Scoping study for sustainable broadleaf weed control in cucurbit crops

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University of New England

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Sustainable broadleaf weed control in cucurbit crops

Final Report

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Brian Sindel et al.

University of New England

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Know-how for Horticulture™

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Media Summary

Weeds are a significant problem for many Australian cucurbit producers (including in pumpkins, melons, cucumber, and zucchini), given the sprawling nature of cucurbit vines and the lack of registered herbicides suitable for selective control of broadleaf weeds.

This project, funded by Horticulture Australia Limited (HAL), was a first step in identifying the impact of weeds in cucurbit production, and areas in which weed control may be improved.

Weeds have a significant impact on cucurbit crop yield and quality, making crop management problematic. Significant weeds include fat hen (*Chenopodium album*), blackberry nightshade (*Solanum nigrum*), caltrop/cathead (*Tribulus terrestris*), pigweed/purslane (*Portulaca oleracea*), African lovegrass (*Eragrostis curvula*), barnyard grass (*Echinochloa* spp.), and nutgrass (*Cyperus rotundus*).

The strategy currently used by many growers to control weeds in cucurbit crops includes a mixture of herbicides, plastic mulch, cultivation, chipping, crop rotation and farm hygiene. Diligence and timing are important factors in a successful approach.

This study identified recent innovative approaches including soil solarisation, biofumigation, cover crops, bioherbicides and biodegradable mulch films. There are also several herbicides registered overseas for use in cucurbit crops that are not currently registered in Australia.

These and other innovations need to be explored fully. The limited range of herbicides registered for use in cucurbit crops restricts growers' ability to control weeds. Furthermore, plastic mulch may become more expensive in the future due to rising disposal costs, while it may become less acceptable as a crop management method due to environmental impact concerns.

Given these findings, the following areas for future research were identified:

- conducting case studies to improve our understanding of the impact of weeds on cucurbit growers;
- studying the most important weeds in detail, and identifying the best way to control these in cucurbit crops;
- evaluating a range of innovative weed control techniques, either used overseas or by organic growers, to determine their relevance to 'conventional' cucurbit producers;
- trialling and, if appropriate, registering additional herbicides to improve the range of products available to growers; and
- making sure that relevant and up to date information on weed control actually reaches cucurbit growers.

Technical Summary

Cucurbits represent a significant component of the Australian vegetable industry. Due to the sprawling nature of the crop vines, highly disturbed crop soil, and a lack of selective herbicides, weeds are a significant issue for growers. Despite this, relatively little attention has been given to developing integrated and sustainable forms of weed control in cucurbit crops. The goal of this scoping study was therefore to evaluate the impact of weeds in these crops, summarise the various weed control options currently used, and identify any innovative approaches to weed control for extension to the industry.

The project involved a review of Australian and international literature, a national survey of growers, a field trip to ground-truth the research findings, and an informal survey of chemical distributors to identify current and potential herbicide options.

We found that weeds have a significant impact on cucurbit crop profitability, yield and quality, and on crop management, although many of these impacts are currently difficult to quantify. Significant weeds include fat hen (*Chenopodium album*) (though some growers may identify *Amaranthus* spp. as fat hen), blackberry nightshade (*Solanum nigrum*), caltrop/cathead (*Tribulus terrestris*), pigweed/purslane (*Portulaca oleracea*), African lovegrass (*Eragrostis curvula*), barnyard grass (*Echinochloa* spp.), and nutgrass (*Cyperus rotundus*).

A successful integrated weed control strategy usually involves a mix of herbicide use, plastic mulch, cultivation, chipping, crop rotation and farm hygiene. Diligence and timing are important factors in a successful approach. A variety of other methods are available but are not in widespread use. The future success of this approach is not assured, however, due to lack of herbicide options, noted instances of herbicide resistance, and questions about the long-term sustainability of plastic mulch.

A number of possible herbicide alternatives are available, and require testing in the Australian context. Biodegradable mulch film shows promise as a viable alternative to plastic mulch, although it is still under development. A range of other approaches, many of which are only used overseas or by organic growers, have also been identified. Many of these have the potential to reduce reliance on herbicides and/or plastic mulch, and deserve closer attention.

Growers prefer to source information on weeds, and crop management, from local resellers and/or horticulturalists, although there is a concern that this expertise is becoming more difficult to source in horticultural regions.

Key recommendations for future research, development and extension arising from this study include:

- Developing an improved understanding of the impact of weeds in Australian cucurbit crops, with case studies exploring the economic impacts, as well as impacts on yield, quality and management.

- Specific information on the ecology and management of the most important broadleaf and grass weeds in cucurbit crops is required to allow growers to manage these more effectively.
- A number of innovative weed control techniques require further exploration for their relevance in Australia, and information on these practices needs to be extended to growers more effectively. These techniques include 'false seedbeds', early pre-plant irrigation, precision agriculture, using plastic mulch for more than one cucurbit crop, and farm hygiene. Concerns over the social acceptability of plastic mulch need to be addressed, and herbicide resistance testing carried out.
- Several herbicide options have been identified, and these warrant further research to identify their potential for registration. They include clethodim, halosulfuron, imazosulfuron, s-metolachlor, glufosinate-ammonium, metribuzin, and haloxyfop. Registration costs may need to be partially met by the industry.
- It is important that HAL make use of local resellers and horticulturalists when delivering information on weed control (or crop management more generally) to growers, as these appear to be their preferred sources of management information. HAL may consider developing extension materials to fill the current gap in information on weeds in cucurbit crops.

Introduction

Background

Cucurbits such as pumpkins, cucumbers, squash, zucchini and melons represent a significant component of the Australian fruit and vegetable industry. Cucurbits also occupy relatively large areas of land for production due to their sprawling vines. This habit, the highly disturbed nature of the soils in which crops are often grown (promoting weed germination), and a lack of herbicides able to selectively control broadleaf weeds in these broadleaf crops, can make weed control difficult. Weeds in cucurbit crops reduce crop yield, adversely affect fruit quality, interfere with sowing and harvesting operations, and can act as hosts for pests, viruses and diseases.

There have been great strides made in integrated and sustainable forms of weed management in broadacre grain crops in Australia over the last ten years. However, relatively little attention has been paid to developing such weed control techniques in vegetable crops, despite some earlier research which looked at experimental herbicides, organic mulches and brassica biofumigants.

The vegetable industry, in its 2010/11 Vegetable Industry Priorities, named a scoping study to provide further details for possible control options for broadleaf weed control in cucurbits as a grower issue of High Priority. This scoping study is the first step in addressing this industry priority.

Research aims

1. What impact are weeds having on cucurbit vegetable production nationally and in regionally and enterprise specific situations?

2. Which weed species (grasses and broadleaf) are causing greatest difficulty?

3. How are such weeds currently being controlled and with what level of success?

4. Do control methods, such as herbicides, lead to crop damage and are they being utilised efficiently and effectively?

5. Can weeds of cucurbit crops be controlled more sustainably (economically, socially and environmentally) with alternative methods that place less reliance on herbicides?

6. Are there likely to be new herbicide options for cucurbit crops coming on to the market in the near future in Australia?

These questions were addressed by a literature review, a survey of Australian cucurbit growers, farm visits and discussion with chemical company distributor representatives.

Literature review

The literature review focused on the extent and value of cucurbit production in Australia, the various impacts of weeds on cucurbit crops, notable weed species, current weed control techniques, and weed control options and innovations that may be introduced in the future. The review suggested that most growers adopt an integrated weed control strategy using plastic mulch with a drip-fed irrigation system, pre- and post-emergent herbicides, and chipping and hand-weeding within the crop rows. The full literature review is included as Appendix 2.

Chemical company survey

An informal survey of Australian herbicide manufacturers and distributors was conducted to identify current herbicides registered for cucurbit crops in Australia, off-labels tests and herbicides with potential to be registered for use in cucurbit crops, and possible forthcoming products. While a number of herbicide options were identified, the relatively small size of Australia's cucurbit market makes local trials and registration costs uneconomical without considerable industry and/or government assistance. Appendix 3 includes a summary of the discussion with herbicide companies.

Grower survey

A survey was conducted of cucurbit growers Australia-wide between March and June, 2011. A mixture of mail and online survey resulted in 46 completed survey responses being received. The survey suggested that there are several broadleaf and grass weeds of particular importance in cucurbit crops, and that it is difficult to estimate their economic impact. Similarly to the literature review findings, important weed control practices include herbicides, tillage/cultivation, plastic mulch, hand weeding/chipping and crop rotation. The survey findings are detailed in Appendix 4.

Field work

Three farms in the Bundaberg region were visited in October, 2011. The farm visits were used to ground-truth the literature review and survey findings. A number of approaches to weed control were suggested by growers as having potential to improve the effectiveness of the dominant herbicide/plastic mulch/cultivation approach. The results are summarised in Appendix 5.

Materials & Methods

Literature review

The impact of weeds and issues relating to their control were explored through a review of Australian and international literature. While broadleaf weeds were the main focus, grass weeds were also included where relevant.

Literature searches were conducted using the University of New England's library catalogue (printed publications and online documents available through several academic literature databases), the Google Scholar and Google search engines, and amongst the literature collection of the School of Environmental and Rural Science, University of New England.

Literature sources in Australia included academic journals and books, government extension documents, relevant reports produced by HAL and other grower peak bodies, industry magazines and newsletters, weed-specific organisations such as the Council of Australian Weed Societies, research organisations, and the Australian Bureau of Statistics. International literature (primarily from the United States) was also sourced for comparative purposes, to fill gaps in the review where Australian literature could not be found, or to identify weed control techniques not yet evaluated fully in Australia.

Despite this extensive search, the authors note that the literature review is relatively 'thin' in some areas, reflecting a lack of information on some aspects of weed impact and control in cucurbit crops. This strongly suggests a need for further research into a number of aspects of weed impact and control options within Australian cucurbit crops, both in the academic field and through industry-funded research. Should weeds remain a high priority issue, it is hoped there will be impetus to improve industry knowledge of this issue.

Grower survey

Questionnaire design was heavily informed by the project goals and review of literature. A draft questionnaire was provided to several government and consulting horticulturalists, industry representative body staff, and HAL staff for review and comment. Following this review, project staff finalised a four page A4 questionnaire, plus a one page covering letter. Ethics approval was received for the survey from the UNE Human Research Ethics Committee.

The questionnaire (Appendix 1) included questions on farm and grower characteristics, the impact of weeds on cucurbit farm operations, and current weed control practices, and sought grower opinion on emerging and future herbicide and non-herbicide weed control techniques.

AusVeg, Australia's peak industry body for vegetable growers, agreed to conduct the questionnaire mail-out using their own mailing house. A questionnaire sample frame was constructed by overlaying a recent map of Australian cucurbit producing regions (RIRDC 2010) on a map of Australian post codes to filter out non-cucurbit growing areas. From this a list of 417 post codes was produced, and AusVeg identified 1,765 vegetable growers in the mailing list with addresses in these post codes. These growers comprised the final sample frame for the mail survey.

The questionnaire was initially posted to growers in March, 2011. This was later than anticipated in the project schedule. However, the rationale for delaying mail-out included the time taken to develop the survey in consultation with industry experts, and to identify and access a nation-wide mailing list. It was also considered important to avoid the Christmas/New Year period, and to postpone the survey following wide-scale flooding in Queensland and Western Australian cucurbit producing regions in late 2010 and early 2011.

Despite these efforts, a low response of 35 completed surveys was obtained between mid-March and early May, 2011. Reasons for this low response may include 'survey fatigue' within the Australian agricultural sector, ongoing effects of flooding within many cucurbit producing regions, and lack of time due to farm operations.

Since project funds prohibited a reminder mailout, it was decided to supplement the survey response by creating an online version of the questionnaire using Survey Monkey (www.surveymonkey.com). This survey was piloted within the University of New England. Growers were advised of the online survey through emails sent out by AusVeg and the Australian Melon Association, as well as key contacts made by project staff with government horticulturalists, regional grower groups, and organic grower groups. A further 11 surveys were completed online, resulting in a total response of 46 completed surveys.

The two data sets (mail and online) were combined into a single file, and data analysis was conducted using Microsoft Excel and SPSS. Written responses were coded where relevant to facilitate quantitative analysis of qualitative data. Analysis, verbatim written responses and data tables are included in Appendix 4. Data analysis included multiple response, means and frequencies. It was originally intended that more sophisticated survey analysis techniques be used, however, the small data set precluded this. For example, statistically significant relationships could not be identified in the data using cross-tabulation.

Field work

Project staff travelled to Bundaberg, Qld, in October 2011. The goal of the field trip was to visit farms and validate the findings of the literature review and survey, or to identify issues that had not been covered in the earlier stages of the project.

Initially, the intention was to visit farms in Central NSW and the Northern Territory. However, after being unable to re-establish contact with growers in these regions, it was decided to pursue alternative arrangements.

Contact was initially made with the Bundaberg Fruit and Vegetable Growers Association (BFVG: www.bfvg.com.au). Information was provided on the goals of the research to BVFG. BFVG staff contacted growers on our behalf to establish whether it was possible to visit their farm. As a result of this process, BFVG identified three suitable growers who were willing to discuss their weed management approach and impact with members of the project team. Approximately two hours were spent with each grower.

Chemical company survey

The review of literature identified herbicides currently registered for use in cucurbit crops in Australia, as well as several options either in use or being trialled outside Australia.

Manufacturers and/or distributors of these herbicides were identified by internet search. Other major herbicide manufacturers and distributors were also identified. Initial contact was made with all identified companies either by telephone or email.

Company representatives were asked to confirm currently registered herbicides for cucurbit situations, whether they were aware of any off-label trials that have shown potential in cucurbit crop situations, whether any currently available herbicides could be tested for weed control in cucurbits, and whether they were aware of forthcoming products that may be useful in cucurbit crops. Contact was made with:

- AgNOVA
- Bayer
- Dow AgroSciences
- Loveland Products (USA)
- Nufarm
- Rygel
- Sumitomo
- Syngenta

Results

Background

The gross value of the cucurbit industry in Australia in 2008-09 was $339 million. Watermelons are the most valuable cucurbit crop in Australia, while the production of pumpkins, zucchinis and button squash, and rockmelons and cantaloupe, is also significant.

The main cucurbit crops produced in Australia include various melons (watermelon, rockmelon, cantaloupe, bitter and honeydew), many varieties of outdoor and greenhouse cucumbers, pumpkins (large grey/Jarrahdale, butternut, jap), zucchini and squash, and gherkins. A number of specialty cucurbit crops are produced at a small scale, including choko, bitter gourd, hairy melon, ornamental gourd, and luffa. Cucurbits are grown in all Australian States, and the Northern Territory.

Cucurbit production in Australia is focused on domestic fresh markets. While some processing takes place for the domestic market, unprocessed cucurbits for the domestic market are most often sold at wholesale fruit and vegetable markets in Australia's major capital cities. Australian cucurbit exports are relatively minor in comparison to domestic sales. Varieties exported include melons, pumpkins, zucchini and gherkins. The main export markets include New Zealand, Singapore, Hong Kong, and the Middle East.

Weed issues in the Australian cucurbit industry

The impact of weeds

Most vegetable crops in Australia, including cucurbits, are grown on intensively cropped land. Common features of vegetable cropping systems, including frequent cultivation that results in highly disturbed soil, irrigation (particularly furrow or flood irrigation), high fertilisation rates, and addition of large quantities of nutritional inputs before planting and during the growing period, means that the potential for weed growth is high.

Economic impact

In Australian vegetable crops, weed management costs have been estimated to range from 2-22% of total variable expenses. Weed control costs for pumpkin, zucchini and furrow-irrigated rockmelons were a similar proportion of variable production costs (approximately 12 per cent). Weed management costs in the first year of drip irrigated rockmelon were considerably higher (approximately 31 per cent), largely due to the initial outlay on plastic mulch (Appendix 2).

However, the grower survey and field visit suggested that growers find it difficult to estimate the economic impact of weed control (both in terms of costs and reductions in crop profitability). This appears to be due to lack of recorded information, and the fact that techniques used to control weeds often have a variety of other crop benefits, making it difficult to separate the impact on weeds from other impacts. One grower indicated during the field visit that nutgrass (*Cyperus rotundus*) can significantly reduce the value of land.

Impact on yield

Weeds compete with vegetable crops for soil nutrients, and for light and space by shading the crop and restricting its development and eventual yield. It is therefore important to control weeds in the early crop stages, allowing the crop canopy to develop to the extent that it provides sufficient shade to make it more difficult for weeds to develop. Research outside Australia suggests that weeds can have a large impact on yield, particularly if weed infestations are heavy during the early growth stages of the crop.

One survey respondent estimated that weeds resulted in a reduction of crop yield of between 20 and 50 per cent. Specific impacts on yield of weeds include crop damage associated with weed control efforts, and difficulties harvesting all the fruit in dense weed infestations.

Impact on quality

Weeds can host pests and diseases that impact on both the yield and the quality of vegetable crops. In cucurbit crops, there is considerable evidence that weeds, particularly broadleaf weeds that share certain characteristics with cucurbit plants, host a range of viruses, diseases and insect pests. Research conducted in Western Australia and the Northern Territory has identified a number of weeds acting as 'infection reservoirs' for several viruses and other diseases. They are also a potential source or host for a number of insect pests. One grower visited during our field research suggested that milk thistle (*Sonchus oleraceus*) acts as a host for white fly. A survey respondent indicated that particular weeds can reduce crop quality through fruit marking.

Impact on farm management

Weeds have a range of implications for managers of vegetable crops. Dense infestations can reduce the effectiveness of insecticide applications, make it difficult to identify pests in the crop, interfere with harvesting equipment, and make harvesting much slower for human pickers (particularly in the case of more mature infestations or weeds that have burrs or sharp spines).

Weeds are a particular issue at certain times of the season, for example after fruit set when the plants start to die off, and after rainfall. Nutgrass is significant for the difficulty it causes growers for plastic mulch and drip line removal post-harvest.

Neighbouring properties can be an important and ongoing source of weeds for growers who maintain an effective weed control strategy. Leasing of fields can also pose a problem for growers where there is a history of poor weed control in the field.

Significant weeds in the Australian cucurbit industry

Individual growers are generally required to manage a large number of weed species on their land. However, the most important weeds vary from one growing region to another, depending on climate and soil conditions and current weed distribution, while the relative impact of weeds within regions may also vary from one district or property to the next, based on a range of factors including cucurbit crop type, grower weed control dedication and diligence, diversity of methods used, and crop management system used.

The most commonly problematic weeds amongst survey respondents (Appendix 4) included fat hen (*Chenopodium album*), blackberry nightshade (*Solanum nigrum*), caltrop/cathead (*Tribulus terrestris*), and pigweed/purslane (*Portulaca oleracea*), all of which are broadleaf weeds. Significant grass species include African lovegrass (*Eragrostis curvula*), and barnyard grass (*Echinochloa* spp.). Other important weeds according to field trip interviewees included nutgrass, milk thistle, amaranth (*Amaranthus* sp.), convolvulus (*Convolvulus* sp.), and peppercress (*Lepidium* sp.). Some growers may actually be identifying amaranth as fat hen.

- *Fat hen:* this weed is able to out-grow the cucurbit crop, and compete with the crop for nutrients, light and moisture. Its size and rapid growth rate makes it quick to establish, and difficult to control by chipping.
- *Blackberry nightshade:* this is a large weed that grows rapidly and is able to out-compete cucurbit vines. It is capable of hosting pests such as white fly, and contaminates or stains fruit.
- *Caltrop/cathead:* makes life difficult for pickers because of its prickles. It germinates and grows quickly, and is able to grow through the cucurbit crop.
- *Pigweed/purslane:* spreads quickly, due in part apparently to the large number of seeds it produces. It harbours pests such as caterpillar moths, and spreads quickly between the crop rows.
- *African lovegrass:* grows quickly, has high potential for seeding or regrowth after herbicide application, and causes problems for fruit pickers.
- *Grasses and sedges:* grass weeds generally spread vigorously, compete for nutrients and water, are difficult to control with spray, and make it difficult to lay plastic mulch at planting. Nutgrass is able to grow through plastic mulch, is difficult to control within the crop, and makes mulch retrieval difficult. Nutgrass appeared to be the most significant weed in the Bundaberg district.

Current weed control approaches

Features of a successful integrated weed control strategy

Survey respondents overall considered their weed control strategy to be moderately successful. The survey and field trip suggested that the most common approach in an individual crop includes black plastic mulch, pre-plant herbicide application, and control of weeds in the inter-row early in the life of the crop plants, before the plant vines have a chance to spread and be damaged by weed control activity. Inter-row weed control may involve shielded spraying or cultivation, depending on the preference of the individual grower. Chipping or hand weeding is undertaken to control larger weeds that may impinge on harvesting, or those growing out of the crop holes in the plastic. Crop rotation is undertaken primarily for its disease control benefits, with weed control flexibility an important subsidiary benefit. Hygiene practices are implemented to restrict the spread of weed propagules.

Diligence is vital to an effective weed control strategy. A diligent approach allows growers to control weeds generally before they set seed, or before they are spread by cultivation or other activities, or from neighbouring properties.

Timing of weed control activities is also vital to ongoing success. One field trip interviewee suggested that appropriate timing of weed control activities was the difference between a weed-free crop and one that was densely populated with weeds by the time the crop was harvested. Survey respondents similarly highlighted the importance of timing, relating it to factors such as crop life stage, weather conditions, and control of recently germinated weeds.

Herbicides

Relatively few herbicides are registered in Australia for use *within* cucurbit crops (see the Table 1 below). Weed control is made more difficult within cucurbit crops by the fact that many significant weeds are broadleaf weeds, so that herbicidal control of these weeds will cause unacceptable damage to the crop. Knock-down herbicides such as glyphosate or paraquat are commonly used in plastic and drip irrigation production systems as a means of inter-row weed control, with shielded sprayers and larger droplet sizes employed to minimise the risk of spray drift and crop damage.

Table 1 Herbicides registered for use in cucurbit crops in Australia

Herbicide (Active Ingredient and trading name/s) and registered crops	Time of application and weeds controlled	Australian distributor
Fluazifop-P (Fuzilier; Fusilade Forte 128 EC) *Cucurbits, rockmelon, pumpkin, honeydew melon, watermelon, zucchini, squash, cucumber, gherkin*	Selective control of certain grasses *post-emergence* (after the 5 true leaf stage of the crop)	Ospray Pty Ltd; Syngenta
Sethoxydim (Sertin 186EC) *Butternut pumpkins, cucumbers, melons, pumpkins, zucchini*	Selective control of certain grasses *post-emergence*	Bayer Cropscience
Clomazone (Command 480EC) *Cucumber, pumpkin, kabocha squash, rockmelons, watermelon, zucchini*	Control of certain annual broadleaf weeds *post-plant pre-emergence*	FMC Chemicals/Serve-Ag
Quizalofop-P-Ethyl (Tzar) *Cucumbers, honeydew melon, pumpkin*	Selective control of certain grasses *post-emergence* (after the 5 true leaf stage of the crop)	DuPont
Dimethenamid-P (Frontier-P) *Pumpkin, kabocha squash*	Control of certain broadleaf and grass weeds *post-plant pre-emergence*	Serve-Ag/BASF
Metham sodium (Metham) *Pumpkin, kabocha squash*	Control of certain germinating weed seeds *pre-plant* (soil fumigant that also controls pests and fungus diseases)	NuFarm

Approximately two thirds of survey respondents considered the lack of herbicides to be a significant problem in their efforts to control weeds. The lack of post-emergent broadleaf herbicide options in cucurbits is considered a major limiting factor. Growers distinguished between their ability to impose some control on grass weeds using herbicides, and their inability to do so for broadleaf weeds.

Growers have experienced damage or reduced crop growth after using herbicides to control weeds in their main cucurbit crop. Examples included leaf damage and growth retardation that did not hinder the crop in the long term, residual damage from herbicides used to control weeds in the previous crop rotation, and damage from herbicides used to control weeds in the inter-row space (despite the common usage of shielded sprayers). One grower interviewed during the field trip was unwilling to risk using glyphosate as an inter-row weed control herbicide, given his experience with residue on the plastic mulch damaging running crop vines.

Survey respondents have observed reduced herbicide effectiveness in their main cucurbit crop, noting resistance or reduced effectiveness in controlling specific weed species, such as summer grass and ryegrass, in their cucurbit crops.

Tillage/cultivation

Mechanical tillage or cultivation, in combination with herbicide use, is the most common form of pre-plant and early post-emergence weed management used on Australian vegetable farms. Cultivation is often used not only to kill existing weeds, but to break seed dormancy and encourage germination of new weed cohorts which are then controlled with a knock-down herbicide or another cultivation before the crop is planted.

Early post-emergence cultivation is relatively cheap and can control weeds effectively, particularly when GPS technology is used to minimise the risk of damage to the crop or plastic mulch. Inter-row cultivation generally ceases once the crop vines have started to run. Slightly wider inter-row spaces may be used to facilitate cultivation.

Plastic mulch

Plastic mulch is an expensive weed control option, although it is feasible in high value cucurbit crops. Despite its cost, growers generally consider it to be the most effective and economical form of weed control. It also delivers other benefits to the crop, such as preventing soil moisture loss, providing water savings, enhancing crop yield and quality, and controlling disease. Plastic mulch is therefore a mainstay of Australian cucurbit production.

Our field trip suggested that innovative uses of plastic mulch with other methods are available to further enhance its effectiveness and affordability. One grower utilises the mulch at times for a second cucurbit crop (melons followed by pumpkins), while another grower implements an early pre-plant drip irrigation under plastic to give germinating weed seedlings time to die before the crop is planted.

Despite its effectiveness, plastic mulch does not eliminate weed problems in crop beds altogether. It is possible for some weeds (such as nutgrass or volunteer sugar cane) to pierce the plastic and establish in the crop rows, while weeds can also be a problem in the crop holes, competing with recently planted cucurbit crops.

However, our review of the literature suggested that plastic mulch is still the most economically viable form of mulch available for cucurbit production, despite ongoing trials into alternative mulches such as living and killed systems, organic mulch and biodegradable paper and polymer-based films. There are concerns over the environmental impact of plastic mulch and rising disposal costs, however growers have indicated that disposal costs are not yet prohibitively expensive.

Crop rotation

Crop rotation is commonly used in Australia to give growers the opportunity to control pests and diseases that impact on cucurbit crops. Generally, a single cucurbit crop will be followed by about five years of rotation crops, such as sugar cane.

The weed control benefits of rotations are often of secondary importance to many growers. Nonetheless, rotation is a key component of an integrated weed control system: by growing a rotation crop or variety of rotations, farmers have the opportunity to control species which are otherwise difficult to control within a cucurbit crop.

However, rotation also presents weed control challenges to growers. During non-cucurbit crop seasons, weeds that are significant in cucurbit crops may not be considered important enough to control effectively, particularly where land leasing arrangements do not give the same farmer control over weed management for successive seasons. Diligence is therefore required during non-cucurbit crop rotations to ensure that the opportunity is taken to manage weeds of significance to cucurbit production.

Farm hygiene

Good hygiene limits the spread of weed seeds and propagules (as well as pests and diseases) across and between properties, and onto crop beds from other parts of a property where weeds are present. Common practices include permanent or set vehicle tracks, equipment wash-down, restricting movement into the property, and buying certified crop seed/seedlings. By implementing a strict farm hygiene approach, a field trip interviewee was able to successfully restrict the spread of nutgrass from leased fields onto his own property. At the same time, we observed the effects of poor farm hygiene on neighbouring properties that had reportedly been relatively weed free until recently.

Other weed control methods

We identified a range of other crop management approaches in the review of literature that have weed control benefits, including organic mulches, permanent and semi-permanent crop beds, fumigation and biofumigation, controlled traffic, and crop competition. Appendix 2 provides more detail on these approaches.

Improving weed management

Other herbicide options

A search of the literature in the United States suggested that a range of herbicide alternatives may potentially be registered for use in cucurbit crops in Australia. During the course of this research we contacted several chemical manufacturers and distributors, to identify any potential herbicide options for use in Australian cucurbit crops. Table 2 below summarises the options.

Three *post-emergence* herbicides currently used in the United States have not yet been registered for cucurbit crops in Australia: clethodim, halosulfuron and s-metolachlor (the latter was de-registered in Australia due to cases of misuse). Another, imazosulfuron, is being trialled in the United States. Appendices 2 and 3 provide more details on these herbicides.

Other options may include glufosinate-ammonium (for which off-label trials have been conducted), metribuzin, and haloxyfop (see table below). Several other herbicides have been trialled in Australia, but would either need to be used with extreme caution, or cause unsustainable damage to the crop (see Appendix 3). A number of bioherbicides are also available to producers in the United States for pre-emergent and nil residual weed control (Appendix 2).

Three *pre-emergence* herbicide alternative options have been identified: terbacil (broadleaf weed control), ethalfluralin, and ethalfluralin + clomazone (both controlling grass and broadleaf weed species). Our discussion with chemical company representatives suggests there is potential for these herbicides to be imported and registered in Australia (Appendix 3), subject to trial work.

Few off-label trials have been conducted by growers contacted during this research (Appendix 4).

Table 2 Potential herbicide options for use in cucurbit crops in Australia

Herbicide (AI and trading name)	Weeds controlled	Has the product been trialled in Australia?	Australian distributor
Glufosinate-ammonium (Basta)	Non-selective grass and broadleaf control	Off-label tests conducted	Bayer
Metribuzin (Sencor)	Selective control of certain grasses and broadleaf weeds	No. Product would need to be used with caution	Bayer
Haloxyfop (Verdict)	Selective control of grass weeds	No. Product mentioned by representative but trial work not suggested	Dow AgroSciences
Clethodim (Status)	Selective control of grass weeds	No. Product worth testing but testing not currently planned by distributor	Sumitomo

Table 2 Potential herbicide options for use in cucurbit crops in Australia (continued)

Herbicide (AI and trading name)	Weeds controlled	Has the product been trialled in Australia?	Australian distributor
Halosulfuron	Selective control of nutsedges and broadleaf weeds	No. No trials planned by distributor given that demand for product is currently low	Rygel
S-Metolachlor (Dual Gold)	Selective control of annual grasses and broadleaf weeds	Yes. Was previously registered in Australia for cucurbits until cases of mis-use led to its withdrawal. Still used off-label in some cases	Syngenta
Imazosulfuron	Selective control of annual grasses and broadleaf weeds	Yes. Trials conducted by distributor suggested herbicide ineffective in Australian conditions	Sumitomo
Terbacil (Sinbar)	Selective control of broadleaf weeds	No	AgNOVA
Ethalfluralin (Curbit)	Control of annual grasses and broadleaf weeds	No. No current Australian distributor. Perhaps Landmark in the next year or two	Loveland Products (US distributor)
Ethalfluralin + Clomazone (Strategy)	Control of annual grasses and broadleaf weeds	No. No current Australian distributor. Perhaps Landmark in the next year or two	Loveland Products (US distributor)

Biodegradable mulch films

Biodegradable polymer and starch-derived (paper) mulches are proposed as an alternative to polyethylene plastic mulches. A HAL-funded trial of biodegradable polymer mulch is underway in Queensland. The film being trialled appears to perform adequately, although a number of technical issues still need to be overcome. CSIRO is working with two garden product companies to produce a biodegradable weed mat from crop stubble.

Growers appear to be uncertain about the performance of biodegradable mulch, and their ability to apply it to the crop beds without significant expense for new equipment. One grower also suggested that biodegradable mulch may be socially unacceptable in highly visible fields (such as those near major roads or densely populated areas), as the mulch tends to break down into large sections that can blow across the field, onto roads and neighbouring properties. Nonetheless, growers overall remain positive about the potential of biodegradable mulch film, with the majority of growers surveyed suggesting that a replacement for conventional plastic mulch should be a high industry priority.

Other non-herbicide innovations

There is a range of innovative non-herbicidal weed control practices being developed overseas and being used by organic growers in Australia, including thermal weed control (soil solarization, flaming and steam), biofumigation, cover crops, bioherbicides, stale and false seedbeds. Research and trials suggest that these have the potential to reduce grower reliance on herbicides and plastic mulch (see Appendix 2). Nonetheless, growers surveyed for this project remain ambivalent about the potential for these approaches to reduce herbicide use or to control weeds as effectively as current approaches. One grower stated that they would be interested in such approaches providing they were as effective and affordable as their current 'conventional' system. Growers appear more likely to embrace biodegradable mulch and precision systems (including precision cultivation and precision herbicide application to reduce the quantity of herbicide used) as an extension of their 'conventional' weed management approach.

Sources of information

Cucurbit growers prefer to source information on weed control and crop management from commercial suppliers and their representatives, other farmers or neighbours, private agronomists/horticulturalists, booklets and fact sheets, and industry newsletters and magazines. The importance of local resellers and horticulturalists in particular was emphasised.

Interviews conducted during the field trip suggest that there may be a looming shortage of trained and experienced horticulturalists in the Bundaberg region. Growers were keen to see development of horticulture courses and training in the region to sustain this important source of advice.

Research priorities

Growers taking part in this research through the survey and field trip consider the following to be high priority issues requiring research or funding to improve the viability and sustainability of cucurbit production:

- Communication and extension of effective weed management strategies.
- Identifying and registering new herbicides.
- Identifying economically viable replacements for plastic mulch.
- Developing cost-effective and relevant organic or non-herbicidal weed control methods.
- Continued research into a viable biodegradable mulch.
- Training programmes to improve the skill base amongst itinerant workers (pickers and machinery operators), and professional development for horticulturalists.

Discussion

Weed issues in the Australian cucurbit industry

It was a goal of this scoping study to identify some of the broad impacts of weeds on the Australian cucurbit industry, to determine which weed species cause cucurbit growers the most problems, and to document typical practices used by growers to manage weeds.

Little information was available about the impact of weeds on Australian cucurbit production in the literature, apparently a consequence of an industry focus on pests and disease impacts on crops rather than weed impacts.

Our research found that growers are unable to give accurate estimates of the economic impact of weeds on their crop, due to lack of recorded information and their inability to separate the weed control benefits of particular farm practices from their various other benefits.

Growers appear to have a better appreciation of the specific impacts of weeds on the yield and quality of their cucurbit crops, and on their crop management strategy. While yield losses due to heavy weed infestations cannot again be quantified, growers were able to estimate the impact, and suggest specific ways in which crop yield was compromised by weeds. Similarly, growers were able to identify specific impacts on crop quality, and several ways in which weeds make the management of their cucurbit crop more difficult.

A case study approach may be the most suitable way forward to quantify more specifically the net dollar impact of weeds in cucurbit crops, taking into account the costs of control efforts as well as lost revenue due to lower yields or lower quality fruit.

More effective weed control is an important issue for the cucurbit industry, but growers and representative bodies may not currently have enough information to quantify the importance of weeds across the industry, and to ensure this remains a high priority issue.

This project has gone some way towards identifying the most significant weeds in Australian cucurbit production. Growers generally need to deal with several significant weeds in their crop, and will tailor their weed management strategy accordingly. For example, field trip interviewees indicated that their choice of knock-down herbicide for use pre-plant or within the crop rows was dependent on whether nutgrass was present in the field, as glyphosate was considered to control this weed more effectively than paraquat. The need to tailor weed management to particular weeds has implications for extension of weed control strategies to growers. In addition to information on general weed control approaches, growers need to know how to control the specific and most important weeds in their cucurbit crops.

Current weed control practices

The ‘standard’ weed control approach currently used by many cucurbit growers (herbicides, plastic mulch, cultivation, hand-weeding, crop rotation and farm hygiene) can be used to control weeds with great effect when combined with diligence and appropriate timing of the various methods. We found three growers in the Bundaberg region using this approach, all of whom managed to keep their cucurbit fields largely weed free, to the extent that weeds were considered to have little overall impact on their cucurbit crop. Growers who are having difficulty controlling weeds in their fields, and the industry more broadly, should take heart from the example set by these growers.

Nonetheless, this research has shown that there is potential cause for concern about the long-term sustainability of this effective approach. Lack of herbicide options means that growers must rely on the continuing effectiveness of a small selection of products, some of which have begun to show reduced effectiveness against particular weed species. Similarly, the longer term sustainability of plastic mulch, which remains one of the most affordable and effective weed control methods, may be brought into question by rising disposal costs and environmental impact concerns.

Improving weed management

It is therefore important that the Australian cucurbit industry continues to explore and implement innovative, effective and economical weed control practices to complement existing approaches and ensure the longer term sustainability of cucurbit production.

This includes identifying potential new herbicide options for cucurbit crop use. Additional herbicide options may offer cucurbit growers greater flexibility in their weed control program, and extend the useful life of the limited number of herbicides currently registered for cucurbit crops in Australia.

This study found that no research has been conducted into new herbicides in Australia since 2000, when Serve-Ag Research evaluated a number of herbicides. This work resulted in clomazone (‘Command’) and dimethenamid-p (‘Frontier’) being registered in Australia, giving growers greater flexibility in controlling broadleaf weeds at the post-plant pre-emergent stage. Clomazone was particularly significant since it was the first herbicide to be registered for broadleaf weed control in cucurbit crops.

This project has identified a number of potential herbicide options that may warrant further exploration in an Australian context. S-metolachlor was previously registered for use in Australian cucurbit crops, however mis-use of the herbicide resulted in its deregistration. This herbicide may be registered again with appropriate modifications to usage in cucurbit situations. Clethodim is registered in the United States for use in cucurbit crops to control grass weeds, and may provide a viable alternative to fluazifop-P, sethoxydim and quizalofop.

Of the other post-emergence options, halosulfuron has the potential to control certain broadleaf weeds within cucurbit crops, however the current distributor of this herbicide does not intend to pursue registration of this herbicide given that it currently has a very small market in Australia. Terbacil, ethalfluralin, and ethalfluralin + clomazone are all worthy of further study.

The market size for herbicide products in the Australian cucurbit industry is generally considered too small to warrant the cost involved with Australian registration. Industry and government support may be required to facilitate new herbicide options for cucurbit growers. The use of cultivation to control weeds, for example in between the crop rows, appears to be increasingly viable due to the refinement of GPS technology. This and other practices (such as early pre-sow irrigation) may enable growers to reduce their reliance on herbicide.

Innovative weed control techniques in vegetable or cucurbit crops have been trialled in Australia and overseas, and show some promise despite limited understanding of their effectiveness.

Biodegradable mulch film appears to have promise as a viable alternative to standard plastic mulch, and costs have decreased in recent years. Although growers are currently uncertain about its viability, further research is essential to develop this product further, and to ensure its effectiveness. Growing concern over the use of plastic mulch may make biodegradable alternatives an essential component of future horticultural production. However, concerns over the social acceptability of biodegradable film, and its practicality where a drip fed irrigation system is used, need to be addressed.

While the economic viability of soil solarization has been questioned in Australia, trials in the United States suggest it is an effective weed control technique. Australian research into soil solarization has been limited, and so further study may be required to determine whether the technique is economically viable and effective. Demonstrating its effectiveness using biodegradable mulch may be of particular importance to demonstrate its value where conventional plastic mulch is not available.

Further research is also required to explore other factors that improve the effectiveness of brassica cover crops as biofumigants, including factors such as soil nutrient levels, cover crop mixtures, management and selection of species, and development of low till and cover crop incorporation systems suitable to organic production.

Similarly, bioherbicide research in Australia appears to be behind trial work overseas. A range of bioherbicide products are available. If they are effective, bioherbicides may give growers a safe and viable alternative to pre-plant, pre-emergence and in-crop spot spraying with synthetic herbicides.

Local experts (such as trained horticulturalists and experienced staff of rural supplies stores) are the most sought after information source for cucurbit growers, and yet this project suggests that there may be a growing shortage of such expertise. It is important not only that such experts are utilised in the extension of new methods to growers, but that their expertise is retained in the horticultural production regions of Australia.

Technology Transfer

Critical success factors for adoption of the weed control methods explored in this project may include the willingness and ability of growers to trial or implement new or innovative techniques, and the relative advantages that these techniques provide over their existing weed control strategy. It is important to note, however, that some of the innovative issues identified in this project require further research in an Australian context.

This study sought to directly inform HAL regarding the current issues, practices and options for weed control in cucurbit crops. HAL will be responsible for feeding this information back to cucurbit growers, and collate feedback for ways in which the findings may be used to direct future research, development and extension efforts.

Recommendations

This scoping study sought to identify in broad terms the impact of weeds in Australian cucurbit crops, the most significant weeds, standard and novel approaches to weed control that may facilitate the sustainability of cucurbit production (including ways to reduce grower reliance on herbicides), and new herbicide options.

The recommendations provided below focus on areas of future research, development and extension that may be undertaken by the Vegetable Industry. The overall focus should be to provide a greater understanding of the impact of weeds, and ways to improve their management.

Impact of weeds on cucurbit production

The research has shown that weeds have a very significant impact on the productivity of Australian cucurbit crops, and that the most important weeds create a range of problems for growers.

Recommendation

Further research is required to determine more clearly the impact of weeds on Australian cucurbit crops. Potential areas of research include an economic impact study (including the direct costs of weed control and indirect costs associated with yield and quality decline), field work to determine the degree of yield and quality impacts in different cucurbit crops, and qualitative research to identify the crop management issues associated with weeds.

Significant weeds

As far as we are aware, this is the first Australian study to collate a list of weeds of significance to cucurbit producers. The survey and field work components of the project identified some of the most important broadleaf and grass weeds, and growers indicated some of the ways in which these impact on crop yield, quality and management. Broadleaf weeds appear to be of the most importance given the inability of growers to control most of these with selective herbicide, while nutgrass is also important for its ability to pierce plastic mulch, resist damage from cultivation, and spread rapidly through a crop.

Recommendation

If the Vegetable Industry intends to explore in detail the specific impacts of weeds on cucurbit production, the greatest research benefit will be achieved by focussing on these most significant weeds first. This scoping study suggests that these weeds include fat hen, blackberry nightshade, caltrop/cathead, pigweed/purslane, African lovegrass, and nutgrass. At times, management approaches need to be tailored to a particular weed species. Growers may benefit from research that demonstrates the best way to manage particular weeds in cucurbit crops.

Recommendation

A greater understanding of the importance of weeds in cucurbit production may give more incentive to develop novel weed control approaches, and extend these approaches to growers. Specific research and information on the ecology and management of these most important weeds of cucurbit crops is required. Issues of interest could include factors influencing germination and early growth, timing of emergence in field situations, optimising herbicide effectiveness, and methods for reducing seed set.

Improving weed control – innovative approaches

As this report identified, cucurbit growers are able to minimise the impact of weeds on their crop using 'conventional' approaches such as herbicide, plastic mulch and cultivation. However, herbicide options for growers are limited, and herbicide resistance (or reduced effectiveness) has been noted by growers. Furthermore, while plastic mulch remains a cheap and effective control tactic, it may become unviable in the future.

Recommendation

More work is required to identify, trial, and extend to the industry, innovative weed control tactics that may either increase the efficiency of the conventional approach, or act as viable alternatives. A range of tactics are listed below. Research should include identifying new weed control tactics either in use or being trialled overseas, and exploring the validity of these techniques in Australian circumstances.

This scoping study has identified a number of issues, and techniques that warrant further study and extension to the cucurbit industry:

- Pre-sowing irrigation followed by tillage and/or herbicide application (*false seedbeds*). This strategy was rated highly by growers for its affordability and effectiveness, but has a relatively low uptake. It has the potential to reduce the soil weed seed bank and germination of weeds during the life of the crop.
- Similarly, *earlier pre-plant irrigation* appears to be a useful and minimal cost technique for controlling weeds under plastic mulch. More research may be required to quantify the benefits of this approach, and if effective it should be promoted to growers as an option to improve weed control within the crop, in a plastic mulch system. This technique should also be trialled using biodegradable mulch, on the assumption that conventional plastic mulch may become unsustainable in the longer term.

- *Precision agriculture* (cultivation using wider row spaces and GPS technology) appears to be a very effective alternative to herbicide use in the inter-row space, and may reduce grower reliance on herbicides over the longer term. It also appears to be an effective follow-up to pre-plant application of herbicide (e.g. paraquat), and the effectiveness of cultivation compared with early post-plant herbicide application should be explored further. Similarly, precision agriculture may enable growers to reduce the quantity of herbicide they apply to their fields.
- The viability (profitability and management) of *using plastic mulch and drip line infrastructure for more than one cucurbit crop* should be explored further. This technique maximises the use of a plastic mulch system, but may result in a build-up of disease. More research may be required to determine the relationship of this approach to disease. The technique has been used effectively by one of the grower participants in this study. It may also be applicable to growing a second non-cucurbit crop, such as capsicum.
- The benefits of *effective farm hygiene* as a means of controlling weeds should be extended to cucurbit and other vegetable producers. Clean farm hygiene clearly offers considerable benefits to growers and so, as a start, this should be an area of farm operation that is researched and developed, e.g. through successful farmer case studies that can be extended throughout the industry. Such an approach has also proven highly successful in non-cucurbit horticulture.
- *Concerns over the social acceptability of biodegradable mulch films* need to be addressed, especially regarding its tendency to break up into large pieces and create a litter problem on neighbouring properties and public roads. Is this a valid concern in all situations, and can the technology be developed to the extent that the biodegradable films are more robust and litter build-up won't be an issue?
- A number of growers indicated during this study that they had observed cases of herbicide resistance within their cucurbit crop. *Herbicide resistance testing* may be required to gauge the ongoing effectiveness of the herbicides currently registered for use in cucurbit crops.

New herbicide options

Lack of herbicides, particularly selective post-plant products for broadleaf weeds, is a real impediment to maximising cucurbit production in Australia, and may become a more important issue in the future if reduced herbicide effectiveness or resistance becomes common.

Growers consider it to be a high priority to identify herbicides that may be used to control weeds within cucurbit crops, with little or no negative impact on crop plants, particularly for the control of broadleaf weed species, in addition to viable non-herbicide techniques that will reduce their reliance on chemical application.

Recommendation

Additional herbicide options may offer cucurbit growers greater flexibility in their weed control program, and extend the useful life of the limited number of herbicides currently registered for cucurbit crops in Australia. This study identified a number of herbicides that may be useful to cucurbit growers. Further research, and registration if warranted, should be pursued for the following products:

- *clethodim;*
- *halosulfuron;*
- *imazosulfuron;*
- *s-metolachlor;*
- *glufosinate-ammonium;*
- *metribuzin; and*
- *haloxyfop.*

Recommendation

High registration costs, and the relatively small size of Australia's cucurbit industry, means that herbicide distributors are unlikely to be willing to meet the full cost of trial and registration work. Registration of effective herbicides may therefore require in-kind or financial support from the Vegetable Industry and/or other relevant industry groups, to offset registration and trial costs for herbicide distributors.

Delivering information to growers

Cucurbit growers indicated during this study that there is little information available to them on weed control options, an opinion confirmed during the literature review stage of this research, when it was found that most Australian non-academic literature on cucurbit management pertains to pests and diseases rather than weeds.

Recommendation

While cucurbit growers can be a difficult horticultural segment to reach for research, extension and education purposes, this study found that they consider local resellers and horticultural advisors to be their most important potential sources of information. The Vegetable Industry needs to consider these vital avenues for promoting research findings and new approaches to weed control or crop management. Documents should also be made freely available online, and promoted through industry publications.

Recommendation

The Vegetable Industry should also support, where possible, efforts to sustain or establish new horticultural courses in universities or other educational institutions. It is vital that growers can continue to call on local expertise to help them manage their cucurbit crops effectively, and are made aware of the latest techniques.

Recommendation

A targeted 'best practice guide' for weed control in cucurbit crops, distributed through these accessible avenues, may benefit growers. Such a document could bring together the disparate 'best practice' sources available from various State and Territory and national sources and include details on emerging weed control techniques. The document may also incorporate some of the key findings of this study, as well as further research designed to quantify the methods, effectiveness and impact of promising weed control techniques.

Other research priorities

Recommendation

Growers were asked to indicate their preferred research priorities to improve weed control efficacy in the industry. In addition to those already mentioned here, these include:

- *Developing cost-effective and relevant organic or non-herbicidal weed control methods.*
- *Continued research into a viable biodegradable mulch.*
- *Training programmes to improve the skill base amongst itinerant workers (pickers and machinery operators).*

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Sustainable broadleaf weed control in cucurbit crops:

Appendix 1 – survey of producers

Prepared for Horticulture Australia Limited (VG10048)

Brian Sindel, Michael Coleman, Paul Kristiansen and Ian Reeve

University of New England

Armidale, NSW

August 2011

PROFESSOR BRIAN SINDEL
SCHOOL OF ENVIRONMENTAL AND RURAL SCIENCE,
UNIVERSITY OF NEW ENGLAND
ARMIDALE NSW 2351

15 February 2011

Dear Grower,

As you will no doubt be aware, weeds can have a major impact on and be difficult to control in cucurbit crops such as pumpkin and gramma, zucchini, squash and marrow, cucumber (field grown), gourd, bitter melon, watermelon, rockmelon, and honeydew melon. The University of New England is currently undertaking a research project on behalf of Horticulture Australia Limited (HAL) to identify better weed control options for cucurbit growers. If you are a cucurbit grower, I would like to invite you to participate in our research on this topic by spending a few minutes completing the enclosed questionnaire, which has been sent to cucurbit growers across Australia. I hope you will consider being involved.

The overall results of the research will be made available to growers like yourself through HAL and other grower representative groups. Your experience will help Australian cucurbit growers to improve their ability to control weeds.

The information to be gathered in this survey will, of course, remain confidential, and all respondents will remain anonymous. The survey documents and data will be stored securely at the University of New England for five years, and then destroyed. Face-to-face interviews are also being conducted with some cucurbit growers as part of this research project.

If you would like to talk about this survey, please don't hesitate to phone me on 02 6773 3747, or email bsindel@une.edu.au.

Thank you for your cooperation.

Yours faithfully,

Brian Sindel (research team leader)

Research team members:

Paul Kristiansen – paul.kristiansen@une.edu.au

Ian Reeve – ireeve@une.edu.au

Michael Coleman – michael.coleman@une.edu.au

Know-how for Horticulture™

This project has been approved by the Human Research Ethics Committee of the University of New England (Approval No. HE11/003 Valid to 31/01/2012)
Should you have any complaints concerning the manner in which this research is conducted, please contact the Research Ethics Officer at the following address:
Research Services, University of New England, Armidale, NSW 2351.
Telephone: (02) 6773 3449 Facsimile: (02) 6773 3543 Email: Ethics@une.edu.au

Weed Control in Cucurbit Crops

A Survey of Growers

Please have the farm owner or manager complete all sections of the survey relevant to your main farm (if more than one farm is owned), and return using the reply-paid envelope provided as soon as possible.

Current Involvement in Cucurbit Production

Have you grown a cucurbit crop in the past three years? *(Please tick one)* ❒ Yes ❒ No

If 'No', you do not need to complete the survey. Please discard the survey in the recycling bin.

Section 1: Your Farm

1. **How many years experience do you have working in agriculture?** _________Years
2. **How many years experience do you have growing cucurbits?** _________Years
3. **What is your nearest town?** ________________
4. **Please indicate the <u>total area</u> of your main property.**

   Hectares:_______ *OR* Acres:_______

5. **<u>Over the last three seasons</u>, what average area have you had under each cucurbit crop listed below?**

Cucurbit crop	**Approx. area of land per crop per season**
Pumpkin (inc. Gramma)	Hectares:_____ *OR* Acres:_____
Zucchini	Hectares:_____ *OR* Acres:_____
Squash or Marrow	Hectares:_____ *OR* Acres:_____
Cucumber (field grown)	Hectares:_____ *OR* Acres:_____
Bitter melon	Hectares:_____ *OR* Acres:_____
Gourd	Hectares:_____ *OR* Acres:_____
Watermelon	Hectares:_____ *OR* Acres:_____
Rockmelon	Hectares:_____ *OR* Acres:_____
Honeydew melon	Hectares:_____ *OR* Acres:_____
Other *(please specify)* __________________	Hectares:_____ *OR* Acres:_____
Other *(please specify)* __________________	Hectares:_____ *OR* Acres:_____

6. **Which sources of information about <u>weed management</u> do you use?** *(Please tick all that apply)*

Commercial suppliers and representatives	❒
Private agronomists and horticulturalists	❒
Government extension professionals	❒
Workshops and field days	❒
Conferences and courses	❒
Other farmers/neighbours	❒
Booklets and fact sheets	❒
Industry newsletters or magazines	❒
Industry web sites	❒
Government web sites	❒
Other *(please specify)* ______________________	❒

Section 2: The Impact of Weeds on Your Cucurbits

7. **What <u>type of impacts</u> have weeds had on your cucurbit crops?**

   (Please tick any that apply)

   ❒ Reduction in *yield*

   ❒ Reduction in *quality*

   ❒ Management of crop made more difficult

   ❒ Other *(please specify)* ____________________

   Please describe the important impacts briefly:

   ____

   ____

   ____

   ____

8. **For each of the cucurbit crops that you grow, please estimate the costs associated with weed control in dollars per hectare.**

Cucurbit crop	Weed cost
Pumpkin (including Gramma)	________$/Ha
Zucchini	________$/Ha
Squash or Marrow	________$/Ha
Cucumber (field grown)	________$/Ha
Bitter melon	________$/Ha
Gourd	________$/Ha
Watermelon	________$/Ha
Rockmelon	________$/Ha
Honeydew melon	________$/Ha
Other *(please specify)* ________________	________$/Ha
Other *(please specify)* ________________	________$/Ha

9. **In the past three years, has the cost of weed control in your cucurbit crops:** *(Tick one)*

❒ Increased
❒ Stayed about the same
❒ Decreased

10. **Which weeds cause the most problems in your cucurbit crops and why?**
(Please list in order of importance, with the worst weed first)

Weed name	Why is this a problem weed?
1. ____________	
2. ____________	
3. ____________	
4. ____________	
5. ____________	

Section 3: Your Current Weed Control Practices

11. **What is your most important cucurbit crop?**

____

Please answer the rest of Section 3 only in relation to your most important cucurbit crop.

12. **On a scale of 1 to 5 (where '1' is not successful and '5' is highly successful), how would you rate the level of success with your weed control strategy?**
(Please circle one)

Not successful **1 2 3 4 5** Highly successful

13. **What methods have you used to control weeds in your most important cucurbit crop?**
Please score each of the methods you've tried previously, or are using now, on a scale of 1 to 5, where '1' is not effective or affordable, and '5' is highly effective or affordable.

	Affordable (1, 2, 3, 4, 5)	Effective (1, 2, 3, 4, 5)
Herbicides (pre-emergent)	____	____
Herbicides (post-emergent)	____	____
Chipping and hand weeding	____	____
Tillage/cultivation	____	____
Slashing	____	____
Plastic mulch	____	____
Organic mulch	____	____
Crop rotation	____	____
Increase plant density	____	____
Pre-irrigate and spray/till	____	____
Thermal (steam/flame)	____	____
Stale seedbed technique	____	____
Other *(please specify)* ____________	____	____
Other *(please specify)* ____________	____	____

14. What are the critical factors for achieving success with weed control in your most important cucurbit crop?

____

____

____

____

____

____

____

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____

____

15. In the table below, please tick what you believe are the three most important agronomic factors to consider when applying herbicides to control weeds in your most important cucurbit crop

❐	Crop life stage	❐	Weed life cycle
❐	Weather conditions	❐	Withholding period
❐	Effect on crop	❐	Weeds present or expected
❐	Delay for next crop	❐	Herbicide rotation
❐	Seed or transplants used?		
❐	Other *(please specify)* ________________	❐	Other *(please specify)* ________________

16. Is the lack of effective herbicides a significant problem for you in trying to control weeds in your most important cucurbit crop?

❐ Yes ❐ No

If yes, please describe the problem (e.g. weed, herbicide opportunity, impact):

____

____

____

____

17. Have you ever experienced damage or reduced growth in your most important cucurbit crop as a result of using herbicide to control weeds?

❐ Yes ❐ No

If yes, please describe the herbicide, conditions, and the type and scale of impact on the crop:

____

____

____

____

18. Have any of the herbicides you have used in your most important cucurbit crop become less effective over time?

❐ Yes ❐ No

If yes, please give details of the weed, herbicide name/active ingredient, and years of use:

____

____

____

____

19. Are you aware of changes to regulations that have impacted on herbicide use in your most important cucurbit crop?

❐ Yes ❐ No

If yes, please give details, e.g. herbicide removal from permitted lists, longer withholding periods, buffer zones, drift management:

____

____

____

____

Section 4: Future Weed Control in Cucurbit Crops

20. Future weed control approaches: please give your opinion on the following statements by indicating your level of agreement or disagreement. *(Please tick one)*

The cucurbit industry should give high priority to…	**Agree**	**Unsure**	**Disagree**
Identifying new **herbicides** for weed control in cucurbits.	❒	❒	❒
Identifying **economic replacements** for polyethylene plastic mulch.	❒	❒	❒
Communication and extension of effective weed management strategies.	❒	❒	❒
Identifying new **organic** or non-herbicidal weed control methods.	❒	❒	❒
Other *(please specify)* ______ ______ ______	❒	❒	❒

Do you have any other comments on these issues?

______

______

______

______

21. For your situation, would it be feasible to reduce herbicide use by implementing any of the following techniques for your cucurbit crops? *(Please tick one for each)*

	Yes	**No**	**Unsure**
Precision systems (spray, tillage)	❒	❒	❒
Plastic mulch	❒	❒	❒
Biodegradable mulch	❒	❒	❒
Organic mulch	❒	❒	❒
Controlled traffic	❒	❒	❒
Low till (mulching) systems	❒	❒	❒
Semi-permanent/permanent beds	❒	❒	❒
Other *(please specify)* ______	❒	❒	❒

22. Have you trialled any useful <u>new herbicides</u> in your cucurbit crops in the last <u>five years</u>?

❒ Yes ❒ No

If yes, please briefly describe and comment on their effectiveness:

______

______

______

______

23. Are you aware of any currently unregistered herbicides that are effective for controlling weeds in cucurbit crops? *(Please list)*

______

______

24. Have you trialled any <u>new non-herbicide or organic</u> weed control methods in your cucurbit crops in the last <u>five years</u>?

❒ Yes ❒ No

If yes, please briefly describe and comment on their effectiveness:

______

______

______

______

25. Please provide any other comments.

______

______

______

______

Follow-up

Would you be willing for us to contact you at a later date to talk about aspects of this research, or to find out more about your weed management methods? If so, please fill in the details below.

Your Name ______

Telephone Number ______

Email Address ______

Thank you for your time in completing this survey.

We greatly appreciate your input.

Sustainable broadleaf weed control in cucurbit crops:

Appendix 2 – literature review

Prepared for Horticulture Australia Limited (VG10048)

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August 2011

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Know-how for Horticulture™

Executive Summary

Introduction

There have been great strides made in integrated and sustainable forms of weed management in broadacre grain crops in Australia over the last ten years. However, relatively little attention has been paid to developing such weed control techniques in vegetable crops (such as cucurbits), despite some earlier research which looked at experimental herbicides, organic mulches and brassica biofumigants. This scoping study is the first step in addressing this industry priority.

Cucurbit production in Australia

The gross value of the cucurbit industry in Australia in 2008-09 was $339 million. Watermelons are the most valuable cucurbit crop in Australia, while production of pumpkins, zucchinis and button squash, and rockmelons and cantaloupe, is also significant.

The main cucurbit crops produced in Australia include various melon cultivars (watermelon, rockmelon, cantaloupe, bitter and honeydew), many varieties of outdoor and greenhouse cucumbers, pumpkins (large grey/Jarrahdale, butternut, jap), zucchini and squash, and gherkins. A number of specialty cucurbit crops are produced at a small scale, including choko, bitter gourd, hairy melon, ornamental gourd, and luffa. Cucurbits are grown in all Australian states, and the Northern Territory.

Cucurbit production in Australia is focused on domestic fresh markets. While some processing takes place for the domestic market, unprocessed cucurbits for the domestic market are most often sold at wholesale fruit and vegetable markets in Australia's major capital cities. Australian cucurbit exports are relatively minor in comparison to domestic sales. Varieties exported include melons, pumpkins, zucchini and gherkins. Main export markets include New Zealand, Singapore, Hong Kong, and the Middle East.

Impact of weeds on cucurbit production in Australia

Most vegetable crops in Australia, including cucurbits, are grown on intensively cropped land. Common features of vegetable cropping systems, including frequent cultivation that results in highly disturbed soil, irrigation (particularly furrow or flood irrigation), and addition of large quantities of nutritional inputs before planting and during the growing period, means that the potential for weed growth is high.

Economic impact

In Australian vegetable crops, weed management costs have been estimated to range from 2-22% of total variable expenses. Per hectare weed control costs for pumpkin, zucchini and furrow-irrigated rockmelons were a similar proportion of variable production costs (approximately 12 per cent). Weed management costs in the first year of drip irrigated rockmelon were considerably higher (approximately 31 per cent), largely due to the initial outlay on plastic mulch.

Impact on yield

Weeds compete with vegetable crops for soil nutrients, and for light and space by shading the crop and restricting its development and eventual yield. It is therefore important to control weeds in the early crop stages, allowing the crop canopy to develop to the extent that it provides sufficient shade to make it more difficult for weeds to develop. Research outside Australia suggests that weeds can have a large impact on yield, particularly if weed infestations are heavy during the early growth stages of the crop. One study suggested that weed-free rockmelon plots yield between 2.7 and 3.3 times as much as weed-infested plots, while another suggested that yield loss from weeds may be up to 40 per cent.

Impact on quality

Weeds can host pests and diseases that impact on both the yield and the quality of vegetable crops. In cucurbit crops, there is considerable evidence that weeds, particularly broadleaf weeds that share certain characteristics with cucurbit plants, host a range of viruses, diseases and insect pests. Research conducted in Western Australia and the Northern Territory has identified a number of weeds acting as 'infection reservoirs' for several viruses and other diseases. They are also a potential source or host for a number of insect pests.

Impact on farm management

Weeds have a range of implications for managers of vegetable crops. Dense infestations can reduce the effectiveness of insecticide applications, make it difficult to identify pests in the crop, jam harvesting equipment, or make harvesting much slower for human pickers.

Weeds in the Australian cucurbit industry

The most important weeds for Australian cucurbit growers will vary from one growing region to another, depending on climate and soil conditions and current weed distribution, while the relative impact of weeds within regions may also vary from one district or property to the next, based on a range of factors including cucurbit crop type, grower weed control dedication and diligence, diversity of methods used, and crop management system used. No comprehensive list of weeds that have a significant impact on cucurbit production in Australia could be found in the literature, however Chapter 4 includes two tables listing broadleaf and grass weeds mentioned in the literature as existing in Australian cucurbit crops. Survey work being conducted as part of this research project will ask Australian growers to identify significant weeds in their cucurbit crops.

Current weed control approaches

Herbicides

Relatively few herbicides are registered in Australia for use *within* cucurbit crops. Weed control is made more difficult within cucurbit crops by the fact that many significant weeds are broadleaf weeds, either wild cucurbits or species with similar attributes, so that herbicidal control of these weeds will cause unacceptable damage to the crop. Herbicides are also commonly used in plastic and drip irrigation production systems as a means of inter-row weed control.

Fluazifop-P, sethoxydim and quizafolop-P-ethyl are successful herbicides for controlling grass weeds in pumpkin and grammas, as well as in zucchini and squash. Clomazone provides good pre-emergence control or suppression of various grasses as well as apple of Peru and potato weed. The number of herbicides available for use within cucurbit crop rows (pre-plant, pre- or post-emergence) is limited.

Tillage/cultivation

Mechanical tillage or cultivation, in combination with herbicide use, is the most common form of pre-plant and early post-emergence weed management used on Australian vegetable farms. Cultivation is often used not only to kill existing weeds, but to break seed dormancy and encourage germination of new weed cohorts which are then controlled with a knock-down herbicide or another cultivation before the crop is planted. Post-emergence cultivation is relatively cheap and can control weeds effectively. Inter-row cultivation generally ceases once the crop vines have started to run.

Plastic mulch

Plastic mulch is an expensive weed control option, although it is feasible in high value cucurbit crops, and delivers a number of other benefits to the crop. The mulch is used not only to restrict weed growth but to prevent soil moisture loss, provide water savings, enhance crop yield and quality, and control disease. In Australia, black film is used in the cooler months or regions, and white film in the warmer months or regions, to regulate soil temperature. Plastic mulch controls weeds by restricting the amount of light available for seed germination. However, it is possible for some weeds (such as nutgrass) to pierce the plastic and establish in the crop rows.

Plastic mulch still appears to be the most economically viable form of mulch available for vegetable production, despite ongoing trials into alternative mulches such as living and killed systems, organic mulch and biodegradable paper and polymer-based films. Nonetheless, some mitigating factors call into question the longer term viability of plastic mulch for cucurbit production, including rising disposal costs and environmental concerns.

Transported organic mulch

Transported organic mulch options include sawdust, sugarcane byproducts, composted vegetative mulch, forage sorghum hay, recycled newspaper and cardboard cartons, and hessian. Organic mulches do not appear to be viable alternatives for cucurbit growers on the basis of price, relative ineffectiveness for weed control, and logistical difficulties in transporting these mulches to the farm and applying evenly over a large area of land. They do, however, give farmers an opportunity to improve the quality of the soil.

Cover crop organic mulch

Cover crop organic mulches, often referred to as living and killed mulch systems, involve planting a cover crop in the crop rows and then either maintaining it as a living mulch, or killing the cover crop and planting vegetables into the stubble. Living and killed mulches have been found to control weeds within crops with some success, suppressing weed populations to the extent that they do not compete with the crop, and improve the condition of the soil. However, other studies suggest that cover crop mulches may shift the weed spectrum to different species, and compete with the crop for nutrients. Cover crop organic mulch systems are in limited use in Australia, though the viability of this approach is likely to be refined given the likely long-term unsustainability of plastic mulch.

Permanent or semi-permanent beds

Low- or no-till permanent or semi-permanent crop beds, with a semi-permanent drip irrigation system, are becoming popular, often in combination with an organic cover crop mulch, as an alternative to heavily cultivated soil and plastic mulch. There is a trend in Northern Queensland to move towards this type of production system, one that is expected to continue if a wider range of non-residual herbicides become available to growers.

Crop rotation

Crop rotation is commonly used in Australia to give growers the opportunity to control pests and diseases that impact on cucurbit crops. The weed control benefits of rotations are often of secondary importance to many growers. Nonetheless, rotation is a useful weed management tool for controlling broadleaf species on a farm where cucurbits are grown: by growing a rotation crop or variety of rotations, farmers have the opportunity to control species which are otherwise difficult to control within a cucurbit crop.

Fumigation and biofumigation

Soil fumigation under plastic mulch using broad spectrum chemicals such as methyl bromide and metham-sodium has been a common practice amongst Australian vegetable producers, largely for its benefits for managing nematodes, diseases, and insect pests, such as verticillium wilt. However, fumigation may have secondary weed control benefits, and render herbicide use unnecessary in some circumstances. The uncertain future of chemical fumigation has led to research into 'biofumigation', using organic cover crop mulches to deliver soil fumigation. Some brassica plants such as canola and mustard release fumigant-like compounds into the soil as they decompose. Ongoing work seeks to refine the use of biofumigants and overcome limitations such as acceptability of weed control and potential crop damage.

Controlled traffic

Controlled traffic farming (CTF) involves establishing permanent wheel tracks outside of the crop growing area and in between crop rows (using Global Positioning Systems and related technology), along which all wheeled farming equipment operates. CTF gives vegetable farmers greater scope to operate an effective permanent bed zero till system which is not subjected to soil compaction. One of the benefits of zero till systems is reduced weed seed stimulation, and therefore less weed competition in the beds.

Crop competition

Crop competition means ensuring that good crop cover is established quickly to give the crop a competitive advantage over weeds. This includes sufficient plant density to allow the crop to form a dense canopy, making it difficult for weed seeds to germinate for lack of light. Weeds are not a significant problem once the crop canopy closes fully. Factors taken into account include fertility, choice of crop variety, ensuring good water control (irrigation and drainage), and sowing or planting adequate plant populations.

Farm hygiene

Farm hygiene practices limit the spread of weed seeds and propagules (as well as pests and diseases) across and between properties, and onto crop beds from other parts of a property where weeds are present. Common practices include permanent or set vehicle tracks, equipment wash-down, restricting movement into the property, and buying certified crop seed/seedlings.

Stale and false seedbeds

A stale seedbed involves preparing the seedbed for planting and then leaving it for anywhere between several days and several weeks before planting. During this fallow period, weeds are allowed to germinate, and may even be stimulated through pre-irrigation. Before crop planting, the weeds are controlled with a knock-down herbicide. A false seedbed is similar to a stale seedbed, although weed control prior to planting is achieved by repeated shallow cultivations and knock-down herbicide applications, designed to encourage germination and/or control recently germinated weeds. Stale and false seedbed techniques appear to control weeds more effectively, and contribute to higher crop yield in cucumbers, than seedbeds managed by conventional cultivation practices alone.

Thermal weed control

Thermal weed control methods are particularly useful in low-till and permanent bed systems. Techniques include flaming (using natural gas- or propane-fuelled burners to expose weeds to sufficient heat to disrupt cell membranes, destroying leaf and merismatic tissues), steam weeding, and soil solarization (trapping solar radiation in moist soil using clear plastic mulch).

Field-grown trellis crops

In some field-grown cucurbit crops (for example, Lebanese cucumbers and ornamental gourds) trellises are used. In trellis-grown cucurbits, weed control becomes easier using inter-row knock-down herbicides.

Integrated weed management in Australian cucurbit crops

Most of these techniques are particularly suitable at particular times during the season, or for particular management circumstances. However, it is rare for them to be used in a cucurbit crop in isolation: nearly all Australian cucurbit growers integrate a number of these techniques into a weed management strategy, because no single technique alone will effectively manage weeds in the crop during the growing season. The majority of Australian cucurbit growers are currently thought to use a simple integrated weed management (IWM) system, including pre- and post-emergent herbicides, chipping and hand weeding in the crop, and plastic mulch. However, case studies in Australia have shown a variety of other techniques being used successfully in an IWM strategy to control weeds in vegetable and cucurbit crops.

Organic weed management in Australian cucurbit crops

Weed control techniques available to organic growers include cultivation (the most common form of control used), transported and cover crop mulches, CTF and permanent-semi-permanent crop beds, crop competition, farm hygiene, false seedbeds, and bioherbicides.

Future weed control options in cucurbit crops

Factors influencing weed control practice change

Repeated use of herbicides with the same mode of action can lead to herbicide resistance in weed populations. Herbicide resistant weeds are found in all cropping regions of Australia, and the number of resistant species and geographic areas impacted by weed resistance is increasing. The growing importance of herbicide resistance means that cucurbit growers need to be conscious not only of more effective and strategic use of herbicides, but also to integrate non-chemical techniques into their overall weed strategy. Growers have a limited range of herbicide choices already, particularly for broadleaf species, and so resistance is an especially important issue. Instances of weed resistance to several herbicides currently used by Australian cucurbit producers have been identified.

At the present time, little information is available regarding the specific impact of changing climate for weed management in Australian cucurbit crops. However, potential implications may include changing distribution patterns and density of weeds and introduction of new weeds, reduced effectiveness of pre-emergent herbicides, and possibly growing ease of weed management in some areas.

Chemical use is particularly intensive in fruit and vegetable production in comparison with most other forms of agriculture, and many widely used weed and pest control practices have come under closer scrutiny over the last two decades. High reliance on herbicides for weed control in Australian agriculture has raised environmental concerns. The challenge for growers has been and will remain to reduce their reliance on herbicides while still controlling weeds effectively in their crop. Many industries have introduced Quality Assurance (QA) or Best Management Practice (BMP) guidelines for their growers to facilitate integrated and environmentally sustainable approaches to weed and pest management.

While plastic mulch is still the most viable mulching technique for cucurbit growers, it is not a sustainable practice in the longer term. The use of plastic mulch is coming under increasing pressure, due largely to the environmental problems posed by disposal. Disposal options such as ploughing the mulch into the soil, burning or disposing at local land-fill sites are being progressively banned or restricted, and are also becoming less acceptable to the community. Despite its cost competitiveness, the longer-term future viability of plastic mulch in Australian vegetable production therefore appears doubtful.

Fumigation has a similarly uncertain future. Methyl bromide use is being phased out in Australia from 2005 (with some limited exemptions such as strawberry production) as part of Australia's international obligation under the Montreal Protocol to restrict use of this and other ozone-depleting substances. Alternative fumigants are available, but may not be socially acceptable in the longer term.

There has been a tendency in Australian cucurbit production of farm aggregation into fewer and larger, more professional growers, who focus strongly on improving growing techniques, best management practices and quality. The implication for weed control is that the cost effectiveness of particular techniques may be partially dependent on farm scale.

Innovations in weed control outside Australia

This review focussed on innovative practices and products being researched overseas, particularly in the United States. Innovative practices identified in the review (some of which have been trialled in Australia) include new herbicides, soil solarization, biofumigation, cover crops, and bioherbicides.

Herbicide options

A search of the literature in the United States suggests that a range of herbicide alternatives may potentially be registered for use in cucurbit crops in Australia. Three post-emergence herbicides currently used in the United States have not yet been registered for cucurbit crops in Australia: clethodim, halosulfuron and s-metolachor while another, imazosulfuron, is being trialled in the United States. Of these, halosulfuron has the potential to control certain broadleaf weeds within cucurbit crops. A number of bioherbicides are also available to producers in the United States for pre-emergent and nil residual weed control.

Biodegradable mulch films

Biodegradable polymer and starch-derived (paper) mulches are proposed as an alternative to polyethylene plastic mulches. They are designed to degrade several months after being laid, so that they maintain sufficient weed control and moisture retention in crop, but degrade sufficiently that they may be cultivated into the field post-harvest, leaving no toxic residues or plastics in the soil. Recently, the price of biodegradable mulch has decreased to the extent that it is now about twice the cost of standard polyethylene. A HAL-funded trial of biodegradable polymer mulch is underway in Queensland. This work suggests that the film being trialled performs adequately, although a number of technical issues still need to be overcome. CSIRO is working with two garden product companies to produce a biodegradable weed mat from crop stubble. Trials were due to start after publication of this review.

Greater organic integration in conventional cucurbit production

Weed management options commonly used in organic systems have the potential to expand the range of weed management options available to conventional growers, many of whom currently rely heavily on plastic mulch and drip irrigation, and pre-emergent herbicides. Practices such as stale and false seedbeds that allow growers to reduce the amount of herbicide they use will extend the useful life of the limited range of herbicides currently available to cucurbit growers.

Conclusions and recommendations

For most conventional growers, plastic mulch with a drip-feed irrigation system, pre- and post-emergent herbicides, and chipping and hand-weeding within the crop rows, is the preferred weed control approach. Many growers may not yet fully appreciate the potential benefits of expanding their range of weed control techniques. Information on 'alternative' approaches tends to be disparate and at times difficult to locate.

Recommendation

The Vegetable Industry should explore whether producing a 'best practice guide' for weed control in cucurbit crops would benefit growers.

Recommendation

More research is required to determine more exactly the impact of weeds on Australian cucurbit crops. A greater understanding of impact may demonstrate the importance of effective weed control in cucurbits for improved yield, quality and profit margin for growers.

Recommendation

The literature in the United States suggests that a number of pre-emergence herbicides may be suitable for use in Australian cucurbit crops. The Vegetable Industry should consider funding research into the post-emergent herbicides halosulfuron, imazosulfuron, and s-metolachor, to determine their efficacy in Australian conditions.

Recommendation

The potential impacts of climate change on Australia's vegetable industry, particularly as it pertains to weed management and the weed species that may be important for growers in a changing climate, needs to be explored further.

Recommendation

More work is required to identify innovative weed control techniques either in use or being trialled overseas, and to explore the validity of these techniques in Australian circumstances. Techniques that appear worthy of further research include soil solarization, biofumigation, and bioherbicide use. Since techniques such as plastic mulch, fumigation and conventional herbicides may be restricted further in the near future, sustainable and effective alternatives may be required to maintain crop yield and quality.

Table of Contents

1. Introduction

1.1. Background

Cucurbits such as pumpkins, cucumbers, squash, zucchini and melons represent a significant component of the Australian vegetable industry. Cucurbits also occupy relatively large areas of land for production due to sprawling vines. This habit, the highly disturbed nature of the soils in which crops are often sown (promoting weed germination), and a lack of herbicides able to selectively control broadleaf weeds in these broadleaf crops can make weed control difficult. Weeds in cucurbit crops reduce crop yield, adversely affect crop quality, interfere with sowing and harvesting operations, and can act as hosts for pests, viruses and disease.

There have been great strides made in integrated and sustainable forms of weed management in broadacre grain crops in Australia over the last ten years. However, relatively little attention has been paid to developing such weed control techniques in vegetable crops, despite some earlier research which looked at experimental herbicides, organic mulches and brassica biofumigants.

The vegetable industry, in its 2010/11 Vegetable Industry Priorities, has named a scoping study to provide further details for possible control options for broadleaf weed control in cucurbits as a grower issue of High Priority. This scoping study, funded by Horticulture Australia Limited (HAL) and conducted by the University of New England (UNE) is the first step in addressing this industry priority.

1.2. Objectives

The research questions to be addressed by this scoping study are as follows:

1. What impact are weeds having on cucurbit vegetable production nationally and in regionally and enterprise specific situations?

2. Which weed species (grasses and broadleaf) are causing greatest difficulty?

3. How are such weeds currently being controlled and with what level of success?

4. Do control methods, such as herbicides, lead to crop damage and are they being utilised efficiently and effectively?

5. Can weeds of cucurbit crops be controlled more sustainably (economically, socially and environmentally) with alternative methods that place less reliance on herbicides?

6. Are there likely to be new herbicide options for cucurbit crops coming on to the market in the near future in Australia?

These questions are being addressed by this literature review, as well as a survey of Australian cucurbit growers to be conducted in early 2011, and farm visits to two regionally diverse environments to ground truth the findings of the literature review and the survey. The findings from all stages of the scoping study will be delivered to HAL in a final report.

1.3. Methodology

Weed impact and weed control issues, as they pertain to broadleaf weeds but also grass weeds where relevant, were explored through a review of Australian and international literature.

Literature searches were conducted using the University of New England's library catalogue (printed publications and online documents available through several academic literature databases), the Google Scholar and Google search engines, and amongst the literature collection of the School of Environmental and Rural Science, University of New England.

The initial scope of the literature search was Australian academic literature (a key word search of relevant journals), although the lack of relevant articles led us to expand our search to include extension publications produced by various government departments across Australia. The HAL web site was searched for relevant reports, and these acquired either from HAL or from the authors. Other relevant web sites were searched, including those of the Council of Australian Weed Societies (where a library of Australian Weeds Conference papers is freely available), grower peak bodies, research organisations, and the Australian Bureau of Statistics. Some unpublished reports and data were acquired from their authors, while a number of horticultural experts were consulted on specific points where literature could not be found, or was insufficient. International literature (primarily from the United States) was also sourced for comparative purposes, to fill gaps in the review where Australian literature could not be found, or to identify weed control techniques not yet evaluated fully in Australia. Discussions with chemical companies will seek identify whether there is any possible off-label effectiveness of herbicides that may require further exploration, as well as possible new herbicide products.

Despite this extensive search, the authors note that the literature review is relatively 'thin' in some areas, reflecting a lack of information on some aspects of weed impact and control in cucurbit crops. This strongly suggests a need for further research into a number of aspects of weed impact and control options within Australian cucurbit crops, both in the academic field and through industry-funded research. Should weeds remain a high priority issue, it is hoped there will be impetus to improve industry knowledge of this issue.

1.4. Report structure

In Chapter 2 we summarise the value, volume and area of cucurbit production in Australia, identify the main cucurbit varieties grown in Australia and where they are grown, and discuss domestic and international markets for Australian cucurbits. In Chapter 3 we discuss the impact of weeds on cucurbit production in Australia, including their economic impact, impact on yield and quality, and impact on farm management. In Chapter 4 we identify the weed species commonly found in Australian cucurbit crops. Some of the more important weeds, as well as those with potential to have a greater impact in the near future, are highlighted.

In Chapter 5 we identify the range of weed control techniques currently used by Australian cucurbit growers. These techniques include herbicides, tillage and cultivation, plastic, transported organic and cover crop mulches, permanent and semi-permanent crop beds, crop rotation, fumigation and biofumigation, controlled traffic, crop competition, farm hygiene, stale and false seedbeds, thermal weed control methods, and field-grown crops using trellises. This chapter also includes a discussion of integrated weed management in cucurbit crops, and techniques suitable for organic growers.

Chapter 6 includes a discussion of the future of weed control for Australian cucurbit growers. Some of the factors that may require growers to adapt their weed control strategy are discussed, including: herbicide resistance; changing climate; the environmental impacts and social perceptions of herbicide; plastic mulch disposal and fumigation; and changes in farm size and scale. Recent innovations in weed control are discussed, with a particular focus on potential new herbicide options being researched or used outside Australia, biodegradable polymer mulch trials being conducted in Australia, and the potential for conventional growers to integrate organic approaches into their weed control strategy. In Chapter 7 we conclude the review and offer some recommendations for future extension and research activity. Attachment 1 includes production estimates for cucurbits for 2008-09 for each state, from ABS data (area, tonnes of production, number of growers and gross value).

2. Cucurbit production in Australia

2.1. Value, volume, area of cucurbit production in Australia

As Table 2.1 shows, Australian Bureau of Statistics estimates for 2008-09 put the gross value of the cucurbit industry in Australia at $339 million. Of this, the cucurbit crop in Qld was valued at $170.8 million, NSW $64.9 million, WA $51.2 million, NT/ACT $23.8 million, SA $18.9 million, Vic $8.4 million and TAS $1 million. Watermelons are the most valuable cucurbit crop in Australia, while production of pumpkins, zucchinis and button squash, and rockmelons and cantaloupe, is also significant (ABS 2010a, b). Cucurbit production data for each Australian State/Territory are included in Attachment 1.[1]

Table 2.1 Estimated area, production, number of growers, and gross value of cucurbit production in Australia, 2008-09

Cucurbit category	Area (ha)	Production (tonnes)	No. of Growers	Gross Value ($M)
Asian Gourds	27	133.6	10	0.69
Cucumber (outdoor)	274	3,311.2	223	7.78
Cucumber (undercover)		8,631.3	334	20.39
Rockmelons & Cantaloupe	2,888	60,510.0	168	65.18
Bitter Melons	42	258.0	18	1.33
Honeydew Melons	472	8,861.0	43	9.45
Watermelons	4,168	131,112.0	401	94.08
Other Melons	207	5,990.0	32	6.15
Pumpkins	5,771	103,729.0	1,079	68.76
Zucchini and Button Squash	2,220	23,989.0	621	65.20
TOTAL	***16,069***	***346,525.1***	***2,929***	***338.98***

While cucurbits comprise a valuable component of the Australian vegetable industry, Australia is responsible for only a small proportion of world cucurbit production, as Table 2.2 illustrates (ABS 2010a, b; FAO 2010).

[1] ABS data on cucurbit production for 2008-09 are estimates only, with many figures having a large relative standard error. The data should therefore be read only as a guide.

Table 2.2 Australian cucurbit production as a proportion of world production

	Australia 2008-09	World 2008-09	Australian Proportion (%)
Area (thousands of hectares)	16.07	9250.43	0.17%
Production (millions of tonnes)	0.35	190.03	0.18%

** FAO data are available for 2008 and 2009 as separate years, hence an average figure for these two years has been used here for comparison with ABS 2008-09 data for Australia. FAO figures are the sum of four cucurbit categories: cucumbers and gherkins; pumpkins, squash and gourds; watermelons; and other melons (including cantaloupes).*

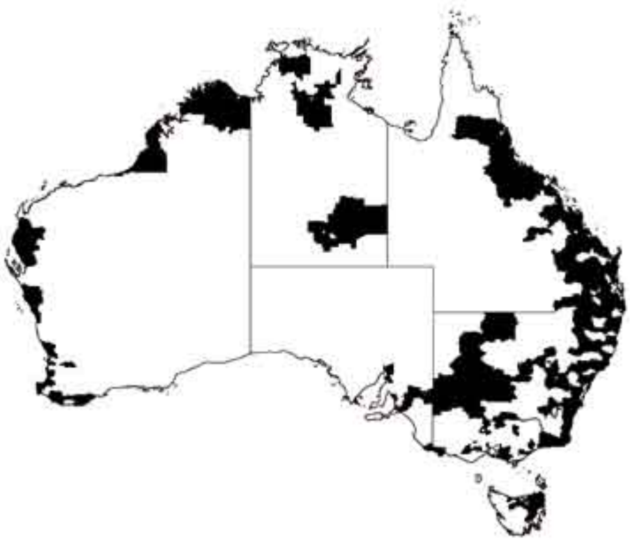
2.2. Cucurbit types produced in Australia

The main cucurbit crops produced in Australia include various melon cultivars (watermelon, rockmelon, cantaloupe, bitter and honeydew), many varieties of outdoor and greenhouse cucumbers, pumpkins (large grey/Jarrahdale, butternut, jap), zucchini and squash, and gherkins. A number of specialty cucurbit crops are produced at a small scale, including choko, bitter gourd, hairy melon, ornamental gourd, and luffa (Kelly 2007).

2.3. Where cucurbits are grown

As Figure 2.1 illustrates, cucurbits are grown in all Australian states and the Northern Territory.

Figure 2.1 Cucurbit production regions in Australia (RIRDC 2010a)

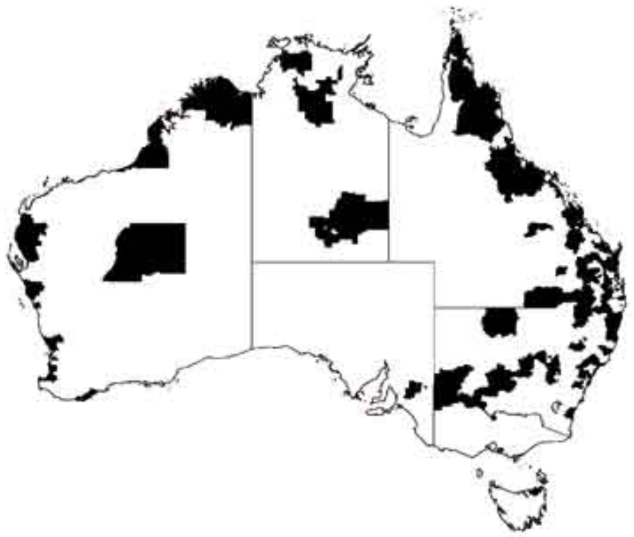


2.3.1. Melons

Melons are grown in a variety of climates including semi-arid and sub-tropical, in both inland and coastal locations (Figure 2.2). Larger growing regions in Australia include northern Qld and WA, southeast Qld, southern NSW, and the Sunraysia/Riverland regions of Vic and SA respectively (Kelly 2007). Melon production is most widespread in Qld, NSW and WA, with recent ABS (2010a, b) data suggesting that production is limited in SA and Vic, while the data also suggest that melons are not produced commercially in either Tas or the ACT (Attachment 1). Chinchilla in Qld is considered the 'watermelon capital of Australia', courtesy of its annual Watermelon Festival (Salvestrin 1995).

Watermelons are grown as a winter crop in northern Australia, and as a summer crop in southern Australia (AMA 2010), while rockmelon harvesting occurs in Australia throughout the year (Bethonga Whole Foods 2010). Rockmelons are grown across much of Australia, with harvesting generally occurring in southern states or regions between December and May, and in northern states or regions between May and November. Major Cantaloupe producing regions include Kununurra in WA, Burdekin in Qld, and the Murrumbidgee Irrigation Area in NSW (Salvestrin 1995).

Figure 2.2 Melon production regions in Australia (RIRDC 2010b).



2.3.2. Cucumbers

The majority of cucumbers produced in Australia are grown in greenhouses, in the outer metropolitan areas of Sydney, Adelaide, Perth and Melbourne, as well as near Bundaberg in Qld and Carnarvon in WA. Outdoor or field cucumber production is becoming less common as growers move to greenhouse production systems. Around Bundaberg, nearly all cucumber production takes place in undercover facilities (Lovatt pers. comm.). NSW I&I has a greenhouse research facility near Gosford, while there is also a greenhouse demonstration site near Adelaide (Kelly 2007).

2.3.3. Pumpkins

The largest quantity of pumpkins is produced in Qld, WA and NSW, although pumpkins are grown commercially in all Australian states and territories apart from the ACT (Lovatt 1995; ABS 2010a, b). Pumpkin production in Qld takes place in the Lockyer Valley and South-East Queensland regions, as well as the Atherton Tablelands, Bowen-Burdekin, Rockhampton and Bundaberg (Lovatt

1995; Coleman 2004). In WA, pumpkin production occurs for much of the year, with Carnarvon producing pumpkins for market from May to January and Kununurra (where the largest proportion of pumpkins are grown in WA) from June to November. Summer and autumn production occurs in the south around Perth, Manjimup, Harvey, Donnybrook, Vasse and Albany (Department of Agriculture 2005). Some cane growers in the Burdekin Valley in Qld grow pumpkin as an opportunist crop (Wright pers. comm.). Major pumpkin production areas in NSW include the North and Central Coast areas, the Sydney peri-urban area, the north and central-west of the state, within the Murrumbidgee Irrigation Area, and around Dareton in the south of the state (Lovatt 1995).

2.3.4. Zucchini and squash

Zucchini and squash production occurs year-round in Australia, ranging from summer production in Tasmania, to spring-autumn production in SA, NSW, southern/central Qld and southern WA, to winter production in the warmer climates of northern WA and North Queensland. Major growing districts include Bundaberg, Burdekin and Gympie in Qld, the North Coast and Sydney Basin in NSW, and Perth in WA. Tasmania is a major producer of Kabocha Squash (Murison 1995; Kelly 2007).

2.3.5. Gherkins

Gherkin production in Australia takes place primarily in Griffith, NSW, where one large enterprise grows approximately 200 Ha of gherkins, and operates processing and packaging facilities (Kelly 2007).

2.4. Domestic and export markets

Cucurbit production in Australia is focused on domestic fresh markets. Some processing takes place for the domestic market, including gherkins (pickling and slicing for fast food chains), and melons and pumpkins (processed into various forms for the food service sector) (Kelly 2007). Unprocessed cucurbits for the domestic market are most often sold at wholesale fruit and vegetable markets in Australia's major capital cities (Salvestrin 1995; RIRDC 2010b).

Kelly (2007) notes that Australian cucurbit exports are relatively minor in comparison to domestic sales. Varieties exported include melons, pumpkins, zucchini and gherkins. Main export markets include New Zealand, Singapore, Hong Kong, and the Middle East. In the mid-1990s, Australia's melon export trade was valued at just under $9 million (of a total export revenue for vegetables, fruit and nuts of approximately $365 million). Australia's primary markets for melons at this time were Hong Kong, Singapore and New Zealand (Coombs 1995). Melon exports consist primarily of rockmelons, although the export market accounts for only about 5% of rockmelons produced in Australia (RIRDC 2010b). Export markets for cucumbers include New Zealand, Hong Kong, Singapore and Papua New Guinea, while Japan is an important export market for Australian pumpkins (RIRDC 2010a). Production of Kabocha Squash in Tasmania for export to Japan has expanded in recent years, given that state's fruit fly-free status, although Tasmanian producers face significant competition from New Zealand Kabocha Squash producers (Murison 1995; Kelly 2007). In the 1990s, the United Kingdom was the main market for the small quantity of pumpkins exported (Lovatt 1995). A small quantity of processed gherkins are exported to Asia (Kelly 2007).

3. Impact of weeds on cucurbit production in Australia

Most vegetable crops in Australia, including cucurbits, are grown on intensively cropped land. Common features of vegetable cropping systems, including frequent cultivation that results in highly disturbed soil, irrigation (particularly furrow or flood irrigation), and addition of large quantities of nutritional inputs before planting and during the growing period, means that the potential for weed growth is high (Henderson and Bishop 2000). The following sections summarise some of the impacts of weeds on cucurbit crops.

3.1. Economic impact

In Australian vegetable crops, weed management costs have been estimated to range from 2-22% of total variable expenses (Henderson and Bishop 2000). In a case study of PMG Agriculture's watermelon and pumpkin farm near Condobolin, NSW, Watt (2009) found the cost of weed control to be approximately $267/Ha for 133Ha of watermelons and 54Ha of pumpkins. This cost included weed control activities pre-plant and during the growing season.

In 2001, the NSW Department of Primary Industries (now Industry & Investment NSW) prepared gross margin budgets for several cucurbit crops, to illustrate the relative profitability of these and other farm enterprises (NSW Agriculture 2001a-f). These budgets included several items related to weed control, which have been used in Table 3.1 to calculate weed control costs as a proportion of all pre-harvest variable production costs. As Table 3.1 shows, per hectare weed control costs for pumpkin, zucchini and furrow-irrigated rockmelons were a similar proportion of variable production costs (approximately 12 per cent). Weed management costs in the first year of drip irrigated rockmelon were considerably higher, largely due to the initial outlay on plastic mulch, while in the second year of production weed management costs dropped considerably, to under 3 per cent of variable production costs.

Table 3.1 Weed control cost estimates per hectare – NSW 2001

	Weed control operations	Total weed control costs	Total pre-harvest variable production costs	Weed control % of costs*
Pumpkin - Jarrahdale (Furrow Irrigation)	Cultivation, machinery, casual labour	$116.70	$954.08	12.2%
Pumpkin - Butternut (Furrow Irrigation)	Cultivation, machinery, casual labour	$116.70	$954.08	12.2%
Zucchini (Spray Irrigation)	Cultivation, herbicide, chipping	$389.00	$3,244.73	12.0%
Rockmelon (Furrow Irrigation)	Cultivation, inter-row cultivation, machinery, casual labour	$241.95	$2,073.33	11.7%
Rockmelon (Drip Irrigation, Year 1)	Cultivation, inter-row cultivation, plastic mulch, plastic mulch application	$1,030.45	$3,302.56	31.2%
Rockmelon (Drip Irrigation, Year 2)	Chipping	$72.50	$2,627.81	2.8%

** The cost of weed control operations has been calculated as a percentage of total pre-harvest variable production costs for each cucurbit crop.*

3.2. Impact on yield

Weeds compete with vegetable crops for soil nutrients, and for light and space by shading the crop and restricting its development and eventual yield (Henderson and Bishop 2000). It is therefore important to control weeds in the early crop stages, allowing the crop canopy to develop to the extent that it provides sufficient shade to make it more difficult for weeds to develop (Burt 2005; Dimsey 2009).

For cucurbit crops, then, there is an optimum period during which weed control should take place to ensure that weeds have a minimal impact on yield. No studies that attempted to quantify the impact of weeds on yield in Australian cucurbit crops were identified for this review. However, research outside Australia suggests that weeds can have a large impact on yield, particularly if weed infestations are heavy during the early growth stages of the crop. A study conducted in Israel in muskmelon (rockmelon) crops suggested that weed-free plots yield between 2.7 and 3.3 times as much as weed-infested plots. Impact on yield during fruit development and maturation included both fruit weight and, to a lesser degree, fruit quantity (Nerson 1989). Studies of weed impact on yield in watermelon crops in the United States (Macrae *et al.* 2008) suggest that yield is impacted heavily by dense infestations of particular weed species: up to a 40% yield loss for yellow nutsedge (*Cyperus esculentus*) weeds in watermelon crops in Florida (Buker *et al.* 2003); and approximately 35% yield loss where large crabgrass (*Digitaria sanguinalis*) infestations were studied in watermelon crops in North Carolina (Monks and Schultheis 1998).

Finally, weeds have an indirect impact on crop yield through crop damage associated with residual herbicide use. This is discussed in more detail in section 5.1.3.

3.3. Impact on quality

Weeds can host pests and diseases that impact on both the yield and the quality of vegetable crops (Henderson and Bishop 2000).

In cucurbit crops, there is considerable evidence that weeds, particularly broadleaf weeds that share certain characteristics with cucurbit plants, host a range of viruses, diseases and insect pests. In Western Australia, five principal viruses have been found infecting cucurbit crops, all of which infect wild or native cucurbits (considered weeds in cucurbit crops), which when not sufficiently controlled can act as 'infection reservoirs' (Coutts 2006; Aftab *et al.* 2010; Coutts and Kehoe 2010) (listed below).

- Zucchini yellow mosaic virus (ZYMV): all vegetable cucurbits and melons are susceptible to ZYMV, as well as species from other families such as mallow (*Malva parviflora*), and native, wild or weedy cucurbits such as headache vine (*Mukia maderaspatana*) and Afghan melon (*Citrullus lanatus*).
- Papaya ringspot virus (PRSV): infects principal cucurbit crops but not non-cucurbit crops or plants. Wild or native cucurbit species such as paddy/Afghan melon are susceptible.
- Squash mosaic virus (SqMV): infects cucurbit crops and wild or native cucurbits, but does not infect non-cucurbitaceous species.
- Watermelon mosaic virus (WMV): infects all cucurbit types as well as plants in the Solanaceae and Asteraceae families, many of which are considered weeds in cucurbit crops.
- Cucumber mosaic virus (CMV): all cucurbits are susceptible, as well as a range of non-cucurbit crops and many weeds including common sowthistle (*Sonchus oleraceus*), bifora (*Bifora testiculata*), prickly lettuce (*Lactuca serriola*), Indian hedge mustard (*Sisymbrium orientale*), and *Medicago* spp.

Coutts and Jones (2005) conducted a survey of cucurbit farms in Western Australia (Kununurra, Broome, Carnarvon and Perth) and the Northern Territory (Darwin and Katherine) to determine the incidence and distribution of these viruses. The study found that in WA 78% of farms surveyed, and 56% of crops, were infected, while in the NT 55% of farms and 54% of crops were infected. Virus epidemics were more likely to occur on farms in close proximity to other cucurbit-growing farms, or those with relatively poor farm hygiene. Cucurbit volunteer plants and weeds were considered important since they provide a 'bridge' for viruses to persist in or near a field between crop growing seasons. Viruses are spread within the crop, or from weeds to crops, by insect pests. Aphids are an important vector for cucurbit mosaic viruses. Management of these viruses therefore includes insect pest control, effective farm hygiene, rigorous control of potential host weeds, and removal of old crops (Grattidge *et al.* 2001; Coutts and Jones 2005; Napier 2009).

High incidence of disease in a cucurbit crop results in quality downgrades, and renders the crop either less likely to be sold, or likely to be sold at a downgraded quality. Impacts on the quality of crops include 'knobbles' or mottled skin on the fruit, discolouration, and reduced shelf-life. The main impact on yield is a shortened harvesting period, where the worsening effects of a virus render the fruit no longer worth harvesting (Coutts and Jones 2005).

Weeds are a potential source or host for other diseases and pests, including powdery mildew (*Podosphaera xanthi*), gummy stem blight (*Didymella bryoniae*), fungal root rot (including *Pythium*, *Rhizoctonia* and *Fusarium*), melon thrips (*Thrips palmi*, which may be hosted by a variety of weeds including pigweed (*Portulaca* spp.), amaranthus (*Amaranthus* spp.), gomphrena (*Gomphrena celosioides*) and potato weed (*Galinsoga parviflora*)), mites (several species), and silverleaf whitefly (*Bemisia tabaci*) (vegetablesWA 2007; Nagle 2008; Webb 2008; McDougall 2009; Watson and Napier 2009).

3.4. Impact on farm management

Weeds have a range of implications for managers of vegetable crops. Dense infestations can reduce the effectiveness of insecticide applications, make it difficult to identify pests in the crop, jam harvesting equipment, or make harvesting much slower for human pickers (Henderson & Bishop 2000).

Paddock inspection and hand weeding within crops is often carried out by casual staff, particularly on large farms. Casual staff might have insufficient training to identify weeds that appear similar to the crop (for example paddy melon, *Cucumis myriocarpus*, which has a similar physical appearance to watermelon plants) (Watt 2009).

Weeds that compete strongly with cucurbit crops interfere with the harvest. Cucurbit crops are at a competitive disadvantage with weeds in the first few weeks after emergence before the crop canopy develops (Lonsbary *et al.* 2003).

Weed management, particularly for broadleaf weeds after crop emergence, is made difficult for farmers by the lack of registered herbicides for controlling weeds within the crop rows. Such weeds are difficult to control with herbicides without causing significant damage to the crop, so that use of plastic mulch, precision shallow cultivation in the early post-emergence stage of the crop, or hand weeding once the crop vines have started to spread, are the only realistic options for growers. These techniques are discussed further in Chapter 5.

3.5. Conclusion

Australian literature on the impact of weeds on cucurbit crops is scarce, and tends to focus on the indirect impact of weeds as hosts for viruses and other diseases and insect pests. Nevertheless, the literature on overseas economic impacts and impacts of yield and crop quality, as well as local estimates of the direct costs of weed control, suggests that weeds are a significant issue for Australian cucurbit growers.

4. Weeds in the Australian cucurbit industry

The most important weeds for Australian cucurbit growers will vary from one growing region to another, depending on climate and soil conditions and current weed distribution, while the relative impact of weeds within regions may also vary from one district or property to the next, based on a range of factors including cucurbit crop type, grower weed control dedication and diligence, diversity of methods used (van der Meulen *et al.* 2006), and crop management system used. For example, growers using an organic crop cover mulch are likely to face a different set of weed issues to those using polyethylene mulch, or those who do not mulch the crop beds. Organic producers may find it more difficult to control particular weed species than neighbouring conventional producers, and vice versa.

No comprehensive list of weeds that have a significant impact on cucurbit production in Australia could be found in the literature. Table 4.1 lists broadleaf weeds that are mentioned in the literature as existing in Australian cucurbit crops, while Table 4.2 lists grass weeds. These lists come from a number of sources, and may not be comprehensive. Some of these weeds may be problematic within the crop, while others may act as disease or virus hosts in areas in or near the crop rows (e.g. Coutts 2006; Aftab *et al.* 2010).

Survey work being conducted as part of this research project will ask Australian growers to identify significant weeds in their cucurbit crop.

Table 4.1 Broadleaf weeds in Australian cucurbit crops

Weed botanic and common name	Literature Sources
Amaranthus powellii (amaranthus)	Nagle 2008; Serve-Ag 2008
Amaranthus viridis (green amaranth)	Wright 2000
Chenopodium album (fat hen)	Serve-Ag 2008
Citrullus lanatus (Afghan melon)	Coutts 2006
Cucumis myriocarpus (paddy melon or wild melon)	Watt 2009
Fumaria spp. (fumitory)	Macleod *et al.* 2000
Galinsoga parviflora (potato weed)	Henderson 2000; Nagle 2008; Serve-Ag 2008
Gomphrena celosioides (gomphrena weed)	Nagle 2008
Malva parviflora (mallow)	Coutts 2006
Medicago spp. (burr medic, snail medic, barrel medic)	Aftab *et al.* 2010
Nicandra physalodes (apple of Peru; wild hops)	Henderson 2000; Serve-Ag 2008; Wright 2000
Polygonum aviculare (hogweed or wireweed)	Macleod *et al.* 2000
Portulaca spp. (pigweed)	Nagle 2008
Raphanus raphanistrum (wild radish)	Macleod *et al.* 2000
Sisymbrium orientale (Indian hedge mustard)	Aftab *et al.* 2010
Solanum spp. (devil's fig; blackberry nightshade)	Nagle 2008; Macleod *et al.* 2000; Wright 2000
Sonchus oleraceus (common sowthistle)	Henderson and Bishop 2000; Aftab *et al.* 2010
Trianthema portulacastrum (giant pigweed)	Wright 2000
Tribulus terrestris (bullhead, caltrop or cathead)	Watt 2009; Wright 2000
Trifolium repens (white clover)	Macleod *et al.* 2000

Table 4.2 Grass weeds in Australian cucurbit crops

Weed botanic and common name	Literature Sources
Agropyron repens (English couch)	Pest Genie 2010
Agrostis spp. (bent grass)	Pest Genie 2010
Avena spp. (wild oats)	Pest Genie 2010
Axonopus spp. (carpet grass)	Pest Genie 2010
Brachiaria milliformis (green summer grass)	Pest Genie 2010
Brachiaria mutica (Para grass)	Pest Genie 2010
Bromus spp. (brome grass)	Pest Genie 2010
Cynodon spp. (couch grass)	Pest Genie 2010; Wright 2000
Cyperus rotundus (nutgrass)	Macleod *et al.* 2000
Digitaria spp. (summer grass; crab grass)	Pest Genie 2010; Hidayat and Preston 2001
Echinochloa spp. (barnyard grass)	Pest Genie 2010; Wright 2000
Eleusine indica (crowsfoot grass)	Pest Genie 2010
Eragrostis cilianensis (stinkgrass)	Pest Genie 2010
Hordeum spp. (barley grass)	Pest Genie 2010; Watt 2009
Lolium rigidum (Wimmera or annual ryegrass)	Pest Genie 2010; Malone *et al.* 2010; Powles and Holtum 1990
Panicum maximum (Guinea grass)	Pest Genie 2010
Paspalum paspalodes (water couch)	Pest Genie 2010
Paspalum spp. (paspalum)	Pest Genie 2010
Paspalum urvillei (giant paspalum)	Pest Genie 2010
Pennisetum clandestinum (kikuyu grass)	Pest Genie 2010
Sorghum halepense (Johnson grass)	Pest Genie 2010
Urochloa spp. (liverseed grass)	Pest Genie 2010

4.1. Most significant weeds

No single reference source was found during our literature search that ranked the *most significant* weeds in cucurbit crops in Australia. A number of sources mentioned weeds in particular circumstances, or provided several examples of important weeds:

- Apple of Peru (*Nicandra physalodes*), potato weed (*Galinsoga parviflora*) and various grass species were in pumpkin trial crop work in Qld (Henderson 2000).
- Watt's case study of a cucurbit farm in Condobolin, NSW, found that the main weeds in watermelon and pumpkin crops included paddy melon (*Cucumis myriocarpus*), barley grass (*Hordeum leporinum*), and cathead (*Tribulus terrestris*), as well as a number of other broadleaf and grass weed species (Watt 2009).
- Weeds that host melon thrips within cucurbit crops in Australia include pigweed (*Portulaca oleracea*), amaranthus (*Amaranthus* spp.), gomphrena (*Gomphrena celosioides*), potato weed, devil's fig (*Solanum* spp.), and various weedy cucurbit and *Solanum* plants (Nagle 2008).
- A number of weeds occurring in cucurbit crops in Western Australia and the NT can act as virus hosts. These include wild or native cucurbits (wild melon – *Cucumis myriocarpus,* and Afghan melon – *Citrullus lanatus*) and mallow (Coutts 2006).
- Weeds identified in cucurbit crops in Australia include blackberry nightshade (*Solanum nigrum*), hogweed or wireweed (*Polygonum aviculare*) and white clover (*Trifolium repens*) (Macleod *et al.* 2000).
- Weed species dominating trial mulch treatments in Bowen, Qld, included giant pigweed (*Trianthema portulacastrum*), barnyard grass (*Echinochloa colonum*), blackberry nightshade, wild hops or apple of Peru, volunteer tomatoes, green amaranth (*Amaranthus viridis*), bullhead or cathead, and couch grass (*Cynodon dactylon*) (Wright 2000).

Broadleaf weeds such as potato weed, blackberry nightshade, paddy melon, and other weeds closely related to cucurbits, are possibly more significant given that they can be difficult to control within a cucurbit crop. It is particularly difficult to find sufficiently selective herbicides (see Section 5.1). However, weeds such as nutgrass (*Cyperus rotundus*) are also significant, given their ability to pierce plastic mulch layers and establish in the crop.

4.2. Weeds of likely future importance to the Australian cucurbit industry

No information was found during the literature search regarding weeds that are likely to become more important in cucurbit crops in the future. If herbicides are used continually in some cucurbit crops, then herbicide resistance is likely to emerge as an issue with respect to some already significant weed species. Herbicide resistance is discussed in more detail in Section 6.1.1.

5. Current weed control approaches

5.1. Herbicides

Relatively few herbicides are registered in Australia for use *within* cucurbit crops. Weed control is made more difficult within cucurbit crops by the fact that many significant weeds are broadleaf weeds, either wild cucurbits or species with similar attributes, so that herbicidal control of these weeds will cause unacceptable damage to the crop.

Herbicides are also commonly used in plastic and drip irrigation production systems (described below) as a means of inter-row weed control. Knock-down herbicides such as paraquat/diquat mixes, glufosinate and similar herbicides are used for inter-row control, particularly between plastic covered crop beds (Henderson and Bishop 2000; Wright pers. comm.).

5.1.1. Fertilisers with herbicide-like properties

Some fertiliser products release chemicals into the ground on application which appear to have herbicide-like properties. One such product is 'Perlka'. This product contains calcium cyanamide, which is released when the fertiliser is applied. Calcium cyanamide is believed to remain active in the soil for about two weeks. It is most effective when the fertiliser is applied to moist ground when weeds are beginning to germinate (AlzChem n.d.).

No scientific studies could be located that have tested the effectiveness of such products in cucurbit crops. However, the Australian distributor of Perlka has indicated that an increasing number of cucurbit growers are using this product in part for its effectiveness in weed control (Cathcart pers. comm.). Further research may be required to quantify the benefits of these products.

5.1.2. Currently available herbicides for use within cucurbit crops

Table 5.1 lists herbicides registered for use in cucurbit crops in Australia, according to distributor/manufacturer labels. The table also includes one fungicide, metham sodium, which is used to control germinating weeds as well as pest and fungus outbreaks in cucurbit crops. Pre-plant and post-harvest 'knock-down' herbicides are not listed, though options available to Australian cucurbit producers include glyphosate, paraquat/diquat mixes, and oxyfluorfen/N-methyl pyrrolidone.

Table 5.1 Herbicides registered for use in cucurbit crops in Australia

Herbicide (Active Ingredient and trading name/s) and registered crops	Time of application and weeds controlled	Australian distributor
Fluazifop-P (Fuzilier; Fusilade Forte 128 EC) *Cucurbits, rockmelon, pumpkin, honeydew melon, watermelon, zucchini, squash, cucumber, gherkin*	Selective control of certain grasses *post-emergence* (after the 5 true leaf stage of the crop)	Ospray Pty Ltd; Syngenta
Sethoxydim (Sertin 186EC) *Butternut pumpkins, cucumbers, melons, pumpkins, zucchini*	Selective control of certain grasses *post-emergence*	Bayer Cropscience
Clomazone (Command 480EC) *Cucumber, pumpkin, kabocha squash, rockmelons, watermelon, zucchini*	Control of certain annual broadleaf weeds *post-plant pre-emergence*	FMC Chemicals/Serve-Ag
Quizalofop-P-Ethyl (Tzar) *Cucumbers, honeyew melon, pumpkin*	Selective control of certain grasses *post-emergence* (after the 5 true leaf stage of the crop)	DuPont
Dimethenamid-P (Frontier-P) *Pumpkin, kabocha squash*	Control of certain broadleaf and grass weeds *post-plant pre-emergence*	Serve-Ag/BASF
Metham sodium (Metham) *Pumpkin, kabocha squash*	Control of certain germinating weed seeds *pre-plant* (soil fumigant that also controls pests and fungus diseases)	NuFarm

5.1.3. Herbicide crop damage

The range of herbicides available for use within cucurbit crop beds is restricted since cucurbits are highly susceptible to damage from residual herbicides (Lovatt 1995). In a trial of several potential pre-emergence herbicides for use in Australia, Macleod *et al.* (2000) found that several were unsuitable due either to unacceptable crop damage or limited weed spectrum control. Even herbicides that are registered for use in cucurbits in Australia can damage the crop, although damage is often minor, within acceptable limits, or may be minimised by correct application. Henderson (2000) conducted an experiment using clomazone for post-sowing pre-emergence weed control in a pumpkin crop. He found that '[a]lthough it caused some transient whitening of the seedling leaves, pumpkin growth and yield were not significantly affected'. Similarly, trial work with dimethenamid-P showed that, while this herbicide was considered relatively safe in pumpkin and kabocha crops, some damage did occur when higher rates were employed on lightly textured soils (Macleod *et al.* 2000). Residual herbicide has been observed to cause little crop damage one season, followed by significant damage the following season for no apparent reason (Lovatt pers. comm.).

5.1.4. Weed control success

Fluazifop-P, sethoxydim and quizafolop-P-ethyl are successful herbicides for controlling grass weeds in pumpkin and grammas, as well as in zucchini and squash. It is possible to spray these herbicides within the crop post-emergence to achieve control of grasses, but they have long withholding periods (Lovatt 1995; Murison 1995). Clomazone provides good pre-emergence control or suppression of various grasses as well as apple of Peru (*Nicandra physalodes*) and potato weed (*Galinsoga parviflora*) (Henderson 2000). It can be used to control a range of other broadleaf weeds but is ineffective against *Raphanus raphanistrum*, *Amaranthus* spp. and *Fumitory* spp. (Macleod *et al.* 2000). Growers in Australia have the option of using clomazone in conjunction with organic mulches (either transported organic material or cover crop mulches) to control weed outbreaks within the crop rows (Wright pers. comm.). Inter-row weed control during the growing season using knock-down herbicides gives good success, particularly when combined with drip irrigation to minimise moisture and weed germination between the rows (Watt 2009).

Table 5.1 shows that the number of herbicides available for use within cucurbit crop rows (pre-plant, pre- or post-emergence) is limited. As far as broadleaf weed control in cucurbit crops in Australia using herbicides is concerned, options available to growers are even more limited to clomazone (Macleod *et al.* 2000) and the more recently registered dimethenamid-P, which has only been registered for pumpkins and kabocha, as well as a number of non-cucurbit vegetable and cereal crops (AUSVEG 2008). Both are pre-emergence herbicides, while post-emergence herbicides such as fluazifop-P, sethoxydim and quizafolop-P-ethyl are only registered for controlling grass weeds and volunteer cereal crop plants. Therefore, only non-herbicide techniques (such as shallow cultivation or hand weeding) are currently suitable for controlling broadleaf weeds within the crop bed post-emergence (Dimsey 2009).

5.2. Tillage/cultivation

Mechanical tillage or cultivation, in combination with herbicide use, is the most common form of pre-plant and early post-emergence weed management used on Australian vegetable farms (Henderson and Bishop 2000).

5.2.1. Weed control success and viability

Cultivation is often used not only to kill existing weeds, but to break seed dormancy and encourage germination of new weed cohorts which are then controlled with a knock-down herbicide or another cultivation before the crop is planted (Stall 2009). Post-emergence cultivation is relatively cheap and can control weeds effectively, however timing is crucial: cultivating too early may uproot crop plants before they have had a chance to establish properly; while delayed cultivation may damage crop roots that have established in the inter-row space, and may not be sufficient to control weeds that have had more time to establish (Henderson and Bishop 2000). Cultivation within and between rows should only be deep enough to control weeds effectively (less than 8cm deep). Deeper cultivation can break or damage crop plant roots (negatively impacting on crop nutrient and water uptake), bring more weed seeds to the surface, and disturb soils treated with a residual herbicide. Inter-row cultivation generally ceases once the crop vines have started to run (Burt 2005; Stall 2009).

In organic production systems, a shallow cultivation is recommended for controlling weeds that have recently germinated as a result of rainfall or pre-irrigation. Equipment is available that allows growers to remove weeds by cultivating the soil within the crop rows, until the crop has spread to cover the beds at which point weeds become less of an issue due to crop competition (see Section 5.10). One such implement is the 'Weedfix' cultivator that is able to remove many young weeds while protecting the recently emerged crop from damage (Neeson 2003). Henderson and Bishop (2000) note that a number of such implements were available overseas, but at that time had been rarely used inside Australia. *Intra-row* cultivation of this nature requires high precision and appropriate timing to minimise crop damage and maximise weed control (Henderson and Bishop 2000).

5.3. Plastic mulch

5.3.1. A mainstay of weed control in cucurbits

Polyethylene plastic mulch is 'the mainstay of weed control in several high value fruiting vegetable industries in Australia' (Henderson and Bishop 2000). Plastic mulch is an expensive weed control option, although it is feasible in high value cucurbit crops, and delivers a number of other benefits to the crop. The mulch is used not only to restrict weed growth but to prevent soil moisture loss, provide water savings, enhance crop yield and quality, and control disease (Henderson and Bishop 2000; Heisswolf and Wright 2010). In Australia, black film is used in the cooler months or regions, and white film in the warmer months or regions, to regulate soil temperature (Henderson and Bishop 2000). Although plastic mulch has been in widespread use in northern Australia for some time, water scarcity has resulted in increased adoption in southern Australia (Heisswolf and Wright 2010).

Plastic mulch controls weeds by restricting the amount of light available for seed germination. Fumigation is often used before planting to increase the effectiveness of black plastic as a pest and disease control agent. Fumigation is also an effective method of controlling weeds (Henderson and Bishop 2000; see also Section 5.8).

While plastic mulch is a key technique for weed control in Australian cucurbit crops, it is possible for some weeds (such as nutgrass, *Cyperus rotundus*) to pierce the plastic and establish in the crop rows (Henderson and Bishop 2000), while weeds may also grow through the small holes in the plastic mulch where the crop is planted. Other methods of control such as hand weeding, spot-spraying using a selective herbicide, or reliance on crop competition are necessary in these circumstances.

5.3.2. Viability

Plastic mulch still appears to be the most economically viable form of mulch available for vegetable production, despite ongoing trials into alternative mulches such as living and killed systems, organic mulch and biodegradable paper and polymer-based films (Heisswolf and Wright 2010; see also Sections 5.4, 5.6, and 6.4). Olsen (2000) found plastic mulch to be not only the most cost-effective form of 'transported mulch' on a per hectare basis (Table 5.2), but as effective in terms of crop yield as the biodegradable mulch films tested, and more effective for crop yield and weed control than transported organic mulch options, and killed *in-situ* organic mulch.

Table 5.2 'Transported mulch' costs per hectare (Olsen 2000)

Transported mulch type	Cost ($/Ha)
Plastic mulch (polyethylene)	$860
Recycled newspaper	$1,300
Sawdust	$1,600
Gromulch paper film	$1,630
Sorghum hay	$2,000
Mater-Bi biodegradable polymer	$3,300
Hessian	$4,000
Sugarcane trash	$5,900
Composted mulch	$9,300

Nonetheless, some mitigating factors call into question the longer term viability of plastic mulch for cucurbit production. Plastic mulch is difficult and expensive to recycle, while the costs of removing it from the paddock and disposing of it in Australia were between $150 and $249 per hectare in 2000, a similar cost to that in the United States (Olsen 2000; Olsen and Gounder 2001).

Perhaps the most significant mitigating factor, however, has been growing concern over the environmental impact of used plastic mulch disposal. This factor alone may make plastic mulch use untenable in the longer term. This issue is discussed in more detail in Section 6.1.4.

5.4. Transported organic mulch

Wright (2000) and Olsen and Gounder (2001) reviewed a number of transported organic mulches (organic material transported onto the farm) as possible substitutes for plastic in Australia. These included sawdust, sugarcane byproducts, composted vegetative mulch, forage sorghum hay, recycled newspaper and cardboard cartons, and hessian.

5.4.1. Weed control success and viability

Table 5.2 above suggests that organic mulches are not viable alternatives for cucurbit growers on the basis of price alone (Wright 2000). However, Olsen and Gounder (2001) also found that weed control under hessian, sawdust and sugarcane trash mulches was relatively ineffective, to the extent that weeds in unweeded plots had an unacceptable negative impact on yield ('weight of marketable fruit') for the capsicum crops used in the trial. Wright (2000) discovered that recycled newspaper mulch also provided relatively poor weed control, although suggested the layer of paper used may have been too thin. For newspaper, recycled waxed fibre cardboard cartons, and bagasse (a by-product of sugarcane harvesting) trials, yield was impacted by weed competition in unweeded plots. The depth and cover of organic mulches is often insufficient to provide an effective barrier to weed development (Wright pers. comm.).

Organic mulches offer growers an opportunity to improve soil quality by adding large amounts of organic material to the soil. However, in addition to their uneven weed suppression capability (relative to plastic, biodegradable polymer and paper film mulches) organic mulches are costly and logistically difficult to transport to farms and to apply evenly over a large area of land. The vegetable industry lacks suitable machinery to apply organic mulches effectively, and organic material in crop beds may be associated with nutrient immobilisation, increased disease and pest activity, increased pesticide phytotoxicity, and allelopathic crop suppression (Henderson and Bishop 2000; Wright 2000; Olsen and Gounder 2001).

Relative ineffectiveness and high cost means that, in economic terms, transported organic mulches are an unrealistic alternative to polyethylene plastic mulches at this stage, particularly for large-scale farming enterprises (Olsen and Gounder 2001). However organic mulch may be a suitable alternative for smaller-scale producers who have ready access to a supply of mulch, or for organic producers who are keen to find an alternative to plastic mulch.

5.5. Cover crop organic mulch

Cover crop organic mulches, often referred to as living and killed mulch systems, involve planting a cover crop in the crop rows and then either maintaining it as a living mulch if the cover crop is 'either dormant, or sufficiently retarded (e.g. by low rates of herbicide) so as not to significantly compete with vegetable crops', or killing the cover crop and planting vegetables into the stubble (Henderson and Bishop 2000, 369). In either case, the organic cover crop mulch is intended to suppress weed growth until the vegetable crop has covered the beds, at which point weeds are unlikely to penetrate the crop surface.

5.5.1. Success

Living and killed mulches have been found to control weeds within crops with some success, suppressing weed populations to the extent that they do not compete with the crop. The effectiveness of cereal crops such as wheat and ryecorn as cover crops may be due to their allelopathic effects in preventing weed germination (Horticulture Australia 2005). However, such systems (particularly living mulches) can be difficult for growers to implement, as a balance needs to be struck between suppressing weeds and ensuring the crop establishes successfully through the mulch (Henderson 1998).

Henderson and Bishop (2000) summarise a number of overseas and Australian studies of killed mulch systems used in tomatoes, lettuce, brassicas, and broccoli. Yield losses compared to using plastic mulch were found to be minimal, although some modifications to planting equipment and crop management were required (Henderson and Bishop 2000; Horticulture Australia 2005). Living mulches can reduce weed populations to non-competitive levels, and improve the condition of the soil. However they may provide insufficient weed control, or shift the weed spectrum to biennial or perennial weeds. Living mulches may also compete with the crop for nutrients, although competition may be managed by killing the mulch in a narrow strip along the planted row (Henderson 1998).

The proposed advantages and disadvantages/problems of living and killed mulch systems (excerpt from Henderson and Bishop 2000)

Advantages

- being more environmentally acceptable than standard plastic film systems;
- improved soil structure and biological activity, achieved through extended periods of vegetative ground cover, increased organic matter cycling and faunal activity;
- improved nutrient cycling and/or generation by using deep-rooted or nitrogen-fixing cover crops, plants that host mycorrhiza, and incorporation of inorganic nutrients into organic pools;
- allelopathic impacts on weeds (cereal rye is an often quoted example);
- acting as reserves for beneficial fauna (predators or parasites of pest species), and providing more crop-friendly microclimates;
- reduced potential for wind and water erosion; and
- reduced wind and soil contact damage to crops, e.g. rockmelons and watermelons (plant mulches give tendrils from these crops an anchor point to resist foliage displacement by wind).

Problems

- adverse impacts on vegetable crops (allelopathy, nutrient immobilisation, increased pest or disease activity and colder soil temperatures);
- increased expense for ground preparation and planting through the cover crop, as well as the opportunity costs of tying up resources in the mulch that could otherwise be used for cash cropping;
- insufficient mulch present to give effective weed control, or evolution of weed spectrums able to establish under mulch/minimum tillage conditions (common sowthistle seems to be a weed favoured by these circumstances);
- binding of many soil-applied herbicides to the organic matter; and
- the requirement for advanced management skills to implement killed- and living-mulch systems.

5.5.2. Viability

Cover crop organic mulch systems are in limited use in Australia (Henderson and Bishop 2000), though the viability of this approach, and best practice techniques for its implementation, are likely to be refined given the likely long-term unsustainability of plastic mulch. Research in the United States suggests that cover crops can be used effectively in conjunction with pre- and post-emergence herbicides to suppress broadleaf weed growth and result in higher cucurbit yields (Walters and Young 2010).

Where living and killed mulches are used in Australia, they are generally implemented in a permanent or semi-permanent bed with semi-permanent drip irrigation systems. The cover crop is grown over summer and controlled with a mixture of slashing and knock-down herbicide application (Wright pers. comm.).

Experimental work funded by HAL (Rogers 2001) on a number of trial sites in Australia led to a best practice manual being developed for no-till permanent beds in horticultural production. Weeds within the various cover crops were controlled successfully by several herbicides including Fusilade® (fluizafop-p butyl) to control grass weeds in Centro stands, Kamba® (MCPA) to control broadleaf weeds in grass cover crops, and Jaguar® (hydroxybenzonitrile + nicotinanilide) to control some broadleaf weeds in legume cover crops. This manual suggests that cover crops may be killed prior to planting either with herbicide, or mechanically with a crimping roller or flail mulcher. Pre-emergent herbicides may be used to control weeds in a cover crop system, although their effectiveness is reduced by the organic mulch layer, while herbicide damage may occur in the crop once it emerges.

The cost of establishing a killed mulch is approximately a quarter of the cost of plastic mulch (including plastic mulch disposal costs). Killed mulches also have the potential to improve soil health. Currently, however, many commercial growers do not consider killed mulches a viable alternative to plastic. This is because killed mulches lead to uneven crop growth, lower yield, long establishment time, possible build-up of soil pathogens, emergence of volunteer weeds from the cover crop, and *relatively* poor weed control (Olsen 2000).

As with transported organic mulches, cover crop mulch systems are still not as effective as plastic for weed control, although the logistics and costs are less of an issue than they are for transported organic mulches. However, the longer-term viability of these systems is still dependent on further research that may refine the ability of these systems to control weeds more effectively, and on the comparative viability of plastic or biodegradable polymer films. Research is also required to overcome poor soil contact with the root ball of the crop during planting, and to address nutrient tie-up and allelopathy impacts on the crop (Olsen 2000).

5.6. Permanent or semi-permanent beds

Low- or no-till permanent or semi-permanent crop beds, with a semi-permanent drip irrigation system, are becoming popular (often in combination with an organic cover crop mulch – see Section 5.5; and controlled traffic – see Section 5.9) as an alternative to heavily cultivated soil and plastic mulch to restrict weeds and maintain soil moisture under drip irrigation. Suitable in-crop and inter-row pre-emergent and non-residual post-emergent herbicides are used strategically to control weeds during the cucurbit season. There is a trend in Northern Queensland to move towards this type of production system, one that is expected to continue if a wider range of non-residual herbicides become available to growers (Wright pers. comm.). A best practice manual for permanent beds using killed mulch cover crops has been produced by HAL (Rogers 2001).

5.7. Crop rotation

Crop rotation is commonly used in Australia to give growers the opportunity to control pests and diseases that impact on cucurbit crops, such as fusarium which may be controlled by several years of growing other crops in the infected paddock, accompanied by fumigation (Dimsey 1995; Coleman 2003). Other benefits of crop rotation include maintaining species diversity (and therefore soil health) optimising the use of resources (land, equipment and capital) outside the cucurbit season or in response to commodity prices, and diversifying their production base (Henderson and Bishop 2000; Watt 2009).

5.7.1. Weed control success and viability

The weed control benefits of rotations are often of secondary importance to many growers (Henderson and Bishop 2000). Nonetheless, rotation is a useful weed management tool for controlling broadleaf species on a farm where cucurbits are grown: by growing a rotation crop or variety of rotations, farmers have the opportunity to control species which are otherwise difficult to control within a cucurbit crop (Masiunas 2008). For example, on one farm in NSW (Watt 2009), crop rotations with wheat and other broadacre cereal crops make it possible to control paddy melon (*C. myriocarpus*) using selective herbicides and fumigation, options that are not available to control this weed when cucurbits are grown. This means the weed is less prevalent, and consequently easier to manage, in the following cucurbit crop. Some cover crops such as forage sorghum or brassicas may also be grown as a rotation crop with its own economic value, with many of the benefits discussed in Section 5.5 (Henderson and Bishop 2000).

5.8. Fumigation and biofumigation

Soil fumigation under plastic mulch using broad spectrum chemicals such as methyl bromide and metham-sodium has been a common practice amongst Australian vegetable producers, largely for its benefits for managing nematodes, diseases, and insect pests, such as verticillium wilt. However, fumigation may have secondary weed control benefits, and render herbicide use unnecessary in some circumstances (Dimsey 1995; Henderson and Bishop 2000; Ullio 2004). Fumigation at least two weeks before crop planting allows the fumigant to dissipate in the soil effectively. Fumigation with metham, in combination with the herbicide halosulfuron (see Section 6.3.1) controlled a number of species under plastic mulch in a US study, including yellow nutsedge (*Cyperus esculentus*), without having a negative impact on watermelon yield (Johnson and Mullinix 2002). The precise effects of fumigation on weeds are not widely understood amongst growers (Henderson and Bishop 2000), and its impact does not appear to have been explored in detail in Australia. Nonetheless, fumigation does appear to be effective in controlling difficult weeds in Australia such as nutgrass (Ullio 2004).

Chemical fumigation faces an uncertain future due to environmental and social concerns (see Section 6.1.5).

5.8.1. Biofumigation using killed mulches

The uncertain future of chemical fumigation has led to research into 'biofumigation', using organic cover crop mulches to deliver soil fumigation. Some brassica plants such as canola and mustard release fumigant-like compounds into the soil as they decompose. Where brassica plants are used as a killed mulch, this process is thought to have some positive impact on insects and diseases within vegetable crops, and may have some benefits for weed control as well (Henderson and Bishop 2000).

A number of brassica varieties have been developed in Australia for biofumigation and suppression of weeds in horticultural crops. Some of these were evaluated by Kristiansen *et al.* (2005) for their ability to control weeds pre-crop (as a living mulch) and in the lettuce crop (as a killed mulch incorporated into the soil) during the growing season. After ten weeks growth, the brassica cover crops were cultivated into the soil. The study found that brassica cover crops were effective at suppressing weeds in the pre-crop phase as a living mulch, but that weed control effectiveness within the crop as a killed mulch was not significant. Similarly, Macleod *et al.* (2000) trialled two brassica biofumigant mulches (BQ Mulch and Weedcheck), which were incorporated into the soil prior to crop sowing. They also found that weed control was not acceptable within the crop.

Mustard biofumigant cover crops have been trialled in the United States for their potential to allow pumpkin and cucumber growers to shift to post-emergence herbicide use and ensure that weed resistant biotypes do not develop. The research found that some crop damage resulted from use of a mustard biofumigant crop, while the effectiveness of the method depended on weed species, timing, and the mustard cultivar. Ongoing work seeks to refine the use of mustard biofumigants and overcome some of these limitations (Masiunas and Anderson 2009).

5.9. Controlled traffic

Controlled traffic farming (CTF) is an effective way to manage soil compaction in cropping and horticulture situations. CTF involves establishing permanent wheel tracks outside of the crop growing area and in between crop rows (using Global Positioning Systems and related technology), along which all wheeled farming equipment operates. When combined with planned efficiencies in farm layout, CTF delivers a range of management benefits to farmers using raised growing beds (such as cucurbit growers) including fuel savings, improved and more consistent soil structure and health across the paddock, improved soil moisture retention, and higher yield (McNeill *et al.* n.d.; Williams 2007; Brennan 2010; DPIPWE 2010). CTF is increasingly being adopted by European organic vegetable farmers in recent years given the improving accuracy of guidance technology. Many European farmers have implemented a seasonal CTF system (SCTF) in which all pre-harvest equipment tracks are maintained, while allowing for harvest traffic to be random (Brennan 2010).

CTF gives vegetable farmers greater scope to operate an effective permanent bed zero till system which is not subjected to soil compaction. One of the benefits of zero till systems is reduced weed seed stimulation, and therefore less weed competition in the beds (McNeill *et al.* n.d.; DPIPWE 2010). Controlled traffic and permanent beds can be integrated with cover crop organic mulches and strategic use of pre- and post-emergent herbicides to control weeds in the early crop stages. One large enterprise in North Qld has successfully grown around 40-50ha of zucchini annually for some years using this integrated system (Wright pers. comm.). Australia is a world leader in CTF in dry-land grain and sugar farming, however CTF does have shortcomings in the vegetable industry. These include the initial cost of satellite guidance systems, and major design changes required for harvesting equipment to implement a 'season-to-season CTF system' (Brennan 2010).

5.10. Crop competition

Crop competition means ensuring that good crop cover is established quickly to give the crop a competitive advantage over weeds. This includes sufficient plant density to allow the crop to form a dense canopy, making it difficult for weed seeds to germinate for lack of light. Weeds are not a significant problem once the crop canopy closes fully (Masiunas 2008). Factors taken into account include fertility, choice of crop variety, ensuring good water control (irrigation and drainage), and sowing or planting adequate plant populations. Trials in the United States have shown that if broadleaf weeds (such as smooth pigweed - *Amaranthus hybridus*) emerge 4-5 weeks after the crop, they have little or no impact on yield (Stall 2009). Similarly, recent research in Australia has found that native vegetation may be used in non-crop areas of the farm (next to traffic areas and waterways, along fencelines and so on) to out-compete weeds in these areas of the farm that harbour pests and diseases potentially damaging to the crop. Native plants in these areas have been found to harbour less pests, while also hosting higher numbers of beneficial insects (Powell 2006; Acton 2008).

5.11. Farm hygiene

Farm hygiene practices limit the spread of weed seeds and propagules (as well as pests and diseases) across and between properties, and onto crop beds from other parts of a property where weeds are present. Hygiene practices available to farmers that will limit the spread of weeds (Henderson and Bishop 2000; Grundy 2007; Watt 2009) include:

- Establishing permanent or set vehicle tracks and laneways to restrict the amount of soil spread by machinery onto cropped areas of the farm (controlled traffic).
- Restricting weed growth along these and other traffic and drainage areas on the farm, including by controlling weeds in these areas before they have set seed, or by maintaining ground cover with suitable grass species (e.g. Kikuyu) to limit the ability of weeds to establish.
- Washing down or disinfecting equipment (particularly when using contractors) before bringing it onto the property or transferring it from one part of the property to another.
- Restricting movement of machinery and people onto the property as much as possible, and establishing a single delivery point near the property entrance.
- Buying certified seed and seedlings, and being aware of potential weed spread if transported organic mulch is used.

5.12. Stale and false seedbeds

A stale seedbed involves preparing the seedbed for planting and then leaving it for anywhere between several days and several weeks before planting. During this fallow period, weeds are allowed to germinate, and may even be stimulated through pre-irrigation. Before crop planting, the weeds are controlled with a knock-down herbicide. Stale seedbeds are a beneficial weed control technique as soil disturbance before crop planting is limited, so that buried seeds are less likely to germinate (Lonsbary *et al.* 2003; Taylor 2009).

A false seedbed is similar to a stale seedbed, although weed control prior to planting is achieved by repeated shallow cultivations and knock-down herbicide applications, designed to encourage germination and/or control recently germinated weeds. The goal of the false seedbed approach is to break down the weed seedbank in the top layer of soil, so that fewer weeds emerge during the crop growing season (Taylor 2009). False seedbeds raked before planting to control weeds and break up soil compaction also appear to improve crop germination and establishment in comparison with organic cover crop mulch systems such as wheat, 'possibly due to improved seed/soil contact' (Sherriff *et al.* 1999).

5.12.1. Weed control success

Stale and false seedbed techniques appear to control weeds more effectively, and contribute to higher crop yield in cucumbers, than seedbeds managed by conventional cultivation practices alone (Johnson and Mullinix 1998; Lonsbary *et al.* 2003). Lonsbary *et al.* (2003) explored the efficacy of stale seedbeds prepared at different lengths of time before crop planting. They found that the optimal seedbed was prepared 20 to 30 days before planting, using a knock-down herbicide (glyphosate) to control the weeds pre-plant. Johnson and Mullinix (1998) showed that repeated shallow tillage of a false seedbed reduced the number of weed seeds and weed diversity within a seedbed, partially replacing the use of post-emergence herbicides. False seedbeds also resulted in greater cucumber yield than beds treated pre-plant with glyphosate. In both cases, minimal soil disturbance during planting is also desirable to minimise weed germination during the early crop stages, reducing the farmer's reliance on post-emergence herbicide treatments (Johnson and Mullinix 1998; Taylor 2009).

Stale seedbeds can also be established using plastic mulch to control weeds (Wright pers. comm.):

> *A modified 'stale seedbed' technique is often employed where plastic mulch and drip irrigation is used. The beds are irrigated following plastic mulch being laid out and the crop is planted around 3-4 weeks later. This allows time for weeds to germinate and die due to a lack of sunlight (except for nutgrass which easily penetrates the mulch). The crop can then be planted by either direct seeding or using container grown transplants. This method greatly reduces weed growth around the hole in the mulch through which the plant/seed is planted.*

Stale seedbed techniques are of particular relevance to organic cucurbit growers, most of whom rely heavily on cultivation for pre-plant and early post-plant weed control. It is possible for organic producers to control weed germinations in a stale seedbed using thermal control (flaming or steam weed control – see Sections 5.13.1 and 5.13.2), achieving a good weed control with minimal soil disturbance, and decreasing subsequent weed emergence (Taylor 2009).

5.13. Thermal weed control

Thermal weed control methods are particularly useful in low-till and permanent bed systems. While the initial outlay for thermal weeding equipment is higher than for tillage equipment, it can be between 50% and 80% cheaper than hand-weeding, and viable for relatively small farms of 6-20 hectares (Kristiansen and Smithson 2008).

5.13.1. Flaming

Flaming involves the use of natural gas- or propane-fuelled burners to expose weeds to 'sufficient heat to disrupt cell membranes, destroying leaf and meristematic tissues' (Henderson and Bishop 2000). The technique is commonly used pre-plant or early post-plant as a replacement for knock-down herbicides, and is therefore of particular interest to organic growers. Flaming is generally more successful against broadleaf weeds with growing points above the ground than it is against grasses, where the growing point (meristem) is often either below the surface or concealed within new leaves (Henderson and Bishop 2000; Kristiansen and Smithson 2008; Mutch *et al.* 2008).

Flaming has other limitations in addition to its relative ineffectiveness against grass species. Optimal control often requires a number of flame applications, while smaller crop plants are generally more susceptible to damage from flaming than larger plants, so optimal control of weeds is achieved when the weeds are smaller than the crop plants (Mutch *et al.* 2008). Flaming has been recommended in Australia for organic growers as an option for pre-plant weed control, once rainfall or pre-irrigation has allowed weeds to germinate in the beds (Neeson 2003).

5.13.2. Steam

The advantages of steam weeding over flaming include better heat transfer and reduced fire hazard risk. A comparative trial of steam weeding in Australia found that weed control was equivalent to organic techniques such as tillage and chipping, and to glyphosate (Kristiansen and Smithson 2008). Steam weeding may also be an option for spot control of weeds after crop planting in a killed mulch system (Diver 2002).

As with flaming, however, steam weeding is of limited effectiveness in controlling grass weed species. Kristiansen and Smithson (2008) found that steam weeding equipment reduced broadleaf weeds by around 50% to 60%, whereas its control of grass weeds was much less effective. However the authors suggest that thermal methods *can* be used to control grass weeds, requiring application when the grass weeds are very young, and slower application speeds to improve the effectiveness of the steam or other thermal control technique.

Is may be a viable option for farmers to use selective herbicides such as clomazone to control grass weeds in the crop, and use steam spot-control equipment to control broadleaf weeds before the crop canopy closes.

5.13.3. Soil solarization

Research in the United States suggests that clear plastic may also be effective at controlling weeds and pests through 'soil solarization', a process that involves trapping solar radiation in moist soil (thermal weed control) as an alternative to the non-transparent plastic/fumigation strategy. Soil solarization was explored in more detail in the US as a result of methyl bromide fumigation being phased out of use (Stapleton *et al.* 2005). However, Henderson and Bishop (2000) consider soil solarization to be uneconomic in Australia, given that the planting areas must be under clear film for anywhere between four and eight weeks for the solarization process to occur effectively.

5.14. Field-grown trellis crops

In some field-grown cucurbit crops (for example, Lebanese cucumbers and ornamental gourds) trellises are used. In trellis-grown cucurbits, weed control becomes easier using inter-row knock-down herbicides (Wright pers. comm.).

5.15. Integrated weed management in Australian cucurbit crops

In this chapter we have discussed a range of weed control techniques currently available to Australian cucurbit growers. Most are particularly suitable at particular times during the season, or for particular management circumstances. However, it is rare for the techniques described in this chapter to be used in a cucurbit crop in isolation: nearly all Australian cucurbit growers integrate a number of these techniques into a weed management strategy, because no single technique alone will effectively manage weeds in the crop during the growing season. For example, fumigation is commonly used in conjunction with plastic mulch and drip irrigation, cover crop organic mulches may be incorporated into a permanent bed system with controlled traffic and use of pre-emergent or selective post-emergent herbicides, and pre-plant cultivation is commonly followed by knock-down herbicide application to encourage weed germination and allow effective weed control before the crop is planted.

Integrated weed management (IWM) has been defined as 'a sustainable management system that combines all appropriate weed control options' (Sindel 2000). IWM seeks to minimise the chance of weed control failure, reduce the impact of weed management activities on the environment (notably by minimising the farmer's reliance on herbicide use), and ensure that the mix of techniques used will remain viable into the future (for example by reducing the risk of herbicide resistant weeds developing) (Sindel 2000; Newley and Treverrow 2006). IWM should also take into account the points along their life-cycle at which weeds are most vulnerable to the range of management options available, and implement an appropriate control strategy accordingly (Henderson 1998).

In cucurbit production, the sustainability of current weed control techniques such as herbicide and fumigant use, and plastic mulch, is being questioned, and these commonly used techniques may become less viable in the near future. The majority of cucurbit growers in Australia are currently thought to use a simple IWM system, including pre- and post-emergent herbicides, chipping and hand weeding in the crop, and plastic mulch (Napier pers. comm.; Watt 2009). The mix of techniques used as part of IWM in cucurbit production will vary depending on circumstances and personal preferences, however IWM is considered essential to the future of the industry (Badgery-Parker pers. comm.).

Henderson and Bishop (2000) presented a case study of successful IWM implemented by a Queensland celery and lettuce producer facing a heavy infestation of potato weed (*Galinsoga parviflora*). Many of these techniques were implemented for other reasons, or had other benefits, but nonetheless had a positive impact on weed control. The strategy included:

- Farm hygiene to restrict the ability of weeds to recolonize crop beds.

- Establishing cereal cover crops during 'non-cash crop periods' to not only build up the organic matter in the soil, but to allow selective control of broadleaf weeds with herbicide, and weed control with knock-down herbicide before the cover crop was planted.
- Using a drip irrigation system so that the non-irrigated inter-row space remained relatively dry and less likely to support weed growth.
- Growing crops (lettuce) with a short cropping period (transplant to harvest), so that weeds did not have time to establish properly in the crop rows.
- Habitually removing older weeds, especially those close to setting seed, once the bulk of the weed outbreak had been controlled.

The net result was to virtually eradicate potato weed on the property at little additional cost to the grower. As Henderson and Bishop (2000) noted, '[a]ll that was required was a planned strategy to link the key management components in a sensible sequence, and the persistence to ensure that each step was diligently carried out'.

Watt's (2009) case study of PMG Agriculture's cucurbit operation in NSW also illustrates IWM in practice on a cucurbit farm. On this farm, pumpkins and watermelons were grown in addition to pomegranates and winter wheat. The following weed control techniques were employed in the pumpkin and watermelon crops:

- Plastic mulch: used to prevent weed emergence within the crop rows, as well as to implement a drip-fed irrigation system.
- Knock-down herbicides (primarily glyphosate): used to control weeds emerging in between the crop rows. Knock-down herbicides were applied either using spot-spray or using a spray-unit fitted to a quad bike.
- Physical removal of weeds: a technique employed for minor weed problems or when weeds emerged within the crop rows. The latter was a particularly important technique to control broadleaf weeds within crop rows given the lack of suitable broadleaf herbicides, although at times casual staff were unable to differentiate between crop plants and broadleaf weeds with a similar appearance.
- Crop ground cover: good ground cover provided by the crops at their later stages achieved relatively good weed suppression.
- Organic mulch: transported organic mulch was trialled as an alternative to plastic, and the mulch was considered to be a viable alternative despite application issues and potential to encourage pests and disease (discussed in Section 5.4).
- Crop rotation: allowed more effective control of weeds that are otherwise difficult to manage in a cucurbit crop.
- Drip irrigation: ensuring the inter-row spaces were relatively dry and less likely to support weed growth.

- Farm hygiene: equipment wash-down and weed management along roadways and other traffic areas.

5.16. Organic weed management in Australian cucurbit crops

A national survey of organic vegetable and herb growers in Australia during the 1990s showed that most relied on hand weeding, slashing, mulch, and cultivation to control weeds (Kristiansen *et al.* 1999). Of the weed control techniques evaluated in this chapter, the following are relevant to organic cucurbit producers:

- Cultivation (including early post-emergence shallow cultivation, and hand weeding).
- Transported and cover crop organic mulches.
- Controlled traffic, incorporating permanent or semi-permanent crop beds and possibly an organic mulch cover crop.
- Crop competition.
- Farm hygiene.
- False seedbeds (incorporating pre-irrigation to stimulate weed growth and control recently germinated weeds using shallow cultivation or thermal weed control).
- Bioherbicides (see Section 6.3.4).

Since organic producers are often (though not always) reluctant to use plastic mulch, organic mulch may be required not only for its moisture retention benefits but to 'provide a "clean" barrier between fruit and the bare soil, thus preventing staining of the underside of the [fruit]' (Neeson 2003).

Of these methods, cultivation is possibly the most widely used form of weed control by organic producers. With correct timing and approach, mechanical cultivation can remove 90% of weeds from a crop, while the remainder need to be removed by other means such as hand weeding (Lanini 2009).

6. Future weed control options in cucurbit crops

6.1. Factors influencing weed control practice change

6.1.1. Herbicide resistance

Repeated use of herbicides with the same mode of action can lead to herbicide resistance in weed populations (Preston 2000). Herbicide resistant weeds are found in all cropping regions of Australia, and the number of resistant species and geographic areas impacted by weed resistance is increasing (DAFWA 2010). Herbicide resistance in Australia is most notable amongst grass species, although a number of resistant broadleaf weeds have also been identified (Preston 2000). Broadleaf weed herbicide resistance cases have been recorded in North America and Europe (Henderson 1998).

> *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. (Henderson 1998).*

The growing importance of herbicide resistance means that cucurbit growers need to be conscious not only of more effective and strategic use of herbicides, but also to integrate non-chemical techniques into their overall weed strategy. Growers have a limited range of herbicide choices already, particularly for broadleaf species, and so resistance is an especially important issue. Some examples are provided below of weeds that have developed resistance to herbicides available for cucurbit production. Resistance in pre-plant knock-down herbicides such as glyphosate is not dealt with here, although considerable research into resistance, and resistance minimisation strategies, for this invaluable herbicide are ongoing (AGSWG 2010). Currently, resistant populations appear to be limited to grass species (notably annual ryegrass). The ability of cucurbit growers to control these weeds in their crop pre- and post-emergence may be impacted over time by resistance biotypes, and this may already be an issue in some areas. However the potential for herbicide resistant weed populations to develop has implications for pre-emergence broadleaf weed control in cucurbits as well.

Fluazifop-butyl and Quizalofop

As Powles and Holtum (1990) discuss, annual ryegrass (*Lolium rigidum*) biotypes in South Australia have shown resistance to aryloxyphenoxypropionate herbicides such as fluazifop-butyl and quizafalop, dating back to the early 1980s. Intensive herbicide use on this significant weed for southern Australian cropping systems has resulted in biotypes developing that are resistant to 'at least nine dissimilar herbicide chemistries' (Malone *et al.* 2010). Annual ryegrass resistance to commonly used herbicides in broadacre cropping have been reported after the initial failure of the herbicide diclofop-methyl. Two-three years continuous use of fluazifop-butyl or quizalofop, may encourage resistant annual ryegrass biotypes to develop (Powles and Holtum 1990). Similarly, resistance has been identified to fluazifop-butyl and quizalofop amongst crabgrass (*Digitaria sanguinalis*) populations, also in South Australia (Hidayat and Preston 2001). Fluazifop-butyl and quizalofop are registered to control both of these weeds in Australian cucurbit crops.

Sethoxydim

Sethoxydim resistance has also been identified in annual ryegrass populations in South Australia (Powles and Holtum 1990), while another study conducted by Henskens *et al.* (1996) demonstrated the ability of annual ryegrass to develop resistance to sethoxydim in Victoria. Significant wild oat resistance to this herbicide has also been demonstrated in a study conducted in the Western Australian grain belt (Owen and Powles 2009).

Clomazone

Preliminary research suggests that clomazone resistant biotypes of barnyard grass (*Echinochloa* spp.) do not appear to have developed yet in Australia. Despite this, barnyard grass is considered one of the worst weeds for herbicide resistance, and resistance is widespread outside Australia (Pratley and Broster 2004; Pratley *et al.* 2008). This summer crop weed is most significant in Australian rice production, however clomazone is registered in Australia to control barnyard grass in cucurbit crops. While this is a relatively new herbicide for Australian cucurbit production (Macleod *et al.* 2000), growers will need to remain aware of the potential for resistance to develop and manage their use of clomazone accordingly.

Dimethenamid-P

No evidence of weed resistance to dimethenamid could be identified either in Australia, or overseas.

6.1.2. Changing climate

At the present time, little information is available regarding the specific impact of changing climate for weed management in Australian cucurbit crops. HAL has identified changing distribution and abundance of pests and weeds in Australian vegetable growing regions as an issue it will seek to address in its 'Horticulture Climate Change Action Plan' (HAL 2009).

The Australian Government-funded cooperative venture 'National Agriculture and Climate Change Action Plan' (NACCAP 2008) predicts in general terms changes in pest animal and weed issues for primary producers as a result of climate change. The potential implications for cucurbit producers include:

- Weeds that may be dispersed efficiently over longer distances (for example by wind, water or birds) may invade areas faster than weeds that rely on vegetative dispersal. This change may influence the distribution patterns of weeds already prevalent in cucurbit crops, or introduce new weeds.

- Changes in average temperature and rainfall across Australia may affect the distribution and density of weeds in cucurbit growing regions.
- 'Pre-emergent herbicides or herbicides absorbed by plant roots need soil moisture and actively growing roots to reach their target species. Drying winter and spring rainfall trends have the potential to reduce the effectiveness of pre-emergent herbicides such as triazines (NACCAP 2008).
- Changes in climate may actually make it easier for growers in some regions to manage weeds, as their natural range contracts or shifts.

6.1.3. Environmental impacts of herbicide

Chemical use is particularly intensive in fruit and vegetable production in comparison with most other forms of agriculture, and many widely used weed and pest control practices have come under closer scrutiny over the last two decades (Stringer 1998). High reliance on herbicides for weed control in Australian agriculture has raised environmental concerns regarding the short- and long-term fate of herbicide residues in the environment, chemical container disposal, herbicide impact on non-target systems and organisms (such as nearby waterways), and whether herbicide application practices can be improved, or agricultural reliance on herbicides be reduced, to make herbicide use more sustainable (Adkins and Walker 2000; ANRA 2007).

The challenge for growers has been and will remain to reduce their reliance on herbicides while still controlling weeds effectively in their crop. Many of the practices that facilitate reduced and more sustainable herbicide use are discussed in Chapter 5, including crop competition, and living mulches and cover crops. Precision agriculture and weed mapping also have potential to reduce the amount of herbicide used on a farm. Chemical companies have also developed herbicides that are effective at lower rates and have a lower mammalian toxicity (Adkins and Walker 2000).

Many industries have introduced Quality Assurance (QA) or Best Management Practice (BMP) guidelines for their growers to facilitate integrated and environmentally sustainable approaches to weed and pest management (Adkins and Walker 2000). In Western Australia, vegetablesWA (2007) have published a 'Good Practice Guide', which details approaches growers can take to maintain yield and quality while reducing the environmental impact of production (although the current edition of the guide focuses on sustainable insect pest management rather than weed management). Similarly, Queensland Fruit & Vegetable Growers Ltd (Growcom n.d.) have published the 'Farmcare Code of Practice for Sustainable Fruit and Vegetable Production', although again this document (unsighted for this review but summarised in Growcom n.d.) appears to focus more on the impacts of pesticide and fertiliser use.

6.1.4. Plastic mulch disposal issues

While plastic mulch is still the most viable mulching technique for cucurbit growers, it is not a sustainable practice in the longer term (Wright pers. comm.).

The use of plastic mulch is coming under increasing pressure, due largely to the environmental problems posed by disposal. Plastic mulch disposal options such as ploughing the mulch into the soil, burning or disposing at local land-fill sites are being progressively banned or restricted, cause pollution and other local environmental problems, and are also becoming less acceptable to the community (Henderson and Bishop 2000; Wright 2000). 'Options for disposal of the mulch at the end of its useful life are becoming increasingly untenable around Australia with municipal authorities rejecting, restricting or increasing the costs of dealing with plastic mulch at their waste management plants' (Heisswolf and Wright 2010). In Bowen, Qld, for example, the local council stopped accepting plastic mulch at its local landfill facility, forcing growers to dump used mulch down a disused mine shaft as a temporary solution (Olsen and Gounder 2001).

Despite its cost competitiveness, the longer-term future viability of plastic mulch in Australian vegetable production therefore appears doubtful. Other mulches or options for managing weeds, diseases and pests, and soil moisture levels in the crop bed may, out of necessity, come into more widespread use. Organic and living/killed mulches are discussed in more detail in Sections 5.4 and 5.5. Some investigation is also taking place to determine the viability of biodegradable mulch film as a replacement for conventional plastic mulch, although this approach doesn't appear to have gone beyond the trial phase in Australia. Biodegradable mulch film is discussed further in Section 6.4.

6.1.5. Fumigation – an uncertain future

Methyl bromide use is being phased out in Australia from 2005 (with some limited exemptions such as strawberry production) as part of Australia's international obligation under the Montreal Protocol to restrict use of this and other ozone-depleting substances (DEWHA 2007). There are a number of alternative fumigants on the market in Australia, including Telone (1,3-dichloropropene plus chloropicrin), Metham (metham sodium) and EnviroFume (metham potassium) (Vock and Greer 2007). However, Henderson and Bishop (2000) have questioned the long-term community acceptance of chemical soil fumigation. They argue that farmers should not rely on fumigation as a key factor in their overall weed control strategy, and that more socially acceptable alternatives will need to be developed.

6.1.6. Changes in farm size and scale

There has been a tendency in Australian cucurbit production of farm aggregation into fewer and larger, more professional growers, who focus strongly on improving 'growing techniques, best management practices and quality produce' (Kelly 2007).

The implication for weed control is that the cost effectiveness of particular techniques may be partially dependent on farm scale. For example, larger scale growers may find transported organic mulches to be a viable alternative to plastic mulch on a large area, whereas smaller growers might prefer a crop cover organic mulch or plastic mulch. The establishment and infrastructure costs for controlled traffic systems and permanent beds, farm hygiene, and thermal weed control, may be more easily absorbed by larger growers. Crop rotation may also be more feasible on a larger farm, allowing growers to diversify their production and maintain cucurbit crops on some parts of their property each year. Larger producers are also more likely to be able to justify on economic grounds investment in a modified IWM strategy that incorporates these and other emergent and novel weed management techniques (possibly including biodegradable and paper films).

6.2. Innovations in weed control outside Australia

In addition to exploring current and innovative weed control techniques in Australia, this review has focussed on innovative practices and products being researched overseas, particularly in the United States, since cucurbit growers there share many similarities with their Australian counterparts in the management problems they face. Some of these practices and products have been trialled in Australia, or are in limited use, while others are yet to be introduced in Australia. Innovations include:

- new herbicides (see Section 6.3);
- soil solarization (Stapleton *et al.* 2005; see Section 5.13.3);
- biofumigation (see Section 5.8.1);
- cover crops (Walters and Young 2010; see Section 5.5); and
- bioherbicides (see Section 6.3.4).

Nuffield Scholarship holder Tim Harslett conducted an overseas study tour and identified a number of emerging weed control methods in use around the world (Harslett 2008):

> *For weed control the focus was on developed and developing technologies of sensor-guided inter- and intra-row mechanical weeding, GPS logging of plant placement to allow autonomous weeding, fumigants, ammonium- based sprays, mulches, crop rotation, planting density and spacing, pre-planting kill off, steaming, flaming, solarisation, night land-prep/planting, glass-house production and genetic modification potential.*

6.3. Herbicide options

A search of the literature in the United States suggests that a range of herbicide alternatives may potentially be registered for use in cucurbit crops in Australia. Table 6.1 Lists herbicides registered in the US (but not currently in Australia) for use in cucurbit crops (Lanini 2009; Olson *et al.* 2009; Stall 2009).

Table 6.1 Herbicide options available for cucurbit growers in the United States not currently registered in Australia

Herbicide (Active Ingredient and US trading name/s)	Crops	Time of application	Weeds controlled
Bensulide (Prefar 4E)	Cucumber, melon, squash, pumpkin, gourd, bitter melon	Pre-plant, pre-emergence	Germinating grass weeds
Bensulide & Naptalam (Prefar 4E & Alanap)	Cantaloupe, muskmelon, cucumber, watermelon	Pre-plant, pre-emergence	Not stated, assumed to be germinating grass weeds
Carfentrazone (Aim)	All cucurbit crops	Pre-plant, directed-hooded, row-middles	Pre-plant or row-middle 'burndown treatment' of emerged broadleaf weeds
Clethodim (Select, Arrow, Select Max)	All cucurbit crops	Post-emergence	Annual and perennial grasses
DCPA (Dacthal W-75, Dacthal 6F)	Squash	Pre-emergence, row-middles	Not stated
Ethalfluralin (Curbit)	Cucumber, melon, pumpkin, squash, watermelons	At planting (pre-emergence)	Annual grasses and broadleaf weeds
Ethalfluralin & Clomazone (Strategy)	Cucumber, melon, watermelon, squash, pumpkin	Pre-emergence, post-directed	Grasses and broadleaf weeds
Flumioxazin (Chateau)	Melons, muskmelon, watermelon	Directed, row-middles	Not stated
Halosulfuron (Sandea)	Cucumber, cantaloupe, honeydew and crenshaw melon, watermelon, squash, winter squash, pumpkin	Pre-emergence, post-emergence, row-middles, pre-transplant, post-transplant	Nutsedges and broadleaf weeds (use timing depends on cucurbit crop)
Naptalam (Alanap-L)	Cantaloupe, cucumber, watermelon	Pre-emergence, pre-plant, post-emergence, post-transplant	Germinating annuals controlled pre-emergence/pre-plant. Post-emergence/post-transplant weeds controlled not stated

Paraquat (Gramoxone Inteon, Firestorm)	Watermelon, squash, pumpkin, cantaloupe, muskmelon, cucumber, melon	Pre-plant, pre-emergence, post-emergence directed spray row-middles (melons)	Not stated
Pelargonic Acid (Scythe)	All cucurbit crops	Pre-plant, pre-emergence, directed-shielded	Non-selective
S-Metolachlor (Dual Magnum)	Pumpkin	Inter-row, inter-hill	Not stated
Terbacil (Sinbar)	Watermelon	Pre-emergence, pre-transplant, row-middles	Annual broadleaf weeds
Trifluralin (Treflan)	Watermelon and other cucurbit crops (not stated)	Layby (post-thinning)	Annual grasses and broadleaf weeds

Table 6.1 shows that a number of pre-plant and pre-emergence herbicides are available as alternatives for currently registered herbicides in Australia. Another option is sulfentrazone ('Authority'), which is not registered in the United States for cucurbits, but which has been identified by Macleod *et al.* (2000) as a potentially useful pre-emergence option.

Perhaps more importantly, three post-emergence herbicides currently used in the United States have not yet been registered for cucurbit crops in Australia: clethodim, halosulfuron and s-metolachor. Of these, clethodim is registered in the US for control of grass weeds only, so that its primary usefulness in Australia might be as an alternative to fluazifop-P, sethoxydim and quizalofop. Halosulfuron and s-metolachor are discussed below, as is imazosulfuron, which is in the early stages of evaluation in the United States for its efficacy in cucurbits.

6.3.1. Halosulfuron

Halosulfuron shows promise for its ability to control grass *and broadleaf* weeds within cucurbit crops in the United States. Halosulfuron was studied in the US as a replacement for methyl bromide (a fumigant) for controlling nutsedge (*Cyperus* spp.) in vegetable crops (Webster and Culpepper 2005). Brandenberger *et al.* (2005) researched the effects of halosulfuron treatments in commercial honeydew (*Cucumus melo*) crops in three US states, both on the crop itself and on three weeds: yellow nutsedge (*Cyperus esculentus*), golden crownbeard (*Verbesina encelioides*) and tumble pigweed (*Amaranthus albus*). Golden crownbeard and tumble pigweed are both broadleaf plants. *Amaranthus* spp. are present in cucurbit crops in Australia (Wright 2000; Nagle 2008).

Brandenberger *et al.* (2005) found that application of halosulfuron to a honeydew crop post-emergence reduced crop growth and caused some yellowing of foliage, however the crop recovered quickly and no difference was recorded in yield, earliness, or percentage of marketable fruit. Furthermore, halosulfuron was estimated to have controlled 85-97 per cent of yellow nutsedge, achieved complete control of golden crownbeard, and controlled 83-95 per cent of tumble pigweed. Comparative studies of the effectiveness of halosulfuron on golden crownbeard were not available, however halosulfuron was noted in other studies to have variable efficacy of control for tumble pigweed, ranging from 33-86 per cent control. It was suggested that this variability may have been associated with the growth stage of tumble pigweed in each study (Brandenberger *et al.* 2005).

A number of other studies in the United States have explored the potential of halosulfuron as a pre- and post-emergence herbicide for various cucurbit crops. Trader *et al.* (2008) found that halosulfuron was effective at controlling smooth pigweed (*Amaranthus hybridus*) pre-emergence (in combination with clomazone and ethafluralin) and yellow nutsedge (*Cyperus esculentus*) post-emergence in summer squash crops. Some injury to yellow summer squash and zucchini plants was noted, but the plants quickly recovered. A related study found halosulfuron to be an effective herbicide for controlling a number of broadleaf weeds in cucumber and pumpkin crops without having a negative impact on crop yield (Trader *et al.* 2007). Indeed, cucumbers appear better able to tolerate halosulfuron treatment than squash (Webster *et al.* 2003; Webster and Culpepper 2005). Halosulfuron is more effectively used in watermelons pre-emergence. It has been found in a number of studies to damage watermelons when applied post-emergence, although the extent of damage depended on the stage it was used, with damage being greater in the first two weeks after emergence (Dittmar *et al.* 2010). However, it was found to be effective at controlling pigweeds, nutsedge, and cutleaf groundcherry (*Physalis angulata*) in watermelon crops (Shrefler *et al.* 2007; Macrae *et al.* 2008).

Halosulfuron is currently available in Australia from Globe and Rygel Australia, and is registered for post-emergence control of nutgrass and Mullumbimby couch (*Cyperus brevifolius*) in turf, cotton, sugarcane, corn and maize, and sorghum (Rygel 2010). The effectiveness of halosulfuron in suppressing or controlling *Amaranthus* spp. is significant since clomazone does not control this weed (Macleod *et al.* 2000). However, the Rygel representative we contacted indicated that they sell very little halosulfuron as there is no significant market for it in Australia, and as a result Rygel is not interested at this stage in developing the market for this product or conducting trial work and registration for particular situations such as cucurbits

6.3.2. Imazosulfuron

Imazosulfuron is currently in the early stages of evaluation in the United States for use in vegetable crops. It was originally developed for controlling broadleaf weeds and nutsedge in rice crops, and has also been trialled for controlling nutsedge in potato and Bermuda grass turf. Like halosulfuron, it is a sulfonylurea herbicide. Dittmar *et al.* (2010) studied the response of diploid watermelon to imazosulfuron. Some crop injury was recorded at various stages of crop growth, however at later stages of growth the plants showed a higher tolerance to imazosulfuron. Internal fruit quality was unaffected. Again, more research of the impact of this herbicide on various cucurbit crops, and its efficacy in controlling weeds, is needed.

Imazosulfuron is manufactured by Sumitomo, but is not currently imported into Australia by Sumitomo's Australian operation. We contacted Sumitomo Australia, and were advised that imazosulfuron has been trialed in Australia but was found to be ineffective in Australian conditions. Sumitomo therefore does not consider it worthwhile to import this product, or to pursue registration for use in Australian cucurbit crops.

6.3.3. S-Metolachlor

S-metolachlor (Dual Gold; distributed in Australia by Syngenta) is currently registered in Australia for a range of broadacre crop, turf and vegetable situations, either pre-emergence or immediately post-transplant (in the case of broccoli, brussel sprouts, cabbages and cauliflowers) (Syngenta 2010). As Table 6.1 shows, s-metolachlor is currently registered for use in the United States in pumpkin crops, but only as an inter-row/inter-hill herbicide. However, research by Sosnoskie *et al.* (2008) found that low rates of s-metolachlor applied post-emergence in summer squash crops had no discernible impact on yield. This herbicide is effective at controlling or suppressing many of the important weeds found in cucurbit crops in the US state of Georgia, where this study was carried out (Sosnoskie *et al.* 2008).

The s-metolachlor-based herbicide 'Dual' was evaluated by Macleod *et al.* (2000) for use either alone or as a tank mix with clomazone as a pre-emergent herbicide in pumpkin crops in Australia. S-metolachlor controlled a number of weeds effectively both alone and when mixed with clomazone, with an acceptable level of crop damage. Nonetheless, s-metolachlor remains unregistered for Australian cucurbit crops.

Our survey of chemical companies conducted as part of this scoping study (Appendix 3 of the final report) found that s-metolachlor had been deregistered for cucurbits following mis-use involving herbicide application combined with excessive irrigation, resulting in crop damage or retardation.

6.3.4. Bioherbicides

Several organic herbicides or 'bioherbicides' are available in the United States for organic producers, including citric acid, clove oil, cinnamon oil, and lemongrass oil. These can be used as a pre-emergent weed control method, having no residual impact on the crop once it germinates (Lanini 2009). Pine oil bioherbicide has been trialled in Australia for its comparative effectiveness in vegetable cropping, and was found to be as effective as steam weeding (Kristiansen and Smithson 2008; see also Section 5.13.2). Bioherbicides may have limited effectiveness in controlling grass weeds in comparison with broadleaf weeds, as the growing point of grass weeds is often concealed by new leaves (Kristiansen and Smithson 2008).

6.4. Biodegradable mulch films

6.4.1. Polymer-based films

Biodegradable starch-derived polymer mulches are proposed as an alternative to polyethylene plastic mulches. They are designed to degrade several months after being laid, so that they maintain sufficient weed control and moisture retention in crop, but degrade sufficiently that they may be cultivated into the field post-harvest, leaving no toxic residues or plastics in the soil (Heisswolf and Wright 2010).

These mulches have been under evaluation in Australia for more than a decade. At that time, though biodegradable polymer performed reasonably well as a replacement for plastic mulch in trials, it was a cost-prohibitive substitute, at $3,300/Ha compared with $860/Ha for plastic. Other problems identified at this time included the difficulties of laying biodegradable mulch effectively with existing equipment, and many products 'failing the biodegradability test' (Heisswolf and Wright 2010), generally by being only photodegradable. Even at this stage, however, polymer was considered the most promising alternative to plastic, assuming that price and laying difficulties could be overcome (Olsen *et al.* 2000; Table 5.2).

Since then, the price of Mater-Bi biodegradable polymer mulch has decreased significantly (due in part to manufacturing trials beginning in Australia using local raw materials), such that it is now about twice the cost of standard polyethylene – 15 micron Mater-Bi now costs approximately $0.44/m, while polyethylene costs between $0.17m and $0.23/m, not including disposal costs estimated at about 50% of the cost of purchasing the mulch (Heisswolf and Wright 2010).

A HAL-supported trial of biodegradable mulch options is currently underway, being conducted by HFS Agri-Science Qld near Bowen, in North Queensland (Heisswolf and Wright 2010). Two generations of Mater-Bi polymer (one manufactured in Italy, the other in Australia) are being trialled, competitor products Biopak and Biograde, as well as EcoCrop, a paper-based product manufactured in New Zealand. This trial is discussed in more detail below.

Another biodegradable mulch option has been developed in the UK by Terraseed (2010). This product includes a top layer of degradable plastic and a second layer of absorbent material, with crop seeds placed in rows between the two layers. The product is laid out in the crop row, and when irrigated the seeds germinate through slits cut in the top degradable plastic layer. In addition to controlling weeds within the crop rows, Terraseed has additional benefits to growers including moisture retention and reduced evaporation, ensuring that crops germinate evenly, and preventing soil contamination. As a degradable material, Terraseed can also be cultivated into the soil after harvest (Terraseed 2010; Horticulture Australia 2005). Terraseed does not appear to be in use in Australia at present, and is not being evaluated in the Queensland trial (Heisswolf *et al.* 2010; DEEDI 2010).

6.4.2. Paper-based films

AgNOVA is currently developing a biodegradable starch (paper) mulch film in conjunction with Peracto. AgNOVA expects to commercialise this product in late 2011 (Thomas pers. comm.). Little information is available on the product at this stage.

6.4.3. Biodegradable weed mats

The CSIRO Future Manufacturing Flagship has recently partnered with two garden product companies to convert agricultural waste into biodegradable weed mats. The benefits of these mats, which are constructed from crop stubble (including linseed, flax and industrial hemp), is that they allow rainfall through onto the soil, while minimising soil evaporation, encouraging worm activity, and suppressing weed growth. At the time of writing (July 2011), field trials were about to be conducted, and economic analysis conducted to determine the net economic impact on producers (CSIRO 2011).

6.4.4. Australian field trials

In early trials of biodegradable mulch films, Olsen *et al.* (2000) found that paper film had a number of disadvantages in comparison with standard plastic mulch, including its weight (being much heavier than plastic), cost of field application, a need to modify mulch applicators to prevent tearing while laying, tearing at plant, and a tendency to break down too quickly. In contrast, Mater-Bi biodegradable polymer performed reasonably well, and apart from its cost-effectiveness it was considered by Olsen *et al.* (2000) to have potential to replace conventional plastic mulch.

Mater-Bi product testing in 2009 by Heisswolf *et al.* (2010) showed that this product appears capable of being laid with most (but not all) conventional polyethylene-laying equipment, and that in cropping trials (where it was laid up to six weeks before planting), it performed adequately, being likely to provide adequate cover for up to four months assuming it was not damaged greatly by laying activities or by animals. Further trials in 2010 confirmed the performance of Mater-Bi (DEEDI 2010).

Nonetheless, Heisswolf *et al.* (2010) have identified a number of technical limitations associated with Mater-Bi that may be overcome with more trial work:

- Modifications will be required to some plastic mulch laying equipment to lay Mater-Bi without significant damage.
- Growers need to remain vigilant during laying to avoid damaging the mulch, as it is considerably thinner than conventional plastic.
- Hard ground may need to be irrigated before laying to avoid wheel damage to the mulch.
- The mulch should not be laid more than four weeks before crop planting. Crops that produce shade (such as cucumbers and melons) may extend the life of Mater-Bi by reducing photo-degradation.
- The product needs to be less than six months old (manufacturing date), and stored in a cool shaded area to maximise its integrity.
- The product may not perform well on some soil types.

A similar product, BioPak, was evaluated, and while it performed well it was not quite as effective as Mater-Bi (DEEDI 2010).

Ongoing research and decrease in price over the past decade suggest that biodegradable film mulches such as Mater-Bi, while still relatively expensive, are getting closer over time to being an economically viable alternative for growers to plastic mulch. The improved relative economic viability of biodegradable film mulches in the near future may result from a growing supply in Australia (particularly as local manufacturing capacity increases), while disposal problems may increase the true cost of plastic relative to its biodegradable alternatives.

6.5. Greater organic integration in conventional cucurbit production

Rather than viewing conventional and organic weed control strategies (or 'productivity and sustainability') as mutually exclusive weed control approaches, Kristiansen *et al.* (1999) propose that purely conventional and purely organic approaches should instead be viewed at opposite ends of a continuum of crop (and weed) management options.

Considered in this way, weed management options commonly used in organic systems have the potential to expand the range of weed management options available to conventional growers, many of whom currently rely heavily on plastic mulch and drip irrigation, and pre-emergent herbicides. For example, stale and false seedbed techniques (discussed in Section 5.12) provide effective weed control pre- and early post-plant with reduced herbicide requirements. Since cases of herbicide resistance have already been found that are relevant to Australian vegetable producers, and since there is a risk of further herbicide resistance developing (see Section 6.1.1), practices that allow growers to reduce the amount of herbicide they use will extend the useful life of the limited range of herbicides currently available to cucurbit growers.

7. Conclusions

7.1. Current best practices and areas for improvement

Current best practice weed control on Australian cucurbit farms involves an IWM strategy incorporating a range of the techniques discussed in Chapter 5. Suitable techniques will vary from one cucurbit growing region and producer to another. Efficient weed control will involve techniques that have other production benefits, without adding disproportionately to the grower's input costs. For most conventional growers, plastic mulch with a drip-feed irrigation system, pre- and post-emergent herbicides, and chipping and hand-weeding within the crop rows, is the preferred approach.

Many growers who are firmly wedded to this conventional approach may not yet fully appreciate the potential benefits of expanding their range of weed control techniques, which could improve their capacity for controlling weeds (both broadleaf and grass) and reduce their reliance on repeated herbicide use, fumigation and conventional plastic mulch (see Section 5.15).

This review identified a range of Australian extension documents that briefly deal with weed impact and weed control techniques, either as a minor part of a broader discussion on cucurbit production, or as part of a discussion on weed control in horticulture or vegetable crops more generally. However, we generally found this information disparate and at times difficult to locate. A national best practice weed control guide for growers that draws this information together may help growers to implement an IWM strategy that is sustainable in the longer term.

Recommendation

The Vegetable Industry should explore whether producing a 'best practice guide' for weed control in cucurbit crops would benefit growers. The guide could be distributed to growers through local and regional grower groups, peak industry organisations such as AusVeg, and made freely available on the HAL web pages. Such a document could bring together the disparate 'best practice' sources available from various State and Territory and national sources and include details on emerging weed control techniques.

The needs of growers, gaps in knowledge, regional or situational requirements, and other best practice guide content may also be informed by the grower survey being conducted as part of this project.

7.2. Areas for future research

7.2.1. The impact of weeds on Australian cucurbit production

As is discussed in Section 3.5, little information is available about the impact of weeds on Australian cucurbit production. The available literature deals either with the direct economic costs of controlling weeds, or weeds as an important host for viruses, other diseases and pests.

Lack of information possibly reflects minimal research and R&D investment in the areas of weed impact and innovative control techniques in Australia's cucurbit crops. A greater understanding of impact may demonstrate the importance of effective weed control in cucurbits for improved yield, quality and profit margin for growers. We suggest that more effective weed control is an important issue for the cucurbit industry, but growers and representative bodies may not have enough information to quantify the importance of weeds across the industry, and to ensure this remains a high priority issue.

Recommendation

More research is required to determine more exactly the impact of weeds on Australian cucurbit crops. Potential areas of research include an economic impact study (including the direct costs of weed control and indirect costs associated with yield and quality decline), field work to determine the degree of yield and quality impacts in different cucurbit crops, and qualitative research to identify the crop management issues associated with weeds.

The grower survey being conducted as part of this project may shed some light on these issues, and help determine specific issues for more detailed impact research.

7.2.2. Herbicide evaluation

As far as we can determine, no research has been conducted into possible new herbicide options for use within cucurbit crops in Australia since 2000, when Serve-Ag Research (Macleod *et al.* 2000) evaluated a number of herbicides (Frost pers comm.). This work resulted in clomazone ('Command') and dimethenamid-p ('Frontier') being registered in Australia, giving growers greater flexibility in controlling broadleaf weeds at the post-plant pre-emergent stage. Clomazone was particularly significant since it was the first herbicide to be registered for broadleaf weed control in cucurbit crops (Horticulture Australia 2005).

Evaluation of the literature in the United States, however, suggests that a number of other pre-emergence herbicides may be suitable for research in Australia, as well as three post-emergent herbicides that have potential to control broadleaf weeds: halosulfuron, imazosulfuron, and s-metolachor (see Section 6.3). Research will need to determine, amongst other things, the effect on plant back of both halosulfuron and imazosulfuron in Australian conditions (Frost pers. comm.).

> ***Recommendation***
>
> *The Vegetable Industry should consider funding research into the post-emergent herbicides halosulfuron, imazosulfuron, and s-metolachlor, to determine their efficacy in Australian conditions.*

7.2.3. Climate change impact

More research is required to detail the potential impacts of changing climate on weed management issues for vegetable production (see Section 6.1.2). This may include mapping the potential distribution and density of weeds that are currently important to the industry, identifying weeds that may become more important due in part to changing climate, and identifying current weed management techniques (such as herbicide use), that may become less effective or require modification.

> ***Recommendation***
>
> *The potential impacts of climate change on Australia's vegetable industry, particularly as it pertains to weed management and the weed species that may be important for growers in a changing climate, needs to be explored further.*

7.2.4. Innovative techniques

Innovative weed control techniques in vegetable or cucurbit crops have been trialled outside Australia, and show some promise despite limited understanding of their effectiveness in Australia.

Although the economic viability of soil solarization has been questioned in Australia (Section 5.13.3), trials in the United States suggest it is an effective weed control technique. Australian research into soil solarization has been limited, and so further study may be required to determine whether the technique is economically viable and effective. The future viability of this technique may also be restricted by increasing disposal costs and social unacceptability of plastic waste products used in horticulture.

Further research is also required to explore other factors that improve the effectiveness of brassica cover crops as biofumigants, including factors such as soil nutrient levels, cover crop mixtures, management and selection of species, and development of low till and cover crop incorporation systems suitable to organic production (Kristiansen *et al.* 2005).

Similarly, bioherbicide research in Australia appears to be behind trial work overseas. A range of bioherbicide products are available. If they are effective, bioherbicides may give growers a safe and viable alternative to pre-plant, pre-emergence and in-crop spot spraying with synthetic herbicides.

Recommendation

More work is required to identify innovative weed control techniques either in use or being trialled overseas, and to explore the validity of these techniques in Australian circumstances. Since techniques such as plastic mulch, fumigation and herbicides may be restricted further in the near future, sustainable and effective alternatives may be required to maintain crop yield and quality.

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Attachment 1: 2008-09 State/Territory Production Estimates

Table A1.1 Estimated area, production, number of growers, and gross value of cucurbit production in Qld, 2008-09

Cucurbit category	Area (ha)	Production (tonnes)	No. of Growers	Gross Value ($M)
Cucumber (outdoor)	173	2,033.3	87	4.08
Cucumber (undercover)		3,363.3	25	6.76
Rockmelons & Cantaloupe	1,237	29,921.0	30	30.48
Bitter Melons	1	14.0	3	0.07
Honeydew Melons	206	3,309.0	7	3.28
Watermelons	2,298	60,088.0	190	41.72
Other Melons	141	5,290.0	13	5.35
Pumpkins	3,054	45,614.0	454	29.68
Zucchini and Button Squash	1,624	17,651.7	170	49.36
TOTAL	***8,734***	***167,284.2***	***979***	***170.78***

Table A1.2 Estimated area, production, number of growers, and gross value of cucurbit production in NSW, 2008-09

Cucurbit category	Area (ha)	Production (tonnes)	No. of Growers	Gross Value ($M)
Cucumber (outdoor)	43	397.0	84	0.83
Cucumber (undercover)		1,772.8	181	3.44
Rockmelons & Cantaloupe	1,022	17,198.0	63	19.89
Bitter Melons	4	15.0	1	0.08
Honeydew Melons	125	2,421.0	14	2.45
Watermelons	728	29,364.0	79	19.35
Other Melons	28	227.0	7	0.23
Pumpkins	1,322	25,005.0	214	14.46
Zucchini and Button Squash	232	1,333.1	257	4.13
TOTAL	***3,504***	***77,732.9***	***900***	***64.87***

Table A1.3 Estimated area, production, number of growers, and gross value of cucurbit production in WA, 2008-09

Cucurbit category	Area (ha)	Production (tonnes)	No. of Growers	Gross Value ($M)
Cucumber (outdoor)	32	516.7	24	1.97
Cucumber (undercover)		780.5	22	2.98
Rockmelons & Cantaloupe	487	10,105.0	49	10.62
Bitter Melons	6	57.0	4	0.30
Honeydew Melons	141	3,129.0	20	3.71
Watermelons	572	17,274.0	91	13.55
Other Melons	20	376.0	1	0.47
Pumpkins	778	18,527.0	148	14.36
Zucchini and Button Squash	103	1,537.9	63	3.25
TOTAL	***2,139***	***52,303.1***	***427***	***51.21***

Table A1.4 Estimated area, production, number of growers, and gross value of cucurbit production in NT, 2008-09

Cucurbit category	Area (ha)	Production (tonnes)	No. of Growers	Gross Value ($M)
Asian Gourds	27	133.6	6	0.69
Cucumber (outdoor)	6	127.3	5	0.28
Cucumber (undercover)		105.5	5	0.23
Rockmelons & Cantaloupe	120	3,132.0	6	4.06
Bitter Melons	30	171.0	10	0.88
Watermelons	470	18,293.0	13	15.43
Other Melons	11	80.0	8	0.08
Pumpkins	109	2,877.0	14	1.94
Zucchini and Button Squash	24	76.4	7	0.24
TOTAL	***797***	***24,996.7***	***75***	***23.84***

Table A1.5 Estimated area, production, number of growers, and gross value of cucurbit production in SA, 2008-09

Cucurbit category	Area (ha)	Production (tonnes)	No. of Growers	Gross Value ($M)
Cucumber (outdoor)	18	228.0	17	0.60
Cucumber (undercover)		2,537.3	93	6.83
Rockmelons & Cantaloupe	8	14.0	5	0.02
Watermelons	37	1,936.0	19	1.28
Other Melons	7	17.0	3	0.02
Pumpkins	193	5,965.0	90	4.51
Zucchini and Button Squash	66	1,457.6	46	5.68
TOTAL	***329***	***12,154.9***	***273***	***18.94***

Table A1.6 Estimated area, production, number of growers, and gross value of cucurbit production in Vic, 2008-09

Cucurbit category	Area (ha)	Production (tonnes)	No. of Growers	Gross Value ($M)
Cucumber (outdoor)	1	8.8	4	0.02
Cucumber (undercover)		50.3	4	0.10
Rockmelons & Cantaloupe	15	139.0	16	0.12
Watermelons	63	4,157.0	10	2.74
Pumpkins	242	4,174.0	122	2.92
Zucchini and Button Squash	167	1,868.7	58	2.47
TOTAL	***488***	***10,397.8***	***214***	***8.36***

Table A1.7 Estimated area, production, number of growers, and gross value of cucurbit production in Tas, 2008-09

Cucurbit category	Area (ha)	Production (tonnes)	No. of Growers	Gross Value ($M)
Cucumber (undercover)		21.7	4	0.05
Pumpkins	72	1,567.0	36	0.87
Zucchini and Button Squash	6	63.7	20	0.07
TOTAL	***78***	***1,652.5***	***61***	***0.99***

Sustainable broadleaf weed control in cucurbit crops:

Appendix 3 – survey of chemical company representatives

Prepared for Horticulture Australia Limited (VG10048)

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August 2011

Know-how for Horticulture™

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1. Currently registered herbicides

A review of chemical company web sites and discussion with representatives has identified a small number of herbicides, and one soil fumigant (Metham), currently registered for either pre- or post-emergence weed control in cucurbit crops in Australia (Table 1.1).

Table 1.1 Herbicides registered for use in cucurbit crops in Australia

Herbicide (Active Ingredient and trading name/s) and registered crops	Time of application and weeds controlled	Australian distributor
Fluazifop-P (Fuzilier; Fusilade Forte 128 EC) *Cucurbits, rockmelon, pumpkin, honeydew melon, watermelon, zucchini, squash, cucumber, gherkin*	Selective control of certain grasses *post-emergence* (after the 5 true leaf stage of the crop)	Ospray Pty Ltd; Syngenta
Sethoxydim (Sertin 186EC) *Butternut pumpkins, cucumbers, melons, pumpkins, zucchini*	Selective control of certain grasses *post-emergence*	Bayer Cropscience
Clomazone (Command 480EC) *Cucumber, pumpkin, kabocha squash, rockmelons, watermelon, zucchini*	Control of certain annual broadleaf weeds *post-plant pre-emergence*	FMC Chemicals/Serve-Ag
Quizalofop-P-Ethyl (Tzar) *Cucumbers, honeydew melon, pumpkin*	Selective control of certain grasses *post-emergence* (after the 5 true leaf stage of the crop)	DuPont
Dimethenamid-P (Frontier-P) *Pumpkin, kabocha squash*	Control of certain broadleaf and grass weeds *post-plant pre-emergence*	Serve-Ag/BASF
Metham sodium (Metham) *Pumpkin, kabocha squash*	Control of certain germinating weed seeds *pre-plant* (soil fumigant that also controls pests and fungus diseases)	NuFarm

2. Off-label herbicide tests and use

Representatives were asked whether they were aware of any off-label herbicide tests that have shown potential to control broadleaf weeds in cucurbit crops.

The Bayer representative understood that some off-label tests had been conducted of glufosinate-ammonium (Basta), and that this herbicide has been used 'in some circumstances'. Basta is a non-selective herbicide that is used in Australia mainly to control broadleaf and grass weeds in vineyards and orchards. The Bayer representative also suggested another non-selective herbicide, metrabuzin (Sencor), but suggested that this and Basta would need to be used with caution.

NuFarm have trialled several of their products, particularly for inter-row applications in cucurbit crops. However, in each case the herbicide caused damage to the crop: the plant runners were susceptible to uptake of the product once they had reached the inter-row space where the herbicide had been applied.

Syngenta indicated that some growers are using s-metolachlor (Dual Gold) off-label to control weeds in cucurbits, with varying success. This herbicide was registered for use in cucurbit crops several years ago, however Syngenta approached the AVPMA to have the product de-registered for cucurbits following several cases of product mis-use which led to severe crop retardation.

3. Testing currently available products

The representative from Sumitomo Australia was not aware of any tests but suggested that clethodim (Status) may be worth testing. Status is a post-emergent selective herbicide that has been registered for control of grasses in several vegetable crops other than cucurbits.

Dow AgroSciences distribute haloxyfop (Verdict), a selective grass weed herbicide used in lucerne, clover and tree fruit situations. However their representative did not suggest that trials or registration be pursued for cucurbits, because the cucurbit industry market size is considered too small to make it profitable to pursue licencing and registration costs.

No other company representatives contacted identified a product that could be tested in cucurbits.

4. Products available in the near future

None of the representatives could identify a product that may be available in the near future to control weeds in cucurbit crops.

5. Potential new post-emergence herbicides

Three post-emergence herbicides currently used in the United States that have not yet been registered for cucurbit crops in Australia were identified in the literature review: clethodim, halosulfuron and s-metolachor. Imazosulfuron is in the early stages of evaluation in the United States for its efficacy in cucurbits.

5.1. Clethodim

While Sumitomo (www.sumitomo-chem.com.au) considers clethodim (Status) worth testing in cucurbit crops, it does not currently plan to pursue development or registration of this product as it is not profitable for the company to do so. Nonetheless, clethodim may be a viable alternative to currently available selective grass weed control herbicides such as fluazifop-P, sethoxydim and quizalofop. Clethodim has already been registered in the US for use in cucurbits to control grass weeds, and is distributed in Australia by Generex and Rygel as well as Sumitomo.

5.2. Halosulfuron

Halosulfuron shows promise for its ability to control grass *and broadleaf* weeds within cucurbit crops in the United States. In Australia, halosulfuron is registered for post-emergence control of nutgrass and Mullumbimby couch (*Cyperus brevifolius*) in turf, cotton, sugarcane, corn and maize, and sorghum. Further details on halosulfuron studies in the United States are provided in Chapter 6 of the literature review.

Rygel Australia Pty Ltd (www.rygel.com.au) distributes halosulfuron in Australia as 'Gullf Ag Halosulfuron 750 WG'. However, the Rygel representative we contacted indicated that they sell very little halosulfuron as there is no significant market for it in Australia, and as a result Rygel is not interested at this stage in developing the market for this product or conducting trial work and registration for particular situations such as cucurbits.

5.3. S-Metolachlor

S-metolachlor (Dual Gold; distributed in Australia by Syngenta – www.syngenta.com.au) is currently registered in Australia for a range of broadacre crop, turf and vegetable situations, either pre-emergence or immediately post-transplant (in the case of broccoli, brussel sprouts, cabbages and cauliflowers). This herbicide has previously been evaluated in Australia in pumpkin crops with some success. Further details are included in Chapter 6 of the literature review.

The Syngenta representative suggested that s-metolachlor might be re-registered for cucurbit crops if there were appropriate use constraints imposed with registration (and listed on the product label), and if there was strong industry co-operation to ensure that cases of s-metolachlor mis-use did not occur as when it was previously registered for cucurbits. Mis-use involved herbicide application combined with excessive irrigation, and resulted in crop damage or retardation in some cases.

However, the representative also suggested that re-registration of this herbicide is a low priority for Syngenta, given previous problems and the fact that it is now off-patent.

5.4. Imazosulfuron

Imazosulfuron is currently in the early stages of evaluation in the United States for use in vegetable crops. It was originally developed for controlling broadleaf weeds and nutsedge in rice crops, and has also been trialled for controlling nutsedge in potato and Bermuda grass turf.

Imazosulfuron is manufactured by Sumitomo, but is not currently imported into Australia by Sumitomo's Australian operation. We contacted Sumitomo Australia, and were advised that imazosulfuron has been trialed in Australia but was found to be ineffective in Australian conditions. Sumitomo therefore does not consider it worthwhile to import this product, or to pursue registration for use in Australian cucurbit crops.

6. Potential new pre-emergence herbicides

6.1. Terbacil

Terbacil (Sinbar) is a selective residual pre-emergence herbicide registered for use in watermelon crops in the United States. It controls a variety of broadleaf weeds. Terbacil is distributed in Australia by AgNOVA (www.agnova.com.au).

We spoke to a representative of AgNOVA, and were advised that they are developing the market for this herbicide in other situations such as tree fruit, and are definitely prepared to look at developing the market further.

The representative was not aware that terbacil had been registered for use in watermelons in the US. Before trial and registration work commences, the representative suggested that AgNOVA would need to determine the potential market size to warrant the costs involved.

6.2. Ethalfluralin and Ethalfluralin + Clomazone

Ethalfluralin (Curbit) is registered in the United States as an at-plant pre-emergence herbicide to control annual grasses and broadleaf weeds in a variety of cucurbit crops. Ethalfluralin + Clomazone (Strategy) is similarly a pre-emergence herbicide registered in the US to control weeds in a variety of cucurbit crops. There is currently no Australian distributor for either product.

We contacted the US distributor of these two herbicides, Loveland Products (www.lovelandproducts.com). The company representative we spoke to indicated that there are no plans to register either product in Australia for at least the next year. However, they also advised that the parent company of Loveland Products (Agrium) recently purchased Landmark, a leading Australian agricultural supplies company. This relationship means that the Loveland Products range will be distributed in Australia by Landmark in the next year or two.

Consequently, these two herbicides have the potential to be registered in Australia, again depending on whether the level of demand warrants the costs associated with trials and registration.

7. Registration costs – an issue in the small Australian cucurbit market

Several chemical company representatives contacted indicated that the market size for their herbicide products in the Australian cucurbit industry would need to be large enough to warrant the cost involved with testing the product in various scenarios, and pursuing registration.

Additional herbicide options may offer cucurbit growers greater flexibility in their weed control program, and extend the useful life of the limited number of herbicides currently registered for cucurbit crops in Australia. If this is the case, financial and in-kind involvement from the Vegetable Industry may be required to offset registration and trial costs for herbicide distributors.

8. Summary – potential herbicide options

Table 8.1 Potential herbicide options for use in cucurbit crops in Australia

Herbicide (AI and trading name)	Weeds controlled	Has the product been trialled in Australia?	Australian distributor
Glufosinate-ammonium (Basta)	Non-selective grass and broadleaf control	Off-label tests conducted	Bayer
Metribuzin (Sencor)	Selective control of certain grasses and broadleaf weeds	No. Product would need to be used with caution	Bayer
Haloxyfop (Verdict)	Selective control of grass weeds	No. Product mentioned by representative but trial work not suggested	Dow AgroSciences
Clethodim (Status)	Selective control of grass weeds	No. Product worth testing but testing not currently planned by distributor	Sumitomo
Halosulfuron	Selective control of nutsedges and broadleaf weeds	No. No trials planned by distributor given that demand for product is currently low	Rygel
S-Metolachlor (Dual Gold)	Selective control of annual grasses and broadleaf weeds	Yes. Was previously registered in Australia for cucurbits until cases of mis-use led to its withdrawal. Still used off-label in some cases	Syngenta
Imazosulfuron	Selective control of annual grasses and broadleaf weeds	Yes. Trials conducted by distributor suggested herbicide ineffective in Australian conditions	Sumitomo
Terbacil (Sinbar)	Selective control of broadleaf weeds	No	AgNOVA
Ethalfluralin (Curbit)	Control of annual grasses and broadleaf weeds	No. No current Australian distributor. Perhaps Landmark in the next year or two	Loveland Products (US distributor)
Ethalfluralin + Clomazone (Strategy)	Control of annual grasses and broadleaf weeds	No. No current Australian distributor. Perhaps Landmark in the next year or two	Loveland Products (US distributor)

Sustainable broadleaf weed control in cucurbit crops:

Appendix 4 – producer survey results

Prepared for Horticulture Australia Limited (VG10048)

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Know-how for Horticulture™

Executive Summary

Producer profile

The most commonly grown crops amongst respondents included pumpkins, watermelons, zucchini and cucumbers.

Respondents generally have less experience growing cucurbits than they have in general agriculture. Cucurbit production appears to be a secondary or sideline form of production for many respondents, who often devote a much larger proportion of their land to other forms of production such as sugar cane or broadacre cereals. Cucurbit growing is an intensive form of production that delivers relatively high profits on a per hectare basis. This means that in some cases growers need only devote a small proportion of their land to cucurbit production (a mean of 36.5 per cent across the response group, ranging from a mean of 6.7 per cent for zucchini growers to 100 per cent for watermelon and gherkin growers). However, according to our discussion with growers and anecdotal evidence in the literature, growers derive a significant proportion of their income from cucurbit production.

Preferred sources of information on weed control amongst growers included commercial suppliers and their representatives, other farmers or neighbours, private agronomists/horticulturalists, booklets and fact sheets, and industry newsletters and magazines.

The impact of weeds

The economic impact of weeds on growers (measured in terms of weed control *cost*) appears to vary considerably depending on cucurbit crop type and perhaps the control strategy used (from around $500 per hectare to around $1,750 per hectare), although the low response to the survey makes it difficult to estimate average cost with any accuracy. The responses suggest that the cost of weed control may have increased a little over the past three years.

The majority of respondents have experienced crop management problems or reductions in crop yield as a result of having weeds in their cucurbit crop, while a significant minority have also witnessed an impact on crop quality. These impacts are difficult for growers to estimate in dollar amounts, however they appear to be significant, particularly when the costs of control, secondary impacts on management, and negative impacts on income (reduced yield and quality) are taken together.

Important weeds

The most problematic weeds amongst respondents include fat hen (*Chenopodium album*), blackberry nightshade (*Solanum nigrum*), caltrop or cathead (*Tribulus terrestris*), and pigweed/purslane (*Portulaca oleracea*), all of which are broadleaf weeds. Significant grass species include African lovegrass (*Eragrostis curvula*), and barnyard grass (*Echinochloa* spp.). Broadleaf weeds are a more significant problem in cucurbit crops than grass weeds, due to the availability of selective herbicides that are able to control grass species. Closely related cucurbit weeds did not appear to be particularly problematic in this survey.

Problems commonly attributed to broadleaf weeds by respondents include their ability to grow and spread quickly and out-compete the crop for resources, difficulty controlling the weeds (lack of herbicides and difficulty chipping), their ability to host pest insects and diseases, and physical characteristics such as prickles or thorns which make harvesting more difficult.

Though often less problematic, grass weeds are often able to spread quickly in the crop and produce many seeds (competing with the crop for resources), can be difficult to control with herbicides, make it difficult to lay plastic mulch if they have a significant presence on the crop beds, and, in the case of the grass-like sedge, nutgrass, are able to grow through plastic mulch.

Current weed control approaches

Respondents were asked to detail their current weed control strategy in their most important cucurbit crop.

Respondents overall considered themselves to have implemented a moderately successful weed control strategy. The most important factors for achieving success with weed control in cucurbits include timing of weed control, specifically to implement effective control of germinating weeds, and implementing the weed strategy during favourable weather conditions. Other specific weed control methods (such as chipping, herbicide use and cultivation) were commonly listed.

The most highly rated weed control methods, in terms of both affordability and effectiveness, included pre- and post-emergent herbicide, tillage/cultivation, plastic mulch, crop rotation, and chipping/hand weeding, suggesting that a large proportion of growers use a mixture of these approaches as part of an integrated strategy. The most *affordable* methods included tillage/cultivation, crop rotation and plastic mulch, while the most *effective* methods included plastic mulch, pre-irrigate spray/till, pre-emergent herbicides, and chipping/hand weeding.

Crop life stage and prevailing weather conditions were considered by the response group overall to be the most important agronomic factors influencing the effectiveness of herbicide use. *Timing* is particularly important in weed control activities, and relates to these and other factors considered by growers.

Approximately two thirds of respondents considered lack of herbicides to be a significant problem in their efforts to control weeds, suggesting that identifying more herbicide options for cucurbit growers may be considered a priority amongst growers. A number of respondents mentioned the lack of post-emergent broadleaf herbicide options in cucurbits as a major limiting factor in the effectiveness of herbicidal weed control. Growers distinguished between their ability to impose some control on grass weeds within their cucurbit crops using herbicides, but their inability to do so for broadleaf weeds.

About one third of survey respondents have experienced damage or reduced crop growth after using herbicides to control weeds in their main cucurbit crop. Examples included leaf damage and growth retardation that did not hinder the crop in the long term, residual damage from herbicides used to control weeds in the previous crop rotation, and damage from herbicides used to control weeds in the inter-row space.

Herbicide resistance appears to be an important issue, with approximately 20 per cent of respondents having observed reduced herbicide effectiveness in their main cucurbit crop, noting resistance or reduced effectiveness in grass weed species in particular. This is perhaps not surprising given that the limited range of herbicides available means that the same herbicide needs to be applied for a number of years in cucurbits, while cucurbits are often grown in rotation with cereal crops, where numerous cases of resistance have been documented. Respondents noted several cases of reduced effectiveness of herbicides in controlling specific weed species, such as summer grass and ryegrass, in their cucurbit crops.

Approximately 20 per cent had observed changes in herbicide use regulations, impacting on buffer zones, removing herbicide residues from crops for sale, drift management, recording herbicide use in spray diaries, and removal of some herbicides from permit lists.

Future weed control approaches

Out of a range of possible research priorities within the Australian cucurbit industry, the largest proportion of respondents felt that priority should be given to communication and extension of effective weed management strategies, and identifying new herbicides to use within cucurbit crops. A majority of respondents also felt that priority should be given to identifying non-herbicidal or organic weed control methods, and economically viable replacements for polyethylene plastic mulch. However, methods commonly used by organic growers, such as organic mulch, thermal weeding or stale seedbeds, were more likely to be considered unaffordable or ineffective by respondents.

Respondents appeared overall to be ambivalent about the feasibility of reducing herbicide use through other weed control methods, although clean farm hygiene was considered beneficial by one respondent who specifically listed this factor. However, growers appear more likely to embrace precision systems (including precision herbicide application as a way of reducing herbicide use), and plastic and biodegradable mulch, than adopting low till mulching systems, organic mulches and semi-permanent or permanent beds.

Less than 10 per cent of respondents had trialled a new herbicide in their cucurbit crops in the last five years. Of these, Frontier (dimethenamid) is currently registered for use in cucurbit crops in Australia, Dual Gold (s-metolachlor) was previously registered and has been withdrawn (although some off-label use continues), and Goal (oxyfluorfen) is not currently registered for use in cucurbit crops. Those respondents who trialled new herbicides found them to be only somewhat effective.

Recommendation

As it extends the findings of this and other relevant research to cucurbit growers, the Vegetable Industry should consider involving commercial suppliers such as rural merchandise stores and herbicide suppliers, both private and government agronomists and horticulturalists, and develop targeted booklets or fact sheets that may be distributed through these and other sources.

Recommendation

Weeds have a very significant impact on the productivity of Australian cucurbit crops, and that the most important weeds create a range of problems for growers in the areas of crop management and maintaining crop growth. Further research, perhaps in the form of case studies conducted on-farm, may quantify more specifically the impact of different weeds on a variety of cucurbit crop types. Specific research on the ecology and management of the most important weeds of cucurbit crops is also required.

Recommendation

Since it received a relatively high rating for affordability and effectiveness but has a low uptake, research and extension are required on the benefits of pre-sowing irrigation followed by tillage or herbicide application ('false seedbeds'), which has the potential to reduce the weed seed bank and weed germination during the life of the crop.

Recommendation

Lack of herbicides is a real impediment to maximising cucurbit production in Australia, and may become a more important issue in the future if reduced herbicide effectiveness or resistance becomes common. The survey suggests that a high priority for growers is to:

1. identify herbicides that may be used to control weeds within cucurbit crops, with little or no negative impact on crop plants, particularly for the control of broadleaf weed species; or

*2. identify non-herbicide weed control approaches, and develop these to the extent that their effectiveness is comparable to herbicide control, thereby giving growers a **viable** alternative to herbicide use. More detailed research may be needed in Australian conditions to evaluate the potential of non-herbicide methods.*

Clean farm hygiene should be researched and developed e.g. through successful farmer case studies that can be extended throughout the industry. Such an approach has proven highly successful in non-cucurbit horticulture.

A number of respondents had observed cases of herbicide resistance. Herbicide resistance testing may be required to gauge the ongoing effectiveness of herbicides registered for cucurbit crops.

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1. Producer profile

1.1. Experience

The data presented in Tables 1.1 and 1.2 was intended for use in identifying patterns in the response group by cross-tabulating these variables with others relating to weed impacts, management practices and so on. Unfortunately the small response received to the survey precluded such analysis.

Nonetheless, it is interesting to note that many respondents have less experience growing cucurbits than they have in agriculture more generally. More than 43 per cent of respondents had more than 30 years experience in agriculture, whereas just over 27 per cent had experience growing cucurbits.

Table 1.1 Respondent experience in agriculture

Years experience in agriculture (% of respondents) *(n = 46; mean = 30.09 years)*	
15 Years or Less	22.8
16-30 Years	34.1
More Than 30 Years	43.2

Table 1.2 Respondent experience growing cucurbits

Years experience growing cucurbits (% of respondents) *(n = 46; mean = 21.5 years)*	
< 5 Years	13.6
5-15 Years	29.5
16-30 Years	29.5
More Than 30 Years	27.3

1.2. Cucurbit growing area

Table 1.3 shows the mean area of respondents' main property (an option provided in the event that some respondents had more than one property.

A comparison with Table 1.4 suggests that cucurbit production is often a secondary or sideline form of production for landholders, who often devote a much larger proportion of their land to other forms of production. It is important to note however that cucurbit growing is an intensive form of production, and that in some cases producers may only devote a small proportion of their land to cucurbit production, but derive a significant proportion of their income.

Table 1.3 Mean area of main property

Mean area (hectares) of main property			
	Mean Ha.	*Median Ha.*	*n*
NSW	193.4	60.0	11
QLD	123.6	51.7	10
WA	85.3	52.7	14
VIC	66.3	5.0	3
SA	15.7	5.6	3
TAS	2.4	2.4	1
Total	*114.4*	*46.5*	*42*

Table 1.4 Mean area under each cucurbit crop

Mean area (hectares) over the last three seasons under each cucurbit crop						
	Mean Property Ha.	*Median Property Ha.*	*Mean Crop Ha.*	*Median Crop Ha.*	*Mean % of Property Producing Cucurbits Ha.*	*n*
Pumpkin (inc. Gramma)	127.5	57.5	9.0	4.0	7.0	31
Zucchini	49.0	40.5	3.3	2.0	6.7	13
Squash or Marrow **	396.9	44.5	144.0	1.6	36.3	7
Cucumber (field grown)	65.2	44.5	2.1	0.5	3.2	9
Watermelon	25.1	5.6	25.1	5.2	100.0	17
Rockmelon	49.0	44.5	15.7	0.7	32.0	8
Honeydew melon	73.8	61.0	5.1	5.1	6.9	3
Gherkin	0.2	0.2	0.2	0.2	100	1

*** The figure for Squash or Marrow is heavily influenced by the one respondent who had 1,000 hectares under a Squash or Marrow crop. With this figure taken out the mean property Hectare figure is 1.35.*

1.3. Most important cucurbit crop

The number of landholders producing each type of cucurbit (Table 1.5) indicates that landholders prefer to produce pumpkins, watermelons, zucchini and cucumbers, a possible reflection of the value of these types as a proportion of Australia's cucurbit production (see Chapter 3 of the literature review).

Table 1.4, above, similarly shows that larger areas of land are dedicated amongst the response group to production of pumpkin, watermelon and rockmelon than other cucurbit types.

Table 1.5 Most important cucurbit crop grown

Most important cucurbit crop grown (% of respondents) (n = 38)	
Pumpkin (inc. Gramma)	42.1
Watermelon	21.1
Zucchini	15.8
Cucumber (field grown)	7.9
Squash or Marrow	5.3
Rockmelon	5.3
Gherkin	2.6

1.4. Information about weeds

Growers were asked to identify which sources they use to find out more information about weed control in cucurbit crops. As Table 1.6 suggests, the most important sources of information to growers are commercial suppliers and their representatives and other farmers or neighbours, while other important sources include private agronomists/horticulturalists, booklets and fact sheets, and industry newsletters and magazines.

This data will be significant for HAL as it plans the most effective way to extend the findings of this and other relevant research to cucurbit growers. It indicates that an effective extension strategy will need to involve commercial suppliers such as rural merchandise stores and herbicide sellers and both private and government agronomists and horticulturalists, and develop targeted booklets or fact sheets that may be distributed through these and other sources. The internet is also a relatively important source of information for growers, though perhaps less than may have been expected.

Table 1.6 Sources of information about weed management

Sources of information about weed management used (% of respondents) (n = 46)	
Commercial suppliers and representatives	65.2
Other farmers/neighbours	50.0
Private agronomists and horticulturalists	34.8
Booklets and fact sheets	32.6
Industry newsletters or magazines	32.6
Workshops and field days	19.6
Government web sites	13.0
Industry web sites	13.0
Conferences and courses	10.9
Government extension professionals	10.9
Internet search	4.3

2. The impact of weeds

2.1. Economic impact

Table 2.1 shows the mean estimates of costs per hectare for controlling weeds in several cucurbit crops. We suggest that due to the low response to the survey, it is difficult to use these data to provide an accurate estimate of cost.

Nonetheless, it is relevant to note that the mean cost is not too dissimilar for pumpkin, watermelon and cucumber producers surveyed (from approximately $500-$650 per hectare), of which there were more producers than for most other cucurbit types. The weed control cost estimates provided in section 3.1 of the literature review suggest that factors such as type of cucurbit crop and the type of weed control methods used (e.g. plastic mulch or herbicide) will have a significant impact on weed control costs per hectare.

It is also important to note that practices such as using plastic mulch have benefits other than for weed control, and so it is difficult for growers to disaggregate the various benefits of a management practice from the cost involved for putting the practice into place. According to respondents, it is cheaper to control weeds in the more commonly grown cucurbits (Table 1.5), other than perhaps zucchini, than the less commonly grown cucurbit crops such as squash, rockmelon, honeydew melon and gherkin (Table 2.1).

Respondents indicated that weed control costs have increased on average over the last three years, though half of the respondents said that costs had stayed about the same. Only two respondents considered that weed control costs had decreased. This may be due to changes in their weed control strategy, to using more cost-effective methods.

Table 2.1 Estimated costs associated with weed control

Estimated costs associated with weed control ($/Ha.)		
	Mean $/Ha.	*n*
Squash or Marrow	$1,750.00	2
Rockmelon	$1,440.00	5
Zucchini	$1,072.86	7
Honeydew melon	$1,066.67	3
Gherkin	$1,000.00	1
Cucumber (field grown)	$651.43	7
Watermelon	$613.08	13
Pumpkin (inc. Gramma)	$500.80	25

Table 2.2 Change in the cost of weed control over the past three years

Change in the cost of weed control over the past three years (% of respondents) *(n = 36)*	
Increased	44.4
Stayed about the same	50.0
Decreased	5.6

2.2. Impact on yield, quality and management

The literature identified that the impacts of weeds in cucurbit crops include impacts on yield (reduction), impacts on quality (fruit size or appearance), and impacts on the ability of the grower to manage their crop. As Table 2.3 shows, respondents to the survey considered management difficulties to be the most significant impact of weeds on their cucurbit crops (nearly 72 per cent), although over half of respondents also considered impacts on yield to be important. Just under 40 per cent of respondents had experienced a reduction in crop quality. Respondents were given the option to note other types of impacts, with suggestions including difficulty harvesting, an increase in pests and diseases, and cost.

Respondents were also asked to comment on these issues (Table 2.4).

- *Management made more difficult:* weeds making harvesting more difficult (particularly in the case of more mature weeds) by interfering with harvesting equipment or providing a physical barrier for pickers (e.g. in the case of weeds that have burrs or sharp spines), adding to the time and costs associated with managing the crop because of the various control measures required (including measures to control the increased number of pests and diseases in the crop associated with weeds), while weeds also appear to be an issue at crucial times of the season – 'weeds become prolific after fruit set when plants start to die off, and after rain'.
- *Reduction in yield:* this occurs due to weeds out-competing the crop for light, nutrients and water, reducing not only the quantity of fruit set but also the size of the fruit. One respondent estimated that weeds had resulted in a reduction of between 20 and 50 per cent of their yield. Another suggested that the presence of weeds reduces crop yield indirectly due to crop damage associated with weed control measures, particularly during wet weather.
- *Reduction in quality:* some respondents appear to have understandably interpreted reduction in fruit size, as well as reduction in the productivity of the crop as a whole, to be a quality issue as well as a yield issue. However, one respondent did note that particular weeds result in marking of fruit.

Table 2.3 Types of impacts weeds have had on cucurbit crops

Type of impacts weeds have had on cucurbit crops (% of respondents) *(n = 46)*	
Management of crop made more difficult	71.7
Reduction in yield	58.7
Reduction in quality	39.1
Difficulty harvesting	4.3
Increased pests/diseases	4.3
Cost	2.2

Table 2.4 Respondent descriptions of important weed impacts on cucurbit crops

	Types of impacts of weeds on cucurbit crops
Impact/s	*Description of important impacts*
Management more difficult	Difficulty in harvesting, too many weeds make picking harder Hard to control weeds, need to be taken out manually, time consuming Weeds grow along trickle lines, weeds become prolific after fruit set when plants start to die off, and after rain
Yield reduction	Weeds will out-compete crop sometimes by two fold.
Yield reduction, Management more difficult	Attraction of some grubs and insects Grass and wild radish Much more chipping Prevents planting in ground that is known to have weeds Reduction in yield means less profit, increase in costs i.e. labour, chemicals, diesel, environmental impact from chemicals, diesel fumes Very hard to harvest, pickers miss zucchini in the mass of weeds, weeds compete with zucchini for nutrients and water Weed control especially in wet conditions affects yield and quality Weeds compete for moisture etc, reducing yield, harvesting is more difficult if crop overgrown with weeds
Yield reduction, Quality reduction	Overcrowding affecting yield and marking from some weeds A lot of weeds means a lot less crop and smaller fruit
Yield reduction, Quality reduction, Management more difficult	Time spent pulling weeds in the glasshouses, mowing and slashing Competes for moisture, nutrient, sunlight Harvest made slow and difficult, yield losses by 20-50%, size of product reduced significantly Melons do not grow as well where there are a lot of weeds, not sure whether weed growth is due to unhealthy melon plants or whether weeds decrease vigour of melon plant then take over Reduction in yield, all fertilizers and nutrients consumed by weeds Stains on produce Weeds block light and use up fertiliser, reducing fruit set, ripening and size, difficult to harvest when weeds are mature and thick, deadly nightshade major host for white fly
None	We control our weeds as a priority so they have had no impact on our crops, otherwise all of the impacts listed would apply

3. Important weeds

Respondents were asked to list up to five weeds which they considered to cause the most problems in their cucurbit crop, and to comment as to why each was considered a problem weed. Weeds were listed by respondents in order of importance.

Each of the weeds identified by respondents is listed in Table 3.1, though because respondents only provided common names, botanical names have been inferred. In most cases we are confident of the species identification and certainly for the dominant weeds. It is evident that growers are required to manage a large number of weed species, although the species listed and their relative importance will be related to factors such as geographic location and cucurbit crop/s grown.

However, of the individual weeds listed, the most commonly problematic amongst respondents include fat hen (*Chenopodium album*), blackberry nightshade (*Solanum nigrum*), caltrop or cathead (*Tribulus terrestris*), and pigweed/purslane (*Portulaca oleracea*), all of which are broadleaf weeds. Significant grass species include African lovegrass (*Eragrostis curvula*), and barnyard grass (*Echinochloa* spp.).

Blackberry nightshade and fat hen are considered particularly important weeds amongst respondents, given that their mean importance score places them, on average, as either the most important or second most important weed out of the up to five weeds that it was possible to list (Table 3.1). Though not as common, pigweed and *Amaranthus* were also very important for some growers.

In Table 3.2, weeds have been categorised into families, showing that Poaceae are the most common weed family (due to the variety of grass weeds listed by respondents), followed by Chenopodiaceae and Portulacaceae. Although the Cucurbitaceae family contains a number of weed species, and closely related weeds can often be more troublesome to control, cucurbit weeds did not appear to be particularly problematic in this survey. Annual weeds are a more significant problem for respondents than biennial or perennial weeds (Table 3.3), a result of the greater selective pressure for annual weeds that results from frequent disturbance in a cucurbit production system. Broadleaf weeds are also a more significant problem than grass weeds (Table 3.4).

Respondents were asked to suggest why each of the weeds was considered a problem in their crop. Not all respondents who listed weeds included a comment, but below is a summary of responses for some of the most frequently listed weeds in the data.

- *Fat hen:* four respondents indicated that this weed is a problem as it is able to out-grow the cucurbit crop, while three respondents also said that fat hen competes with the crop for nutrients, light and moisture. The size and rapid growth rate of this weed makes it quick to establish, and difficult to control by chipping. One respondent suggested that fat hen had a competitive advantage in dry conditions.
- *Blackberry nightshade:* this is also a large weed that, according to several respondents, grows rapidly and is able to out-compete cucurbit vines. Other problems associated with blackberry nightshade include its ability to host pests such as white fly, and its association with fruit contamination or staining.

- *Caltrop/cathead:* three respondents indicated that this weed makes life difficult for pickers because of its prickles. Others suggested that it is a problem as it germinates and grows quickly, and is able to grow through the cucurbit crop.
- *Pigweed/purslane:* spreads quickly, due in part apparently to the large number of seeds it produces. One respondent noted that it harbours pests (in this case, caterpillar moths) and another suggested that it spreads quickly in the inter-row space, presumably making it more of a management issue for that respondent rather than a crop yield or quality issue.
- *African lovegrass:* this weed is considered to grow quickly and have high potential for seeding or regrowth (presumably after herbicide application), and causes problems for fruit pickers.
- *Miscellaneous grasses and sedges:* respondents commented that grass weeds spread vigorously, compete for nutrients and water, are difficult to control with spray, and make it difficult to lay plastic mulch at planting. One respondent noted that nutgrass is able to grow through plastic mulch, although this issue was not mentioned as frequently as may have been expected given that this issue is covered in the literature (see literature review section 5.3.1.).

Table 3.1 Weeds that cause the most problems – all species

Weeds that cause the most problems (multiple response)			
	% of responses	*Mean importance (where "1" is "worst weed")*	*n*
Fat hen (*Chenopodium album*)	13.0	2.3	17
Grass (misc)	10.7	2.8	14
Blackberry nightshade (*Solanum nigrum*)	9.2	1.8	12
Broadleaf weeds (misc)	6.9	3.1	9
Caltrop or Cathead (*Tribulus terrestris*)	6.1	2.8	8
Pigweed or purslane (*Portulaca oleracea*)	6.1	2.1	8
Wireweed or hogweed (*Polygonum aviculare* or *Polygonum arenastrum*)	4.6	2.7	6
Amaranthus (several)	3.1	1.5	4
African lovegrass (*Eragrostis curvula*)	2.3	2.3	3
Barnyard grass (*Echinochloa* spp.)	2.3	2.0	3
Bathurst burr (*Xanthium spinosum*)	2.3	3.0	3
Castor oil plant (*Ricinus communis*)	2.3	2.3	3
Nutgrass (*Cyperus rotundus*)	2.3	2.7	3
Redshank (*Persicaria maculosa*)	2.3	2.0	3
Wild radish (*Raphanus raphanistrum*)	2.3	2.3	3
Farmer's friend or cobbler's pegs (*Bidens pilosa*)	1.5	2.0	2
Fleabane (*Conyza* spp.)	1.5	2.0	2
Mallow (*Malva parviflora*)	1.5	1.5	2
Milk thistle (*Sonchus oleraceus*)	1.5	3.0	2
Potato weed (*Galinsoga parviflora*)	1.5	2.0	2

Weeds that cause the most problems (multiple response) – *continued*			
	% of responses	*Mean importance (where "1" is "worst weed")*	*n*
Wild gooseberry (*Physalis minima*)	1.5	1.0	2
Wild melon or Afghan melon (*Citrullus lanatus*)	1.5	4.0	2
Apple of Peru (*Nicandra physalodes*)	0.8	1.0	1
Bell vine (*Ipomoea plebeia*)	0.8	1.0	1
Black crumbweed (*Chenopodium melanocarpum*)	0.8	2.0	1
Blue billygoat weed or blue top (*Ageratum houstonianum*)	0.8	3.0	1
Bluebell creeper (*Billardiera heterophylla*)	0.8	3.0	1
Chickweed (*Stellaria media*)	0.8	4.0	1
Crowsfoot or crab grass (*Eleusine indica*)	0.8	2.0	1
Hibiscus or bladder ketmia (*Hibiscus trionum*)	0.8	1.0	1
Mintweed (*Salvia reflexa*)	0.8	1.0	1
New Zealand spinach (*Tetragonia tetragoniodes*)	0.8	3.0	1
Rhodes grass (*Chloris gayana*)	0.8	2.0	1
Sand burr (*Cenchrus longispinus*)	0.8	3.0	1
Sesbania (*Sesbania cannabina*)	0.8	5.0	1
Shepherd's purse (*Capsella bursa-pastoris*)	0.8	3.0	1
Silverleaf nightshade (*Solanum elaeagnifolium*)	0.8	1.0	1
Wild carrot (*Daucus carota*)	0.8	3.0	1
Wynn cassia (*Chamaecrista rotundifolia*)	0.8	2.0	1
Thistles (misc)	0.8	3.0	1

Table 3.2 Weeds that cause the most problems – by family

Weeds that cause the most problems (by family, multiple response)			
	No. species mentioned in family	*% of responses*	*n*
Poaceae	6	17.7	23
Chenopodiaceae	2	13.8	18
Portulacaceae	1	13.0	8
Solanaceae	5	12.3	16
Asteraceae	6	9.9	13
Misc. broadleaf	n/a	6.9	9
Zygophyllaceae	1	6.1	8
Amaranthaceae	1	3.1	4
Brassicaceae	2	3.1	4
Cyperaceae	1	2.3	3
Euphorbiaceae	1	2.3	3
Malvaceae	2	2.3	3
Fabaceae	2	1.6	2
Cucurbitaceae	1	1.5	2

Weeds that cause the most problems (by family, multiple response) – *continued*			
	No. species mentioned in family	*% of responses*	*n*
Aizoaceae	1	0.8	1
Apiaceae	1	0.8	1
Caryophyllaceae	1	0.8	1
Convulvulaceae	1	0.8	1
Lamiaceae	1	0.8	1
Pittosporaceae	1	0.8	1

Table 3.3 Weeds that cause the most problems – by perenniality

Weeds that cause the most problems (by perenniality, multiple response)			
	No. species mentioned in category	*% of responses*	*n*
Annual	22	56.1	73
Biennial/perennial	16	26.2	34
Misc. uncategorised broadleaf	n/a	6.9	9
Misc. uncategorised grass	n/a	10.7	14
Misc. uncategorised thistles	n/a	0.8	1

Table 3.4 Weeds that cause the most problems – broadleaf or grass

Weeds that cause the most problems (multiple response)			
	No. species mentioned in category	*% of responses*	*n*
Broadleaf	33	41.5	105
Grass	7	34.1	26

Table 3.5 Why certain weeds cause problems

Why do certain weeds cause the most problems in cucurbit crops?	
Weed	*Why the weed causes problems*
African lovegrass (*Eragrostis curvula*)	Grows quickly, seeds regrowth Problem for pickers
Amaranthus (several)	Harbours caterpillar inside stem, competes with cucurbits for water and nutrients Large bushes, crowding out cucurbits Prolific seeder, very fast growth, long growing season, spreads quickly
Apple of Peru (*Nicandra physalodes*)	There is no weedicide available
Barnyard grass (*Echinochloa* spp.)	Does not cause problems but is a control focus
Bathurst Burr (*Xanthium Spinosum*)	Competition
Bell vine (*Ipomoea plebeia*)	It is quick growing and overgrows crop in a short time

Why do certain weeds cause the most problems in cucurbit crops? – *continued*	
Weed	*Why the weed causes problems*
Black crumbweed (*Chenopodium melanocarpum*)	Loss of yield and difficult to roll mulch
Blackberry nightshade (*Solanum nigrum*)	Competition and contamination Grows rapidly, quite large, drops seed, competes for nutrients Harbours pests and hard to walk through and work in pumpkins, mainly a problem where you can't control because of weather conditions Host for white fly Large bushes, crowding out/out-competing cucurbits (3 responses) No effective post- or pre-emergent control Staining/contamination (2 responses) Unable to control with spray
Bluebell creeper (*Billardiera heterophylla*)	Outcompetes vine
Broadleaf weeds (misc)	Downy mildew Fast growing and bulbs come fast Grows tall and vigorous Spreads out Too many seeds Unable to control with spray Woody tap roots
Caltrop/Cathead (*Tribulus terrestris*)	Does not cause problems but is a control focus Germinates quickly after rain, also grows through the crop Grows rapidly and shades everything out, and uses valuable moisture Make it difficult for pickers/prickles (3 responses) Not controlled by DUAL
Castor Oil Plant (*Ricinus communis*)	Does not cause problems but is a control focus It grows so fast it smothers the pumpkin vine Unable to control with spray
Crowsfoot/Crab grass (*Eluesine indica*)	Forms thick stands if not brought into check, showing resistance to glyphosate and Basta
Farmer's friend/Cobbler's pegs (*Bidens pilosa*)	Makes harvest very hard Makes harvesting unpleasant, seed adhere to clothing and cause skin irritation
Fat hen (*Chenopodium album*)	Can out-grow crop/vines (4 responses) Does not cause problems but is a control focus Germinates quickly after rain and grows rapidly (2 responses) Competes for nutrients/moisture/light (3 responses) A nuisance plant Hard to get good control due to dry conditions Large plant once established/difficult to chip (2 responses) Totally takes over, not sure what spray works well Unable to control in pumpkins
Fleabane (*Conyza* spp.)	Competition Difficult to kill

Why do certain weeds cause the most problems in cucurbit crops? – *continued*

Weed	*Why the weed causes problems*
Grass (misc)	Coming into hot houses and in outside crops, hard to remove successfully Competes for nutrients and water Competition Difficult to roll mulch It grows so fast it smothers the pumpkin vine (2 responses) Nuisance grass prickle that attaches to clothing and socks in very high numbers Over populates Takes over at an early stage Unable to control with spray Virulent spreader, competes vigorously, problem when moving from cane to cucurbits or close to headlands (worse in watermelon)
Mallow (*Malva parviflora*)	Hard to pull out with long tap roots Pre-emergent herbicides have little effect
Milk thistle (*Sonchus oleraceus*)	Fast spreader, can grow higher than cucurbit crop, can overtake cucurbit crop Large bushes, crowding out cucurbit
Mintweed (*Salvia reflexa*)	Fast spreader, can grow higher than cucurbit crop, can overtake cucurbit crop
New Zealand spinach (*Tetragonia tetragoniodes*)	Quick growing
Nutgrass (*Cyperus rotundus*)	Competes for moisture Growing through the plastic and severely competing with the cucurbits
Pigweed/purslane (*Portulaca oleracea*)	Can choke out watermelon plants, competes for nutrients Can take over the crop Mainly in the inter-row, spreads rapidly, harbours caterpillar moths (web worm) Too many seeds
Potato weed (*Galinsoga parviflora*)	It grows so fast it smothers the pumpkin vine There is no weedicide available
Redshank (*Persicaria maculosa*)	Competes for nutrients and water Outgrows crop Unable to control with spray
Rhodes grass (*Chloris gayana*)	Grows strongly with water and heat
Sand burr (*Cenchrus longispinus*)	Prickles
Sesbania (*Sesbania cannabina*)	In clay areas after wet, tall, becomes a problem with the Micronaire sprayer fans
Shepherd's purse (*Capsella bursa-pastoris*)	Fast spreader, can grow higher than cucurbit crop, can overtake cucurbit crop
Silverleaf nightshade (*Solanum elaeagnifolium*)	Competition
Thistles (misc)	Hard to get good control due to dry conditions
Wild gooseberry (*Physalis minima*)	Grows over crop Very big weed

Why do certain weeds cause the most problems in cucurbit crops? – *continued*	
Weed	*Why the weed causes problems*
Wild melon/Afghan melon (*Citrullus lanatus*)	Hard to see initially and reseeds well Wipes out the melon crop, takes over
Wild radish (*Raphanus raphanistrum*)	Use more water
Wireweed/hogweed (*Polygonum aviculare/Polygonum arenastrum*)	Covers a wide area Fast spreader, can grow higher than cucurbit crop, can overtake cucurbit crop Hard to get good control due to dry conditions Not so bad, tangles with melon plants Smothers We spray with Sprayseed down furrows and it only burns then grows back

4. Current weed control approaches

4.1. Weed control success

In the survey we asked respondents to rate the overall level of success with their weed control strategy, bearing in mind their most important cucurbit crop (indicated in the previous question). Respondents overall considered themselves to have implemented a somewhat successful weed control strategy (a mean overall score of 3.4 where a score of 1 represented a strategy that was not successful and a score of 5 highly successful – Table 4.1). Mean scores by crop type suggest that cucumber and gherkin growers consider their weed control strategy to be the most successful, while squash or marrow growers consider their strategy to be the least successful. For those growing pumpkins as their most important crop, the same mean score of 3.4 was recorded, while those who consider zucchini and watermelon to be their most important crop appear to be having less success (mean scores of 3.2 and 3.1 respectively – Table 4.1). However, it is important not to read too much into these results given the small numbers of respondents involved for these crops.

Respondents were also asked to list the critical factors for achieving success with their weed control strategy in their most important cucurbit crop. The responses were coded, with the resulting data presented in Table 4.2. As this table shows, the most important factors appear to be timing weed control, specifically to implement effective control of germinating weeds, and implementing the weed strategy during favourable weather conditions. Specific weed control methods (such as chipping, herbicide use and cultivation) were listed by respondents. Other 'non-method' factors included implementing clean crop rotation, attempting to prevent weed seeding, and ensuring a healthy crop to out-compete weeds. Verbatim responses are listed in Table 4.3.

Table 4.1 Level of success with weed control strategy

Mean level of success with weed control strategy (where '1' is not successful and '5' is highly successful)		
	Mean score	*n*
Pumpkin (inc. Gramma)	3.4	14
Zucchini	3.2	6
Squash or Marrow	2.5	2
Cucumber (field grown)	4.5	2
Watermelon	3.1	8
Rockmelon	3.5	2
Gherkin	5.0	1
Total	*3.4*	*35*

Table 4.2 The critical factors for successful weed control in cucurbits

The critical factors for achieving success with weed control in the most important cucurbit crop (multiple response)							
	% of responses (n)						
	Pumpkin (inc. gramma)	*Zucchini*	*Squash or marrow*	*Cucumber (field grown)*	*Watermelon*	*Rockmelon*	*Total ***
Timing: early control of germinating weeds	15.8 (3)	80 (4)		33.3 (1)	25.0 (4)		*24.0 (12)*
Favourable weather conditions	15.8 (3)	20 (1)		33.3 (1)	18.8 (1)	25.0 (1)	*18.0 (9)*
Chipping	5.3 (1)				12.5 (2)		*6.0 (3)*
Clean crop rotation	10.5 (2)				6.3 (1)		*6.0 (3)*
Prevent weed seeding (e.g. slashing, grazing)	15.8 (3)						*6.0 (3)*
Removing all weeds			100 (1)		6.3 (1)	25.0 (1)	*6.0 (3)*
Crop health (competition)	15.8 (3)						*6.0 (3)*
Cultivation	10.5 (2)						*4.0 (2)*
Herbicide use				33.3 (1)			*4.0 (2)*
Inter-row shielded herbicide					12.5 (2)		*4.0 (2)*
Irrigation management	5.3 (1)				6.3 (1)		*4.0 (2)*
Plastic mulch use					6.3 (1)		*4.0 (2)*
Cost						25.0 (1)	*2.0 (1)*
Good control in previous crop					6.3 (1)		*2.0 (1)*
Labour availability						25.0 (1)	*2.0 (1)*
Pre-emergent herbicide use	5.3 (1)						*2.0 (1)*

*** Some respondents answered this question but did not indicate their most important cucurbit crop, hence some totals add up to greater than the sum of responses under particular crop headings.*

Table 4.3 The critical factors for successful weed control in cucurbits (written responses)

The critical factors for achieving success with weed control in the most important cucurbit crop	
Crop	*Description of factors*
Cucumber	Chemical spray (herbicide)
	Spray at right time
	Weather conditions allowing timely inter-row cultivation and hand weeding
Gherkin	Timing of sprays, always lay plastic mulch
Pumpkin	Better crop
	Clean crop rotation including cereal, lucerne and other vegetables, prevent all weeds from seeding with a slasher and sheep. I use Farmall tractors with mid-mounted cultivation equipment, this gear was developed pre weedicide usage in the 1950s
	Crop rotation, delay planting until weeds have germinate, intensive cultivation
	Early control.
	Late control of weeds, early control OK
	Less staining, less competition
	Less weeds more crop, more money to be made
	Prevent seed set, early irrigation management
	Slashing before weed seeds set and mature
	Timing of pre-emergent herbicides and rain events
	Weather
	Weather conditions, crop growth speed
	Well prepared and cultivated soil with weed germination and destruction before planting, well fertilized site, not watering until plants are sprouted and once only manual weeding to clear initial small weed growth
Rockmelon	A must to be 100% clean of weeds, for the highest yields for maximum return on investment, also for satisfaction to see a nice clean crop of rockmelons growing
	Weather and temperature, availability of labour, all round costs
Squash or Marrow	Getting rid of weeds
Watermelon	Getting weeds to germinate prior to planting, irrigation timing - hope for not too much rain
	Having good weed control in previous crops
	Plastic mulch (moving to biodegradable), shield spray soil between plastic mulch with herbicide, chip what is left as a last resort
	Removing weeds while they are very young, making sure you remove all of them
	Soil moisture, size of weed, heat on day
	Timing, e.g. spray shielding and chipping
	Weather
	Weather (excessive rain), paddock history (e.g. previous crop)
Zucchini	Early management
	Planting seedlings, cultivate between rows while still small enough, then chip the remainder: you still end up with weeds but they are manageable
	Rain prior to planting weed, weeds germinate for a good knockdown, and rain after pre-emergent herbicide.
	Timeliness of operation
	Weeding at appropriate time - be early not late
	Zucchini not much weed

4.2. The affordability and effectiveness of weed control methods

We asked survey respondents to indicate, for each of a list of weed control methods that they had either used previously or were currently using, to rate the affordability and the effectiveness of each method. A high score meant that respondents considered the methods to be highly affordable or effective, and a low score not affordable or effective. It was important to distinguish between the affordability and effectiveness of weed control methods, as some methods may be highly effective but expensive to implement (or conversely, cheap methods that are relatively ineffective).

The mean ratings for each of the methods listed in the survey are presented in Table 4.4 and 4.5. The most highly rated weed control methods, in terms of both affordability and effectiveness, were generally those for which the most responses were received, suggesting that a large proportion of cucurbit growers use a mixture of the following weed control methods:

- pre-emergent herbicide;
- post-emergent herbicide;
- tillage or cultivation;
- plastic mulch;
- crop rotation; and
- chipping and hand weeding.

Further, the results suggest that respondents overall consider the above methods to be somewhat or relatively affordable and effective (an average score of between approximately 2.5 and 4).

The most affordable methods overall were considered to be tillage or cultivation, slashing and crop rotation. Respondents also considered these to be relatively effective weed control methods, with the exception of slashing. Tillage is one of the more common weed control methods used by vegetable growers, often in combination with herbicide application to control weeds pre-plant and early post-emergence (see literature review section 5.2). Similarly, crop rotation is commonly used by growers, and in particular gives growers the opportunity to control broadleaf weeds otherwise difficult to control in a cucurbit crop (see literature review section 5.7).

Despite the growing costs associated with its production and disposal (see literature review section 5.3), plastic mulch was also considered to be one of the more affordable weed control methods (Table 4.4). As we also found in our review of literature, plastic mulch delivers a number of non-weed control benefits to the cucurbit crop, and still appears to be more economical than mulch alternatives. Plastic mulch was considered by respondents to be the most effective weed control method available, and so remains a mainstay of weed control in cucurbits (Table 4.5).

The number of responses to each method indicates that pre- and post-emergent herbicides are less commonly used than tillage, hand weeding and crop rotation, perhaps a consequence of the limited herbicide options available to cucurbit growers, particularly for broadleaf weed control, and post-emergence. However, the relative affordability and effectiveness attributed to existing herbicides in this survey suggests that new herbicide options may be worth pursuing to give growers an effective and economically viable alternative to plastic mulch in particular.

Pre-irrigating and then spraying herbicide or tilling the soil once weed seedlings emerge was regarded as effective (score of 3.8), third only to plastic mulch and chipping, and is relatively affordable (3.5), but is not apparently widely used compared with other methods. There may be unknown but valid reasons for the relatively low use of this technologies, such as the ability to irrigate, but the results also suggest that it may be a technique that requires further investigation by growers.

Other less commonly used weed control methods, such as organic mulch, thermal weeding or the stale seedbed technique were considered not to be affordable or effective, or both.

Table 4.4 Affordability of methods used to control weeds

***Affordability* of methods used to control weeds in your most important cucurbit crop (where '1' is not affordable and '5' is highly affordable)**							
	Mean score (n)						
	Pumpkin (inc. gramma)	*Zucchini*	*Squash or marrow*	*Cucumber (field grown)*	*Watermelon*	*Rockmelon*	*Total ***
Herbicides (pre-emergent)	3.4 (9)	3.5 (2)		5.0 (1)	2.3 (4)		*3.3 (17)*
Herbicides (post-emergent)	3.3 (4)	4.0 (2)	3.0 (1)		3.2 (5)	3.0 (2)	*3.3 (15)*
Chipping and hand weeding	2.8 (13)	2.3 (4)	5.0 (1)		2.0 (8)	2.0 (2)	*2.6 (29)*
Tillage/cultivation	3.9 (14)	4.6 (5)	5.0 (2)		3.8 (8)	4.5 (2)	*4.1 (31)*
Slashing	4.3 (4)	4.0 (2)			3.5 (2)		*4.0 (8)*
Plastic mulch	3.3 (4)	1.0 (1)	5.0 (2)	4.0 (1)	3.5 (6)	3.5 (2)	*3.6 (17)*
Organic mulch	4.0 (2)				1.0 (3)		*2.2 (5)*
Crop rotation	4.0 (10)	3.7 (3)			3.4 (5)	3.0 (1)	*3.7 (19)*
Increase plant density	3.6 (5)	3.0 (1)	3.0 (1)		2.0 (3)	3.0 (1)	*3.0 (11)*
Pre-irrigate and spray/till	3.0 (1)				3.7 (3)		*3.5 (4)*
Thermal (steam/flame)					1.0 (1)		*1.0 (1)*
Stale seedbed technique					1.0 (1)		*1.0 (1)*

*** Some respondents answered this question but did not indicate their most important cucurbit crop, hence some totals add up to greater than the sum of responses under particular crop headings.*

Table 4.5 Effectiveness of methods used to control weeds

***Effectiveness* of methods used to control weeds in your most important cucurbit crop (where '1' is not effective and '5' is highly effective)**							
	Mean score (n)						
	Pumpkin (inc. gramma)	*Zucchini*	*Squash or marrow*	*Cucumber (field grown)*	*Watermelon*	*Rockmelon*	*Total ***
Herbicides (pre-emergent)	3.3 (9)	3.5 (2)		5.0 (2)	3.3 (4)		*3.6 (18)*
Herbicides (post-emergent)	3.0 (5)	3.5 (2)	5.0 (1)		3.2 (5)	3.0 (2)	*3.4 (16)*
Chipping and hand weeding	4.0 (13)	4.0 (4)	4.0 (2)	4.0 (1)	3.6 (8)	3.5 (2)	*3.9 (31)*
Tillage/cultivation	3.4 (13)	3.6 (5)	3.0 (1)	4.0 (1)	3.5 (8)	3.0 (2)	*3.4 (30)*
Slashing	3.3 (4)	2.5 (2)			1.5 (2)		*2.6 (8)*
Plastic mulch	3.8 (4)	5.0 (1)	5.0 (2)	4.0 (1)	4.2 (6)	4.5 (2)	*4.3 (17)*
Organic mulch	2.5 (2)				3.7 (3)		*3.2 (5)*
Crop rotation	2.7 (10)	3.8 (4)		2.0 (1)	3.3 (4)	3.0 (1)	*3.0 (20)*
Increase plant density	1.8 (4)	3.0 (1)	3.0 (1)		2.0 (3)	4.0 (1)	*2.3 (10)*
Pre-irrigate and spray/till	4.0 (1)			3.0 (1)	4.0 (3)		*3.8 (5)*
Thermal (steam/flame)					1.0 (1)		*1.0 (1)*
Stale seedbed technique				2.0 (1)	1.0 (1)		*1.5 (2)*

*** Some respondents answered this question but did not indicate their most important cucurbit crop, hence some totals add up to greater than the sum of responses under particular crop headings.*

4.3. Herbicide use

4.3.1. Agronomic factors to consider when applying herbicides

In the survey we asked respondents to consider a range of agronomic factors, and indicate which of these they believe are most important to consider when using herbicides to control weeds. Table 4.6 shows that crop life stage and prevailing weather conditions were considered by the response group overall to be the most important agronomic factors influencing the effectiveness of herbicide use. Other important factors include the effect of herbicides on the crop, the weed life cycle, and whether weeds are present or expected in the crop.

Most of the factors in Table 4.6 relate to *timing*, specifically to maximising the vulnerability of the weeds, minimising the vulnerability of the crop, and increasing herbicide effectiveness. Awareness of the importance of herbicide rotation did not appear to be widespread amongst respondents (receiving only two responses overall). This suggests that raising awareness of herbicide rotation may need to be undertaken in the industry, to extend the effective life of the few herbicide options available to cucurbit growers.

Table 4.6 Important agronomic factors to consider when applying herbicides

Important agronomic factors to consider when applying herbicides to control weeds in the most important cucurbit crop (multiple response)							
	% of responses (n)						
	Pumpkin (inc. gramma)	*Zucchini*	*Squash or marrow*	*Cucumber (field grown)*	*Watermelon*	*Rockmelon*	*Total ***
Crop life stage	19.4 (7)	25 (2)	16.7 (1)	25.0 (2)	19.0 (4)	28.6 (2)	*20.2 (18)*
Weather conditions	11.1 (4)	12.5 (1)	16.7 (1)	12.5 (1)	28.6 (6)	28.6 (2)	*18.0 (16)*
Effect on crop	13.9 (5)		33.3 (2)	12.5 (1)	14.3 (3)	28.6 (2)	*14.6 (13)*
Weed life cycle	13.9 (5)	25 (2)		25.0 (2)	4.8 (1)		*12.4 (11)*
Weeds present or expected	16.7 (6)	12.5 (1)			9.5 (2)		*11.2 (10)*
Organic/do not use herbicides	11.1 (4)	25 (2)					*6.7 (6)*
Withholding period	2.8 (1)		16.7 (1)	12.5 (1)	9.5 (2)	14.3 (1)	*6.7 (6)*
Delay for next crop	2.8 (1)			12.5 (1)	4.8 (1)		*3.4 (3)*
Herbicide rotation	2.8 (1)				4.8 (1)		*2.2 (2)*
Seed or transplants used?			16.7 (1)		4.8 (1)		*2.2 (2)*
Early timing	2.8 (1)						*1.1 (1)*
Soil type	2.8 (1)						*1.1 (1)*

*** Some respondents answered this question but did not indicate their most important cucurbit crop, hence some totals add up to greater than the sum of responses under particular crop headings.*

4.3.2. Lack of herbicide options

Approximately two thirds of respondents considered lack of herbicides to be a significant problem in their efforts to control weeds (Table 4.7). As has already been indicated in section 4.2 above, this suggests that identifying more herbicide options for cucurbit growers may be considered a priority issue, and appears to be a priority amongst growers themselves.

The respondents were also asked to detail why they think lack of herbicides is a problem (Table 4.8). A number of respondents mentioned the lack of post-emergent broadleaf herbicide options in cucurbits as a major limiting factor in the effectiveness of herbicidal weed control, noting that particular weed species such as caltrop and potato weed are consequently difficult to control. One respondent noted that '[l]ack of effective broadleaf herbicide adds to costs and time spent hand chipping'. A pumpkin grower considered that, due to a lack of 'over the top' herbicides for cucurbits, the weeds will 'overwhelm the crop every time'.

Growers also distinguished between their ability to impose some control on grass weeds within their cucurbit crops using herbicides, but their inability to do so for broadleaf weeds, with one respondent commenting that 'grass weeds are effectively controlled with effective post-emergence grass herbicides. Broadleaf weeds are the problem.' Another suggested that, ideally, they would have access to a herbicide that controls broadleaf weeds effectively within the crop, and another that controls grass weeds.

Ineffective weed control using herbicides was noted for a number of the important weeds identified by respondents (Table 3.5). These included blackberry nightshade (two responses), caltrop/cathead, castor oil plant, crowsfoot/crab grass, fat hen (two responses), mallow, potato weed, redshank, and wireweed/hog weed, while one respondent each also noted difficulties controlling unspecified broadleaf and grass weeds respectively. This indicates that herbicide resistance may be an issue for these weeds.

Table 4.7 Is the lack of effective herbicides a significant problem?

Is the lack of effective herbicides a significant problem in trying to control weeds in the most important cucurbit crop? (% of respondents) *(n = 34)*	
Yes	64.7
No	35.3

Table 4.8 Is the lack of effective herbicides a significant problem? (written response)

Is the lack of effective herbicides a significant problem in trying to control weeds in the most important cucurbit crop? (written response)	
Crop	*Description of problem*
Cucumber	Lack of effective broadleaf herbicide adds to costs and time spent hand chipping
Pumpkin	Broad leaf selective herbicides needed
	Broadleaf weed control not available for pumpkin and watermelon without crop damage
	Certain herbicides are not registered to use on pumpkins
	Don't know of any post-emergent herbicide
	I do not use weedicides in cucurbits but do in the rotation crops of cabbage, beetroot, lucerne and cereals
	Lack of pre- or post-emergent herbicide to control broadleaf weeds
	Only get short term control on Prince of Wales feather
	The only registered herbicides require rain or irrigation to incorporate into soil profile, we don't irrigate
	Weeds overwhelm crop every time
	Would like something for caltrop that didn't affect crop or replants
Watermelon	Apple of Peru, potato weed, Lassoo used to control these weeds before it was recalled
	Broadleaf weeds on sandy soil – residual
	I haven't used herbicides post-emergent to try to control weeds
	Post-emergent broadleaf control in pumpkins not generally available
	Rainfall events at the wrong time allow weeds to grow as melons get too big to shield spray furrows. We then have to chip which is costly. If we could spray over the top of watermelons, we wouldn't chip
	We are limited with the use of pre-emerge chemical
Zucchini	Ongoing weed resistance problems
	Very limited affordable broadleaf weed herbicides available

4.3.3. Herbicide damage to crop

As was discussed in the literature review, the range of herbicides available for weed control in cucurbits is restricted as cucurbit crops are highly susceptible to damage from residual herbicides (section 5.1.3 of the literature review). Approximately one third of survey respondents have experienced damage or reduced crop growth after using herbicides to control weeds in their main cucurbit crop (Table 4.9).

Specific instances and herbicides that caused damage to respondent crops, or restricted their growth, are listed in Table 4.10. Herbicides registered for use in cucurbit crops, including Sertin (sethoxydim) and Fusilade (fluazifop-p), appear to cause leaf damage and growth retardation, but do not hinder the crop in the long term. One respondent noted that residual metsulfuron used in the previous wheat crop carried over damage to the succeeding pumpkin crop. Two respondents also noted that damage had occurred to vines as a result of using herbicide to control weeds in the inter-row space, one using glyphosate, and another an unspecified residual herbicide which damaged the crop once the vines had grown off the plastic mulch.

Damage from drift of Sprayseed, a non-selective herbicide, was mentioned by two growers, but this is a risk not specific to cucurbits.

Table 4.9 Has crop damage or reduced growth ever resulted from herbicide use?

Has damage or reduced growth ever been experienced in the most important cucurbit crop as a result of using herbicide to control weeds? (% of respondents) *(n = 32)*	
Yes	34.4
No	65.6

Table 4.10 Has crop damage or reduced growth ever resulted from herbicide use? (written response)

Crop	*Description of circumstances*
Has damage or reduced growth ever been experienced in the most important cucurbit crop as a result of using herbicide to control weeds? (written response)	
Cucumber	Fusilade applied before 3 to 4 leaf stage, retarded growth but recovered
	Very slight, no impact on production
Pumpkin	Crop retardation from over spray of Clincher Plus
	Don't use them
	Not known
	Not that I know of
	Stomp
	Used metsulfuron in wheat break crop, carry over damaged next season crop
Rockmelon	Damage to plants using inter-row spraying with glyphosate
Watermelon	Fusilade, blackening of leaf (leaf burn)
	Sertin, dry conditions, burning of the leaves
	Sprayseed drift and spraying wrong configuration
	Sprayseed drift
	Vine growing off plastic mulch dying of herbicide as it contacts pre-emergent herbicide on/in soil

4.3.4. Reduced herbicide effectiveness

Respondents were asked to indicate whether they had noticed whether any of the herbicides they used to control weeds in their main cucurbit crop had become less effective over time. As Table 4.11 shows, 20 per cent of respondents had noticed reduced herbicide effectiveness. These respondents were given the opportunity to comment on reduced effectiveness. While few details were provided (Table 4.12), there is sufficient anecdotal evidence here to warrant investigation of possible herbicide resistance development in cucurbit crops. This would not be surprising given the comment, for example, that the herbicide Sertin had been used for 15 years (Table 4.12). It is also evident that some cucurbit crops are grown in rotation with cereals, where there is now widespread herbicide resistance in Australia, particularly in various grasses such as annual ryegrass.

Table 4.11 Have herbicides become less effective over time?

Have any of the herbicides used in the most important cucurbit crop become less effective over time? (% of respondents)	
(n = 29)	
Yes	20.7
No	79.3

Table 4.12 Have herbicides become less effective over time? (written response)

Have any of the herbicides used in the most important cucurbit crop become less effective over time? (written response)	
Crop	*Description of circumstances*
Pumpkin	Maybe Summer grass
Watermelon	Roundup seems to have got worse on grasses, fleabane is our new weed which doesn't die with Roundup Seems to be resistance developing Sertin, 15 years
Zucchini	Ryegrass: Clethodim, Fusilade S

4.3.5. Changes to herbicide use regulations

Just under 20 per cent of respondents were aware of changes to herbicide use regulations that had implications for how herbicides were used in their most important cucurbit crop (Table 4.13). As Table 4.14 shows, regulatory changes have impacted on buffer zones, removing herbicide residues from crops for sale, drift management, recording herbicide use in spray diaries, and removal of some herbicides from permit lists.

It is difficult to know, because of the relatively small sample, whether this low level of awareness of herbicide regulatory changes is a cause for concern that requires greater extension effort, but certainly there is a greater proportion of growers who use herbicide than the 19.4 per cent who noted changes here.

Table 4.13 Awareness of changes to herbicide use regulations

Awareness of changes to regulations that have impacted on herbicide use in the most important cucurbit crop? (% of respondents) *(n = 31)*	
Yes	19.4
No	80.6

Table 4.14 Awareness of changes to herbicide use regulations (written response)

Awareness of changes to regulations that have impacted on herbicide use in most important cucurbit crop	
Crop	*Description of changes*
Cucumber	Buffer zones
Gherkin	Herbicide removal, not too much of a problem overall as we do research and don't sell fruit to a market, so we have lower risk factors
Watermelon	Records of spray diaries
Zucchini	Herbicides removed from permit list and drift management Yes, however not applicable to my farm

5. Future weed control approaches

5.1. Research priorities within the cucurbit industry

We asked growers to consider some potential areas of research and development, and whether these should be considered a high priority within the Australian cucurbit industry. The largest proportion of respondents (over 80 per cent) considered that high priority should be given to communication and extension of effective weed management strategies, and identifying new herbicides to use within cucurbit crops (Table 5.1). However, a majority of respondents also felt that priority should be given to identifying non-herbicidal or organic weed control methods, and economic replacements for polyethylene plastic mulch.

Our review of the literature identified little in the way of weed control extension work specifically targeting the cucurbit industry. Extension brochures, booklets etc identified dealt only briefly with weed impact and control, either as part of a broader discussion on cucurbit production, or as part of a discussion on weed control in horticulture or vegetable crops more generally. Furthermore, such information was difficult to locate. The survey results suggest that growers may also feel there is a shortfall of information on weed control in cucurbit production, and that up to date and effective weed control strategies need to be effectively communicated to growers. Table 1.6 indicates some of the most likely avenues through which extension work is likely to reach growers.

The response in Table 5.1 also highlights the perceived need for effective herbicides that may be used within cucurbit crops, a theme that was identified throughout the survey. This is particularly true of growers who currently consider herbicide use to be an important part of their weed control approach: of the growers who disagreed with the need to identify new herbicides (relatively high at 13.9 per cent), several indicated elsewhere in the survey that they were organic producers, while others may simply dislike using herbicides. The diversity of opinion regarding herbicide use is highlighted by two respondent comments included in Table 5.2, one suggesting that 'we should be going away from using too many chemicals in our crops', while another grower stated that '[w]e really need a post-emergent herbicide that can be sprayed over young plants'.

While a majority of respondents believed that non-herbicidal weed control should be an industry priority, nearly one third of respondents were unsure of the need to prioritise this issue. This may be due to ambivalence regarding the likely effectiveness of methods that do not involve herbicide, or possibly even plastic mulch, with one grower commenting that '[o]rganic treatments are pie in the sky for most growers'. Control methods more likely to be used by organic growers, such as organic mulch, thermal weeding and the stale seedbed technique were generally regarded by the respondents to this survey to be either not particularly affordable or effective (Tables 4.4 and 4.5).

A similar proportion of respondents were unsure whether priority should be given to identifying economic replacements for polyethylene mulch. This suggests that polyethylene mulch is still considered a relatively economic crop management tool by many growers, despite rising production and disposal costs (see literature review section 6.1.4). It may also be that some growers remain uncertain about the performance of biodegradable mulch, and their ability to apply it to the crop without significant expense on new equipment. These issues are discussed in the literature review (section 6.4.3). Nonetheless, the fact that a majority of respondents considered research into polyethylene mulch replacements to be a high priority suggests that many growers recognise the difficulties that may be associated with polyethylene mulch use in the near future.

Table 5.1 The cucurbit industry should give high priority to...

The cucurbit industry should give high priority to... (% of respondents)			
(n = 36)	*Agree*	*Unsure*	*Disagree*
Communication and extension of effective weed management strategies.	80.6	16.7	2.8
Identifying new herbicides for weed control in cucurbits.	80.6	5.6	13.9
Identifying new organic or non-herbicidal weed control methods.	66.7	27.8	5.6
Identifying economic replacements for polyethylene plastic mulch.	54.1	32.4	13.5

Table 5.2 Further comments on future weed control priorities

Further comments on future weed control priorities
I believe we should be going away from using too many chemicals in our crops.
Organic treatments are pie in the sky for most growers.
There is a beetle which defoliates castor oil plant, which arrives late in the season. I think it is called cucumber ladybird. It has striped yellow markings. Introduction early in the season could be worthwhile.
We really need a post-emergent herbicide that can be sprayed over young plants.

5.2. Alternatives to herbicide

Growers were asked to consider whether it would be feasible to reduce their reliance on herbicide by using a range of other methods. Respondents appeared overall to be ambivalent about the ability to reduce herbicide use through other weed control methods (Table 5.3), with a relatively even spread of respondents answering 'Yes', 'No', and 'Unsure' for each of the methods listed in the survey, other than for clean farm hygiene, where the one respondent considered this approach a feasible approach to reduce herbicide use. Growers should be encouraged and shown ways, perhaps through case studies, to improve this aspect of their operations. The apparent lack of agreement amongst respondents on this question for the techniques other than clean farm hygiene may be why few respondents have trialled non-herbicide methods in their crop in the last five seasons (Table 5.4).

However, it appears that growers are more likely to embrace precision systems, and plastic and biodegradable mulch. Plastic mulch is often used in combination with herbicide weed control, including pre-plant control of weeds in the beds, or post-plant control of weeds in the inter-row space.

Of the methods listed in the survey, the largest proportion of respondents indicated that they do not believe low till mulching systems, organic mulches and semi-permanent or permanent beds are feasible methods for reducing herbicide use. However, one respondent suggested that herbicide use may be reduced by greater reliance on other approaches, suggesting that 'cultivation, chipping and slashing works OK'.

Table 5.3 Feasibility of reducing herbicide use by implementing other techniques

Would it be feasible to reduce herbicide use by implementing any of the following techniques for cucurbit crops? (% of respondents)	Yes	No	Unsure	n
Clean farm hygiene	100.0	0.0	0.0	1
Precision systems (spray, tillage)	46.9	28.1	25.0	32
Plastic mulch	42.4	27.3	30.3	33
Biodegradable mulch	32.3	29.0	38.7	31
Controlled traffic	30.8	38.5	30.8	26
Low till (mulching) systems	21.4	28.6	50.0	28
Organic mulch	20.7	37.9	41.4	29
Semi-permanent/permanent beds	13.8	55.2	31.0	29

Table 5.4 Have new non-herbicide or organic methods been trialled?

Have any new non-herbicide or organic weed control methods been trialled in cucurbit crops in the last five years? (% of respondents) (n = 34)	
Yes	5.9
No	94.1

5.3. Other herbicide options

Only 8.6 per cent of respondents had trialled a new herbicide in their cucurbit crops in the last five years (Table 5.5). Of these, Frontier (dimethenamid) is currently registered for use in cucurbit crops in Australia, Dual Gold (s-metolachlor) was previously registered and has been withdrawn (although some off-label use continues), and Goal (oxyfluorfen) is not currently registered for use in cucurbit crops. As Table 5.6 suggests, those respondents who trialled new herbicides found them to be only somewhat effective.

Table 5.7 shows that respondents are aware that s-metolachlor and oxyfluorfen (Goal) are not currently registered for use in cucurbit crops but may be useful options, while another respondent noted that Lassoo was an effective herbicide, but its permit was withdrawn some time ago.

Table 5.5 Have new herbicides been trialled?

Have any useful new herbicides been trialled in cucurbit crops in the last five years? (% of respondents) (n = 35)	
Yes	8.6
No	91.4

Table 5.6 Have new herbicides been trialled? (details)

Description of new herbicide trials in the last five years
Don't know of any registered for melons
Dual Gold - 50% effective, Goal - 25% effective. Residual
Frontier
Frontier pre-emergent, 75% effective
I just use Roundup

Table 5.7 Currently unregistered herbicides effective for controlling weeds in cucurbits

Awareness of currently unregistered herbicides that are effective for controlling weeds in cucurbit crops
Clincher Plus (metolachlor)
Metolachlor, Goal
No (22 responses)
Yes - Lassoo (25 years ago)

6. Conclusions

6.1. Information about weeds and weed control

The survey found that the most important sources of information about weeds amongst respondents included commercial suppliers and their representatives and other farmers or neighbours, while other important sources include private agronomists/horticulturalists, booklets and fact sheets, and industry newsletters and magazines. Many respondents also regard more communication of effective weed control strategies to growers as a high industry priority, suggesting that cucurbit growers consider themselves to be inadequately informed at present.

Recommendation

Our experience in the conduct of this survey suggests that cucurbit growers are a difficult primary production segment to reach. However, as it extends the findings of this and other relevant research to cucurbit growers, the Vegetable Industry should consider involving commercial suppliers such as rural merchandise stores and herbicide suppliers, both private and government agronomists and horticulturalists, and develop targeted booklets or fact sheets that may be distributed through these and other sources. Including resources on the HAL website is also a valid and cost-effective extension mechanism.

6.2. The impact of weeds on production costs and income

The economic impact of weeds on growers (measured in terms of weed control *cost*) appears to vary considerably depending on cucurbit crop type and perhaps the control strategy used, although the low response to the survey makes it difficult to estimate average cost with great accuracy. The response indicates that the cost of weed control may have increased a little over the past three years.

The majority of respondents have experienced crop management problems or reductions in crop yield as a result of having weeds in their cucurbit crop, while a significant minority have also witnessed an impact on crop quality. These impacts are difficult for growers to estimate in dollar amounts, however they appear to be significant, particularly when the costs of control, secondary impacts on management, and negative impacts on income (reduced yield and quality) are taken together.

6.3. Important weeds

The most problematic weeds amongst respondents include fat hen (*Chenopodium album*), blackberry nightshade (*Solanum nigrum*), caltrop or cathead (*Tribulus terrestris*), and pigweed/purslane (*Portulaca oleracea*), all of which are broadleaf weeds. Significant grass species include African lovegrass (*Eragrostis curvula*), and barnyard grass (*Echinochloa* spp.). Broadleaf weeds are a more significant problem in cucurbit crops than grass weeds. Closely related cucurbit weeds did not appear to be particularly problematic in this survey.

Problems commonly attributed to broadleaf weeds by respondents include their ability to grow and spread quickly and out-compete the crop for resources, difficulty controlling the weeds (lack of herbicides and difficulty chipping), their ability to host pest insects and diseases, and physical characteristics such as prickles or thorns which make harvesting more difficult.

Grass weeds are often able to spread quickly in the crop and produce many seeds (competing with the crop for resources), can be difficult to control with herbicides, make it difficult to lay plastic mulch if they have a significant presence on the crop beds, and, in the case of the grass-like sedge, nutgrass, are at times able to grow through plastic mulch.

Recommendation

This scoping study has shown that weeds have a very significant impact on the productivity of Australian cucurbit crops, and that the most important weeds create a range of problems for growers in the areas of crop management and maintaining crop growth. Further research, perhaps in the form of case studies conducted on-farm, may quantify more specifically the impact of different weeds on a variety of cucurbit crop types. A greater understanding of the importance of weeds in cucurbit production may give more incentive to develop novel weed control approaches, and extend these approaches to growers. Specific research and information on the ecology and management of the most important weeds of cucurbit crops is required.

6.4. Current weed control approaches

Cucurbit growers surveyed consider their overall weed control strategy to be somewhat successful. Timing (early control of germinating weeds) and favourable weather conditions appear to be the most important factors behind a successful strategy.

Of the range of 'traditional' and 'organic' weed control methods at growers' disposal, respondents considered the most effective and affordable to be pre- and post-emergent herbicides, tillage/cultivation, plastic mulch, crop rotation, and hand weeding/chipping. These methods are often used in various combinations as part of an integrated weed management strategy.

Recommendation

Given its relatively high ratings for affordability and effectiveness but relatively low uptake, research and extension are required on the benefits of pre-sowing irrigation followed by tillage and/or herbicide application ('false seedbeds'). This strategy has the potential to reduce the soil weed seed bank and germination of weeds during the life of the crop.

6.5. Herbicidal weed control and its alternatives

About one third of respondents had experienced some form of cucurbit crop damage as a result of using herbicides to control weeds. Those using herbicides such as Sertin (sethoxydim) and Fusilade (fluazifop-P), observed leaf damage and growth retardation, but no long-term crop damage.

Lack of effective herbicide options is a significant problem for many cucurbit growers in their efforts to control weeds effectively. A number of respondents mentioned the lack of post-emergent broadleaf herbicide options in cucurbits as a major limiting factor in the effectiveness of herbicidal weed control, forcing growers to adopt other more expensive or time-consuming methods such as hand weeding within the crop. Growers distinguished between their ability to impose some control on grass weeds within their cucurbit crops using herbicides, and their inability to do so for broadleaf weeds with currently available herbicides. Approximately 80 per cent of respondents noted that identifying new herbicide options for use in cucurbit production should be a high industry priority.

Reduced herbicide effectiveness or weed resistance may also become a significant issue for cucurbit growers in the future, with instances of reduced effectiveness already observed by some survey respondents. Resistance is particularly important for Australian cucurbit growers, given the already limited range of herbicides available. Respondents noted several cases of reduced effectiveness of herbicides in controlling specific weed species in their cucurbit crops.

Respondents appear to be ambivalent about the ability to reduce herbicide use by adopting other weed control methods, although appear to be most supportive of precision spray equipment and plastic or biodegradable mulch. Low till mulching systems, organic mulch and semi-permanent or permanent beds received the least support.

Recommendation

While survey respondents are having moderate success with their current weed control strategy, lack of herbicides is a real impediment to maximising cucurbit production in Australia, and may become a more important issue in the future if reduced herbicide effectiveness or resistance becomes common. The survey suggests that a high priority for growers is to:

1. identify herbicides that may be used to control weeds within cucurbit crops, with little or no negative impact on crop plants, particularly for the control of broadleaf weed species; or

2. identify non-herbicide weed control approaches, and develop these to the extent that they are at least as cost-effective as herbicide control, thereby giving growers a ***viable*** *alternative to herbicide use.*

The survey and literature review conducted for this scoping study have identified a range of non-herbicide weed control methods. More detailed research may be needed in Australian conditions to evaluate the potential of these methods.

Clean farm hygiene was indicated by one respondent as offering considerable benefits and so, as a start, this should be an area of farm operation that is researched and developed e.g. through successful farmer case studies that can be extended throughout the industry. Such an approach has proven highly successful in non-cucurbit horticulture.

A number of respondents indicated they had observed cases of herbicide resistance within their cucurbit crop. Herbicide resistance testing may be required to gauge the ongoing effectiveness of the herbicides currently registered for use in cucurbit crops.

Sustainable broadleaf weed control in cucurbit crops:

Appendix 5 – field work report

Prepared for Horticulture Australia Limited (VG10048)

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HAL

Know-how for Horticulture™

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1. Background

Three growers were visited in the Bundaberg region in October, 2011. Growers were located in the Wallaville district south-west of Bundaberg, the Farnsfield district between Bundaberg and Childers, and the Bargara district east of Bundaberg.

The goal of the field work was to clarify and ground-truth the findings of the literature review and mail survey (Appendices 2 and 4). We discussed with each grower many of the issues raised during the research. These included:

- the various impacts of weeds on cucurbit production;
- the most significant weeds for the growers, and the reasons some weeds are more problematic than others;
- the various methods, as well as the overall strategy used, to manage weeds, and the advantages and disadvantages of each;
- sources and types of information sought by cucurbit growers; and
- areas where research and development efforts may contribute to a sustainable cucurbit industry in Australia.

In order to maintain the privacy of the growers interviewed, we have labelled each as 'Grower 1', 'Grower 2', and 'Grower 3'.

Rockmelon field near Bundaberg, Qld

2. Production system overview

The three growers we visited all maintained fields that were well managed for weeds. In this they provide a good example for other growers who are having difficulties controlling weeds to emulate. Below is a short summary of the production system used by each grower. Because of the timing of our visit, the crops we saw in the ground were mostly melons, but the production system was similar for pumpkins.

2.1. Grower 1

The main forms of cucurbit production undertaken by this grower include watermelons (with an approximate growing season of July to December), and pumpkins (approximately March to August).

Melons are only grown in a particular field for a single season, with the next 4-6 crops being rotation crops of various other types, including ginger, potato, sweet potato and sugar cane. This approach is designed to avoid build-up of diseases that can have a severe impact on cucurbits, such as fusarium varieties specific to melons. The grower has found that pumpkins are more tolerant of disease and less likely to require as strict rotations.

Watermelon plant

The grower has field swap arrangements in place with neighbours, and leases other land in the district, in order to facilitate more effective rotation. On much of the leased land, sugar cane is the main rotation crop, which is usually in the ground for 3 or 4 years.

2.2. Grower 2

This grower focuses on rockmelon production in spring/summer and pumpkin in winter. The growing season is similar to that of Grower 1.

Also as with Grower 1, rotation is used after a single season to avoid disease build-up in the fields. Sugar cane is used as the rotation crop. Despite the relatively small land area used by the grower to produce cucurbits, they are the most profitable aspect of his farm.

Rockmelon crop on black plastic mulch

2.3. Grower 3

The main form of cucurbit production on this farm includes rockmelon and watermelon in the spring and summer months, and pumpkin in the winter. The grower has experimented with zucchini production but found management and harvesting of the crop to be too difficult, to the extent that the crop was not profitable. Other forms of production include macadamia trees and sugar cane, while a range of other potential rotation options have been trialled, including at the time of the visit an onion crop.

The grower does not consider weed management to be a specific task on the farm, but a part of the overall crop management strategy that is achievable. He considered that disease in cucurbit crops was more of an acute problem than weeds, with gummy stem blight caused by the fungus *Didymella bryoniae* (DEEDI 2011) the most significant cucurbit management issue on this farm.

Recently planted cucurbit crop

3. The impact of weeds

3.1. Economic impact

As the results of the literature review and grower survey (Appendices 2 and 4) suggest, the economic impact of weeds in cucurbit crops is difficult for growers to estimate. The growers interviewed during the field work all indicated lack of recorded information as the main reason for this difficulty. Furthermore, not only do growers tend to consider weed control to be just one aspect of their overall crop management strategy, but some measures that have beneficial effects on weed control (such as plastic mulch) are also implemented for a range of other reasons. Consequently, the costs and benefits as they pertain specifically to weeds are difficult to disaggregate.

One grower indicated that they had recently purchased a computer application used to record crop inputs and outputs, and that this may allow them to estimate the economic impact of weeds (both in terms of inputs and yield reduction) in the future.

Grower 1 suggested that the presence of nutgrass (*Cyperus rotundus*) in a field significantly reduces the value of the land due to the management problems it presents for cucurbit and other vegetable crop producers. He estimated that in his district, its presence may reduce land values from approximately $18,000 per acre to approximately $15,000 per acre.

3.2. Impact on yield, quality and management

Weed control is a continual management problem for cucurbit growers, and requires constant vigilance to ensure that weeds do not become an overwhelming issue.

Since all three growers interviewed maintained relatively weed-free fields, weeds do not appear to have a significant impact on yield or crop quality.

However, Grower 1 did indicate that when fields have been heavily infested with broadleaf weeds, it can be difficult for harvest workers to locate all fruit in a dense infestation, resulting in a reduction in crop yield.

Nutgrass presents a particularly significant problem with regard to crop management. Growers 1 and 3 both suggested that the weed makes retrieval of plastic mulch after harvest much more difficult. Once the weed has pierced the plastic mulch, its large root system means that large clumps of soil attach themselves to the mulch as it is being rolled up during retrieval. Often this results in plastic tearing, and dramatically increases the time and effort it takes to retrieve the mulch. Nutgrass is discussed in more detail in Section 4.

All growers experience greater problems with weeds in particular parts of the fields, for example areas where weed control was less effective while previous crops were being grown. Grower 2 gave an example of a small area on one of their fields where broadleaf weeds were a more significant problem, due largely to spread from neighbouring fields.

Amaranthus *sp. in a rockmelon crop*

Neighbouring properties with dense weed infestations or where less diligent weed control is practised, or weed infested land that is being leased, also present ongoing management problems for growers. Grower 3 indicated that one of his neighbours, who focuses on sugar cane production, is a continual source of weeds on and near their shared property boundary. Grower 1, who leases land in the district in order to sustain an effective crop rotation, has found that weeds are often a much larger problem on leased fields, where weed control has been less rigorous in previous crops. The grower was also concerned that neighbours leasing his own land for various crops may introduce weeds, or be less diligent in their control efforts. Grower 2 did not mention neighbouring landholders as a significant source of weeds.

4. Important weeds

*Nutgrass (*Cyperus rotundus*)*

*Convolvulus (*Convolvulus *sp.)*

*Amaranth (*Amaranthus *sp.)*

*Peppercress (*Lepidium *sp.) foreground, fat hen (*Chenopodium album*) background*

4.1. Grower 1

By far the most significant weed for this grower was nutgrass, given its ability to pierce the plastic mulch and present significant management problems post-harvest. Although the grower has been able to keep his own land largely free of this weed, he has found that on leased land nutgrass is a major management issue. He is therefore highly vigilant with regards to farm hygiene (Section 5.9), and moves quickly to control this weed whenever an outbreak is identified.

Nutgrass piercing the plastic mulch in a recently planted cucurbit crop

Other important weeds include fat hen or amaranth (*Chenopodium album* or *Amaranthus* sp.) and blackberry nightshade (*Solanum nigrum*). Milk thistle (*Sonchus oleraceus*) was considered important for its secondary impact on the crop: that is, its ability to act as a host for white fly.

4.2. Grower 2

Although weeds did not present a significant problem for this grower, he did indicate that the broadleaf weeds blackberry nightshade and fat hen were an ongoing issue. However, closer inspection of fat hen on the grower's property suggested that in fact this was a species of amaranth (*Amaranthus* sp.), not *Chenopodium album*.

This grower did not have any nutgrass infestations on his farm, and suggested that the weed is currently not a significant problem in his district.

4.3. Grower 3

Grower 3 nominated a number of important weeds on his farm, including nutgrass, convolvulus (*Convolvulus* sp.), peppercress (*Lepidium* sp.), and blackberry nightshade. Like Grower 2, what this grower referred to as fat hen was in fact identified as amaranth, suggesting that many growers in the Bundaberg district refer to this weed by a different common name. This may have an impact on future efforts to identify the most significant weeds in the district, and potentially on uptake of the most appropriate control methods for the particular species.

5. Weed control methods

5.1. Herbicide

Growers 2 and 3 both considered shielded spraying of herbicide in the inter-row space of cucurbit crops between the black plastic to be the best and most common method used in the district. Grower 2 uses a custom-made shielded spray system attached to a tractor to spray between the rows (see photograph below). In order to spray between the rows, the grower maintains a slightly wider 1.7 row spacing, and uses larger spray droplets to minimise the risk of drift. He applies a single spray of Gramoxone (paraquat) between the rows soon after the crop has been planted and before the plant vines start to 'run'. Grower 2 prefers paraquat over glyphosate since he has concerns about the residual effects of glyphosate on the plastic mulch which come in contact with the vine. Grower 1 also applies a single spray of paraquat to the inter-row space, but applies the herbicide pre-plant due to concerns regarding spray drift (discussed below).

Customised shielded spray system used by Grower 2

Grower 3 also applies herbicide between the crop rows for weed control. However, due to the nutgrass problem on his farm he uses glyphosate, and applies the herbicide before planting the crop. He has tried a number of herbicides to achieve more effective nutgrass control. This has included Sempra (halosulfuron-methyl), which he has since stopped using after finding some damage to the melon crop, and Flame (imazapic), both of which are registered for use in sugar cane crops. He also uses Eptam (EPTC) for pre-plant nutgrass control, with some success. Other herbicides used include Sprayseed (paraquat/diquat) just prior to plant, and Fusilade (fluizafop-p butyl) to control grass weeds as needed, often by spot spraying.

Grower 1 is concerned about the potential for herbicide use (particularly in the inter-row space, and particularly glyphosate) to damage cucurbit crops, and as a result he uses cultivation as an effective alternative (see Section 5.3 below). Two aspects of inter-row herbicide use concern the grower:

- Firstly, the potential even with a shielded spray applicator for herbicide drift to damage the crop, even in its early stages.
- Second, he has observed damage to cucurbit crops as a result of glyposate residue on the plastic mulch, once the crop vines start to spread across the plastic and into the inter-row space. Lime may be applied to the plastic mulch to neutralise the glyphosate residue. However this is a time consuming additional cost that the grower is happy to avoid by using cultivation for weed control instead.

5.2. Pre-plant irrigation

Grower 1 considered an earlier than normal pre-plant irrigation to be an important part of his weed control strategy. This technique seeks to reduce the germination of weeds through the holes cut in the plastic mulch for crop planting, at a time when the size of the crop seedlings leaves them vulnerable to competition from weeds. The technique is applied as follows:

- A pre-plant irrigation is carried out once the plastic mulch and irrigation lines have been laid, a few days earlier than is the norm for cucurbit producers.
- The early pre-plant irrigation gives weed seeds under the plastic mulch time to germinate and then die under the black plastic mulch due to heat and lack of light.
- Once holes are cut in the plastic for crop planting, it is therefore less likely that recently germinated weed seedlings will have a chance to compete with the recently planted crop seedlings, as many of them will have died.
- Once the crop seedlings have had a chance to grow, later germinating weed seed cohorts are less likely to cause problems, as by this stage the crop plants are better equipped to out-compete the weeds, though weeds in crop holes are often pulled by hand when young.

Nutgrass growing through the crop holes

Grower 1 has had some success with this approach in reducing the number of weeds growing in the crop holes in the mulch.

Grower 2 and 3 indicated that they did not irrigate earlier in a similar way, preferring to irrigate closer to crop planting.

5.3. Tillage/cultivation and hand weeding

Cultivation between the crop rows is also an important part of Grower 1's weed control strategy. He has purchased several GPS systems for his farming operation to control farm machinery during ploughing, bed-forming, mulching and spraying activities, and finds the degree of accuracy sufficient to allow accurate cultivation within the inter-row spaces without damaging the plastic mulch or the crop.

Cultivation is used to control weeds during the early stages of the crop, before the vines have started to run and become susceptible to damage from cultivation equipment. In this sense, Grower 1 uses cultivation to control weeds at about the same time as Growers 2 and 3 apply herbicides to the inter-row space. In both cases, weed control in the inter-row space appears to be quite effective.

A rotary hoe used by Grower 1 for preparation of his plantings

Growers 2 and 3 were ambivalent about the feasibility of cultivation between the crop rows to control weeds, and about its advantages compared with herbicide use. Grower 2 considered it to be too difficult to maintain the necessary degree of accuracy, even with GPS equipment, and was concerned about the potential to rip the plastic mulch or drag the mulch off the crop bed.

Nonetheless, Grower 3 mentioned a neighbour who uses an old Farmall tractor to control weeds in the inter-row space through cultivation. However, this tractor is unique, in that its mid-mounted cultivator and off-centre seating allows the operator to see the cultivator while driving, and ensure that it does not come into contact with the plastic mulch (see also Appendix 4, Table 4.3). Grower 3 considered that the time involved in cultivation, even using this system, was inefficiently used by comparison with herbicide use.

Grower 1 employs a staff member whose role, amongst other things, is to hand weed the plant holes in the first few weeks after the crop has been planted. This helps ensure that weed competition does not stifle crop plant growth, individual plant yield, or make harvesting more difficult.

5.4. Plastic mulch

Plastic mulch: a mainstay of cucurbit production systems

Plastic mulch is a mainstay of all three farms visited during the field work, as much for its weed control properties as for the other benefits it delivers to growers, such as moisture retention and improved fruit quality.

Grower 3 considered the combination of black plastic mulch and herbicide application between the rows still to be the most effective and economical approach to weed control in cucurbit crops. This is despite problems associated with plastic mulch, including the time and effort needed to apply and remove the mulch, and disposal costs. Grower 1 estimated that disposing of a load of used plastic mulch costs between $70 and $140. While the size of a 'load' was not specified, he did not consider this to be a significant crop input cost. Grower 2 also commented that disposal costs are not an issue for growers. This grower also noted that growers were encouraged not to burn their plastic mulch as a means of disposal, but to deposit it at the local landfill centre. However, Grower 2 had observed plastic mulch being destroyed by burning at the landfill centre. Given his relatively remote location, he is therefore willing to dispose of his used plastic mulch by fire, although he would like more sustainable alternatives to be available to growers.

It is possible to use plastic mulch and associated drip irrigation infrastructure for more than one crop, a strategy adopted by Grower 3 in fields where cucurbit disease is less of an issue. For this grower, the general approach involves:

- Planting rockmelons or watermelons as the first crop.
- After harvest, spraying the crop (and weeds) with a knock-down herbicide such as glyphosate, and possibly using a second spray if required.
- Slashing and rolling the old crop to remove the dead vines from the plastic.
- Planting a pumpkin crop into the old plastic.

Generally the plastic mulch will remain viable for long enough to produce the second pumpkin crop before it needs to be removed. The main advantage of this approach for Grower 3 is to make the best use of the plastic mulch and drip irrigation lines that have been laid at considerable expense and effort. However, the grower noted that there is an increased risk of disease in the second (pumpkin) crop, and that this has the potential to impact significantly on the profitability of this crop.

Grower 1 noted that use of a higher grade (thicker) black plastic mulch (30µm instead of 25µm) was somewhat more effective for nutgrass control, but that this weed is still able to pierce the thicker plastic. Sugar cane was also observed to pierce black plastic.

5.5. Biodegradable mulch

Biodegradable mulch is considered one of the more promising research and development activities in horticulture. It is hoped that a viable biodegradable mulch will reduce the environmental impact of cucurbit production, and make it easier for growers to dispose of mulch at the end of a crop simply by ploughing it back into the soil (see Appendix 2, Section 6.4).

Nonetheless, Grower 1 raised some valid concerns regarding the current viability of biodegradable mulch, suggesting that some work is still needed to make this a suitable replacement for 'traditional' plastic mulch.

Firstly the grower noted that, as it degrades, large pieces of biodegradable mulch are likely to break off and be blown off the fields onto neighbouring properties or public roads. He argued that, in a relatively built-up area with a greater volume of traffic, complaints by neighbours and the local community about litter are likely to make biodegradable mulch a socially unacceptable option for growers.

Secondly, the grower considered it impractical to be able to plough biodegradable mulch into the ground at the end of the season as the drip irrigation lines, which are underneath the mulch film, need to be recovered for re-use or disposal anyway.

Growers 2 and 3 were more positive about the potential for biodegradable mulch, though it is notable that their farms were relatively remote, and so they may not feel the same degree of social pressure as Grower 1 would if pieces of biodegradable mulch began littering the public roads surrounding their land. Grower 2 noted that it may be possible to recover drip irrigation lines from a biodegradable mulch system by cutting the mulch, retrieving the line, and then ploughing the mulch into the soil.

5.6. Organic mulch

Grower 1 uses organic mulches (generally wood chips and/or sawdust mixed with manure) in some of his non-cucurbit rotation crops, such as ginger. However, he considered organic mulch to be too expensive an option to be of practical use in cucurbit crops, and has noted that the cost of organic mulch from sources such as saw mills has increased significantly in recent years. All three growers interviewed suggested that cucurbit fruit are less prone to disease and discolouration when sitting on plastic compared to an organic mulch surface.

5.7. Crop rotation

Rotation is a key crop management technique used by all three cucurbit growers interviewed, primarily for its importance in reducing the build-up and incidence of diseases in a field that can impact on a cucurbit crop.

Rotation is therefore considered vital to producing a good quality, high yielding crop. Nonetheless, growers interviewed did note that rotation had advantages and disadvantages for cucurbit production with respect to weed control.

Cucurbits and sugar cane was a common rotation option used by growers interviewed

5.7.1. Advantages

Grower 2 argued that rotating cucurbits with sugar cane gave him the opportunity to control broadleaf weeds with selective herbicides, weeds that would otherwise be much more difficult to control in a cucurbit crop. Grower 3 similarly plants a single cucurbit crop (or sometimes two successive cucurbit crops: melons and then pumpkins), followed by several seasons of sugar cane production, to break down the incidence of disease and allow weeds to be controlled.

5.7.2. Disadvantages

However, Grower 1 argued that, while rotation allowed him to reduce the incidence of disease in his fields, it can work against effective weed control. This is particularly true in the absence of diligent farm hygiene practices, when different fields have different levels of weed infestation (see Section 5.9). This is relevant in circumstances where growers are leasing fields in their district to maintain crop rotation, fields that have different crop and therefore weed control histories.

5.8. Permanent or semi-permanent beds

None of the growers interviewed use permanent or semi-permanent crop beds for cucurbit production, the nearest exception being Grower 3, who at times uses plastic mulch twice (see Section 5.4).

However, growers commented that under a rotation involving a cucurbit crop followed by sugar cane in particular, permanent or semi-permanent beds are impractical. Given different crop planting widths and management systems, the entire field needs to be re-ploughed to allow the sugar cane crop to be planted.

As already discussed (Section 5.7), crop rotation is necessary to break down diseases that can cause significant losses in cucurbit crops. Consequently, Grower 3 is trialling different rotation crops, such as onions, that may allow him to maintain a semi-permanent or permanent bed arrangement.

5.9. Farm hygiene

Farm hygiene is an implicit part of each grower's weed control strategy, and has contributed to their ongoing ability to keep their land relatively weed free.

For example, Grower 1 has successfully minimised the incidence of weeds on his land (in particular restricting nutgrass spread), but is leasing other fields in the district on which to grow cucurbit crops, where nutgrass in particular is a significant problem (see also Section 5.7).

To ensure that nutgrass does not spread from leased land onto his own fields, the grower has implemented a strict farm hygiene routine, including staff training and regular use of wash-down facilities for all equipment used in crops growing in nutgrass-infested fields.

At the same time, the grower and his staff are continually checking for nutgrass outbreaks on the non-infested land, and are quick to control any plants that are discovered.

As this grower stated, it would only take 3-4 seasons for a nutgrass infestation to be spread throughout most of a paddock where cultivation is used regularly. As such, farm hygiene is paramount, and has contributed to the success of Grower 1 in keeping large parts of his land nutgrass free.

Nutgrass infested field

5.10. Agronomic factors

Two agronomic factors stood out amongst the growers interviewed as vital contributors to effective weed control: diligence and timing.

5.10.1. Diligence

As the preceding discussion in Section 5 highlights, *diligence* has been a key factor in the success of each of these growers in minimising the incidence of weeds in their cucurbit crops, and in restricting spread onto their land of new and potentially harmful species.

A diligent approach means that each grower has generally been able to control weeds before they set seed, or before they are spread by cultivation or other activities across large sections of a field. It has also meant they have been able to restrict the impact on their own fields of relatively poor weed control practices on neighbouring properties.

During the field visits, the growers discussed other landholders in the district who were either less diligent in their approach to weeds, or did not pay attention to particular species that have a significant impact on vegetable crop production, since they were not an issue in, for example, sugar cane production. During the field trip we noted examples of cucurbit farms where the crop was heavily infested by weeds, either due to lack of diligence or because the grower had been overwhelmed by the extent of the problem.

5.10.2. Timing

All three growers considered the timing of weed control activities to be vital to ongoing success. For example, Grower 3 noted that it is important to be able to get out into cucurbit fields at the right time to apply herbicide in the inter-row spaces with a shielded sprayer *before the crop vines start to spread.* At the same time, it is important not to spray too early, since further weed cohorts will have time to germinate and establish before the crop plants provide sufficient competition to smother the inter-row space.

This grower provided an example from the previous season where, due to wet weather, he had been unable to apply herbicide in one particular field. By the time the field was dry enough the crop vines had started spreading, and herbicide would have resulted in considerable damage to the crop. Consequently, the field produced a much larger quantity of weeds than other fields on his farm, with a significant impact on crop yield and quality, and greater difficulties harvesting, and increased the weed seed bank for the next few seasons.

6. Other issues

6.1. Information and advice

One of the growers interviewed believed that insufficient information is given to growers on weed control options, such as new herbicides or non-herbicide method trials. He indicated that growers have to seek information out for themselves.

For example, the grower suggested that chemical companies do not do enough to provide information on new herbicides, or on innovative uses of current herbicides. He therefore visits local rural supply stores and looks at herbicide containers and labels, or seeks out and talks to staff at these stores as well as horticulturalists.

He further indicated that due to funding cutbacks there is little information available from Qld DEEDI, the state government department responsible for primary industry, and that most of his information comes from commercial sources. He uses a mix of resellers and independent horticulturalists for advice.

Grower 3 similarly mentioned that the shortage of trained horticulturalists in the Bundaberg district is becoming more noticeable, and that those who arrive in the district often only stay for a year or two before moving on. Consequently, there is a lack of consistency in advice, and increasingly a lack of relevant local knowledge amongst horticulturalists, many of whom are only starting out in their careers.

This grower suggested that the recent development of a horticulture course at Central Queensland University (which has a campus in Bundaberg), is a step in the right direction. He also suggested that more should be done to encourage horticulturalists to stay in the region for longer, so that they develop a bank of relevant local knowledge that will allow them to better serve local growers.

6.2. Improving cucurbit production in Australia

The growers raised a number of 'wish list' issues to which they would like to see research and development efforts dedicated. Some of these issues have already been touched on in other parts of this report. The growers acknowledged that some of these suggestions were more realistically achievable than others, though considered that all would improve the future viability of cucurbit production in Australia:

- A residual herbicide that can be used in cucurbit crops (though this was considered to be a difficult prospect).
- A strong and viable biodegradable mulch.
- Development of a biodegradable drip irrigation line, so that both the line and the biodegradable mulch could be ploughed into the paddock after harvest.
- Further research into organic approaches to weed control and crop management, *providing they are cost effective*. For example, Grower 3 has had some success using composted manure in his macadamia tree crop, and considers this option worth researching for cucurbits.

- Improved training of itinerant labour (harvesters/pickers but also casual machinery operators). Grower 1 and Grower 3 both noted the relationship between untrained labour and more significant weed problems, for example areas that remain unsprayed with herbicide, or harvest workers missing fruit that is lodged in a dense weed mass.

7. Conclusions

7.1. The impact of weeds

The economic impact of weeds in cucurbit crops is difficult for growers to estimate, given lack of recorded information and the fact that techniques used have benefits other than just weed control (such as plastic mulch).

Where there is a dense infestation of weeds, crop yield can be reduced as harvest workers find it difficult to locate all the fruit.

Nutgrass is a particular issue for growers interviewed, given the difficulties it causes for retrieval of plastic mulch once the crop has been harvested.

Neighbouring properties are an important and ongoing source of weeds for growers who maintain an effective weed control strategy. Leasing of fields can also pose a problem for growers where there is a history of poor weed control in the field.

7.2. Important weeds

Perhaps the most important weed in the Bundaberg district for cucurbit growers is nutgrass, though one of the three growers interviewed did not have a nutgrass issue on the land he uses to grow cucurbits.

Other important weeds include fat hen, blackberry nightshade, milk thistle, convolvulus, and peppercress. There appears to be some confusion in the district regarding the identification of amaranth as fat hen, which may have an impact on suitable weed control methods for this plant.

7.3. Weed control methods

Broadly, all three growers use a similar cucurbit production system, involving black plastic mulch, pre-plant herbicide application, and control of weeds in the inter-row space early in the life of the crop plants, before the plant vines have a chance to spread and be damaged by weed control activity.

There were however differences between the three growers. One of these include the choice of pre-plant herbicide. Two growers preferred to use paraquat to control weeds in the inter-row space, one of them as a pre-plant application only given spray drift concerns. These growers had concerns over the potential for glyphosate to leave a residue on the plastic mulch that may damage the crop. However, the third grower uses glyphosate as an inter-row herbicide pre-plant. This is due to circumstances: the grower has a nutgrass in his fields and finds glyphosate to be the most effective knock-down herbicide for this weed.

Similarly, one grower uses an earlier than normal pre-plant irrigation to germinate weed seedlings under the plastic, allowing enough time for germinated seedlings to die in the beds before holes are cut in the plastic mulch for crop planting. He has had some success with this approach in reducing the incidence of weeds in the crop plant holes.

Recommendation

Earlier pre-plant irrigation appears to be a valid and minimal cost technique for controlling weeds under plastic mulch. More research may be required to quantify the benefits of this approach, and if effective it should be promoted to growers as an option to improve weed control within the crop, in a plastic mulch system.

The same grower is also aware of the potential for spray drift and herbicide residue to damage his cucurbit crop, and so instead he cultivates between the crop rows for effective weed control. While the other growers interviewed had some concerns about the potential of this approach to damage the plastic mulch, and the time involved in cultivation *vs* herbicide application, the grower has had considerable success with cultivation, using slightly wider row spaces than his neighbours, and GPS systems to ensure accurate cultivation.

Recommendation

Precision agriculture (cultivation using wider row spaces and GPS technology) appears to be a very effective alternative to herbicide use in the inter-row space, and may reduce grower reliance on herbicides over the longer term. It also appears to be an effective follow-up to pre-plant application of herbicide (e.g. paraquat), and the effectiveness of cultivation compared with early post-plant herbicide application should be explored further.

Plastic mulch is a mainstay of all three growers' cucurbit production systems, and is considered along with herbicide application or cultivation to be the most effective and economical approach to weed control. One grower interviewed has utilised his plastic mulch for a second cucurbit crop (melons followed by pumpkins), finding that the mulch remains viable for the second crop, and that pumpkins are less susceptible to disease. There is, however, an increased risk of disease build-up in the field.

Recommendation

Further study may be required to determine the viability (profitability and management) of using plastic mulch and drip line infrastructure for more than one cucurbit crop. This approach maximises the use of a plastic mulch system, but may result in a build-up of disease. More research may be required to determine the relationship of this approach to disease.

Biodegradable mulch development is supported by two of the three growers interviewed, though the third grower has some concerns regarding its use in its current form. He indicated that biodegradable mulch may be socially unacceptable, particularly on fields with high public visibility (for example near built-up urban areas or main roads), as the mulch tends to break down into large sections that can blow across the field, onto roads and neighbours properties. However this may not be a concern in more remote locations.

Recommendation

Concerns over the social acceptability of biodegradable mulch films need to be addressed: are these valid concerns in all situations, and can the technology be developed to the extent that litter build-up won't be an issue?

Organic mulch is considered by growers to be too expensive for use in cucurbit crops, and to leave cucurbit fruit more prone to disease or discolouration.

Crop rotation is a key component of cucurbit systems as it allows growers to manage diseases within their crops. Generally, a single cucurbit crop will be followed by around five years of other crops, often with sugar cane as a mainstay rotation in the Bundaberg region. Rotation presents benefits and challenges to growers in their efforts to control weeds: it can allow growers to control weeds (such as broadleaf weeds) in a rotation crop such as sugar cane, but at the same time it is less important to control certain weeds in non-cucurbit crops, and so these may become a more significant issue in cucurbits, particularly where land leasing arrangements do not give the same farmer control over weed management for successive seasons. Control of weeds in cucurbit crops therefore requires, insofar as it is possible, effective and diligent control of relevant weeds in the field during non-cucurbit seasons.

Permanent and semi-permanent crop beds are impractical for the growers interviewed, given the different crop width requirements of their rotation crops. However, one grower is experimenting with rotation crops, partly with the goal of looking at the feasibility of a semi-permanent rotation system.

Farm hygiene is an implicit part of each grower's weed control strategy, and has allowed each to keep their land relatively weed free. One farmer has implemented a strict hygiene programme to ensure that nutgrass does not spread from the fields he leases to those he owns, which are currently free of this weed.

Recommendation

The benefits of effective farm hygiene as a means of controlling weeds should be extended to cucurbit and other vegetable producers.

Diligence and timing are also vital to an effective weed control strategy. A diligent approach has meant that each grower has been able to control weeds generally before they set seed, or before they are spread by cultivation or other activities across large sections of a field. It has also meant they have been able to manage the impact of relatively poor weed control on neighbouring properties.

All three growers considered the timing of weed control activities to be vital to ongoing success. An example given by one grower pointed to timing of weed control activities as the difference between a weed-free crop and one that was densely populated with weeds by the time the crop was harvested.

7.4. Other issues

The growers interviewed emphasised the importance of local resellers and horticulturalists as sources of advice and information on new products or weed control approaches.

There appears to be a looming shortage of trained and experienced horticulturalists in the Bundaberg region. As such, growers were keen to see development of horticulture courses and training in the region to sustain this important source of advice.

Recommendation

As our survey suggested, local resellers and horticultural advisors are an important source of information, and so the Vegetable Industry needs to consider these vital avenues for promoting research findings and new approaches to weed control or crop management. The Vegetable Industry should also support, where possible, efforts to sustain or establish new horticultural courses in universities or other educational institutions.

Finally, growers were asked to suggest areas of research and industry development that may help cucurbit production remain viable in Australia in the future. Suggestions included continued research into a viable biodegradable mulch, further research into organic approaches that have the potential to be relevant and cost-effective, and training programmes to improve the knowledge of itinerant labour (pickers and machinery operators).

Bibliography

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