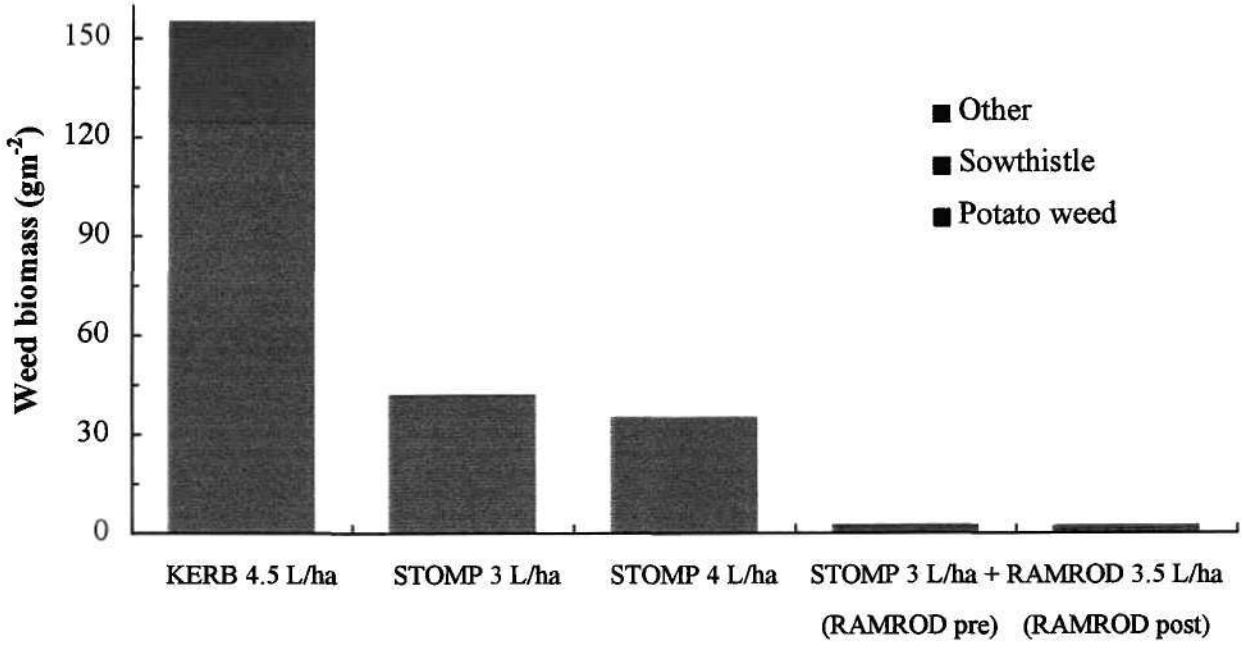


Figure 7. Herbicide strategies significantly affect weed biomass present at the time lettuce were harvested (LETT3).

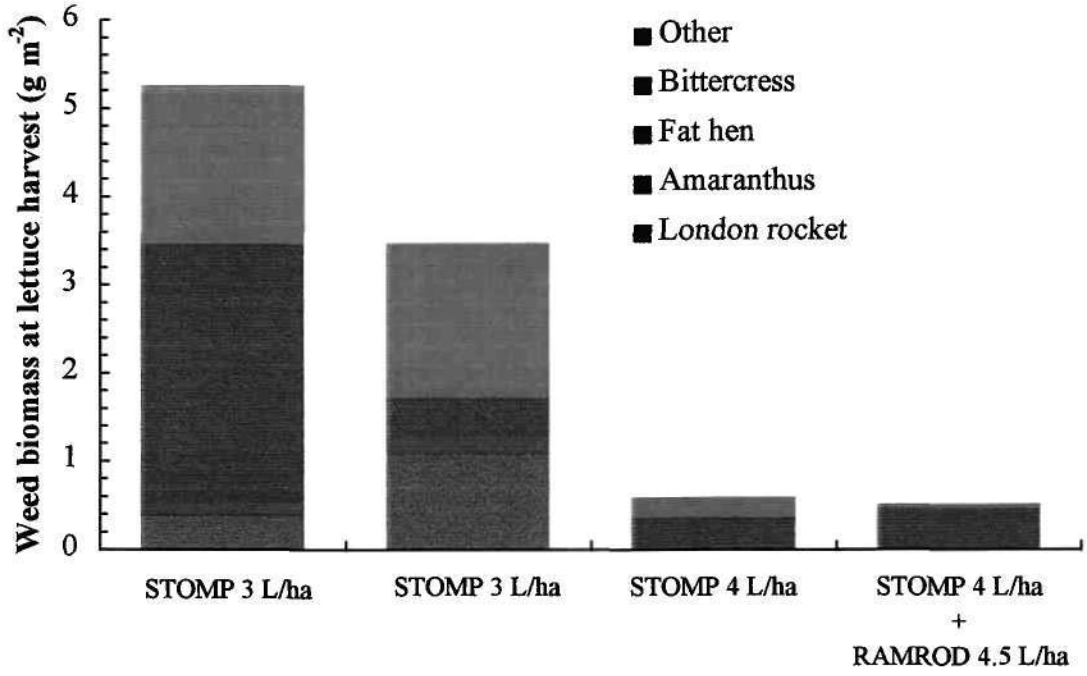


Figure 8. Herbicide strategies significantly affect weed biomass present at the time lettuce were harvested (LETT4).

Brassica vegetables

In this project, a range of herbicides were evaluated for both pre and post-emergence use in various brassica vegetables. The herbicides included DUAL®, STOMP®, RAMROD®, GOAL® (oxyfluorfen), LONTREL® (clopyralid), and LENTAGRAN® (pyridate).

Pre-emergence uses

DUAL®, STOMP® and RAMROD® are all registered for pre-emergence us in several brassica vegetables (broccoli, cabbage, cauliflower). GOAL® is not registered in Australia for brassicas, however it is used in the USA as a pre-emergence herbicide in cabbage, cauliflower and broccoli.

DUAL®

Previous experience with DUAL® in brassicas in southern Queensland has shown that application rates of 4 L/ha (the maximum registered rate) has a substantial probability of causing significant yield suppression. As a consequence, when developing weed management strategies for brassica vegetables, we do not exceed 3.5 L/ha of DUAL® in any post-transplanting, pre-emergence treatments. In this project, 3.5 L/ha of DUAL® caused slight initial stunting of cabbage in one experiment, marginally delayed broccoli maturity in a second experiment, and had no deleterious growth effects on cabbage in a third investigation. In all three of these cases, crops recovered from any initial setbacks, with yields unaffected compared to control treatments (eg. Fig. 9). In a fourth experiment, broccoli yields from plots sprayed with 3.5 L/ha of DUAL® were 10-15% less than from hand-weeded areas.

DUAL® at 3-3.5 L/ha gave acceptable weed control in most brassica experiments. Some follow-up cultivation or hand-weeding was occasionally required, particularly in cabbage (which takes longer to achieve canopy closure and has an extended growing period), or where less-susceptible weed species were present. DUAL® effectively killed pigweed (*Portulaca oleracea*), potato weed, and suppressed blackberry nightshade (*Solanum nigrum*) and sowthistle (Fig. 10). DUAL® was only moderately effective against fat hen and small-flower mallow (*Malva parviflora*), resulting in a build up of these species over time if DUAL® was the only herbicide used (Fig. 11). DUAL® gave marginal suppression of burr medic (*Medicago polymorpha*).

STOMP®/RAMROD®

STOMP® and RAMROD® are registered for use in brassica, either as single herbicides or in combination. RAMROD® rarely causes crop damage, even at the maximum registered rates, however STOMP® can cause stunting and yield suppression in circumstances where growth is inhibited by very cold or waterlogged conditions. In most of our experimental work we investigated STOMP®/RAMROD® combinations, rather than single product strategies, as the broader weed spectrum provided by the former mixture was more applicable to most situations.

In Chines cabbage, where only RAMROD® is registered, in an on-farm case we investigated, application of this chemical did not effectively control potato weed, even though it is generally very effective against this weed.. We think this was due to a slight delay in herbicide application, combined with a huge soil seedbank of this species. Application delays

meant the seedlings, although they were still not visible at the time of spraying, had germinated sufficiently to escape receiving a lethal dose of herbicide in the emergence process. With a huge seed reserve, even if 90% mortality was achieved, the number of surviving weeds was still not commercially acceptable. This case study reinforced the need for optimum application timing, and highlighted the potential benefits of post-emergence alternatives to help resolve such a situation.

RAMROD® used by itself did not adversely affect cabbage yields (Fig. 9). There were slight trends for delayed maturity in broccoli and cabbage where STOMP®/RAMROD® combinations were used, although these effects were probably not commercially significant. In our experimental work in this project, there was little weed management benefit from using more than 8 L/ha of RAMROD®, either alone (Fig. 10) or in combination with STOMP® (Fig. 11). The optimum STOMP® rate in the combination was 2-2.5 L/ha. RAMROD® by itself had a similar weed spectrum to DUAL®, but was slightly less effective against pigweed and blackberry nightshade (Fig. 10). The STOMP®/RAMROD® combination gave effective sowthistle suppression, and better control of fat hen and small-flower mallow than DUAL® (Fig. 11). STOMP®/RAMROD® much less effective than DUAL® in killing bittercress, and had little impact on burr medic.

GOAL®

In all our experiments within this project, pre-emergence use of GOAL® in brassicas has been the most effective herbicide treatment, both in terms of least crop damage risk, and best weed control. In each experiment where GOAL® was applied at 1.5 L/ha before transplanting, yields of cabbage and broccoli were equivalent to the best of all the treatments evaluated.

GOAL® applied pre-emergence controlled sowthistle, bittercress, fat hen and small-flower mallow (eg. Fig. 11) and was the most effective of the pre-emergence products against burr medic. Over all the experiments it controlled the widest diversity of weed spectra.

Pre-emergence application of GOAL® is the most cost-effective of the pre-emergence herbicides we evaluated, with least risk of crop damage and most potential to reduce weed burdens, both in-crop and additions to the soil seedbank. Legalisation of its use in brassica vegetables is a priority.

Post-emergence uses

GOAL®

Although GOAL® is registered overseas in brassica vegetables for pre-emergence use only, in this project we also reviewed its potential for use at low rates post-emergence.

In an on-farm experiment, GOAL® applied in a Chinese cabbage crop at 50 mL/ha, when the cabbage had 4 true leaves, and potato weed had 1 pair of true leaves, killed the weeds. Unfortunately, it also caused significant and commercially unacceptable stunting of the crop plants. Applying 17 mL/ha of GOAL® when the crop had 8 true leaves and potato weed 2 pairs of true leaves resulted in necrotic spotting of the sprayed leaves, however the crop recovered to be marketable. Although not measured, yields would proably have been significantly suppressed. This rate and time of GOAL® application stunted the potato weeds, but sufficient survived to cause later problems if no other management strategies were implemented. Increasing the application rate at this later time of spraying resulted in unacceptable crop damage.

In an experiment on cabbage at Applethorpe, post emergence application of 0.2-0.4 L/ha of GOAL® 20 days after transplanting caused unacceptable crop damage (leaf necrosis, stunting) and reduced marketable yields (Fig. 9). Spraying 0.2 L/ha controlled pigweed, blackberry nightshade, and suppressed potato weed, while doubling the rate killed all weed species present (Fig. 10).

Although GOAL® effectively controlled weeds post-emergence in brassicas, in Chinese and traditional cabbage at least, the levels of crop damage resulting from these treatments were commercially unacceptable. With other products showing potential for post-emergence use in brassicas, further work on GOAL® in this use pattern has been deferred.

LONTREL®

LONTREL® is registered in Australia for use in the brassica field crop canola, as well as a range of cereals. Safe on brassica species, LONTREL® is particularly active against members of the Asteraceae (eg. potato weed, sowthistle) and Fabaceae (eg. burr medic) families.

In experiments with cabbage and broccoli, spraying LONTREL® at up to 0.4 L/ha post-emergence did not affect crop yields (Figs. 9, 12).. There is a suggestion from the broccoli experiment that increasing the rate to 0.6 L/ha may have suppressed yields by 14%.

At 0.2 L/ha, LONTREL® killed potato weed and suppressed blackberry nightshade, whilst doubling the rate improved blackberry nightshade control (Fig. 10). LONTREL® at 0.15 L/ha sprayed 9 days after transplanting gave excellent control of sowthistle in a broccoli crop, whilst 0.3-0.6 L/ha was required to achieve control when spraying was delayed until 37 days after transplanting. LONTREL® was ineffective against pigweed, fat hen and bittercress.

LENTAGRAN®

The active of LENTAGRAN (pyridate) is used commercially in vegetable crops in the USA. It is registered in Australia for use in chickpeas against a range of weed families.

In the broccoli experiment, the lowest rate of LENTAGRAN® evaluated (2 kg/ha), caused necrotic flecking soon after spraying, stunted the plants and reduced yields. As the application rate increased, so did the level of damage symptoms, whilst head maturity, marketability and size declined (Fig. 12). LENTAGRAN® sprayed post-emergence over the cabbage caused initial growth suppression, however crops recovered by harvest to the extent that the highest rate evaluated (2 kg/ha) did not adversely affect yields (Fig. 9). Transient chlorosis of the sprayed cabbage leaves was observed for a few weeks after application.

LENTAGRAN® sprayed at 1 kg/ha killed blackberry nightshade and potato weed, however 2 kg/ha was required to kill pigweed (Fig. 10). In the broccoli experiment, 2 kg/ha of LENTAGRAN® controlled fat hen and sowthistle. Its impact on bittercress is difficult to ascertain, however some suppression appears likely when sprayed at an early growth stage.

In our project work LENTAGRAN® seemed to have a broader weed spectrum than LONTREL®, however the risk of crop phytotoxicity was also increased. Although both herbicides could have a role in brassica production, commercial considerations suggest that LONTREL® would be the more likely product to become legalised for use in Australia. LONTREL® residues remaining in the soil after brassica crops are harvested is a concern, particularly where a sensitive species such as lettuce is being grown in rotation. However, if this can be addressed, legalisation of use in brassica vegetables would increase alternatives available for weed management and reduce the continued reliance on current pre-emergence products. It would minimise the risk of developing resistant weeds or non-susceptible weed spectrums, by enabling rotation of herbicides with different modes of action.

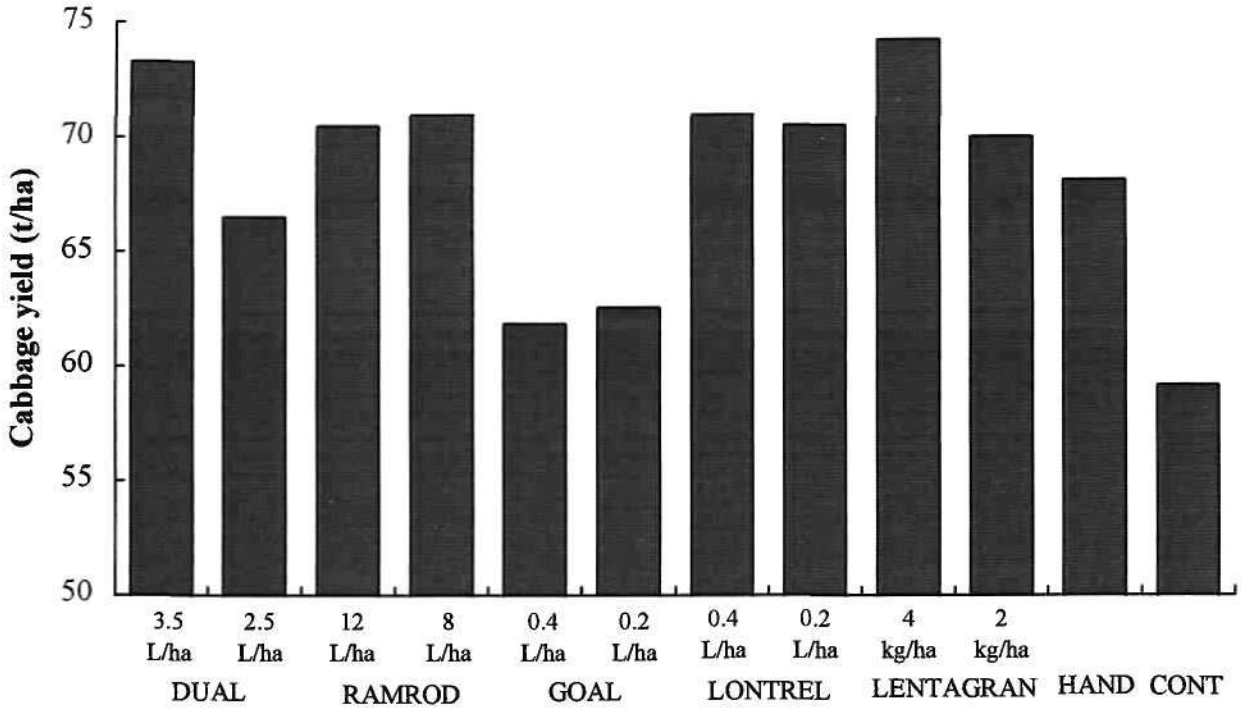


Figure 9. Herbicide strategies affect cabbage yields (CABB1).

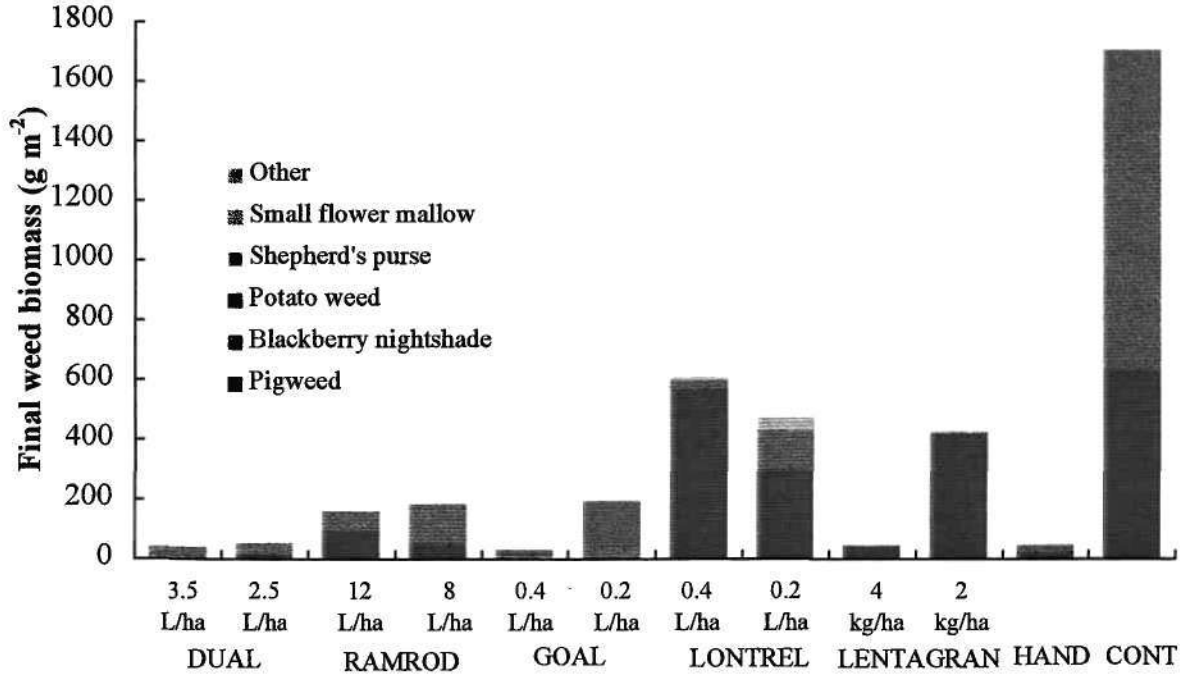


Figure 10. Herbicide strategies affect weed biomass in cabbage (CABB1).

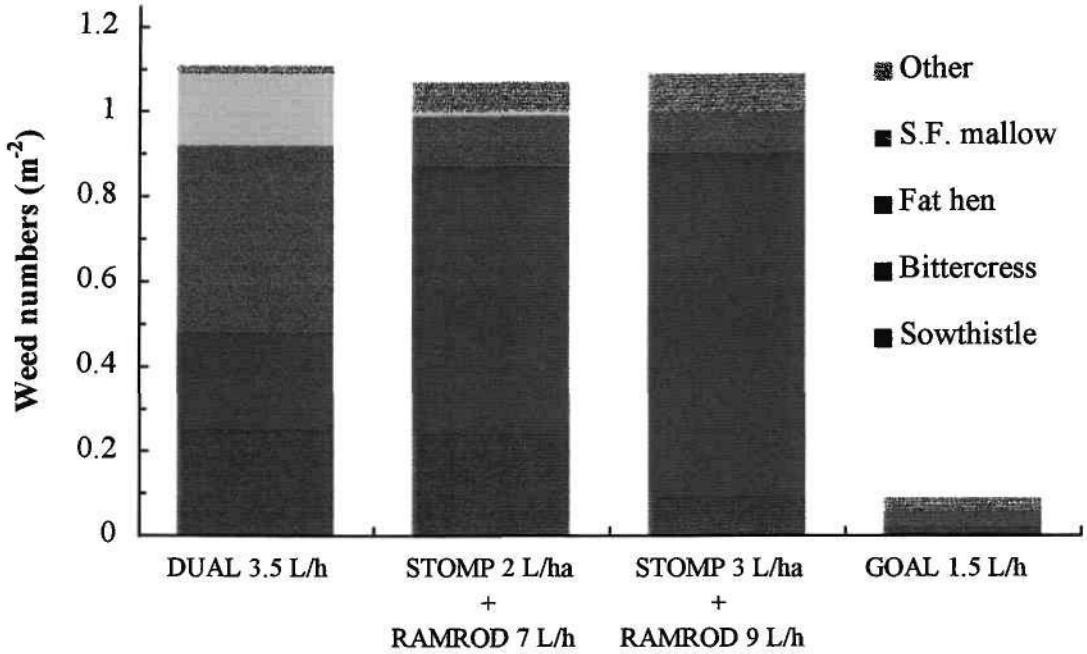


Figure 11. Herbicide strategies affect weed abundance in cabbage (CABB2).

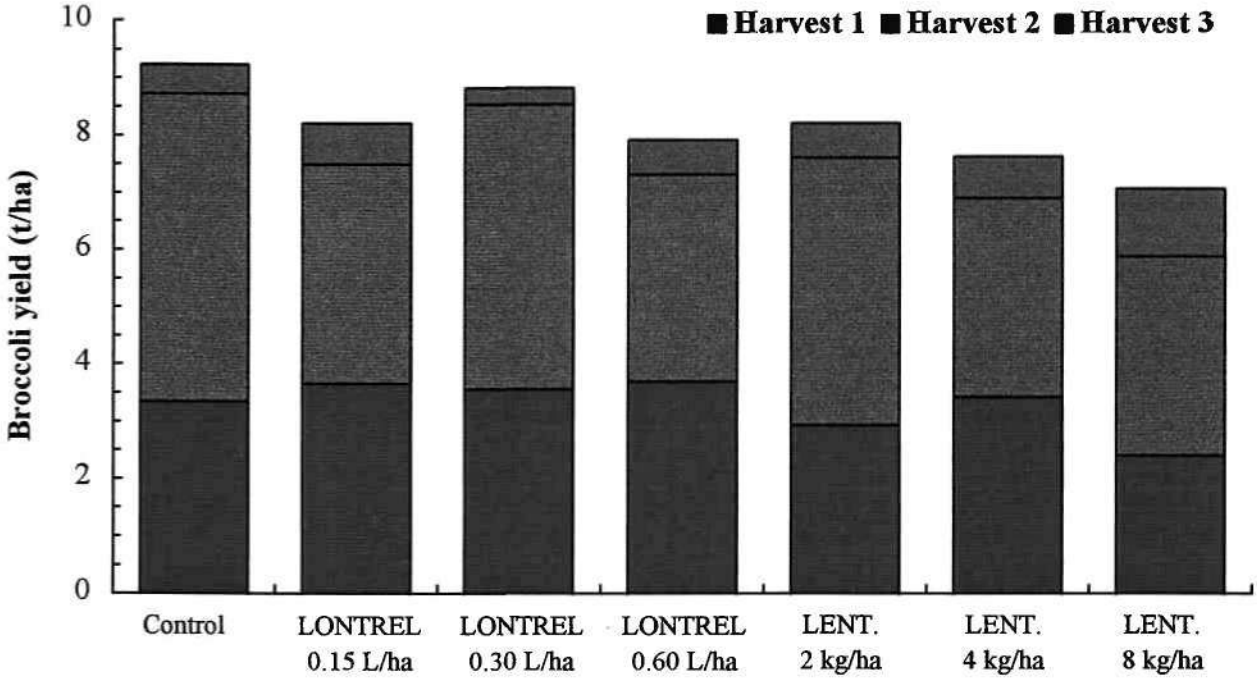


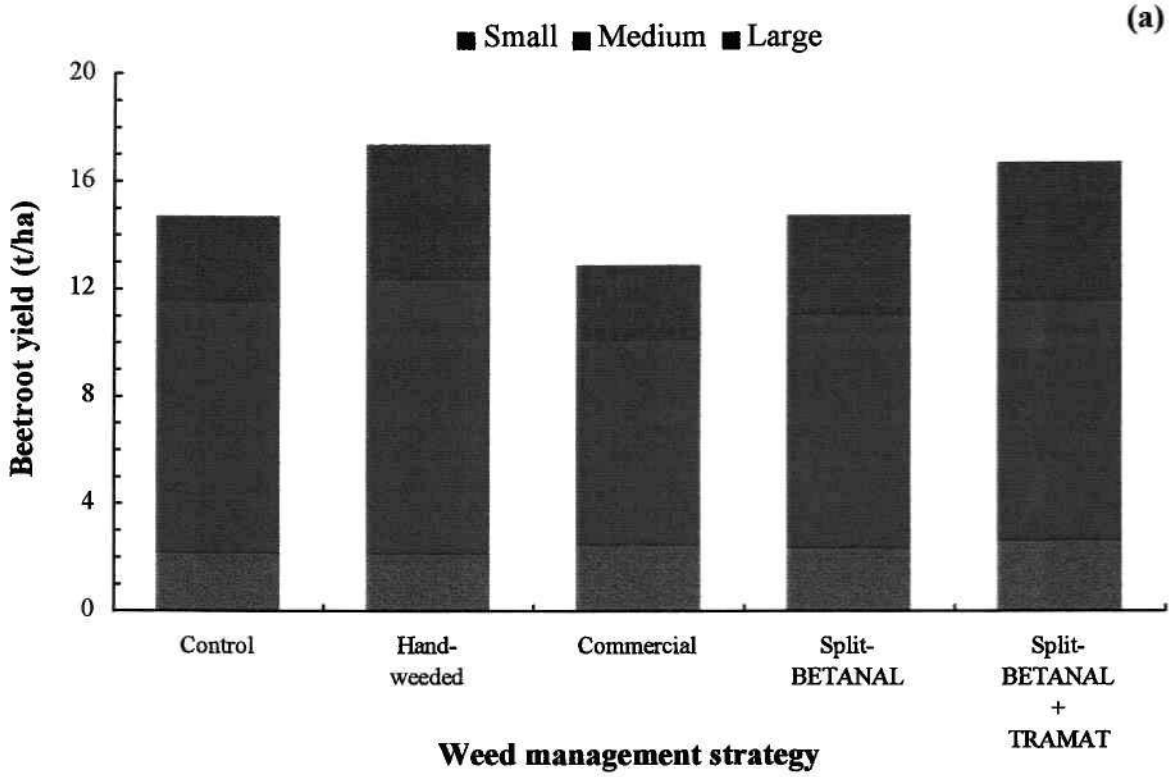
Figure 12. Herbicide strategies marginally affect broccoli yields (BROC1).

Beetroot

Traditional commercial approaches to weed management in beetroot have involved application of maximum rate mixtures of BETANAL® (phenmedipham) and TRAMAT® (ethofumesate) post-emergence, when the beetroots have 4-6 true leaves. Pre-emergence herbicides PYRAMIN® (chloridazon) or RAMROD® (propachlor) may also be sprayed immediately after sowing. In more recent times, there has been less use of the pre-emergence options. In the following discussion, a standard commercial herbicide application is considered to be spraying a mixture of 5 L/ha of BETANAL® and 2 L/ha of TRAMAT® when the beetroot has 4-6 true leaves. TRAMAT® rates will relate to the current formulation comprising 500 g/L ethofumesate.

In both beetroot experiments, hand-weeding resulted in the highest or equal highest yields of any treatments (Fig 13). Note that the *Control* treatment is generally a very low dose of herbicide, associated with substantial numbers of weeds still remaining after treatment. In 1 experiment none of the weed management strategies significantly affected beetroot yields, whilst in the other, the commercial standard mixture of BETANAL® and TRAMAT® (*Commercial*) resulted in significant yield reductions (Fig 13).

Overseas experience and use patterns indicate less risk of crop damage from beet herbicides when the total dose is split across at least 2 applications, separated by 5-10 days. In the *Split-BETANAL®* treatments, 2 sequential applications of 2.5 L/ha of BETANAL® were sprayed about 1 week apart. The first application was generally when the beetroot crop had 2-3 true leaves. The *Split-BETANAL® + TRAMAT®* treatment had very low rates of TRAMAT® (usually 0.2 L/ha) mixed with each BETANAL® spray. In those experiments where crop damage was significant, both split application treatments were less phytotoxic than the standard commercial practice (Fig 13).



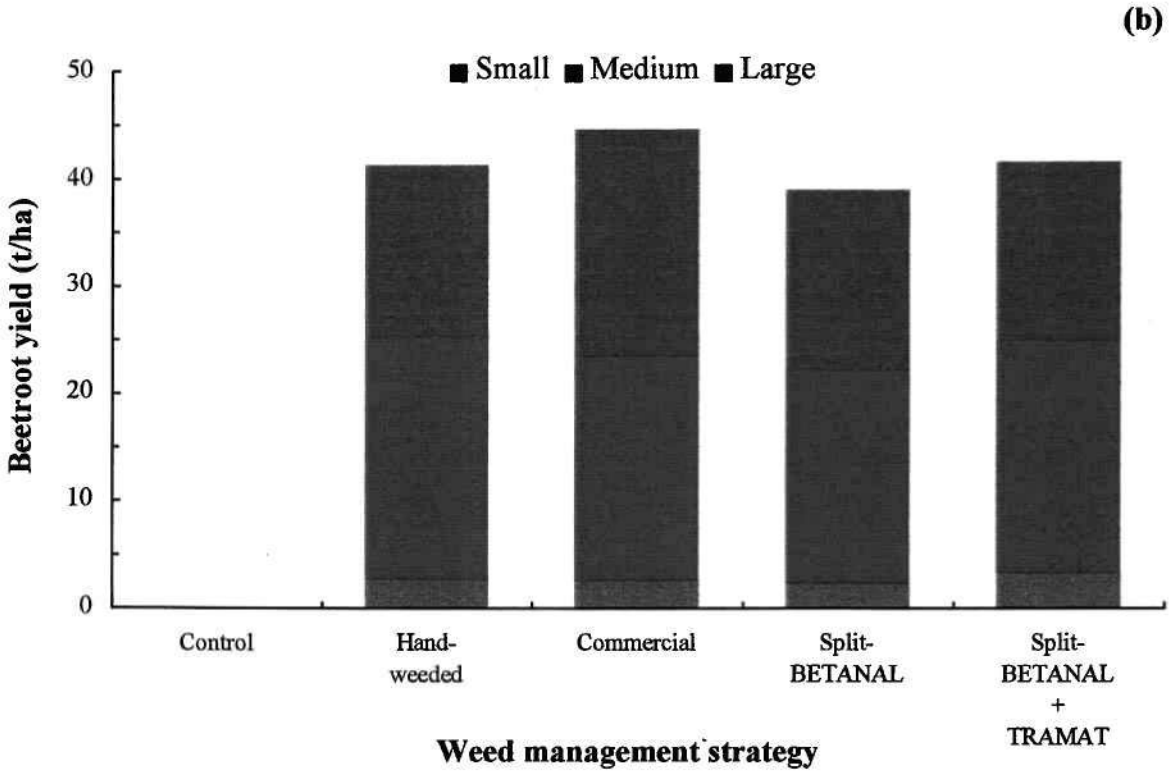


Figure 13. Weed management strategies (a) significantly affect beetroot yields in BEET1, but (b) have no effect on beetroot yields in BEET2.

In each beetroot experiment, the standard commercial single application of BETANAL®/TRAMAT® mixtures gave acceptable weed control (Figs. 14, 15). Split applications of BETANAL® alone gave variable results; in some cases weed control was excellent, in others less so. The addition of very low rates of TRAMAT® (usually one-tenth of the maximum registered rate) consistently improved weed-kill. The only exception was with fleabane in BEET2 (Fig. 15b). In all plantings, the split application treatment with BETANAL® and TRAMAT® gave commercially acceptable weed control.

We are liaising with the relevant herbicide company (AGREVO® P/L) with regard to possible changes in registrations to reflect our proposed application strategies. In the meantime, we will be looking to test the commercial viability of these weed management strategies over larger areas, in producers' crops, and in situations with greater weed burdens.

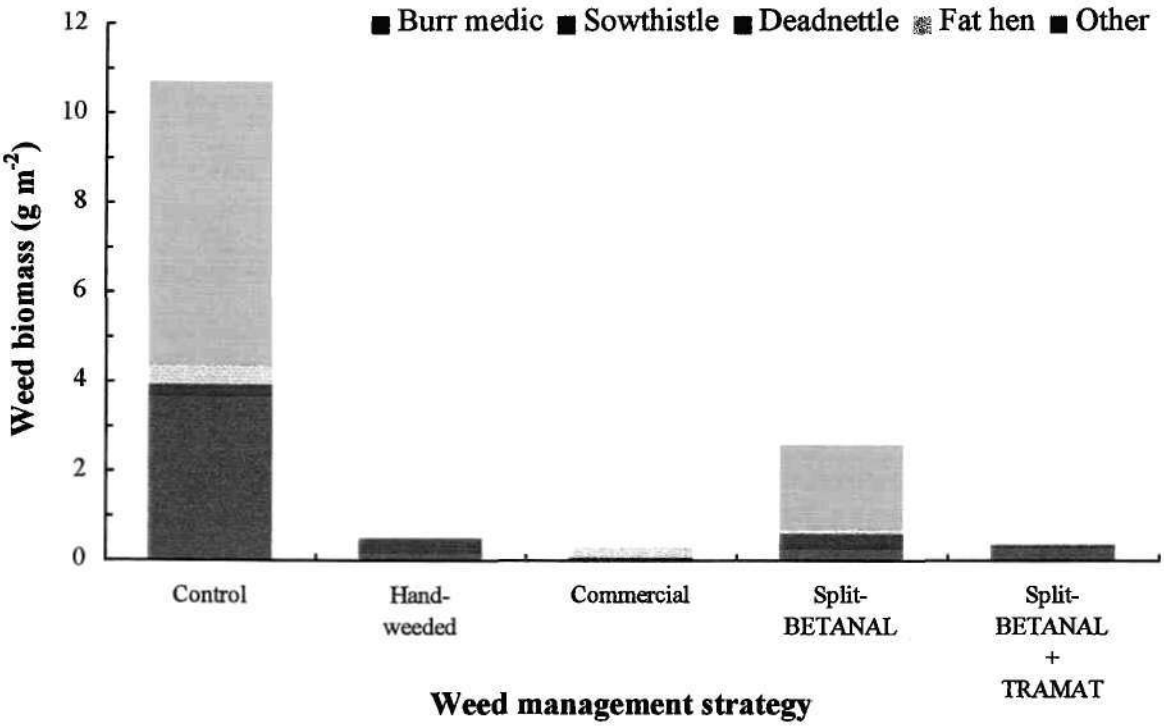


Figure 14. Weed management strategies significantly affect weed biomass present when beetroot are harvested in BEET1.

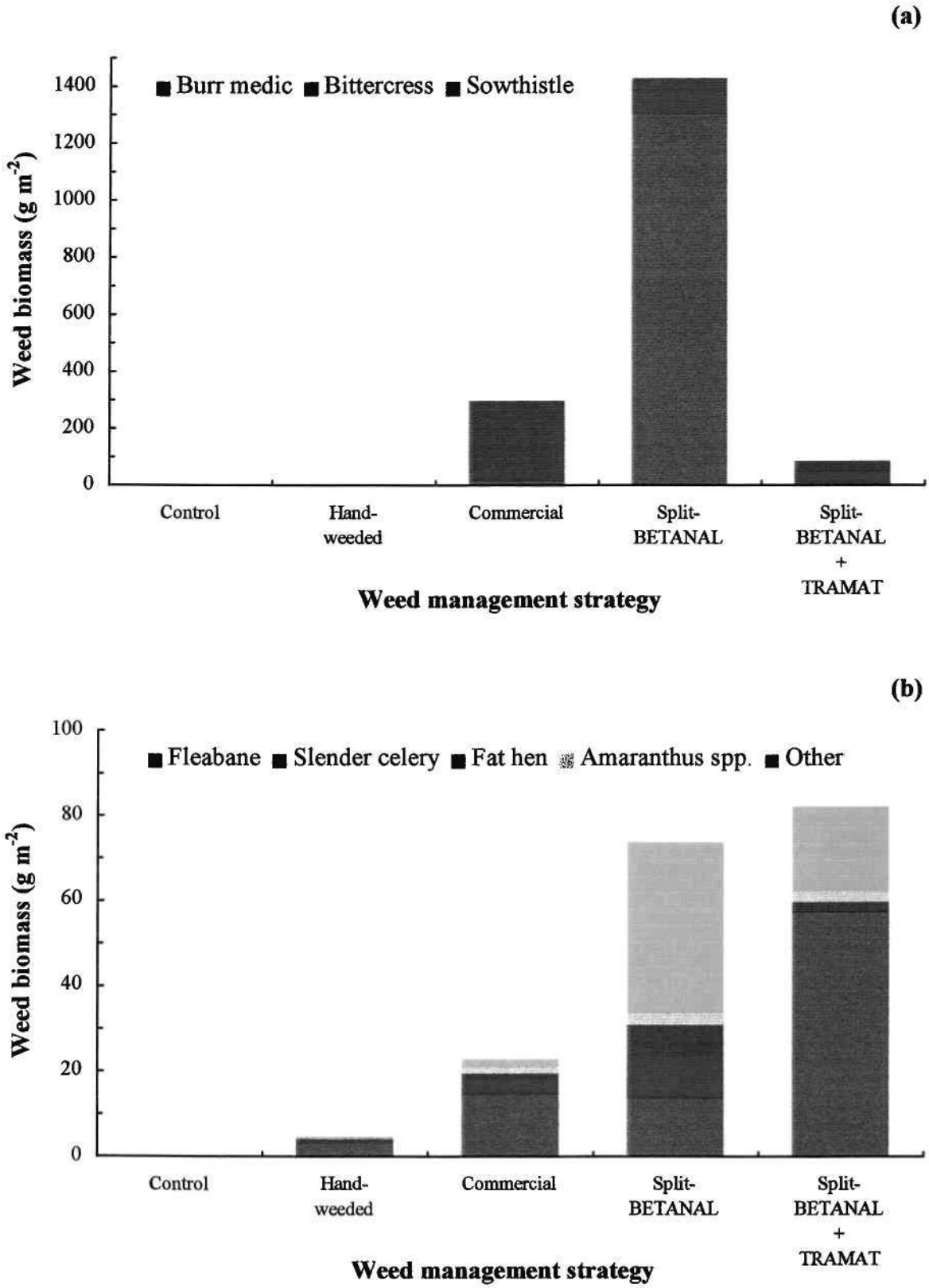


Figure 15. Weed management strategies significantly affect weed biomass present when beetroot are harvested in BEET2 (a) high population species and (b) less common species.

Onions

In the single onion experiment we conducted in this project, we focussed on post-emergence options with regard herbicide strategies. Rain delayed our first spraying of TOTRIL® (ioxynil) until well beyond the desirable application stage. By the time we sprayed, the onions had 4 true leaves and some of the fat hen were flowering! Nevertheless, this TOTRIL® application killed the weeds present at the time of spraying. None of the TOTRIL® treatments adversely affected the onion plants, probably because of their size at the time this herbicide was applied. The early spraying of low rates of GOAL® may have slightly reduced the crop stand, with this effect exacerbated by waterlogged conditions after spraying. Reduced onion densities was not reflected in less yield from this treatment, as shown in Fig. 16.

Because of late weed emergence, the single spraying of TOTRIL® at 2.8 L/ha was insufficient to control weeds for the full onion growing period. Weed competition reduced production from this treatment by about 10 t/ha (Fig. 16); the levels of weed growth would have precluded the onions being harvested. Sequential TOTRIL® applications and a single judicious hand weeding controlled both sowthistle and fat hen, with only a few weeds remaining to set seed. With the sequential GOAL® strategy, initial control of sowthistle and fat hen was satisfactory. However, the third GOAL® application was delayed too long, and as a consequence substantial hand-weeding was required.

Our work in this project confirmed that with proper attention to timing and rates, both TOTRIL® and GOAL® can be successfully used for cost effective post-emergence weed control in onions. TOTRIL® is currently registered, whilst GOAL® is legal to use in some parts of Australia. Because they have different modes of action, a program of alternating these herbicides would be very beneficial for resistance and general weed spectra management.

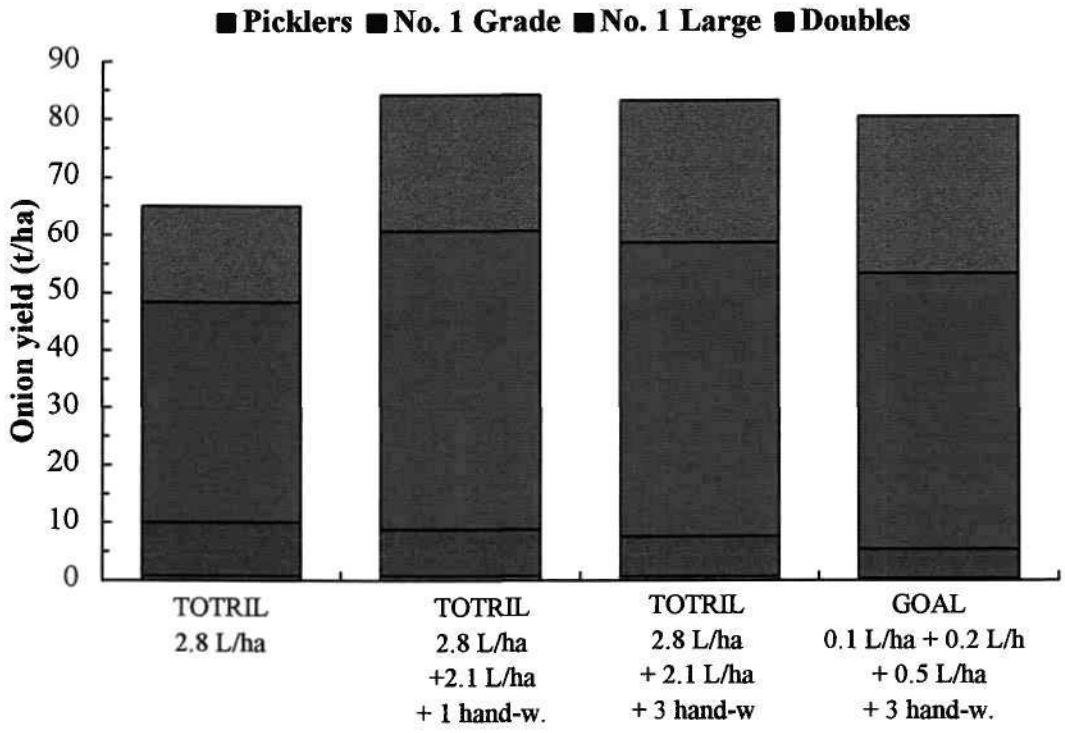
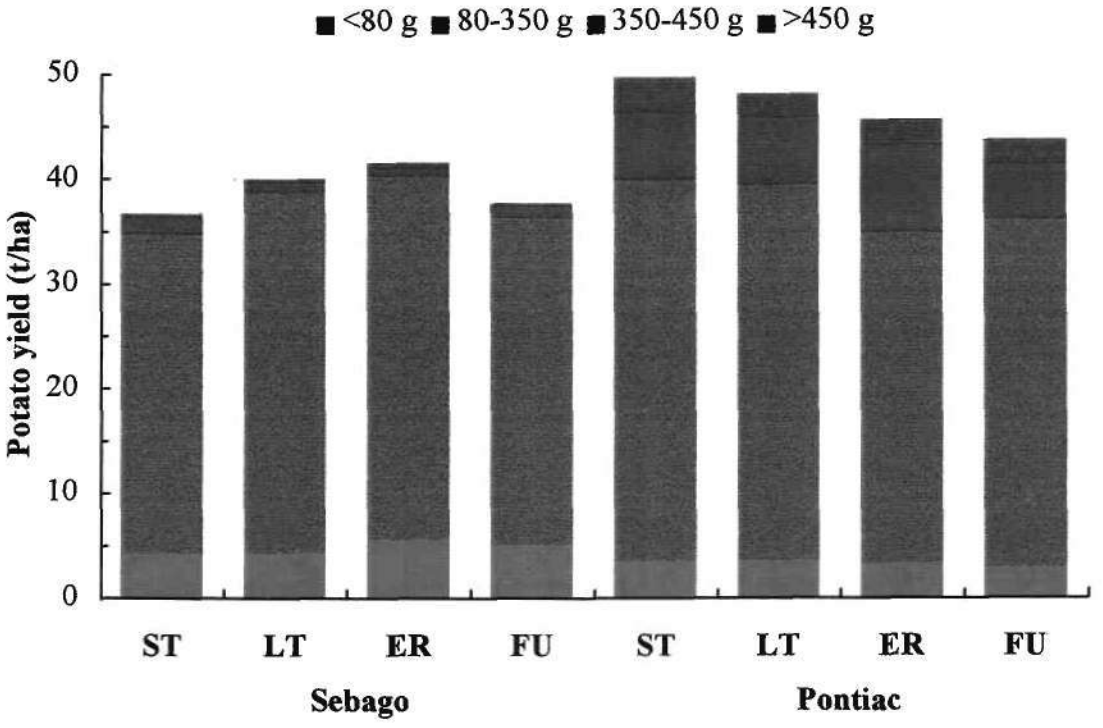


Figure 16. Weed management strategies affect onion yields (ONIN1).

Potatoes

In the single potato experiment conducted on a long-term weed management site, we compared rates of LEXONE® (metribuzin) herbicide and a mixture of LEXONE® and TITUS® (rimsulfuron) with plots where no herbicides were used. Although there were no significant herbicide effects on potato yields, there was possibly a trend for a very slight yield suppression where high rates of LEXONE® or the LEXONE®/TITUS® mixture was sprayed over *Pontiac* compared to *Sebago* cultivar (Fig. 17).

Although LEXONE® sprayed at 350 g/ha effectively controlled sowthistle, fat hen and small-flower mallow, by doubling the LEXONE® rate, or adding TITUS®, blackberry nightshade and burr medic were controlled as well (Fig. 18).



ST - no herbicide

LT - LEXONE 350 g/h

ER - LEXONE 700 g/h

FU - LEXONE 350 g/ha + TITUS 100 g/ha

Figure 17. Weed management strategies did not substantially affect potato yields (POTO1).

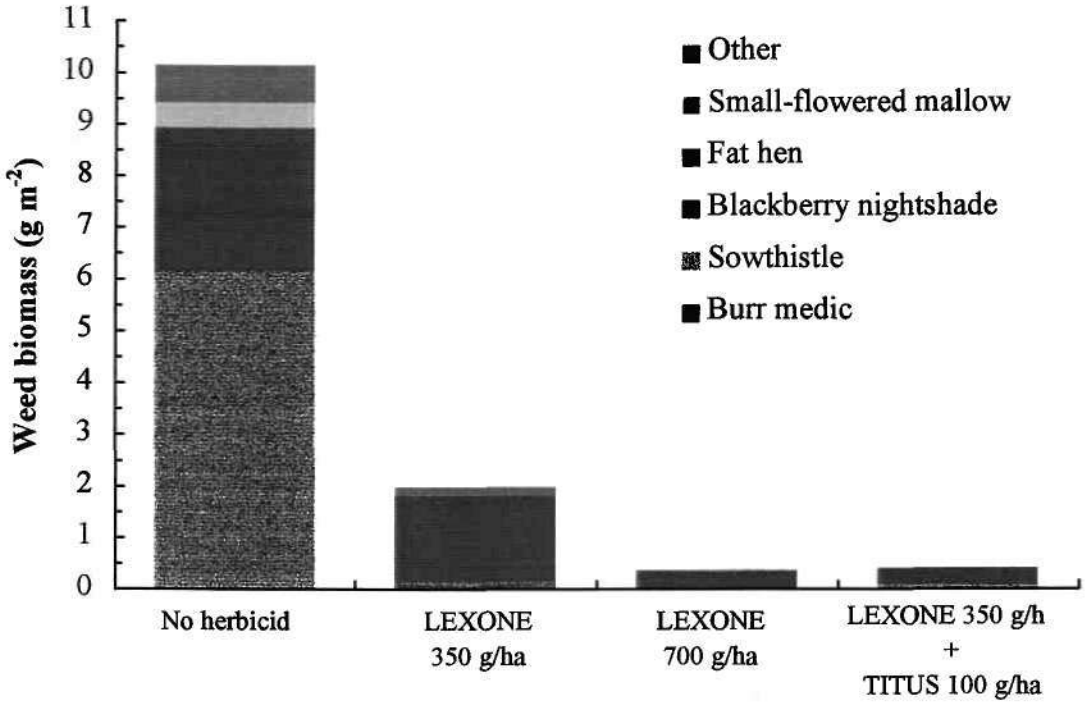


Figure 18. Weed management strategies affect weed biomass in potatoes (POTO1).

Sweet corn

In the sweet corn experiment, there was no evidence of crop phytotoxicity from 4 L/ha of DUAL® sprayed post-planting pre-emergence, nor from spraying 3 L/ha of DUAL® pre-emergence followed by 0.7 L/ha of STARANE® (fluroxypyr) 34 days after planting. With the weed spectrum present, including bellvine (*Ipomoea plebia*), burr medic, fat hen, giant pigweed and sowthistle, there was no advantage to increasing the pre-emergence DUAL® application rate from 3 L/ha to 4 L/ha. The way the experiment was structured, we could not determine the efficacy of STARANE® against the weed species present. Because sweet corn is a relatively vigorous and competitive crop, provided early weed control is achieved, later weed germinations are generally not an issue.

Celery

In the experiment where herbicides were sprayed in celery, neither the pre-emergence treatment with 4 L/ha of STOMP®, nor the post-emergence spraying of 2.2 L/ha of GESAGARD® (prometryn), adversely affected the crop. GESAGARD® controlled the weeds present, mainly sowthistle and fat hen. STOMP® was slightly less effective against sowthistle, although the level of control was still a good commercial result. GESAGARD® is registered for use in celery, while STOMP® is not. For weed population management it would be desirable to have a few more herbicide options in celery production. However, as GESAGARD® has a diverse weed spectrum, and complements other products used in crops rotated with celery, this is not a short-term priority issue.

Long-term weed management strategies

The long-term weed management sites demonstrated many key points in coping with weeds in a variety of vegetable crops, as well as the appropriateness of different philosophies.

Taking a minimalist, short-term approach to weed management is acceptable in competitive crops that achieve canopy closure in a reasonable time frame after planting. In our project, sweet corn (particularly cultivar H_5, which is tall and relatively vigorous) and potatoes are examples of such crops. In both cases, early initial weed control, achieved by low rates of herbicides, achieved commercially acceptable weed control, with very little export of weed seed to the soil seedbank.

In contrast, where crops are slow growing, or non-competitive (or both eg. onions), it is vital to look at maintaining weed control for an extended period, not just for the benefit of the immediate crop, but for following crops as well. In that context, it is also important that long-term approaches have been taken in preceding crops. For example, increasing the STOMP® rate in lettuce from 3 L/ha to 4 L/ha may not increase lettuce yields, but will almost certainly reduce weed seed set for following crops. It may also make a 'rouging' style hand-weeding viable, meaning that weed problems in following crops can be dramatically reduced. This cost of the increased herbicide and hand-weeding can be defrayed against the weed costs in following crops.

The eradication treatments generally involved 'mop-up' hand-weeding at late crop stages. This strategy is only viable where initial weed control practices have been effective (see later discussion).

In our future strategies, we demonstrated a number of herbicides that would be very useful adjuncts to our currently registered portfolios. In particular, GOAL® and LONTREL® in brassicas and onions, and STARANE® in sweet corn were very successful.

Whilst rotation of herbicides is desirable to reduce risks of resistant weed biotypes or selection of non-susceptible weed spectra, an inflexible herbicide rotation program can also be disastrous. For example, in our leafy vegetable site there was a preponderance of bittercress and burr medic. In such an instance, DUAL® would be the appropriate pre-emergence herbicide to spray when growing a brassica crop. Until populations of those weed species were minimised, rotation into a STOMP®/RAMROD® herbicide mixture for following brassica crops would be unsuccessful, and result in commercially unacceptable weed problems. Options would be to continue to use DUAL®, or preferable to grow other crops such as potatoes or celery, where these weeds are more easily managed. If GOAL® were legally able to be used, this would be the alternative to DUAL® in brassica production in that instance.

Knowledge of what weeds are likely to be a problem is critical. For example, in lettuce crops on Gatton Research Station, in circumstances where use of RAMROD® in lettuce was legal, we would still not add it to the pre-emergence STOMP® application, because key weeds where RAMROD® improves control are not common. To include it in such a circumstance would increase costs, but more importantly, substantially increase the risk of crop damage, for no real benefit to weed management. In another example, we would also not use pre-emergence herbicides in beetroot, because our weed spectrum is adequately controlled by the post-emergence alternatives.

Flexibility and opportunistic implementation of weed management strategies are important. For example, in a situation where use of GOAL® in onions was legal, weather may delay early application of this herbicide. Rather than continue with a late application, it would be more appropriate to switch to TOTRIL® (more expensive, but also more likely to kill larger weeds), for the initial spray, and then revert to a sequential GOAL® strategy.

Long-term management is all about managing populations, not individual weeds. It is also about value for effort. Practices such as cultivation and broadcast herbicide spraying are basically population independent, ie. they cost pretty much the same independent of the number of weeds present in a given area. Practices such as hand-weeding and spot-spraying are population dependent, and also tend to be more expensive for a given area. It is vitally important that commercial growers maximise the effectiveness of their population independent practices, particularly in cases where there are significant weed problems. In all our experiments, hand weeding is easily justified when it is a 'mop-up' operation, following successful herbicide and cultivation practices. Hand-weeding becomes grossly uneconomic when it is used to salvage situations where other strategies have failed.

Long-term perspectives, targeted practices, and persistence are keys to successful weed population reduction (the ultimate being eradication). Population reduction is often most cost-effective when not attempting eradication over a short period. For example, applying herbicides that are 95% effective over several consecutive seasons, followed by intensive practices such as hand-weeding in later years, may be more successful and less expensive than attempting 100% kill by hand-weeding in the first season. Eradication strategies require long-term commitment, particularly with weeds that have inherent dormancy, or survive long-periods of burial.

Case study

1. Minimise introduction of new populations, by implementing quarantine, farm hygiene and weed source control practices.
2. Conduct intense but initially relatively cheap reduction strategies to deplete the bulk of the weed population. This commonly involves cultivation (to kill, germinate and exhaust seedbank reserves), and application of knockdown and selective herbicides pre and post-planting.
3. As target weed populations decline, more rigorous but expensive procedures, eg. hand-weeding, become cost-effective. At this mopping up stage, the intensity of monitoring and control measures is increased, ensuring the few remaining plants are not undetected and re-establishing populations.

Successful eradication programs focus on reducing weed populations at each life-cycle stage. For example, field crews at harvesting can note and remove the few weeds remaining during the final phases of eradication programs.

Eradication strategies are most effective against weeds with importance restricted to only a few of the crops grown in the enterprise rotations (ie. they are easily controlled in other crops). Weeds with little innate dormancy or long-term survival traits are also more readily eradicated.

Killed mulch experimentation

Because of the combined factorial treatments, analysis and results presentation from these experiments was very complex. Only the major conclusions are presented; for more detail contact the author. These experiments were also to be repeated in late 1997.

In no experiment were there indications that nitrogen tie-up from incorporation or mulching of cover crops was substantial enough to reduce crop yields. However there were consistent trends for incorporated cover crops (particularly forage sorghum) reducing yields compared to crops grown after a conventional fallow period (Figs. 19-21). Forage sorghum is known to release allelopathic compounds as it breaks down. In the lettuce and celery crops, mulching the cover crops on the surface improved yields compared to the conventional fallow, whilst in the broccoli, mulching the cover crops had no effect. Note that where the cover crops were mulched on the surface prior to planting, the cash crops were transplanted into virtually undisturbed soil; a 'zero-till' situation. There was no evidence of increased nutritional, disease nor insect problems in these treatments, compared to the conventional fallow areas. Presence of surface mulches reduced the risks of damage to the crops from the herbicides we used in lettuce, celery and broccoli, however, the surface mulches also reduced weed control achieved with those herbicides (compared to the fallow plots). This suggests that more of the herbicide was tied up in the residues, and less incorporated into the soil surface. Herbicidal activity of STOMP®, RAMROD®, DUAL®, and pre-emergence GOAL® relies on uptake by plant root and shoot tissues within the soil matrix.

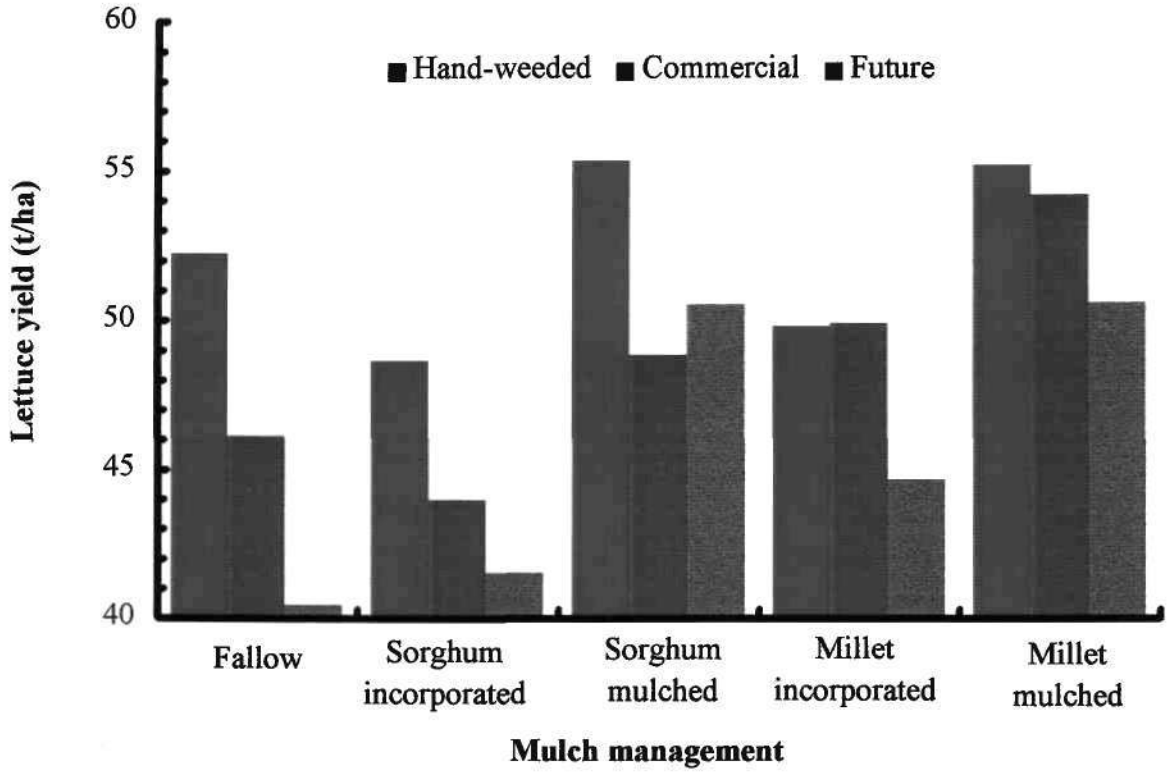


Figure 19. Effects of cover crop and weed management practices on lettuce yields (LETT6).

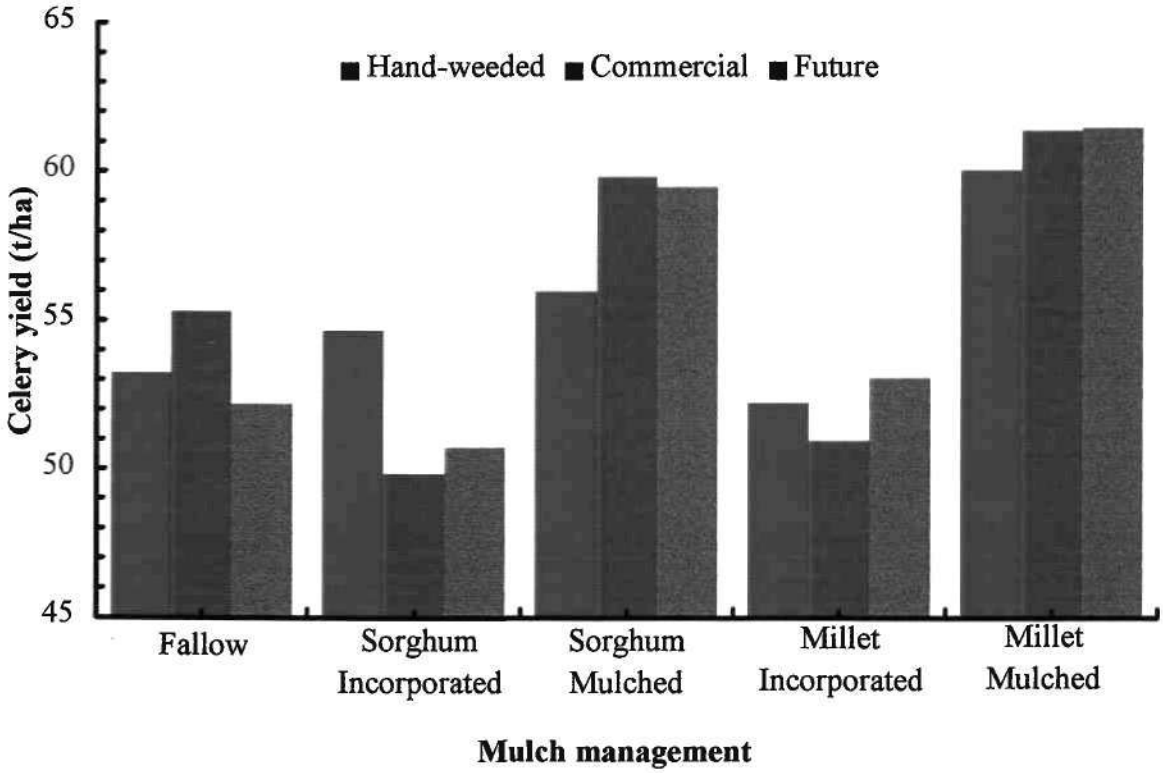


Figure 20. Effects of cover crop and weed management practices on celery yields (CELE1).

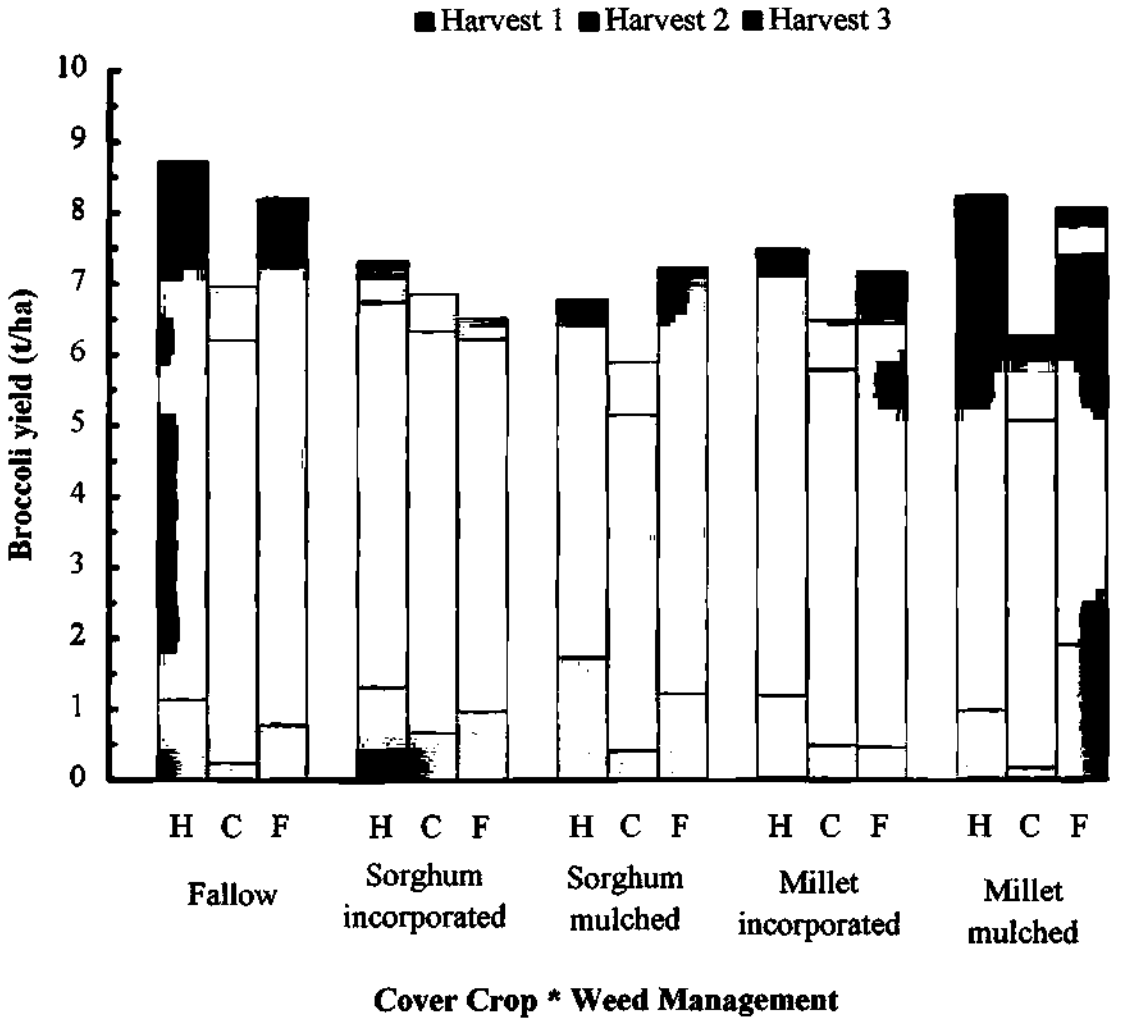


Figure 21. Effects of cover crop and weed management practices on broccoli yields (BROC3).

In all 3 experiments there were consistently more weeds in the plots where millet had previously been grown, irrespective of whether it was mulched on the surface or incorporated. Because the millet cover crop grew relatively poorly, there may have been inadequate competition during the cover crop phase, with subsequent build-ups of weed seeds prior to the cash crop. Early weed counts suggested there was very little weed control benefit from the levels of mulch where the sorghum or millet was left on the surface. Overall there was very little weed suppression of the 2 main weeds present (sowthistle and fat hen) by the mulches, compared to the conventional fallow treatment (Figs: 22-24). Previous experience, and evidence from broad acre cropping areas, suggest sowthistle is a weed that is advantaged by reduced tillage. Nevertheless, there was sufficient production advantage, and previous evidence of weed suppression by mulches, to suggest that research into this type of system should be continued.

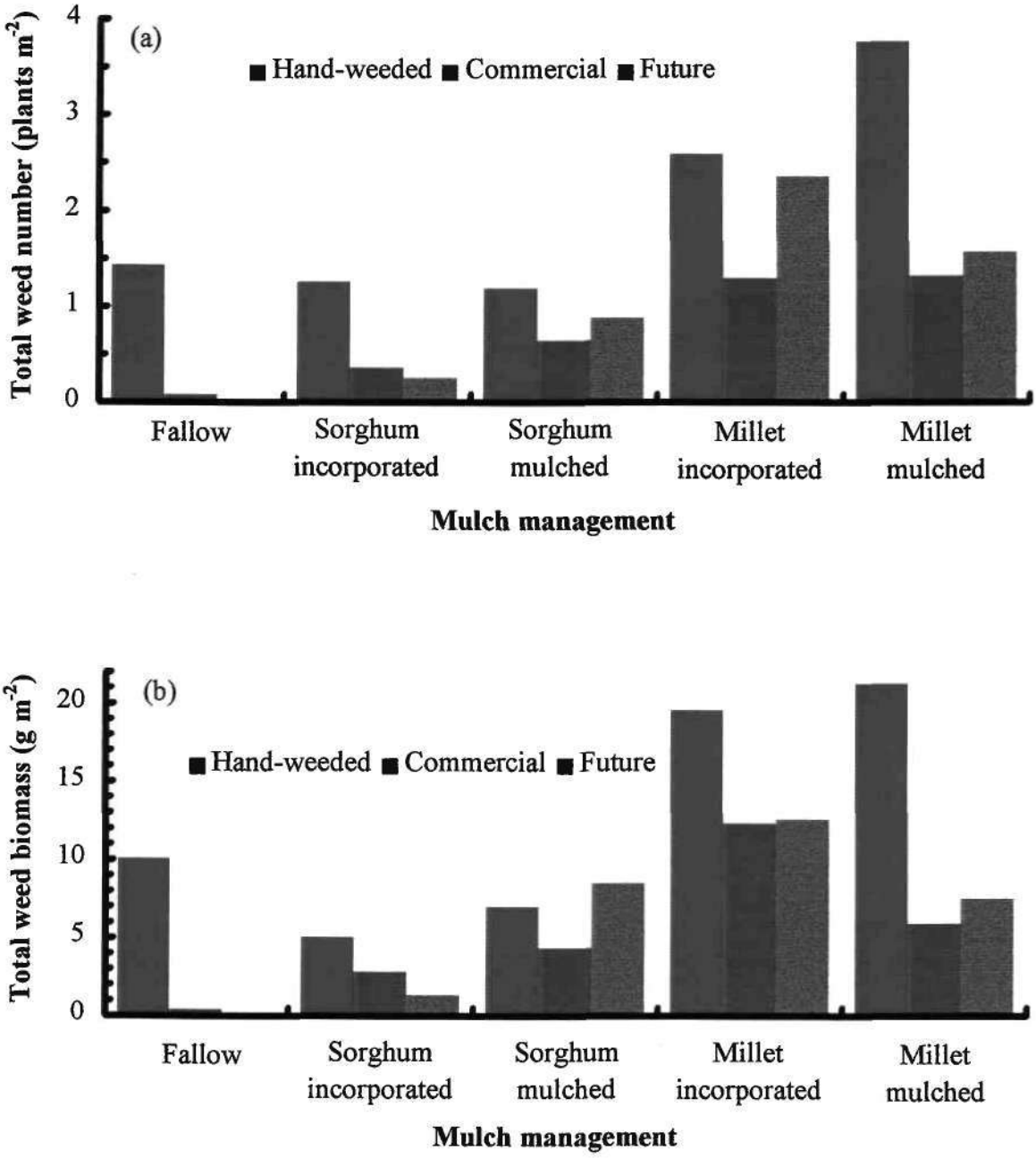
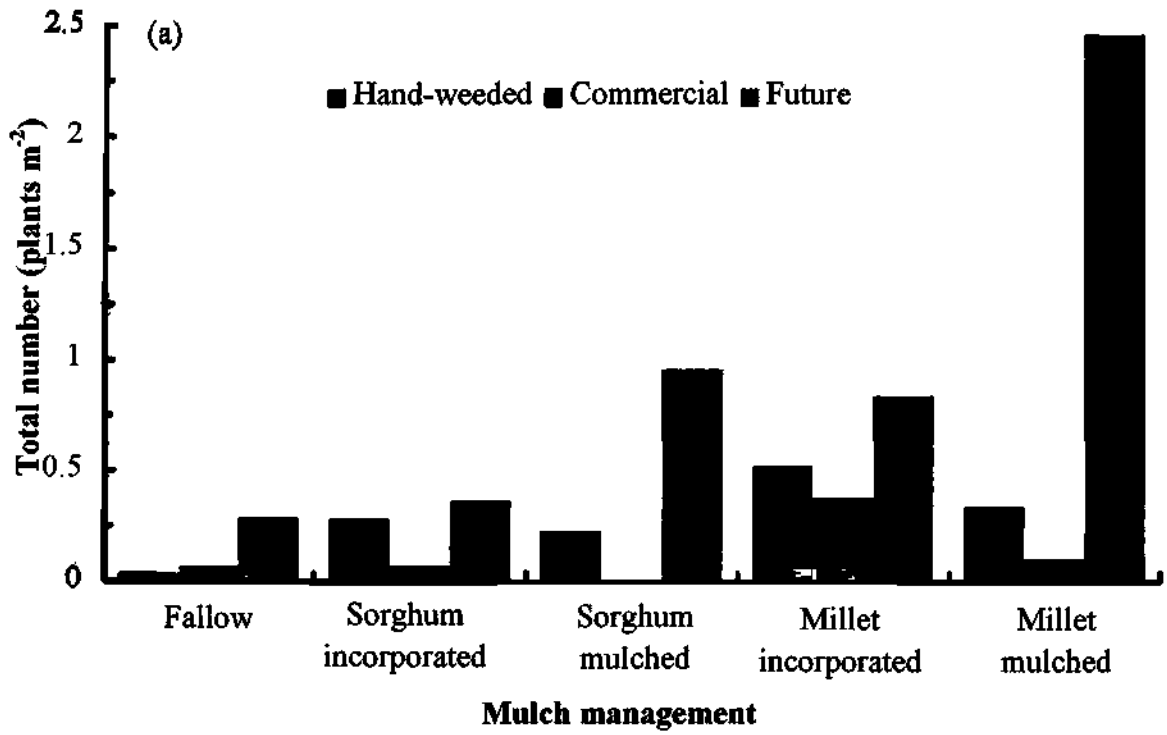


Figure 22. Effects of cover crop and weed management practices on (a) final weed numbers and (b) weed biomass in a lettuce crop (LETT6).



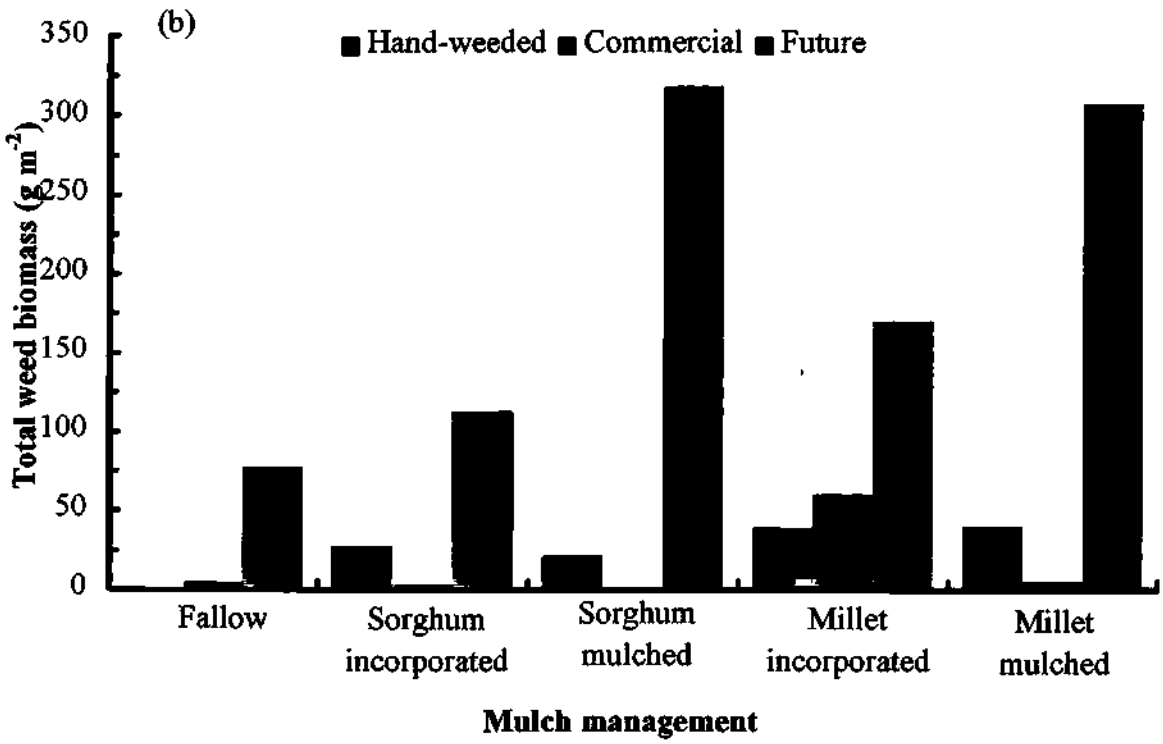


Figure 23. Effects of cover crop and weed management practices on (a) final weed numbers and (b) weed biomass in a celery crop (CELE1).

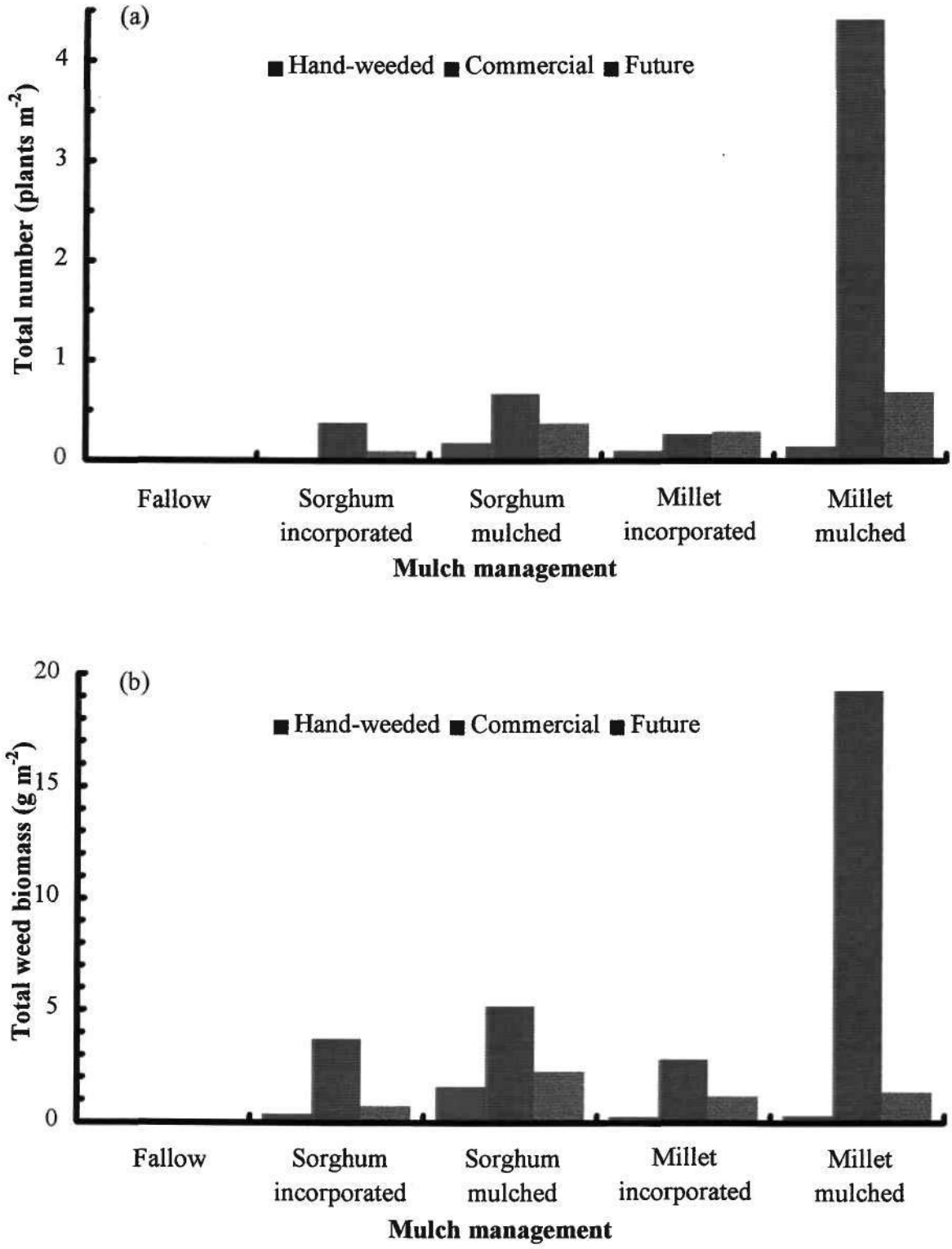


Figure 24. Effects of cover crop and weed management practices on (a) final weed numbers and (b) weed biomass in a broccoli crop (BROC3).

Extension/adoption by industry

This project has involved extension processes at a number of levels, associated with various project activities. During the on-farm weed monitoring work, we discussed the project, its aims and outcomes, as well as general weed management philosophies, with the collaborating growers. These individual one-to-one activities were continued when we conducted herbicide evaluation experiments on growers' properties. As interesting experimental results became apparent, we conducted a series of field walks for growers, which attracted widespread interest and involvement (see activities below).

The results from this project have been, and will continue to be incorporated into diverse extension material, including field walk notes, articles for industry magazines and journals, DPI Farmnotes and Agrilink Information Kits. Many of the weed management techniques outlined in this project are being disseminated through other extension people and agribusiness outlets as part of their standard extension advice.

As a consequence of our activities, and a general recognition of weed management principles as part of total crop management, many vegetable growers are now practising various components demonstrated in this project. They are more conscious of controlling weeds for the benefit of future crops, implementing farm hygiene protocols, and generally being aware of the benefits of managing weeds early, before minor problems escalate over time.

Vegetable growers are very aware of the importance of maintaining a diverse group of herbicide options as a key component of IWM. As such, grower organisations are actively participating in programs to encourage legalisation of new chemicals and new chemical uses.

The main avenues where vegetable industries are collaborating are;
(a) providing resources (land, management, funding) for experimental work on efficacy, phytotoxicity and residue data generation
(b) assist in provision of information to chemical companies on potential use patterns and subsequent sales, to enable cost/benefits of full registration to be assessed.
(c) assist in developing, collating and forwarding cases for Minor Use Approvals via the National Registration Authority.

By being involved at the ground level of product development, there is a very strong adoption rate of new herbicide strategies once they become legal. Growers have had the opportunity to see the effectiveness and use patterns of the products during the experimental stages, and are thus aware of their strengths and weaknesses.

Innovative growers have also expressed interest in being involved in further development of alternative production practices such as killed mulch technologies. These are being pursued in further project work.

Extension activities undertaken directly as part of this project are detailed below.

Field walks/days

Note: most field walks are advertised by announcement on local radio, articles in local papers, flyers in local businesses, and from 1996 on, by issuing individual invitations.

- *Integrated weed management in onions*, International Alliums Conference Tour (+handout) — 8 November 1997
- *Weed management in vegetables*, GRS Opening — 14 August 1997
- *Cabbage weed management*, Stanthorpe — 3 March 1997
- *Lettuce weed management*, Applethorpe (+handout) — 5 February 1997
- *Onion weed management*, GRS (+handout) — 23 August 1996
- *Beetroot weed management*, GRS (+handout) — 9 August 1996
- *Weed/irrigation management in vegetables* (Ausveg group), GRS (+handout) — 10 July 1996
- *Weed management in vegetables* (producers, agribusiness), GRS (+handout) — 19 June 1996
- *Weed management in vegetables*, EXPO 14 (+posters) — 22-23 May 1996
- *Onion irrigation management*, GRS (+handout) — 19 October 1994
- *Weed management display*, EXPO 13 (posters) — 25-26 May 1994

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.

- *Weeds in vegetables*, Applethorpe — 10 April 1997
- *Alternative weed management/ irrigation systems*, Bowen producers — 22 May 1995
- *Alternative weed management/ irrigation systems*, Mareeba producers — 24 May 1995
- *Alternative weed management methods*, Toowoomba — 7 December 1994
- *Irrigation management and weed control in broccoli*, Goondiwindi — 17 May 1994

Tours, seminars and briefings for select groups (not including overseas visitors)

- Briefings on vegetable projects to Horticulture Consultative Group — 29 May 1997
- Tour of GRS weed/irrigation experiments (Horticulture Conference delegates) — 21 August 1996
- Briefing on research to Heavy Vegetable QFVG meeting — 11 October 1995
- Briefing on research to Heavy Vegetable committee meeting — 5 December 1994
- Tour of GRS weed/irrigation experiments for Horticulture Consultative group — 5 May 1994

Conferences

- *Integrated weed management in vegetables*, paper and poster presented at 11th Australian Weeds Conference, Melbourne — September 1996
- *Reduced herbicide use in beetroot production*, paper and poster presented at 11th Australian Weeds Conference, Melbourne — September 1996
- *Reduced herbicide use in beetroot production*, paper presented at 3rd Australian Horticulture Technical Conference, Gold Coast — 19-22 Aug. 1996
- *Integrated weed management in vegetables*, poster displayed at Ausveg Conference, Brisbane (Used by HRDC at another conference later in the month) — 9 July 1996

Other non-publishing extension activities relevant to producers and agribusiness

- Key data and action enabling changes in herbicide registrations, approvals and labels, eg. additions of vegetable crops to STOMP®, DUAL® and potentially other herbicides.
- Discussions and explanations of research activities with:
  Local consultants (David Carey, Graeme Thomas, John Hall, Peter Broomhall, Julian Winch, Brendan Nolan)
  Chemical company representatives
- Other Australian consultants (Sandra Lanz, NSW; Ian Macleod, Matt Sherriff, Tas; Neil Delroy, WA)
- Other Australian scientists and extension officers
- Rural radio (eg. Judy Kennedy / Chrissie Hinde 14 August 1997, 18 April 1996, 29 February 1996)

Significant activities with individual growers

- Weed management experiments and demonstrations with lettuce, cabbage, broccoli, cauliflower and celery producers, including written reports to producers on findings, conducted 1994-97.

- Answering individual weed enquiries from producers and agribusiness, both local and throughout Australia. These may include on-farm visits.

Scientific papers, book chapters, conference papers (reviewed)

Henderson CWL and A Bishop (submitted for editing). Vegetable Weed Management Systems *In* 'Australian Weed Management Systems', (B. Sindel Ed.). A new reference and tertiary education textbook.

Henderson CWL (1996). Weed management strategies in vegetable production and their agronomic, environmental and economic implications. Proceedings of the 11th Australian Weeds Conference, Melbourne pp 78-81.

Henderson CWL (1996). Reduced herbicide use in beetroot production. Proceedings of the 11th Australian Weeds Conference, Melbourne pp 56-58.

Henderson CWL (1996). Reduced rate herbicide sequences in beetroot production. Proceedings of the 3rd Australian Horticulture Technical Conference, Gold Coast pp 102-106.

Conference posters (reviewed)

Henderson CWL (1996). Weed management strategies in vegetable production and their agronomic, environmental and economic implications. 11th Australian Weeds Conference, Melbourne.

Henderson CWL (1996). Reduced herbicide use in beetroot production. 11th Australian Weeds Conference, Melbourne.

Henderson CWL (1996). Integrated weed management in vegetables. at AUSVEG Conference, Brisbane. (Also displayed by HRDC personnel at another conference the same year.)

DPI Agrilink Packages

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

Industry journal papers, magazine, and newspaper articles

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

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Field walk notes

Briefings notes on vegetable projects.	29 May 1997.
Weeds in vegetable.	10 April 1997.
Weed management in onions.	23 August 1996
Weed management in beetroot.	9 August 1996
Weed management in vegetables.	19 July 1996
Weed management in vegetables.	10 July 1996
Weed management in vegetables.	19 June 1996

General comment

At all field walks, and on almost all extension material, addresses and phone numbers for contacting me to get further information are detailed.

Directions for future research

Weed biology studies

In the course of this project we obtained substantial information on the phenological development of sowthistle, and particularly potato weed, that has proven useful in evolving strategies for managing those weed species. This involved significant resource effort, particularly time commitment of DPI and University staff and students. Our experiences indicate that such biological studies may be more suited to post-graduate students, able to spend more time becoming familiar with the species and their nuances of growth.

Because horticulture is comprised of such a diverse spectra of industries, locations and environments, identifying key weeds that have widespread importance can be difficult. In many instances, it is also important to realise that controlling or eradicating one species may (often invariably) result in other weeds becoming important. Development of flexible weed management systems able to cope with a diversity of weeds is probably more important than concentrating efforts on understanding the biology of one or two weeds. Exceptions are circumstances where a particular weed is a significant, industry-wide problem, or has the potential to become one, in which case intensive weed biological studies could be justified.

Herbicide development

Within this project we identified new chemicals or chemical uses that could be very beneficial to sustainable profitability of vegetable industries. As examples from this project, use of GOAL® in onions and brassicas; LONTREL® in several crops including onions, brassicas; are options which both vegetable industries and relevant chemical companies are interested in pursuing. A broader range of herbicide options reduces the risk of developing resistant weed biotypes or non-susceptible weed spectra, as well as enhancing the profitability and sustainability of vegetable industries by enabling more targeted weed control.

A major impediment to developing a wider portfolio of herbicide options for vegetable industries is the current cost and complexity of procedures for legalising new uses. All sectors of the industry (manufacturing companies, producers and legislative bodies) recognise a need for systems that enable promote the safe and effective use of agricultural chemicals. Apart from reducing the costs of full registration, a system of Minor Use Approvals that enables the legalisation of new pesticide uses in a cost and time effective process is an urgent industry need. This has been recognised, and is being acted upon by various stakeholders in this issue, including governments and regulatory bodies, growers and their representative organisations, and the scientific and advisory communities.

Apart from developing an effective legislative, regulatory and operational framework, the vegetable industries also need to look at how the pertinent data to enable approvals could be generated. There needs to be an ongoing process of determining industry issues and priorities, putting together most likely options, evaluating them and submitting the most effective for approval. We are currently implementing such a process for herbicide use in vegetables; there probably needs to be a more expansive program than encompasses all agricultural chemicals across the range of horticultural industries at least. Such a program is being investigated by a HRDC project and working party at this time.

Implementation of weed management strategies

As a result of this and other projects, we have a sound basis of principles for integrated weed management across vegetable industries. These principles need to be developed and elucidated into actual management programs for individual industries and locations. These needs are being addressed by industry specific publications (such as the QHI Agrilink Information Kits), Farmnotes, as well as more general information in industry press. However, in our experience, collaborative work on-farm with producers is the most effective way of extending moderately complicated new technology. In that way, the little hurdles that each producer may encounter can be addressed, without them losing faith in the system because of simple problems that can be easily fixed. This does not mean that each producer needs individual service from the primary researcher. What it does mean is that some network, either through consultants, field officers, industry development officers, agribusiness representatives or even cooperative producer groups, are the best mechanisms for transfer and adoption of new technology.

In the context of weed management, what we are seeking to do in future work is to implement demonstration sites on collaborating producers' properties in key vegetable growing areas. These sites will be in place for several years, with particular emphasis on the benefits of long-term approaches to weed control. Initial indications are that we have more people volunteering to host such sites than we can manage.

Alternative production systems

Because of various environmental considerations, including reduced chemical use, maintenance of resources such as soil condition, issues of disposal of materials such as conventional plastic mulch, there is continued interest in alternative vegetable production systems. Our preliminary research using killed sorghum or millet mulches indicated potential of improved production under such systems, as well as some environmental benefits associated with cover crop management. We have an ongoing commitment to developing such systems where they will lead to improved sustainability of resources and production profitability.

Financial/commercial benefits

Many of the results of this project do not involve expensive new technology, but rather adoption of philosophies and decision making tools. These can be summarised as follows.

1. The weed biology studies have enabled the development of decision making tools for predicting whether seeds will set seed before they can be destroyed (eg. post-harvest). In many cases, this may mean that an unnecessary hand-weeding can be avoided (saving $300-$800/ha). Alternatively, the decision may be that a timely removal of a few weeds in-crop may save costly weed control in a following crop. Either way, the ability to make an informed choice of action based on a simple observation can be very cost-effective in the long term.

2. Outlining of IWM principles, as they specifically apply to potato weed or sowthistle, or more generally to all weeds, leads to more targeted and effective weed management practices. For example, lettuce growers may be more willing to commit to both control of potato weed in non-crop areas (headlands, drainage lines) and intensive in-crop control over a few years, if they believe it will rapidly reduce the soil seedbank and subsequent weed problems. They may also more readily rotate with crops such as brassicas, in order to obtain weed control benefits. By thinking about the weed management implications of agronomic decisions, small changes in practices or enterprises may result in large increases in weed control effectiveness, reductions in costs, or increases in profitability.

   Continuing with the lettuce example, a Granite Belt lettuce grower may currently hand-weed twice, primarily to manage potato weed. By adopting IWM strategies, it is probable that in the short-term at least one hand-weeding ($300-500/ha) would be saved. If the weed population could be substantially reduced, it is possible that the overall saving could increase by several hundred dollars more per ha, based on reduced time required for even a single hand-weeding.

3. Development of new, more cost-effective herbicide uses are obvious outcomes of this project work. Assuming eventual legalisation, there are several examples that demonstrate savings and benefits to industry.
   - Split-rate herbicide applications in beetroot improve profitability by about $500/ha, due to lower herbicide costs, increased weed control efficacy, and improved yields from less crop damage.
   - Effective use of GOAL® as a pre-emergence herbicide in brassicas may improve grower returns by $250-700/ha, again due to lower herbicide costs, increased weed control efficacy, and improved yields from less crop damage.
   - Registration of LONTREL® or LENTAGRAN® for post-emergence control of weeds in brassicas could improve the viability of direct-seeded crops, reduce reliance on pre-emergence chemicals, reduce overall herbicide use, and impact on weed populations in following crops.

   These purely economic considerations ignore the real commercial benefits of reduced herbicide resistance risks, more targeted herbicide use leading to lower total amounts of chemicals used, as subsequent environmental and marketing considerations.

4. In this project we evaluated a range of weed management philosophies, and from those we developed a series of protocols for determining the most cost-effective strategies. Examples include:
   - choosing when hand-weeding is best used (ie. as a rouging or mop-up procedure, rather than as a primary control tool)
   - choosing which crops and which crop stages require the most concentrated weed management efforts (eg. early control in sweet corn vs season-long control in onions)
   - demonstration how long-term approaches can be minimal cost and have extended benefits (eg. reduced weed seed set from increasing STOMP rate in lettuce from 3 L/ha to 4 L/ha - no lettuce yield improvement but reduced weed problems in following crops).

5. A preliminary evaluation of killed mulch production strategies suggests they are certainly in an economic ballpark with current production systems. At this stage, commercial adoption is still a way off, however there is enough initial promise to suggest further work is warranted. In the context of vegetable production, the costs of growing a 7 week cover crop and killing it are not substantial compared to other input costs. Benefits derived from a killed mulch system need to be determined, and the agronomic impediments, particularly planting and establishment issues, overcome.

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