Exploring and extending integrated weed management opportunities in the Australian vegetable industry

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Summary Weeds are a persistent problem for vegetable producers because of the favourable growing conditions, regular soil disturbance and the lack of registered herbicides available to selectively control broadleaf weeds. The potential for weed growth within and between rows of vegetable crops is therefore high. Since 2011, we have been conducting research for Horticulture Innovation Australia to identify the key issues faced by vegetable producers in all the main growing regions of Australia with respect to weed impact and management, including priority weed species and their impact, and innovative approaches that warrant further exploration. This initial work identified a series of research priorities: understanding the ecology of high priority weeds within the industry, including their germination and early growth, and response to management strategies; quantifying weed seed banks on vegetable farms and linking them to farming practices; evaluating the weed management effectiveness of supplementary cultural methods (with a focus on biofumigant and green manure cover crops, and various hand weeding implements); and conducting economic analyses of weed management costs and benefits. These research priorities are the subject of an ongoing project that will address some gaps in the industry's understanding of weed impact and management, and contribute to the first comprehensive integrated weed management manual for the industry. We discuss these research priorities in more detail, including our progress regarding a national baseline seed bank assessment, establishment of cover crop trial sites, and planned extension activities.

Keywords Horticulture, extension, seedbanks, hand weeding, cover crops.

INTRODUCTION

Weeds are a persistent problem for vegetable producers because of the favourable growing conditions, regular soil disturbance and the lack of registered herbicides available to selectively control broadleaf weeds. Given these factors, weeds can have a significant impact on crop profitability, yield, quality and management practices in the Australian vegetable industry, and crop losses can be high if effective weed control is not implemented (Blaesing 2013, Charles 2013, Coleman *et al.* 2015, Henderson and Bishop 2000). There have been substantial advances in sustainable weed management in cotton and broadacre grains production in Australia in the last 20 years (e.g. Charles 2013, McGillion and Storrie 2006). However, despite some limited earlier studies in the vegetable industry (e.g. Henderson 2000), little recent attention has been paid to developing such comprehensive weed control strategies in vegetables.

A recent scoping study (Kristiansen *et al.* 2014) identified the most common weeds in vegetable crops, as well as current industry weed control strategies and research priorities. Based on these priorities, the current project seeks to address the following research objectives:

- understanding the ecology of high priority weeds within the industry, their germination and early growth, and response to management strategies;
- quantifying weed seed banks on vegetable farms and linking them to farming practices;
- evaluating the weed management effectiveness of supplementary cultural methods, including biofumigant and green manure cover crops, and various hand weeding implements; and
- conducting an economic analysis of weed management costs and benefits.

This project commenced in October 2016, and is due for completion in July 2020. Activities relating to each of the project objectives are underway, and in this paper we discuss our progress with regard to each project objective, planned research and extension activities, and some preliminary results from our baseline study of the weed seed bank on Australian vegetable farms.

MATERIALS AND METHODS

Priority weed species Based on extensive nation-wide consultation with vegetable producers and industry experts (on-ground agronomy, research and extension), Kristiansen *et al.* (2014) sought to determine the most important weed species on farms and across diverse vegetable growing regions. Farmer interviews and focus group discussions were conducted in the Lockyer Valley (Queensland, Qld),

Richmond (New South Wales, NSW), Werribee South (Victoria, Vic), Hobart and Devonport (Tasmania, Tas), Adelaide Hills and Virginia (South Australia, SA), Gingin (Western Australia, WA), and Darwin and Katherine (Northern Territory, NT). The interviews and discussions collected information about the major weeds encountered.

From this work, based on the frequency of reporting, as well as the perceived seriousness of their impact on vegetable production, Kristiansen *et al.* (2014) identified a list of high priority weeds for the Australian vegetable industry. These have been taken to be a particular target of research and extension activity over the course of the current project.

Weed seed bank assessment An assessment is underway of the baseline weed seed bank on sample farms in key growing regions across Australia, including the Lockyer Valley (Qld), Sydney Basin (NSW), Cranbourne and East Gippsland (Vic), Hobart and Devonport (Tas), Adelaide Hills and Virginia (SA), Gingin and Myalup (WA), and Darwin (NT).

A review of the global literature was completed to identify suitable methods of weed seed bank assessment in vegetable production. The review focused on paddock sampling approaches, coring depth, subdivision of cores to assess vertical distribution of seed, and sample representativeness (e.g. Buhler *et al.* 2001, Kashe *et al.* 2010, Wortman *et al.* 2010). The sampling method selected following this review involved taking 10 × 50 mm soil cores to a depth of 20 cm, systematically using a single diagonal transect spanning the length and width of the selected paddock. The cores were stratified at depths of 0–5 cm, 5–10 cm and 10–20 cm to assess vertical distribution of the weed seed bank. Five farm sites were sampled in each vegetable growing region (six in Western Australia). For each farm, soil samples from each depth increment were combined to give one bulked sample per depth. Above-ground weed biomass was also recorded within 10 × 0.5 m^2 quadrats using the same systematic paddock sampling approach as for the soil cores. In addition to biomass, data on number of weeds by species were recorded to provide a picture of the above-ground weed load within different crops.

The weed seed enumeration approach (e.g. Hartley and Rahman 1995) was selected to quantify the weed seed bank, involving soil seed germination and counting rather than more complex seed separation techniques (Auškalnienė and Auškalnis 2009, Widderick *et al.* 2010) because of the number of farms sampled and likely weeds present. For each farm, bulked soil samples from each depth increment were mixed, and three replicate samples of approximately 400 g were spread in plastic trays to a depth of 2 cm over a 2 cm layer of vermiculite, with a gauze layer in between. Trays were kept in a glasshouse with a controlled 15°C to 25°C diel temperature cycle. As seedlings emerged over a period of 2–4 months, they were removed and counted by species for each tray. Several dormancy-breaking activities (soil stirring, drying and refrigeration; e.g. Sjursen 2001, Swanton *et al.* 2000) were applied consistently to all trays to maximise the germination of all viable seeds.

Paddock management history data over the two years preceding soil sampling were collected to allow the weed load, species present and depth distribution to potentially be linked to particular management practices or vegetable crops. The management data will be utilised in detailed analysis once the seed bank assessment is complete.

Cultural weed management evaluation Cultural methods of weed control in vegetable production which will be assessed include green manure/biofumigant cover crops, crop rotation, irrigation, crop orientation and hand weeding.

Cover crops have been shown to have some benefit in reducing the weed burden in vegetable production systems, either through suppression and competition for resources (e.g. Bond and Grundy 2001), or through their biofumigant effects which may inhibit seed germination and weed growth (e.g. Al-Khatib *et al.* 1997, Alcántara *et al.* 2011). Replicated field trials have commenced to evaluate cover crop effects on weed seed banks and weed growth, with trials expected to take in two growing seasons of either winter or summer cover cropping. Each site is monitored fortnightly to measure above-ground weed species and biomass, the weed seed bank, and cover crop biomass, to establish the relative performance of the cover crop varieties in suppressing weeds.

A review of the literature was completed to evaluate the suitability of cover crop varieties considered for field trials. This included an assessment of their growing season, climatic and soil-type suitability, use of cover crops in Australia, and their pros and cons from cover crop management and weed control perspectives.

A preliminary literature review of available hand weeding implements has also been completed. Field trials to determine the efficiency and user-comfort of different hand weeding implements and approaches were in the early stages of planning at the time of writing.

Economic analysis A review of the literature suggested that the 'partial budgeting' approach is

the most suitable economic evaluation technique to determine the economic impact of weeds and innovative weed control practices in a cross-section of Australian vegetable production enterprises (e.g. Cho *et al.* 2012, Roth and Hyde 2002). An interview schedule to collect these data from farmers was prepared and piloted. In it we ask farmer interviewees to focus on a single vegetable-growing 'enterprise' within their farm (for example, a particular crop grown in a particular way). The data collected will focus on: the impact of weeds and weed control on the profitability of the enterprise; the profitability of recently implemented/trialled or otherwise innovative weed control practices; and whether the decision to implement innovative weed control practices and their subsequent profitability depended on the weed control efforts of neighbours. At the time of writing the economic analysis had not yet commenced. The results will be published and appear in industry extension materials.

RESULTS AND DISCUSSION

Priority weed species Of all weeds of significance to the vegetable industry identified by Kristiansen *et al.* (2014), approximately 50% were short-lived (annual and/or biennial) broadleaf species. While grasses were commonly found on vegetable farms, they were less likely to be considered a problem from the point of view of vegetable production due to the availability of selective herbicide options. All identifiable weed species will be accounted for in our research, however the following priority weed species have been identified from this earlier research as a focus of our research and extension efforts to improve understanding of their ecology, impact and management in the Australian vegetable industry.

- Fat hen (*Chenopodium album* L.)
- Dwarf nettle (*Urtica urens* L.)
- Mallow (*Malva parviflora* L.)
- Nutgrass (*Cyperus rotundus* L.)
- Pigweed (*Portulaca oleracea* L.)
- Amaranth (*Amaranthus* spp., with a focus on *A. retroflexus* L. and *A. viridis* L.)
- Wild radish (*Raphanus raphanistrum* L.)
- Blackberry nightshade (*Solanum nigrum* L.)
- Milk thistle (*Sonchus oleraceus* L.)
- Chickweed (*Stellaria media* (L.) Vill.)

For each of these weed species, we have completed a detailed review of the literature focusing on: identification of each weed; their ecological characteristics (including form/s of reproduction, required conditions for germination, seed viability and production, preferred soil types, competitive advantages and distribution throughout Australia); their specific impacts in vegetable production systems; and the effectiveness of various management methods. Methods used by vegetable growers include tillage, herbicides, hand weeding, and other cultural practices that may be relevant in some situations such as cover cropping, higher plant densities, stale and false seedbeds, mowing, thermal control, and mulching.

With the exception of the sedge *C. rotundus*, each of the priority weeds for the Australian vegetable industry is a heavy-seeding annual or perennial broadleaf species that can thrive in vegetable cropping systems if not managed diligently. Common impacts of these weeds were reported by farmers to include their capacity to compete with crop plants for resources due to early emergence and rapid growth, interference with harvesting activities and contamination of produce depending on crop (particularly relevant in leafy vegetables and brassicas), and acting as a host for crop viruses, pest insects and diseases.

Weed seed bank assessment At the time of writing, weed seed bank assessment had been completed for soil samples collected from all key vegetable growing regions visited. Preliminary exploration of the data suggests that burial depth in the soil has a relationship with the quantity of viable seeds observed on vegetable farms. In some cases (e.g. *Eleusine indica* (L.) Gaertn., *Lolium* spp.) the vast majority of viable seed was found closer to the soil surface (0–5 cm), while in others (e.g. *Polygonum aviculare* L., *Phalaris* spp.) the largest portion of viable seed was found deeper in the soil profile at 10–20 cm. The data also show inconsistent findings between regions, for example *C. album* appeared more likely to be present as viable seed nearer the soil surface in SA, but more likely at depth in WA. These findings are expected to reflect different paddock management histories on the farms sampled, though they may also be a strategy of the survivability of viable seeds of various weed species at different depths in the soil. With highly disturbed soils in vegetable production systems, long-lived seeds may equally be found at these various depths. Detailed analysis of the data will be completed at a later stage of the project to explore the relationship between viability at different depths, the characteristics of the weeds and their seed, and paddock management history.

Cultural weed management evaluation Four replicated cover crop trial sites were established in 2017/2018 to evaluate the effectiveness of various cover crop species in suppressing weed germination and growth. Three of these sites, Gatton Qld, Peats Ridge NSW and Forthside Tas, are being managed by a partner HIA-funded project ('VG16068 Optimising

Cover Cropping for the Australian Vegetable Industry'). The fourth in Myalup WA, is being managed by our project team. The cover crop varieties under consideration at each site are as follows:

- Gatton, Qld, summer cover crop trial: sorghum (*Sorghum bicolor* (L.) Moench), Caliente (*Brassica juncea* (L.) Czern.), Nemat (*Eruca sativa* Mill.), BQ Mulch (a mix of *Brassica nigra* (L.) Kohl ex Koch, *B. abyssinica* Brummitt and *B. carinata* A.Braun), tillage radish (*Raphanus sativus* L.), bare fallow control.
- Peats Ridge, NSW, summer cover crop trial: millet (*Echinochloa esculenta* (A.Braun) H.Scholz), sunn hemp (*Crotalaria juncea* L.), buckwheat (*Fagopyrum esculentum* Moench), ryegrass (*Lolium* spp.), millet/cowpea/ buckwheat mix, bare fallow control.
- Forthside, Tas, winter cover crop trial: Caliente (*B. juncea*), ryegrass (*Lolium* spp.), bare fallow control.
- Myalup, WA, winter cover crop trial: cereal rye (*Secale cereal* L.), Italian ryegrass (*Lolium multiflorum* Lam.), Caliente (*B. juncea*), BQ Mulch, field pea (*Pisum sativum* L.).

Industry extension The research completed throughout the course of this project will result in the first Integrated Weed Management (IWM) Manual for the Australian vegetable industry, due for publication in 2020. Reviews of literature and industry consultation have contributed to development of a draft structure for the IWM Manual. The Manual will provide background on the weed management problem within vegetable crops, details on the effectiveness of the various weed management methods available to vegetable growers and how to implement these effectively in different crops, and ways to bring these techniques together and implement IWM on the farm.

Additionally, weed management guides for approximately 10 priority weed species of vegetable production will be produced and included with the IWM Manual. These coincide with the priority species listed above, though there is potential to add other commonly encountered species such as potato weed (*Galinsoga parviflora* Cav.). At the time of writing, draft weed management guides for *C. album* and *U. urens* have been produced and provided to the industry for comment.

ACKNOWLEDGMENTS

The authors gratefully acknowledge Horticulture Innovation Australia for funding this research under project VG15070 – A strategic approach to weed management for the Australian vegetable industry. We are very grateful to all farmers, farm advisors and industry extension and support staff who have contributed to our research, particularly those farmers who are participating in the on-farm trials, and who have invited us on to their farm to collect soil and plant samples.

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