Economics of weed management in the Australian vegetable industry

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Executive summary

Weeds are a persistent problem for many vegetable producers in Australia. Although the economic impact of weeds on Australian vegetable production has been estimated at the national level, information on the farm-level economic impacts of weeds in this industry is limited. Previous research suggests that vegetable farmers have difficulty in reliably estimating the economic impacts of weeds within their crops. This research also indicates that there is a variety of innovative weed control practices, which may have been recently developed or have potential for more widespread adoption as part of an Integrated Weed Management (IWM) program. These practices have not necessarily been widely adopted amongst Australian vegetable growers, and evidence of their farm-level economics is lacking.

The review of literature conducted for this project also highlighted a 'collective action' dimension of farm-level weed control that arises from weed management, including adoption of innovative weed control practices on one property affecting weed populations on neighbouring properties. This dimension had been under-researched in respect of Australian vegetable production.

Given these knowledge gaps, the objectives of the research documented in this report were to:

1. evaluate the farm-level economic impacts of weeds in vegetable production;

2. evaluate the farm-level economic impacts of adopting innovative weed control practices in vegetable production; and

3. explore vegetable growers' perceptions of collective action problems in benefiting from innovative weed control practices.

A case study approach was followed in pursuing each of these research objectives. Each of the cases centred on a single crop grown within a particular vegetable growing property and region. The cases were drawn from New South Wales, Victoria, Tasmania and Western Australia, and were selected as far as possible to be suitable for data collection to address all three research objectives.

The method used to address objective 1 was the 'loss-expenditure approach' applied in previous national evaluations of the economic impacts of weeds in Australia. The method in pursuing objective 2 involved the farm business management technique of 'partial budgeting'. Data for objective 3 was sourced by asking case-study growers who had adopted one or more innovative weed control practices three targeted questions, based on relevant previous research. Collection of data from each case study grower across all objectives was standardised by using a common interview schedule.

In respect of research objective 1, the farm-level economic impacts of weeds in vegetable production could be calculated for 19 of the 20 cases investigated. The range of crops focused on in these cases ('focal crops') included: lettuce, iceberg lettuce, cabbage, chard (organic), potato (organic), potato (conventional), radish, leek, celery, continental parsley, parsnip (organic), curly parsley, broccoli, green bean, rocket, baby leaf lettuce, and carrot (organic). The per-hectare reduction in whole farm operating profit due to weeds in various focal crops ranges from $347 to $99,161, and the weighted average per-hectare reduction is $2,090. The weighted average per-hectare reduction in whole farm operating profit due to weeds in the respective focal crops was found to be almost six times higher for the cases involving organic production methods than for the cases involving conventional production methods.

In respect of research objective 2, farm-level economic impacts of adopting innovative weed control practices were evaluated for 15 cases in which at least one such innovative practice was identified. For one case, two innovative practices were identified and evaluated separately. Consequently, a total of 16 evaluations of innovative weed control practices were conducted. Among the innovative weed control practices evaluated were: cover cropping (oats, ryegrass); biofumigant-based cover cropping; diligent hand weeding; sheet steam weeding; stale seed beds; inter-row tillage (sometimes also providing benefits within the crop row); and flame weeding. The crops within which these practices were adopted were: cabbage, chard (organic), potato (organic), potato (conventional), radish, iceberg lettuce, celery, parsnip (organic), curly parsley, broccoli, rocket, and carrot (organic).

The per-hectare impact of adopting the innovative weed control practices on whole farm operating profit ranges across all 16 evaluations from -$5,586 to $152,199. The impact is negative in six of the evaluations.

For four of the six innovative weed control practices evaluated as having a negative economic impact, at least some of their benefits other than for weed control (e.g. benefits for soil health and structure) were noted by interviewees, but could not be accounted for. It is possible then that the economic impact of some of these practices might actually be positive if it were possible to value all of their benefits.

In all 16 cases where an innovative weed control practice had been adopted, objective 3 was addressed by asking each grower about the extent to which effective weed control depends on weed control efforts by other landholders in their locality. 'Not at all' was answered in a majority (nine) of the cases, and the next most frequent response (for three cases) was 'weakly'. The level of dependence was thus perceived to be at most weak for 75 per cent of the cases. The seven growers who did not answer 'not at all' to this question were asked a further two questions. The first of these enquired about the extent to which the grower's decision to adopt the innovative weed control practice under consideration was influenced by their level of confidence that other local landholders would exercise adequate weed control. The answer given in all seven cases was 'not at all'. This pattern of responses from vegetable growers in respect of the collective action dimension of farm-level weed management contrasts markedly with the pattern found by the present research team from an earlier survey of graziers in two regions of NSW affected by the pasture weed serrated tussock. Explaining this difference may be a productive focus for future research, possibly regarding the intensity of vegetable production systems compared with grazing properties and the higher level of active weed control undertaken throughout the year.

1 INTRODUCTION

1.1 The economic problem of weeds in Australian vegetable production

Weeds are a persistent problem for many vegetable producers in Australia. The common features of vegetable cropping systems include frequent cultivation (resulting in highly disturbed soil), regular irrigation, and the addition of large quantities of nutritional inputs before planting and while the crop is being grown. Together with a lack of registered herbicides able to selectively control weeds in many broadleaf vegetable crops (e.g. cucurbits) and minor crops (e.g. parsley), these features result in potentially very high weed growth (Kristiansen et al. 2014b).

This problem impacts negatively on the economics of producing vegetables in Australia. The most recent valuation of the national-level impact is found in McLeod (2018), which reported an average estimate of $44 million per year.

Specific ways in which weeds may negatively affect the economics of Australian vegetable cropping systems include the following.

- *Impact on the cost of growing a vegetable crop*, due to significant weed management expenses (Sinden et al. 2004). These expenses are influenced by the weed management approach being employed on each farm, but may include: labour; herbicides and other chemicals; fuel, machinery and other equipment (such as spray equipment); mulches (natural or artificial); and professional contractors.
- *Impacts on crop yield*, which can include weed competition with crop plants – for water, soil nutrients, light and space – which stunts their growth. Research suggests that significant crop yield reductions occur where no weeding activity takes place, compared with regularly weeded plots (Kristiansen et al. 2008). However, crop damage (and reduced yield) can also occur as a direct result of weed management activities, for example plant stunting due to use of a selective herbicide, or physical damage to crop plants due to hand removal of adjacent weeds (Henderson 2000).
- *Impacts on crop quality*, with many weeds acting as important hosts of pests, diseases and viruses that can reduce the quality of the crop. Pest, disease or virus infestations can start in weed infestations adjacent to crops (Department of Resources (Northern Territory) 2012), while weeds can also act as a 'bridge', enabling these problems to move from one cash crop to the next (Coutts 2006, Aftab et al. 2011). Weeds can also reduce crop quality by causing contamination of harvested produce (Kristiansen et al. 2014b).
- Other impacts on crop and farm management, which may include sowing and harvesting difficulties, and limitations on what vegetable crops that can be grown profitably in a given area (Henderson & Bishop 2000, Henderson 2001, Melander et al. 2005).

1.1.1 Farm-level challenges in responding to the economic problem

Evaluating the economic impacts of weeds at the farm level

Although the economic impact of weeds on Australian vegetable production has been estimated at the national level (Sinden et al. 2004, McLeod 2018), information on the farm-level economic impacts of weeds in this industry is limited. Previous research (Kristiansen et al. 2014c) suggests that vegetable farmers have difficulty in reliably estimating the economic impacts of weeds within their crops. Providing themselves with such estimates requires an ability to disaggregate and accurately account for the factors contributing to these impacts, and this ability is often limited by a lack of detailed records on inputs to their weed management. Estimation of this kind also requires clarity regarding which on-farm activities are conducted primarily for purposes of weed control. The economic impact of weeds at the level of a particular farm will be over-estimated when estimates account for the costs of practices that provide weed control benefits but would be adopted in any case for other reasons (e.g. improving soil health). Such considerations indicate the importance of a methodical approach to evaluating the economic impact of weeds on individual vegetable farms.

Gross margin budgets developed for vegetable crops (NSW DPI 2013, Queensland Government 2018a) offer insights into the factors contributing to the farm-level costs and revenues of the crops covered by such budgets, but a methodical approach to evaluating the farm-level economic impacts of weeds requires a more specific focus. Gross margin budgets are not sufficiently disaggregated to enable the cost and revenue impacts of weeds on these crops to be distinguished from other factors influencing their gross margins. Moreover, these budgets are representative of a limited range of vegetable crops and vegetable producing regions.

Information on the economic impacts of weeds at the farm level can assist decision-making at this level, as well as inform policy and planning in respect of weed control in the vegetable production industry. It enables vegetable growers to better understand the extent of the economic impact of weeds, and why it is important to manage weeds effectively. It is important also for ongoing development of decision-support systems for this industry.

Evaluating the economics of innovative weed control practices at the farm level

Previous research (Sindel et al. 2012, Kristiansen et al. 2014a) indicated there is a variety of innovative weed control practices that currently have relatively low levels of uptake amongst Australian vegetable growers. Some of these practices require further agronomic research to validate their effectiveness and relevance to weed management in this context. Others are already known to benefit at least some vegetable growers, and are slowly becoming more widely known and adopted as a result of industry extension and 'word of mouth'. At the same time, there appears to be misinformation within the industry about some such practices, leading to confusion and lack of adoption (Sindel et al. 2012, Kristiansen et al. 2014a).

Box 1. Definition of the term innovative weed control practice.

> The term *innovative weed control practice* is used in this report to refer to practices that are not used commonly within the Australian vegetable growing industry, which may have been recently developed or have potential for more widespread adoption by vegetable growers as part of an overall Integrated Weed Management program.

In the larger project encompassing the present research, field experiments have been conducted to identify the implications for weed management of certain innovative practices, including growing a green manure or biofumigant cover crop for their potential weed suppressive effects, or hand weeding using different implements.

Given a lack of farm-level economic evaluations conducted on these and other innovative weed control practices, one of the objectives set for the present research was to perform a range of such evaluations. Pursuit of this research objective was seen as strengthening the evidence available to vegetable growers when considering whether to adopt one or more particular innovative weed control practices as part of their overall weed management strategy. It was also seen as modelling an approach to evaluating the farm-level economic impacts of such practices that growers or their advisers might themselves follow in performing evaluations tailored to their own particular circumstances. It was anticipated also that the economic data obtained in pursuing this research objective would be useful for future projects seeking to develop models and decision-support systems for the vegetable industry.

Understanding collective action aspects of weed control, and their implications for the economics of innovative weed control practices at the farm level

Farm-level efforts to control weeds typically involve a 'collective action' dimension whereby the economics of one landholder adopting weed control practices are influenced by control efforts of other landholders in their locality. Some members of the present research team previously demonstrated the significance of this dimension for landholders' weed management decisions in the context of grazing enterprises in the Southern and Northern Tablelands of New South Wales (Sindel et al. 2013, Marshall et al. 2016). However, no studies of this kind appear to have been conducted in Australia or elsewhere with a focus on weed management in vegetable production. In recognition of this knowledge gap, one of the objectives set for the present research was to explore the significance of the collective action problem in controlling weeds in vegetable production for growers' motivations to adopt innovative weed control practices.

1.2 Research objectives

Given the knowledge gaps identified above in respect of the economics of weed control in Australian vegetable production, the objectives of the present research were to:

1. evaluate the farm-level economic impacts of weeds in vegetable production;

2. evaluate the farm-level economic impacts of adopting innovative weed control practices in vegetable production; and

3. explore vegetable growers' perceptions of collective action problems in benefiting from innovative weed control practices.

1.3 Structure of this report

This report continues in Section 2 with a review of the literature relevant to the three research objectives. The case study approach followed in pursuing these objectives as a whole, and the particular research methods applied in respect of each objective, are detailed in Section 3. The case study results are presented in Section 4. The report concludes in Section 5 with a summary of research findings and some areas identified for further research.

2 LITERATURE REVIEW

A review of literature relevant to the three research objectives identified above is presented in this Section as an overview of existing knowledge on these topics and of methods used to establish this knowledge. In Section 2.1 the focus is on literature relating to the first research objective; i.e. concerned with the farm-level economic impacts of weeds on vegetable production in Australia. The focus in Section 2.2 shifts to the second research objective; i.e. to literature concerned with the farm-level economics of innovative approaches to weed control in vegetable production. Finally, the focus in Section 2.3 is on the third research objective; i.e. literature relevant for understanding collective action challenges at the farm level in controlling weeds in vegetable production.

2.1 Studies of the economic impacts of weeds on vegetable production in Australia

Two studies (Sinden et al. 2004, McLeod 2018) have been completed within which the negative on-farm economic impacts of weeds in Australian vegetable production were estimated. As noted above, the most recent of these studies was McLeod (2018), which reported a mean estimate of $44 million per year for these impacts. Of this total annual impact, $9 million was estimated to arise from the costs of weed control and $35 million from production losses experienced despite these costs having been incurred.

The method used in obtaining this estimate was the loss-expenditure approach applied earlier by Sinden et al. (2004). This is the approach used most commonly in national-level evaluations of the economic impacts of weeds (McLeod 2018). It assumes that weeds do not reduce industry production sufficiently to increase the prices that farmers receive for their produce. Use of an alternative – economic surplus – approach is warranted where this assumption does not hold (Sinden et al. 2004, McLeod 2018).

The 'expenditure' focus in the loss-expenditure approach refers to the direct costs of weed control, which were distinguished as herbicide and non-chemical control costs. The latter of these categories included costs of herbicide application, weed chipping, grazing strategies and tillage practices. Crop and pasture chemical expenditure per hectare for an industry was estimated using data from the Australian Bureau of Statistics, and the percentage of this expenditure devoted to herbicides was estimated on the basis of gross margin budgets, consultation and previous reports. For the vegetable industry this percentage was estimated to lie within the range of 2.5% to 20%.

Having noted a lack of data on non-chemical control costs, Sinden et al. (2004) extrapolated from a study of the costs of weeds, pests and disease in the Australian wool industry (Sloane Cook and King Pty Ltd 1988) in assuming for all agricultural industries other than sugar and cotton that $0.60 of non-chemical costs of weed control are incurred for each $1 spent on herbicides. The opportunity costs of using unpaid labour of owner-operators in controlling weeds could not be qualified in their calculations given "the absence of a suitable basis on which to apportion the imputed value of on-farm labour to weed control activities" (Sinden et al. 2004 p. 15).

The 'loss' focus in the loss-expenditure approach accounts for revenue losses across an industry arising from reductions in production experienced despite weed control efforts. Sinden et al. (2004) applied an estimate of weed-induced percentage yield loss in an agricultural industry to a per-hectare gross margin assumed for that industry in order to obtain the annual gross value of production loss in that industry attributable to weeds. These gross margins were obtained from state departments of agriculture and industry reports. For those industries comprising multiple sub-industries, a single 'proxy' gross margin was adopted as representative of the industry-wide gross margin. Although a gross margin for potatoes was chosen as indicative of gross margins across the vegetable industry, no rationale for this choice was provided.

Unlike other agricultural industries for which the percentage yield losses were referenced to the literature, the percentage yield losses for the vegetable and fruit industries (1% in each case) were merely assumed. The rates of weed-induced yield loss assumed for the vegetable and fruit industries were appreciably lower than specified for the other agricultural industries. This is consistent with these authors' unreferenced observation that "horticulture typically involves high control expenditures per hectare but low production losses …, whereas livestock and grazing activities typically involve low control costs per hectare but high production losses" (Sinden et al. 2004 p. 9).

The expenditure and loss estimates for an industry were calculated on a per hectare basis, then aggregated to the national level using ABARES estimates of farm numbers and operating areas.

McLeod (2018) followed the same steps and assumptions as Sinden et al. (2004) in applying the loss-expenditure approach to the Australian vegetable industry, except that an updated gross margin budget for potatoes was used as a proxy for the industry. In neither of these evaluations of the loss-expenditure approach were losses of gross margin arising from weed-induced reductions in the price of produce due to weeds contaminating (e.g. weed seeds adhering to cabbage leaves, or weed leaves being harvested with salad leaves), or due to weeds causing deformation (e.g. weed competition causing warping of leeks) of produce, accounted for. These studies also did not account for weed-induced additions to the costs of harvesting, grading or packing produce. Sinden et al. (2004 p. 16) noted they had not quantified additional grading costs for vegetable crops arising from "presence of weed matter in some produce".

2.2 Studies of the farm-level economics of weed control methods

The literature documenting evaluations of the economics of weed control practices in vegetable crops was reviewed to inform the method to be followed in the present research in evaluating the on-farm economics of innovative practices for vegetable weed control. A literature search was performed using Scopus and Google Scholar search engines with various combinations of the search terms 'vegetable', 'weed', 'weed control', 'weed management', 'economic', 'profit', and 'budget'. Literature located through this process were screened to identify papers that included economic evaluation of at least one on-farm weed control practice in vegetable production. The 27 papers identified in this manner are listed chronologically and summarised in Appendix 1.

Of the 27 papers identified, the evaluations in 20 were based on data obtained from field experiments. Evaluations in a further four of the papers were based variously on data from on-farm trials, field trials, commercial trials with cooperating farmers, and on-farm experiments. Evaluations in two of the papers were based on findings previously documented in the literature. Finally, the evaluation reported in one of the papers relied on data collected in a survey of a random selection of growers.

Field experiments have long been the chief means by which scientists seek to test new agricultural technologies prior to them being recommended to farmers. Given a likelihood that experimental designs will omit some major factors influencing how technologies perform under normal on-farm conditions, economists have warned of the dangers of uncritically using results from field experiments when evaluating the on-farm economics of these technologies (Davidson & Martin 1965). Differences in the scale of experimental treatments and actual on-farm applications also mean that results from the former may fail to reflect economies or diseconomies of scale experienced in the latter. Liu et al. (1987 p. 352) recognised this in observing that their economic evaluation of weed control practices in tomato and pepper production faced "the major constraint of being attained by the extrapolation of small plots into a per hectare basis".

The method used in 14 (Wilcut et al. 1987, Bailey et al. 2001, Ogbuchiekwe & McGiffen 2001, Khokkar et al. 2006, Wang et al. 2009, Bangarwa et al. 2010, Fennimore et al. 2010, Johnson et al. 2010, Patel et al. 2011, Devkota et al. 2013, Fennimore et al. 2014, Eure et al. 2015, Ramachandraiah et al. 2016, Brown et al. 2019) of the 27 papers for economic evaluation of weed control practices involved comparison of the net returns (also referred to in the papers as 'net profit' or 'net farm income') achieved from the relevant crop using the alternative practices, where net returns associated with a practice were measured by deducting the variable costs specific to that practice from the crop returns achieved with its use. Variable costs are those costs which change as the size of the activity changes (Makeham & Malcolm 1993).

One of the papers reviewed (Delate et al. 2011) applied a method of comparing the returns to management arising from the alternative weed control practices under consideration. As defined in this paper, returns to management differ from net returns by virtue of the former accounting for impacts on both variable and overhead costs and the latter accounting only for impacts on variable costs. Overhead costs are those costs that do not vary greatly with changes in the level of production of mixture of activities (Makeham & Malcolm 1993).

The method of partial budgeting was applied in four (Liu et al. 1987, Kristiansen et al. 2003, Cho et al. 2012, Wortman et al. 2018) of the 27 studies. A partial budget is "a budget drawn up to estimate the effect on whole farm operating profit of a proposed change affecting only part of the farm"; operating profit is "gross income less variable and overhead costs" (Makeham & Malcolm 1993 p. 395). This kind of budget accounts only for those cost and revenue factors that will be affected by a proposed change. Developing such a budget thus avoids the time and effort of estimating values for those factors that are common among the practices under evaluation (Liu et al. 1987).

Four types of effects of a change are distinguished when developing a partial budget: costs added; costs avoided; revenue added; and revenue foregone. Overhead as well as variable costs can be affected by a change. A change may involve expenditure on new machinery, for instance, and thus increase overhead costs in the form of depreciation, the opportunity cost of the capital invested in the machinery, and the ongoing costs of repairs and maintenance (R&M) of the machinery. Such effects on overhead costs can be accounted for in a partial budget by annualising their values. Summing the costs avoided and revenue added as a result of a change gives its total benefits of the change. Summing the costs added and the revenue foregone gives the total costs of the change. To the extent that the total benefits of the change are estimated to exceed its total costs, this indicates that whole farm operating profit will be increased by the change.

In five of the papers reviewed (Ogbuchiekwe & McGiffen 2001, Wang et al. 2009, Bangarwa et al. 2010, Devkota et al. 2013, Fennimore et al. 2014) it was stated that the economic method applied therein involved partial budgeting, when in fact the methods used involved comparisons of crop net returns which accounted for cost items unaffected by differences in the weed control practices evaluated.

The economic method applied in three of the papers reviewed (Leela 1987, Henderson 1996, Melander 1998) involved comparison of the costs of the alternative weed control practices under consideration. The assumption implicit in this method that the revenue effects of all practices are the same was not justified in these papers. In one of the papers reviewed (Fontanelli et al. 2015) the economic method used involved comparison of the gross incomes obtained with the alternative weed control practices under consideration. The assumption implicit in this method that the cost effects of all practices are the same was not justified in this paper.

The method of break-even budgeting (Rae 1977) was applied in one of the papers reviewed (Engindeniz 2008). This application involved estimation of the costs added by the weed control practice followed by calculation of the yield increase that the practice would need to deliver for the added cost to be outweighed by additional revenue.

The method applied in another of the papers reviewed (van den Berg et al. 2010) involved comparison of the gross margins arising from the alternative weed control practices under consideration. The gross margin of a cropping or livestock activity is calculated by deducting its variable costs from its gross revenue. Hence the method applied in this paper involved estimation of all types of variable costs for the relevant (i.e. organic carrot) vegetable crops irrespective of whether all types were affected by adoption of the alternative weed control practices being evaluated.

The economic method employed in one of the papers reviewed (Marinan-Arroyuelo et al. 2014) involved calculation of benefit-cost ratios for the alternative weed control practices under consideration. The benefit-cost ratio for a practice was obtained by calculating the difference between gross revenue with and without the practice and dividing this revenue impact by the sum of costs added by the practice.

The diversity of on-farm benefits potentially accruing from weed control practices was highlighted by Engindeniz (2008), who identified benefits from protecting commodity yield and quality, and reducing input use, as the easiest to value, and benefits from maintaining environmental and aesthetic values and protecting human health as much more challenging to value. Cho et al. (2012) discussed the difficulties of accounting for on-farm ecosystem benefits (e.g. for carbon fixation, soil organic matter production, biodiversity, soil water retention, etc.) in economic evaluation of cover crops used for weed control, and emphasised the importance of research focused on measuring and valuing such benefits.

The sensitivity of the economic performance of a given practice for weed control in vegetable production to contingencies of time and place was highlighted by Liu et al. (1987). These authors conditioned their findings regarding the economics of the practices they considered with the proviso that the findings apply to vegetable growers with soils and weather conditions similar to those prevailing at the research station where their study was based. They explained further that the input and commodity prices used in their economic evaluations were those prevailing at the time of their research, and that changes in these prices may change the relative performance of particular weed control practices from what they had reported. The implication was that "those adopting one of these [weed] management systems must make up their own budget" (Liu et al. 1987 p. 357). Brown et al. (2019 p. 61) made a related point when observing that "it is not our aim that [organic onion growers] adopt a single 'best' approach, but for farmers to understand the benefits and risks of each weeding system so that each may be used appropriately".

2.3 Studies of collective action challenges in controlling agricultural weeds

Weed species fall within the broader category of invasive species, which typically face problems of collective action in their management. The propensity of weed seeds and other propagules to disperse across property boundaries means that efforts to control weeds on any one property confer external benefits on other properties, and lack of such efforts confers external costs on other properties. Such externalities create collective action problems by encouraging landholders to undertake less control than is in their common interest, unless they trust other landholders to reciprocate their control efforts (Marshall 2009, Berney et al. 2012, Sindel et al. 2013). Growing recognition of the challenges that governments face in solving problems of collective action in weed control has led over the last decade to an upsurge of research into these problems and how they might be solved more effectively (Epanchin-Niell et al. 2010, Berney et al. 2012, Coutts et al. 2013, Graham 2013, Sindel et al. 2013, Graham 2014, Yung et al. 2015, Marshall et al. 2016, Niemiec et al. 2016, Graham & Rogers 2017, Sullivan et al. 2017, Height 2018, Ma et al. 2018, Lubeck et al. 2019).

The significance of collective action problems in impeding effective weed control in an agricultural setting was corroborated by a survey of graziers in two regions of New South Wales, Australia, affected by the pasture weed serrated tussock. "Neighbouring private landholders who don't attempt to control [this weed]" was identified by 63 per cent of survey respondents as causing difficulty in controlling the weed on their properties (Marshall et al. 2016 p. 106). The survey respondents identified this issue as a barrier to serrated tussock control on their properties more frequently than they did any other issue. Among the other issues they were asked to consider as possible barriers to control were "lack of information about serrated tussock control", "lack of appropriate training or skills", "lack of time due to other property management tasks", and "lack of money" (Marshall et al. 2016 p. 106). The importance of farmers' trust in their neighbours' control efforts was demonstrated by 65 per cent of the survey respondents answering that their trust in neighbours controlling serrated tussock was very important in motivating their own control efforts.

Collective action in control of agricultural weeds occurs in many different socio-economic and bio-physical settings (Epanchin-Niell et al. 2010), however, and landholders' perceptions of the importance of such action for their own control efforts, and of the likelihood of this action occurring, can be expected to vary markedly from one setting to the next. Although the literature search on this topic for the present research did not identify any papers specifically concerned with problems of collective action in weed control in settings of vegetable production, some insights for settings of this kind may be deduced from papers concerned with weed control in agriculture more generally.

One such insight is that reaching agreement among landholders on a need for collective action in weed control, and how it should occur, tends to be more difficult in landscapes with diverse rather than homogeneous land uses (Epanchin-Niell et al. 2010). Diversity of land uses within a landscape can mean that weeds regarded as a serious threat by some landholders are viewed as benign or even beneficial by other landholders. It follows that collective action problems in controlling weeds of concern to vegetable growers will, all else equal, tend to be more easily solved in landscapes that are dominated by vegetable production.

Another insight of this kind is that collective action problems in controlling weeds tend to be more challenging to solve in landscapes populated by a greater number of landholders. This is because establishing the mutual trust between landholders needed for effective collective action becomes more difficult and costly the greater the number of landholders involved (Marshall et al. 2016). It follows that achieving effective collective action in controlling weeds will, all else equal, tend to be easier if vegetable production within a given landscape is performed by larger (and therefore fewer) growers.

A final insight of this kind is that collective action problems in controlling weeds tend to be solved more easily when landholders perceive greater costs to themselves from failing to solve these problems (Pannell et al. 2006). With costs incurred per hectare as a result of a given weed infestation likely to be greater in higher-value crops (due to the higher value of weed-induced yield losses), it follows that collective action in controlling weeds will, all else equal, tend to be easier among vegetable growers (given the relatively high value of their crops per hectare) than among agricultural producers generating lower returns per hectare.

2.4 Concluding comment

The foregoing review of knowledge relevant to the objectives of the present research informed the choice of methods employed to pursue these objectives. These methods are discussed in Section 3.

3 RESEARCH METHODS

3.1 Introduction

The method followed in pursuing the research objectives identified in Section 2.1 is detailed in this Section. The case study approach within which the method was applied is discussed in Section 3.2. The procedures followed in selecting and recruiting vegetable growers for case studies are outlined in Section 3.3. The method by which each case study was conducted is detailed in Section 3.4.

3.2 Case study approach

A case study approach was followed in pursuing the three research objectives. In this approach a number of cases are chosen for in-depth investigation, with the cases selected in accordance with criteria designed to ensure their suitability in contributing to the research objectives. The approach allows for a semi-structured process of collecting data for each case, in contrast to the highly structured process typically involved in collecting data through a survey questionnaire. A semi-structured approach to data collection is appropriate when it is not feasible in advance to develop a standard questionnaire that anticipates all potentially relevant dimensions of each case.

Purposive selection of cases in the case study approach helps to ensure that a limited research budget is allocated to maximise insights from in-depth investigations across the cases. A disadvantage compared with the random-sampling procedure often followed in the survey method is that findings cannot be generalised with known levels of statistical significance from the sample to the population of interest; for the present research this would be the population of vegetable growers in Australia. Llewellyn et al. (2016) surveyed a random sample of 600 Australian grain growers to estimate the nation-wide cost of weeds to growers of this kind. An analogous study for the Australian vegetable growing industry could be feasible in future given industry interest and cooperation.

Each of the cases centred on a particular crop grown within a single vegetable producing operation. The cases were selected as far as possible as suitable data sources in respect of the three different research objectives (Section 3.3). All except three of the case studies involved crops grown commercially. This enabled, firstly, all factors of real-world relevance to the research objectives to be considered in these cases, and, secondly, each of these evaluations to be performed at commercial scale. Crops grown in field experiments are less suitable for the present research since they are not solely commercial in design. They may omit some major factors influencing economic performance under commercial conditions, and that scale differences between field experiments and commercial crops can mean that findings based on data from the former may not reflect commercial scale economies.

Narrowing each of the cases to a particular crop grown within a vegetable production operation, rather than evaluating the operation as a whole, was necessary to reduce the data collection task for each case to one that could be completed within an interview of no longer than the 1.5 hours that we judged to be the limit of what most commercial vegetable growers would accept given their other commitments. Narrowing the scope was also necessary to avoid the complexity from attempting to consider multiple crops, seasonal differences and possibly different weed management approaches during a single interview session.

3.3 Selection and recruitment of vegetable growers for case studies

3.3.1 Selecting growers for potential case studies

The growers to be interviewed for the case studies were drawn from four vegetable growing regions chosen to represent a variety of vegetable crop types as well as a variety of farming systems and environmental circumstances (climate, soil, types of weed burden). These regions were the Sydney Basin NSW, northern Tasmania, Victoria (outer south-east Melbourne and Gippsland), and south-west Western Australia.

Vegetable growers selected for potential case studies in each of these regions included:

- growers who had participated in our earlier weed seed bank work (Task 2). This would allow findings for these cases from the seed bank work to be considered alongside the economics findings.
- growers recommended by industry professionals, notably Hort Innovation-funded VegNET Industry Development Officers (IDOs); researchers from other Hort Innovation-funded projects; or farmers already engaged in our research or involved in other Hort Innovation research activities in the region.
- growers known to be successfully implementing particular weed management practices, particularly where these practices fit our definition of 'innovative weed control practices'. We defined these as practices that are less commonly used within the vegetable growing industry, which may have been recently developed or have potential for more widespread adoption as part of an overall Integrated Weed Management (IWM) program.
- opportunities were taken in a couple of cases to focus on non-levied vegetable crops (e.g. potatoes) where we determined the case would have relevance to Hort Innovation-levied growers.

Further factors influencing our selection of vegetable growers for potential case studies were:

- Our desire to link economic data collected in Task 4 with farmers participating in Task 2 (the national weed seed bank baseline study) as candidates for case studies of successful IWM, therefore enhancing the information contained in the IWM case studies to be extended to the industry on project completion.
- Indications from a grower and/or our industry contacts that a grower would have sufficient records and/or knowledge of crop and weed management to make a good source of the kinds of data we were seeking.
- Logistic and budgetary advantages of being able to interview multiple growers within reasonable proximity of each other.

3.3.2 Recruiting growers for case studies

Several approaches to recruiting growers for case studies were employed, with the approach used for a particular region or grower depending on our existing relationship with the farmer and the recommendation of local extension or industry support contacts:

- Growers were recruited directly by the project team utilising pre-existing networks through prior research or other activity.
- Growers were recruited through VegNET IDOs using their existing networks, where this was the preference of these officers. This was the case in Victoria and Western Australia. In these cases, the IDOs were provided with a clear explanation of the criteria for grower selection, including our preference where possible to focus on growers who were having success with 'innovative weed control practices' as defined in Section 3.3.1.
- Where this was the preference of regional- or state-level IDOs, growers were recruited directly by the project team after confirming potential participants with the IDOs.
- Growers were in some instances self-recruited by approaching the research team asking to be involved.
- Direct recruitment of a grower following a recommendation from another grower.

Once initially recruited, each grower was contacted by phone to arrange a suitable time and venue to be interviewed. During this conversation the grower was also further informed about the purpose of the interview, familiarised with the contents of a letter of introduction sent to them, and made aware of their approximate time commitment to the interview. Preliminary information on each grower's farming system was also obtained during this phone conversation to make the interviewer familiar with the particular circumstances of the vegetable growing operation prior to the interview. This preliminary information included details of the particular cropping enterprise (e.g. organically-grown carrots) to be focused on in a case study, the main weed problems experienced in that crop, and the weed control practices applied in attempting to control those problems. Any practices matching our definition of an innovative weed control practice were identified in this process.

3.4 Data collection

The interview schedule used to structure data collection for each case is described in Section 3.4.1. The media through which the case study interviews were conducted is discussed in Section 3.4.2. The steps undertaken to comply with the University of New England's Code of Conduct for Research are outlined in Section 3.4.3. The particular methods applied in pursuing each of the three research objectives are detailed in Sections 3.4.4, 3.4.5 and 3.4.6, respectively.

3.4.1 Interview schedule

Collection of data from each grower was guided by the interview schedule. The interview schedule consists of four parts. Part A contains questions about the grower's vegetable growing operation, the particular vegetable cropping enterprise (hereafter 'crop') on which the interview will focus ('focal crop'), the weed species affecting the focal crop, and the practices normally followed to control those weeds.

Data required for pursuing the first research objective ('evaluate the farm-level economic impacts of weeds in vegetable production') were collected in Part B of the interview schedule. The focus of this part of the schedule is thus on how the weeds and the weed control practices identified for the focal crop affect the grower's whole farm operating profit. Data collected allowed an estimate of the additional costs incurred in applying these weed control practices, any residual revenue losses incurred despite the weed control practices applied, and any costs avoided (e.g. packing, processing) as a result of weed-induced yield losses.

Data relating to the second research objective ('evaluate the farm-level economic impacts of adopting innovative weed control practices in vegetable production') were collected in Part C of the interview schedule. This part of the schedule focuses accordingly on any innovative weed control practices identified in Part A as having been adopted for the focal crop. For growers identified as not having adopted an innovative weed control practice, the interview ended when Part B of the schedule was completed.

The questions in Part C are concerned with the impacts of adopting the identified innovative weed control practices on the grower's whole farm operating profit, compared with the practices the grower would have adopted under a 'without-innovation' scenario. As discussed in Section 2.2, these impacts include the costs added and/or avoided, and the revenue added and/or foregone, due to having adopted these innovative weed control practices.

Collection of data in various Sections of Parts B and C was structured by the use of tables that were adapted from tables included in AUSVEG (2012) for the purpose of developing gross margin budgets for vegetable crops.

Data in respect of the third research objective ('explore vegetable growers' perceptions of collective action problems in benefiting from innovative weed control practices') were sourced in Part D of the interview schedule. Hence the focus of this part of the schedule is on the grower's perception of a collective action problem in achieving successful outcomes from the innovative weed control practices identified in Part A and on how that perception, together with their confidence that other local landholders would adequately control weeds, influenced his or her motivation to adopt those practices.

3.4.2 Interview media

The preferred medium for interviewing was face-to-face, with 17 of the 20 completed case study interviews conducted in this manner. The remaining three interviews were conducted by telephone. It was necessary in a number of cases to follow up the interview with email or telephone communication in order to collect data that been unavailable at the time of interview, or to seek clarification.

3.4.3 Human ethics

The research undertaken in this project was conducted and reported, and the data collected has been stored, following guidelines of the Human Research Ethics Committee of the University of New England (Approval no. HE18-192). An Information Sheet for Participants was provided to each grower prior to commencement of their interview. This explained the purpose of the interview, its expected duration, and the rights of the interviewee. It explained also that the interviewee and their business would not be identified in any publication of the research findings. The interviewee was asked to sign a Consent Form to confirm they had read the Information Sheet for Participants and that any questions they asked had been answered to their satisfaction.

3.4.4 Research objective 1: evaluating the on-farm economic impact of weeds

The loss-expenditure approach discussed in Section 2.1 was followed in calculating the on-farm economic impact of weeds in each case; i.e. the impact of weeds within the focal crop on the whole farm operating profit of the grower. The impact on whole farm operating profit is obtained in this approach by summing the effects of weeds in terms of the on-farm costs added in producing the focal crop ('expenditure') and the farm-gate revenue earned by that crop ('loss')[1]. These effects were estimated using interview data, including data collected on prices paid for inputs and farm-gate prices received for their produce. The opportunity cost of any additional owner-operator labour involved in controlling weeds was imputed using an hourly rate identified by the interviewee as realistically reflecting its value.

It was recognised when calculating the on-farm costs added due to weeds that on-farm costs varying with crop yield (e.g. costs of washing and packing harvested produce) may be avoided when weeds impact negatively on yield, and that any such avoided costs need to be 'netted out' before arriving at a final estimate of added costs. In a number of cases in the present research it was necessary to impute avoided costs of this kind using data available in relevant gross margin budgets prepared by state government departments of primary industries.

In calculating the costs added in adopting weed control practices it is important to limit these practices to those undertaken *primarily* for the purpose of controlling weeds (Llewellyn et al. 2016). A range of practices with benefits for weed control (e.g. plastic mulch, cultivation, trickle irrigation, cover cropping) may be adopted in vegetable production primarily for other purposes, regardless of the weed control benefits. Cultivation for ground preparation prior to a crop may have weed control benefits, for instance, but be conducted primarily for other reasons (e.g. seedbed formation, enhanced drainage and aeration of the crop root zone, etc.). Accounting for the costs of all cultivation passes as weed control costs, irrespective of whether their primary purpose is weed control, would lead to over-estimation of the costs actually added as a result of weeds.

Once the impact of weeds in the focal crop on a grower's whole farm operating profit is calculated, two variants of this metric are derived to facilitate cross-case comparisons. The first variant involves dividing the impact on whole farm operating profit by the area of the focal crop. This metric of per-hectare impact enables comparisons across cases given differences in the spatial scale on which their respective focal crops are grown. The second variant involves dividing the impact on whole farm operating profit by the annual farm-gate revenue earned by the focal crop. This metric enables comparisons across cases regarding the significance of weed impact on whole farm operating profit relative to scale of focal crop in terms of economic value.

Evaluating the impact of weeds on costs of machinery repair, maintenance and ownership

Where application of weed control practices in a particular case involved use of machinery, a proportion of the costs of repairing and maintaining, and owning, the machinery was accounted for in calculating the costs added due to weeds in the focal crop. The average annual cost of repairs and maintenance (R&M) for a machinery item during its expected life with the grower was obtained directly from the grower.

Two aspects of machinery ownership cost were accounted for: cost of machinery depreciation, and the opportunity cost of capital invested in the machinery. For each item of machinery used in applying weed control practices, data were collected on the current purchase price of the item (or equivalent item), the expected life (in years) of the item with the grower prior to its sale or other disposal, and the price expected to be received for the item at the time of disposal (in current dollar values).

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[1] Farm-gate revenue is calculated as the product of crop yield (e.g. tonnes per hectare) and the farm-gate price received for that yield (e.g. $ per tonne). Farm-gate price is the price received by the grower after costs incurred off-farm in marketing the produce (e.g. freight, agent's commission, R&D levies) have been deducted. Revenue losses due to weeds were calculated in this study using farm-gate prices. When estimating yield-related cost impacts in the process of calculating added due to weeds, therefore, it was appropriate to account only for on-farm impacts of this kind, and not for off-farm cost impacts including on freight costs, agent's commission, R&D levies, etc.

The average annual depreciation cost for the item was calculated by dividing the difference between its purchase and disposal prices by the expected on-farm life of the item. The average annual opportunity cost of the capital invested in the item was calculated by multiplying the average value of the item during its expected life (i.e. obtained by summing its purchase and disposal prices and then divided this sum by two) by a real (i.e. inflation-adjusted) interest rate of 4 per cent per year. This rate was assumed to reflect the annual rate of return that could be achieved if the capital were invested in the most profitable alternative use.

The total average annual cost of a machinery item was obtained as the sum of its average annual R&M cost, its average annual depreciation cost, and the average annual opportunity cost of the capital invested in the item. The average annual cost of the item incurred in weed control within the focal crop was then obtained by multiplying the item's total average annual cost by the proportion of its total annual use accounted for on average by weed control in the focal crop. This proportion was obtained by asking the case study grower to estimate the percentage of total annual use of the machinery item that is typically devoted to weed control in the focal crop.

The total costs of machinery repair, maintenance and ownership incurred in weed control within the focal crop ('machinery ownership and R&M cost') were obtained by summing the costs of this kind incurred in respect of the different machinery items involved in this control.

3.4.5 Research objective 2: evaluating the on-farm economics of innovative weed control practices

The partial budgeting approach discussed in Section 2.2 was followed in calculating the on-farm economic impact of innovative weed control practices in cases where such practices have been adopted. The on-farm economic impact of concern is the effect of adopting these practices within the focal crop on the whole farm operating profit of a grower. This effect was estimated using interview data, including data collected on prices paid for inputs and farm-gate prices received for their produce. The opportunity cost of owner-operator labour that is added or avoided as a result of adopting innovative weed control practices was imputed using an hourly rate identified by the interviewee as realistically reflecting its value.

As discussed in Section 2.2, partial budgeting for the purpose of evaluating innovative weed control practices involves accounting for costs added, costs avoided, revenue added and revenue foregone as a result of adopting these practices, and this requires in turn a 'without-innovation' scenario to be defined against which these various categories of impact can be assessed. In the present research this scenario was defined for each relevant case by asking the grower to identify the weed control practice/s that would be in place in the absence of the innovative weed control practices identified for evaluation.

It was recognised when calculating costs added on-farm due to adoption of innovative weed control practices that on-farm costs varying with crop yield (e.g. costs of washing and packing harvested produce) may be added when the practices impact positively on yield. In a number of cases it was necessary to impute added costs of this kind using data available in relevant gross margin budgets prepared by state government departments of primary industries.

Once the impact of adopting innovative weed control practices weeds in the focal crop on a grower's whole farm operating profit is calculated, two variants of this metric are derived to facilitate cross-case comparisons. The first variant involves dividing the impact on whole farm operating profit by the area of the focal crop. This metric of per-hectare impact enables comparisons across cases given differences in the spatial scale on which their respective focal crops are grown. The second variant involves dividing the impact on whole farm operating profit by the annual farm-gate revenue earned by the focal crop. This metric enables comparisons across cases regarding the significance of the innovation impact on whole farm operating profit relative to scale of focal crop in terms of economic value.

Evaluating the impact of adopting innovative weed control practices on costs of machinery repair, maintenance and ownership

Where application of innovative weed control practices in a particular case changed machinery use compared with the without-innovation scenario, the cost impact of this change (either by way of added or avoided costs) was accounted for. This cost impact was accounted for in any relevant case by calculating the difference between the costs of machinery ownership and R&M with and without adoption of the innovative weed control practices.

The costs of machinery ownership and R&M with and without adoption of the innovative practices were calculated following a similar approach to that outlined in Section 5 for evaluating the impact of weeds on such costs. The repair, maintenance and ownership cost of each machinery item with use affected by adoption of innovative weed control practice/s was calculated with and without that adoption.

The cost *with* adoption of the innovative practice/s was calculated by using estimates from the relevant grower of the percentage of each item's total annual use accounted for by weed control in the focal crop when the practice is adopted. The repair, maintenance and ownership costs of each machinery item with use affected by adoption of the innovative practice/s were summed across items to obtain a with-adoption total of such costs. The cost *without* adoption of these practices was calculated by using the grower's estimates of the percentage of each item's total annual use accounted for by weed control in the focal crop when the practice is not adopted (and other practices are possibly adopted in its place). The repair, maintenance and ownership costs of each machinery item with use affected by adoption of the innovative practice/s were summed across items to obtain a without-adoption total of such costs.

The impact of adopting the innovative weed control practices on total machinery ownership and R&M costs was calculated as the difference between the with- and without-adoption totals of such costs.

3.4.6 Research objective 3: exploring the collective action problem in controlling weeds in vegetable production

Data for addressing the third research objective, concerned with exploring the significance of the collective action problem in controlling weeds for vegetable growers' motivations to adopt innovative weed control practices, was sourced though three questions included in the interview schedule. These questions applied only in those cases where adoption of one or more innovative weed control practices in the focal crop had been identified. They addressed the extent to which:

1. Effective weed control in the focal crop using the innovative weed control practice/s is perceived to depend on weed control efforts by other landholders in their locality;

2. The interviewee's decision to adopt the innovative weed control practice/s in the focal crop had been influenced by their confidence that other landholders in their locality would adequately control the weeds of concern to this crop; and

3. The interviewee was confident that other landholders in their locality would adequately control the weeds of concern to this enterprise.

In answering each of these questions, interviewees could choose between five response options: very strongly; strongly; moderately; weakly; and not at all. They were asked also to discuss the reasons for their choice.

The first of the three questions was asked in all cases where one or more innovative weed control practices had been adopted. The second and third of these questions were relevant only when the interviewee had indicated in responding to the first question that effective weed control in the focal crop using the innovative weed control practice/s depended to some extent on weed control efforts by other landholders in their locality. Hence these questions were not asked when the interviewee answered 'not at all' to the first question.

4 CASE STUDY RESULTS

4.1 Introduction

The results of the case study analyses in respect of the three research objectives are reported in this Section. The results for New South Wales cases, Victorian cases, Tasmanian cases and Western Australian cases are presented in Sections 4.2, 4.3, 4.4 and 4.5, respectively. Summaries of these results are presented in Section 5.1.

4.2 New South Wales case studies

4.2.1 NSW Case 1

Case overview

Key details for this case are shown below.

Type of operation	Family business
Area of property	30 hectares; 100% used for vegetable production
Vegetable crops grown	Potatoes, pumpkins, sweet corn, lettuce, cauliflower, cabbage, leeks, watermelon
Staff for vegetable production	4 full-time equivalent (FTE) permanent staff, and 2 FTE casual staff

Details of the particular vegetable crop chosen for the case study are shown below.

Crop	Lettuce
Growing environment	Hilled rows
Annual crop area	15 hectares
Crop establishment	Transplanted seedlings
Sowing/planting period	April-August
Harvest period	March-September
Market	Small supermarkets, providores, greengrocers
Average annual gross revenue (farm-gate value)	$675,000
Weeds of key concern	Potato weed (*Galinsoga parviflora*), milk thistle (*Sonchus oleraceus*), and stinging nettle (*Urtica urens*)[2]

Current weed management practices for the focal crop

Both pre-emergent herbicide (one application of Stomp® 440 (pendimethalin)) and post-emergent herbicide (1.5 applications of Betanal® Flow (phenmedipham/isophorone) on average) are used to control weeds in this crop.

Hand weeding with Dutch hoes (12 hours labour per hectare) is undertaken three weeks into the crop cycle.

[2] Weed species identification has not been confirmed in all cases by the project team, with grower interviewees providing the list of weeds of key concern, usually using local common names for each species. Botanical names for each weed species have been assumed based on the information provided by each interviewee.

Impact of focal crop weeds on whole farm operating profit

Description of impacts

The herbicide applications and hand weeding increase crop production costs. The cost impact of herbicide applications includes impacts on machinery (tractor and boom-spray) ownership and R&M costs. These impacts are budgeted in Table A2-1 (Appendix 2).

Incomplete weed control in an average year was estimated by the grower to increase the labour required to harvest and wash lettuces prior to packing by 36 hours per hectare.

The grower estimated that incomplete weed control using these practices reduces yield by 10 per cent in an average year. The current average yield is 50 tonnes per hectare, given the average annual farm-gate gross revenue from the crop of $45,000 per hectare and a farm-gate price around $0.90 per kilogram. A yield loss of 10 per cent of 50 tonnes per hectare, i.e. 5 tonnes per hectare, is thus experienced in an average year due to incomplete weed control.

Packing costs of around $0.24 per kilogram[3] are avoided as a result of this yield reduction.

Budgeted impacts

A budget of the impacts discussed in the previous Section is presented in Table 1. The net reduction in whole farm operating profit due to weeds in the lettuce crop is seen to be $69,395, or $4,626 per hectare of lettuce grown. This net reduction in whole farm operating profit represents 10.3 per cent of the farm-gate value of the lettuce crop’s gross revenue.

Loss of revenue due to yield losses from incomplete weed control is seen to have the greatest influence on whole farm operating profit, although this influence is mitigated significantly by the packing costs avoided due to reduced yield.

Labour costs accounts for most of the costs added due to weeds, and hand weeding accounts for the vast majority of these labour costs.

[3] Based on figures in the lettuce gross margin published by NSW DPI (2013), as adjusted for subsequent inflation using the Consumer Price Index series for Australia (ABS 2019).

Table 1. Impact of weeds in lettuce crop on whole farm profit of NSW Case 1

Item		Applications	Quantity	Rate	Area	Price	$	Subtotal	Total
Costs added by weeds									
Chemicals	Pre-emergent herbicide (Stomp® 440)	1		2 L/ha	15 ha	$15.80 /L	474		
	Post-emergent herbicide (Betanal® Flow)	1.5		0.4 L/ha	15 ha	$78.00 /L	702	1,176	
Fuel	Herbicide application		0.5 hr/ha	2.3 L/ha	15 ha	$1.50 /L	26	26	
Labour	Tractor driving		0.5 hr/ha		15 ha	$25 /hr	188		
	Hand weeding		12 hr/ha		15 ha	$25 /hr	4,500		
	Longer harvesting and washing		36 hr/ha		15 ha	$25 /hr	13,500	18,188	
Machinery ownership and R&M							428	428	19,817
Revenue lost by weeds									
Yield loss from incomplete weed control			5 t/ha		15 ha	$0.90 /ha	67,500	67,500	67,500
Costs avoided by weeds									
Avoided packing costs due to yield loss			5 kg/ha		15 ha	$0.24 /kg	17,922	17,922	17,922
Net reduction in whole farm operating profit									*$69,395*
Net reduction in whole farm operating profit as % of crop gross revenue									*10.3%*
Per hectare net reduction in whole farm operating profit									*$4,626*

Impact of the innovative weed control practice on whole farm operating profit

None of the weed control practices applied by this grower were identified as innovative.

Influence of neighbours on adoption of innovative weed control practice

As none of the weed control practices applied by this grower were identified as innovative, data were not collected in respect of this research focus.

4.2.2 NSW Case 2

Case overview

Key details for this case are shown below.

Type of operation	Family business
Area of property	70 hectares; 100% used for vegetable production
Vegetable crops grown	Potatoes, cabbage, and lettuce
Staff for vegetable production	4 FTE permanent staff, 3 FTE casual staff

Details of the particular vegetable crop chosen for the case study are shown below.

Crop	Cabbage
Growing environment	Raised beds; 2 rows of cabbages per bed
Annual crop area	40 hectares
Crop establishment	Transplanted seedlings
Sowing/planting period	Year-round
Harvest period	Year-round
Market	Produce markets and processors
Average annual gross revenue (farm-gate value)	$500,000
Weeds of key concern	Wild radish (*Raphanus raphanistrum*), nutgrass (*Cyperus rotundus*), castor oil plant (*Ricinus communis*), blackberry nightshade (*Solanum nigrum*), stinging nettle (*Urtica urens*)

Current weed management practices for the focal crop

Land to be cropped is fallowed. Fallowed land is typically irrigated to germinate weeds prior to herbicide applications. Glyphosate and Spray.Seed®250 (Paraquat/Diquat) herbicides are typically applied once each during the fallow to control weeds germinating during the fallow.

Baron® 400 WG (oxyfluorfen; post-emergent herbicide) is applied once immediately after seedlings are transplanted, and Dual Gold® (s-metolachlor; post-emergent herbicide) is applied once, 10 days after transplanting.

Inter-row tillage for weed control is conducted once during the crop, to 30 mm depth.

One pass of hand weeding (chipping weeds) is undertaken, normally halfway through crop growing cycle.

Impact of focal crop weeds on whole farm operating profit

Description of impacts

Herbicide applications, inter-row tillage and hand weeding increase crop production costs. The cost impact of herbicide applications and inter-row tillage includes impacts on machinery ownership and R&M costs, which are detailed in Table A2-2 (Appendix 2). Herbicides are applied with a 30 m self-propelled boom-spray unit, while inter-row tillage is performed with a tractor-driven in-crop cultivator.

Slowing of harvesting operations due to weeds causes an extra 12 L of diesel to be used during harvesting in an average year.

Water use in the crop was estimated to increase by 0.8 megalitres (ML) per hectare in an average year as a result of additional evapotranspiration arising from weeds in the crop. The cost of pumping water was estimated at $100 per ML. Additional labour costs of $5 per hectare were estimated to arise from the greater duration of pumping. Pumping costs are also incurred when irrigating at 0.5 ML per hectare to germinate weeds (for subsequent herbicide treatment) during the fallow phase (a stale seed bed).

Labour costs of harvesting, washing and packing the crop were estimated to increase from $2,800 per hectare (if there were no weeds) to $4,000 per hectare in an average year (i.e. by $1,200 per hectare) as a result of weeds in the crop at the time of harvest.

The labour cost for irrigation was estimated at $6.25 to apply 1 ML per hectare.

The grower estimated that 25 per cent of the poultry manure applied during fallow and of NPK (nitrogen, phosphorus and potassium) Compound Fertiliser and Potash applications during the crop is required to compensate for uptake by weeds in an average year. Poultry manure for one hectare costs $200. NPK Compound Fertiliser 12-5-14 costs $935 per tonne and is applied at 0.3 tonnes per hectare, hence costing $280.50 per hectare. NPK 14-0-17 costs $900 per tonne and is applied at 0.2 tonnes per hectare, hence costing $180 per hectare. Potash costs $1,300 per tonne and is applied at 0.15 tonnes per hectare, hence costing $195 per hectare.

Crop yield where weeds are fully controlled was estimated by the grower to be 20 per cent greater than achieved on average by the current weed control regime. The current average yield is 694.4 tonnes per year in total, or 17.35 tonnes per hectare, given the average farm-gate gross revenue from the crop of $500,000 per year, the crop area of 40 hectares, and a farm-gate price around $0.72 per kilogram. A yield loss of 20 per cent of 17.35 tonnes per hectare, i.e. 3.47 tonnes per hectare, is thus experienced in an average year due to incomplete weed control.

Packing costs of around $0.10 per kilogram[4] are avoided as a result of this yield reduction.

Budgeted impacts

A budget of the impacts discussed in the previous Section is presented in Table 2. The net reduction in whole farm operating profit due to weeds in the cabbage crop is seen to be $221,851, or $5,546 per hectare of cabbage grown. This net reduction in whole farm operating profit represents 44.4 per cent of the farm-gate value of crop gross revenue.

[4] Based on figures in the gross margin budget for production of cartons of cabbage presented in Queensland Department of Primary Industries (2018b).

Table 2. Impact of weeds in cabbage crop on whole farm operating profit of NSW Case 2

Item		Applications	Quantity	Rate	Area	Price	$	Subtotal	Total
<u>Costs added by weeds</u>									
Chemicals	Glyphosate	1		2 L/ha	40 ha	$5.00 /L	400		
	Spray.Seed®250	1		2 L/ha	40 ha	$10.00 /L	800		
	Baron® 400 WG	1		0.45 kg/ha	40 ha	$200.00 /L	3,600		
	Dual Gold®	1		1.5 L/ha	40 ha	$16.00 /L	960	5,760	
Fertilisers	Fowl manure			25%	40 ha	$200.00 /ha	2,000		
	NPK 12-5-14			25%	40 ha	$280.50 /ha	2,805		
	NPK 14-0-17			25%	40 ha	$180.00 /ha	1,800		
	Potash			25%	40 ha	$195.00 /ha	1,950	8,555	
Fuel	Cultivation for fallow	1		20 L/ha	40 ha	$1.50 /L	1,200		
	Herbicide applications	4		3 L/ha	40 ha	$1.50 /L	720		
	Inter-row tillage	1		12.5 L/ha	40 ha	$1.50 /L	750		
	Additional harvest fuel due to weeds			12 L/ha	40 ha	$1.50 /L	720	3,390	
Electricity	Irrigation pumping for fallow			0.5 ML/ha	40 ha	$100.00 /ML	2,000		
	Additional irrigation pumping for crop			0.8 ML/ha	40 ha	$100.00 /ML	3,200	5,200	
Labour	Cultivation for fallow				40 ha	$15.00 /ha	600		
	Irrigation for fallow			0.5 ML/ha	40 ha	$6.25 /ML	125		
	Herbicide applications for fallow	2		0.1 hr/ha	40 ha	$33.00 /hr	264		
	Herbicide applications for crop	4		0.1 hr/ha	40 ha	$33.00 /hr	528		
	Hand weeding				40 ha	$600.00 /ha	24,000		
	Inter-row tillage				40 ha	$30.00 /ha	1,200		
	Additional irrigation pumping				40 ha	$5.00 /ha	200		
	Slower harvesting, washing & packing of crop				40 ha	$1,200.00 /ha	48,000	74,917	
Machinery ownership and R&M							37,973	37,973	135,795
<u>Revenue lost by weeds</u>									
	Foregone revenue due to incomplete weed control		3.47 t/ha		40 ha	$0.72	99,936	99,936	99,936
<u>Costs avoided by weeds</u>									
	Reduced post-harvest costs due to yield loss		3.47 t/ha		40 ha	$0.10 /kg	13,880	13,880	13,880
Net reduction in whole farm operating profit									*$221,851*
Net reduction in whole farm operating profit as % of crop gross revenue									*44.4%*
Per hectare net reduction in whole farm operating profit									*$5,546*

Costs added due to weeds are seen to have the greatest influence on whole farm operating profit. Added labour costs are the largest source of this influence, with most of these added costs arising from weeds slowing down harvesting and washing of the crop, and by a need for hand weeding.

Loss of revenue due to yield losses from incomplete weed control nevertheless has a strong impact on whole farm operating profit, although this influence is mitigated significantly by the packing costs avoided due to reduced yield.

Impact of innovative weed control practice on whole farm operating profit

Details of the innovative weed control practice

Cover cropping with oats (*Avena sativa*) was identified as an innovative weed control practice that had been applied for the cabbage crop, although the grower explained that this practice had been adopted in the past primarily for its soil health benefits rather than for weed control. When grown, the oats cover crop substitutes for the fallow phase in the cabbage crop rotation that was noted in Section 5.

The cover crop is normally grown for four months. The land is cultivated and fertilised with poultry manure prior to sowing, at the same rate applied to the fallow phase for which the cover crop substitutes. Inter-row tillage occurs during the cover crop for weed control. The cover crop is irrigated once. The grower explained that the cover crop is not planted in dry seasons since it is uneconomic to irrigate it more than minimally, and because weeds will infest the cover crop unless it thrives. After four months the cover crop is mulched and promptly incorporated with a rotary hoe into the soil.

Description of impacts

Costs added by substituting an oats cover crop for a fallow phase include the costs of ripping for ground preparation, sowing the cover crop, inter-row tillage, and ultimately mulching the crop and incorporating it in the soil using a rotary hoe. Electricity costs of irrigation pumping are also added by irrigating the cover crop more intensively than what would occur during a fallow phase (3 megalitres per hectare rather than 0.5 megalitres per hectare). Costs of advice from a consultant are also added, since such advice is not required for a fallow phase.

Costs avoided by substituting an oats cover crop for a fallow phase are the costs of applying glyphosate during the fallow and cultivating the land prior to fallow.

The impact of substituting an oats cover crop for a fallow phase on machinery ownership and R&M costs are detailed in Table A2-3 (Appendix 2).

The grower observed that the substituting an oats cover crop for a fallow phase has no significant impact on weed incidence within the ensuing cabbage crop, and thus on the yield impact of weeds. Although they expected that the additional costs of cover cropping relative to fallow would be outweighed in the long term by the additional benefits for soil health, they were unable to estimate the value of those additional benefits.

Budgeted impacts

A budget of the impacts discussed in the previous Section is presented in Table 3. Adopting oats cover cropping in the rotation for cabbage production in place of a fallow phase is seen to reduce whole farm operating profit by $22,800, or by $570 per hectare of cabbage grown. Any soil health or other benefits of this adoption (not accounted for in Table 3) would need to exceed $570 per hectare of cabbage grown in order for its impact on whole farm operating profit to be positive. The $22,800 net reduction in whole farm operating profit represents 4.6 per cent of the farm-gate value of crop gross revenue.

Table 3. Impact of innovative weed control practice (oats cover crop) on whole farm operating profit of NSW Case 2

Item		Applications	Quantity	Rate		Area	Price		$	Subtotal	Total
Costs added by innovative practice											
Seed	Oats seed			100	kg/ha	40 ha	$1.20	/kg	4,800		
Fuel	Ground preparation			120	L/ha	40 ha	$1.50	/L	7,200		
	Sowing			15	L/ha	40 ha	$1.50	/L	900		
	Inter-row tillage			15	L/ha	40 ha	$1.50	/L	900		
	Mulch and incorporate cover crop			40	L/ha	40 ha	$1.50	/L	2,400	16,200	
Electricity	Additional irrigation pumping			2.5	ML/ha	40 ha	$100	/ML	10,000	10,000	
Labour	Cover crop field activities					40 ha	$150	/ha	6,000		
	Additional irrigation pumping			2.5	ML/ha	40 ha	$6.25	/ML	625	6,625	
Consultant fees						40 ha	$50	/ha	2,000	2,000	34,825
Costs avoided by innovative practice											
Chemicals	Glyphosate	1		2	L/ha	40 ha	$5	/L	400	400	
Fuel	Glyphosate application	1		3	L/ha	40 ha	$1.50	/L	180		
	Cultivation for fallow			20	L/ha	40 ha	$1.50	/L	1,200	1,380	
Labour	Cultivation for fallow					40 ha	$15	/ha	600		
	Glyphosate application					40 ha	$3	/ha	120	720	
Machinery ownership and R&M									9,525	9,525	12,025
Revenue added by innovative practice											
	Nil								0	0	0
Revenue foregone by innovative practice											
	Nil								0	0	0
Net increase in whole farm operating profit											-$22,800
Net increase in whole farm operating profit as % of crop gross revenue											-4.6%
Per hectare net increase in whole farm operating profit											-$570

The costs added by replacing the fallow phase with an oats cover crop ($34,825) exceed considerably the costs avoided by the practice change ($12,025). Revenue is neither added nor foregone due to the change.

Influence of neighbours on adoption of innovative weed control practice

The neighbours of this grower were also vegetable growers. They were concerned at the potential for inappropriate use of herbicides by their neighbours to lead to herbicide-resistant weed populations that might spread to their property. Hence they answered that the contribution of their innovative weed control practice (oats cover crop, in place of a fallow phase that involves herbicide application) to improving weed control, by reducing the likelihood of herbicide resistance on their property, depended 'moderately' on the weed control efforts of others in the locality.

They answered nevertheless that their decision to adopt the practice of oats cover cropping was 'not at all' influenced by their confidence that other landholders in their locality would adequately control the weeds of concern to their business. They said that they would adopt this practice regardless of what their neighbours were doing in respect of weed control.

They were 'strongly' confident that other landholders in the locality would adequately control the weed species of concern to their business. They observed that while their neighbours are strongly motivated to control weeds on their properties, some are more effective in this than others.

4.2.3 NSW Case 3

Case overview

Key details for this case are shown below.

Type of operation	Government demonstration farm
Area of property	2 hectares; 75% used for vegetable production
Vegetable crops grown	Corn, winter brassicas, Chinese vegetables
Staff for vegetable production	0.5 FTE permanent staff.

Details of the particular vegetable crop chosen for the case study are shown below.

Crop	Cabbage
Growing environment	Raised beds
Annual crop area	486 m^2
Crop establishment	Transplanted seedlings
Sowing/planting period	February-April
Harvest period	July-August (although crop is not harvested – see below)
Market	Produce is not marketed because the crop is grown with treated sewerage water and unfit for human consumption
Average annual gross revenue (farm-gate value)	n.a. (crop not harvested)
Weeds of key concern	Wild turnip (*Brassica tournefortii*), milk thistle (*Sonchus oleraceus*)

Current weed management practices for the focal crop

The weed control strategy for the cabbage crop involves application of pre-emergent herbicide (Dual Gold® (s-metolachlor), and inter-row tillage with a hand-operated scuffler six weeks after seedlings are transplanted. This scuffler is capable of completing a shallow till within the crop beds as well as in the wheel tracks. Diligent hand weeding (pulling or hoeing weeds) is completed throughout the crop cycle.

Impact of focal crop weeds on whole farm operating profit

Description of impacts

Herbicide application, inter-row tillage and hand weeding increase crop production costs.

A single herbicide application with a 6 metre boom-spray unit for the 486 m^2 crop area was estimated to take 2 hours, including 20 minutes for the application itself plus time to prepare for the application and to clean up afterwards.

The cost impact of herbicide applications and inter-row tillage includes impacts on machinery ownership and R&M costs which are detailed in Table A2-4 (Appendix 2).

The impact of weeds on revenue from the cabbage crop (and consequent impacts on yield-related costs) could not be accounted for since the crop is not harvested for reasons explained above.

Budgeted impacts

A budget of the impacts discussed in the previous Section is presented in Table 4. The net reduction in whole farm operating profit due to weeds in the cabbage crop is seen to be $805, or $16,572 per hectare of cabbage grown. Since the crop is not harvested for reasons explained above, the net reduction in whole farm operating profit as a percentage of the farm-gate value of crop gross revenue could not be calculated.

Table 4. Impact of weeds in cabbage crop on whole farm operating profit of NSW Case 3

	Item	Applications	Quantity	Rate	Area	Price	$	Subtotal	Total
Costs added by weeds									
Chemicals	Pre-emergent herbicide (Dual Gold®)	2		2 L/ha	0.0486 ha	$16.00 /L	3	3	
Fuel	Herbicide application	2	0.33 hr	7 L/hr		$1.50 /L	7	7	
Labour	Herbicide application	2	2 hrs			$44.00 /hr	176		
	Diligent hand weeding		6 hrs			$44.00 /hr	264		
	Inter/intra-row tillage (scuffling)		2 hrs			$44.00 /hr	88	528	
Machinery ownership and R&M							267	267	805
Revenue lost by weeds									
	Not estimated						0	0	0
Costs avoided by weeds									
	Not estimated						0	0	0
Net reduction in whole farm operating profit									*$805*
Net reduction in whole farm operating profit as % of crop gross revenue									*n.a.*
Per hectare net reduction in whole farm operating profit									*$16,572*

Labour accounted for the highest proportion of the costs added by weeds, with labour for hand weeding accounting for the largest share of these added costs.

Impact of innovative weed control practice on whole farm operating profit

Details of the innovative weed control practice

The innovative practice for weed control in the cabbage crop that was chosen for evaluation was the combination of diligent hand weeding with inter-row tillage using a hand-operated scuffler (1). This combination has been adopted to reduce reliance on herbicides for weed control. It was estimated that the number of applications of pre-emergent herbicide (Dual Gold®, s-metolachlor) per crop has been reduced by one (from two to one) on average as a result of adopting this combination of practices.

Figure 1. A hand-operated scuffler similar to the one used on the NSW Case 3 farm

Description of impacts

Costs added by adopting this combination of practices relate to the labour utilised in diligent hand weeding and in operating the scuffler, and include the machinery ownership and R&M costs of applying the scuffler. The annual machinery ownership and R&M costs of applying the scuffler to weed control in the cabbage crop are seen from Table A2-4 (Appendix 2) to be $13 for the crop.

Costs avoided by adopting these practices relate to the herbicide, fuel and labour costs saved as a result of reducing by one the number of pre-emergent herbicide applications.

Budgeted impacts

A budget of the impacts discussed in the previous Section is presented in Table 5. Adopting diligent hand weeding and inter-row tillage in the cabbage crop, in place of an additional application of pre-emergent herbicide, is seen to reduce whole farm operating profit by $271, or by $5,586 per hectare of cabbage grown. This result arises from the costs added by adopting these practices ($365 for the crop) exceeding the costs avoided by this adoption ($93 for the crop).

It is important to note that this estimate does not account, for reasons explained above, for any benefits from adopting this combination of practices. These benefits may include increased yield due to better weed control and reduced risks of weeds developing herbicide resistance. These benefits would need in total to exceed $5,586 per hectare of cabbage grown for the impact of adoption on whole farm operating profit to be positive.

This grower also cited off-property environmental benefits of reduced herbicide use as a motivation for adopting this combination of practices.

Table 5. Impact of innovative weed control practice (inter-row tillage (scuffler) and diligent hand weeding) on whole farm operating profit of NSW Case 3

Item		Applications	Quantity	Rate	Area	Price	$	Subtotal	Total
Costs added by innovative practice									
Labour	Diligent hand weeding		6 hrs			$44.00 /hr	264		
	Inter-row tillage (scuffler)		2 hrs			$44.00 /hr	88	352	
Machinery ownership and R&M							13	13	365
Costs avoided by innovative practice									
Chemicals	Pre-emergent herbicide (Dual Gold®)	1		2 L/ha	0.0486 ha	$16.00 /L	2	2	
Fuel	Pre-emergent herbicide application	1	0.33 hrs	7 L/ha		$1.50 /L	3	3	
Labour	Pre-emergent herbicide application	1	2 hrs			$44.00 /hr	88	88	93
Revenue added by innovative practice									
	Not estimated						0	0	0
Revenue lost by innovative practice									
	Nil						0	0	0
Net increase in whole farm operating profit									*-$271*
Net increase in whole farm operating profit as % of crop gross revenue									*n.a.*
Per hectare net increase in whole farm operating profit									*-$5,586*

Influence of neighbours on adoption of innovative weed control practice

The closest vegetable grower is located three kilometres away from this property. Their immediate neighbours use their land for growing turf or grazing horses.

This grower answered 'very strongly' when asked about the degree to which effectiveness of the innovative weed control practice – inter-row scuffling in combination with diligent hand weeding – in controlling weeds on their property depends on weed control efforts by other landholders in the locality. They observed that fireweed can be a particular problem in this respect, with its seeds easily introduced to their property if not controlled by neighbours in their grazing paddocks. They manage this risk by striving to keep the property boundaries free of weeds, in order to provide a buffer against spread from other properties.

Their decision to adopt the innovative weed control practice was 'not at all' influenced by their level of confidence that other landholders in the locality would adequately control the weeds of concern to their business. They said that they would be adopting the innovative practice regardless of how well their neighbours were controlling weeds.

They were 'not at all' confident that other landholders in their locality would adequately control the weed species of concern to their business, given that land-use of a number of surrounding properties involves intensive grazing with a low level of management.

4.2.4 NSW Case 4

Case overview

Key details for this case are shown below.

Type of operation	Business run as a trust
Area of property	58 hectares; 2 hectares is used per year for growing vegetables
Vegetable crops grown	Tomatoes, potatoes, cabbage, broccoli, rhubarb, leeks, lettuce, fennel, chards, Cavelo Nero
Staff for vegetable production	5 FTE permanent staff

Details of the particular vegetable crop chosen for the case study are shown below.

Crop	Chard (organic)
Growing environment	Raised beds
Annual crop area	1,125 m^2 per year (11.25 rows, each 100 m long)
Crop establishment	Transplanted seedlings
Sowing/planting period	August-March
Harvest period	November-September
Market	50% to farmers' markets; 13% in vegetable boxes delivered to Sydney homes, 33% to restaurants, 4% to wholesalers
Average annual gross revenue (farm-gate value)	$30,000
Weeds of key concern	Kikuyu (*Pennisetum clandestinum*), wild turnip (*Brassica tournefortii*), dock (botanical name not confirmed), summer grass (*Digitaria* sp.), fat hen (*Chenopodium album*), capeweed (*Arctotheca calendula*)

Current weed management practices for the focal crop

The practices adopted in the organic chard crop primarily for the purpose of controlling weeds are cover cropping and diligent hand weeding (which includes use of a lawn mower to mow the laneways between the beds.

The cover crop over winter consists of a mix of oats, wheat or cereal rye sown with vetch. Over summer it consists of a mix of millet, sorghum or buckwheat sown with cow peas or a bean crop. Inoculated clover is also sown with cover crops irrespective of season. The cover crop is slashed prior to setting seed and regrows until ground preparation occurs for the chard crop.

Impact of focal crop weeds on whole farm operating profit

Description of impacts

Cover cropping and diligent hand weeding add to the production costs of the organic chard crop.

The costs of cover cropping include the cost of seed and of five machinery operations in establishing, weeding and terminating the cover crop: (1) mulching the prior crop; (2) ground preparation using a rotary hoe; (3) sowing the cover crop; (4) harrowing; and (5) rolling in the cover crop. These operations each involve costs in terms of fuel, labour, and machinery ownership and R&M costs. Cover cropping costs also include use of a lawn mower (2 passes at 5 minutes per row) to mow weeds in laneways.

Diligent hand weeding was estimated to involve in an average year a total of 10 hours labour for each 100 metre row of chard.

The grower estimated that competition from weeds for soil nutrients adds one-third to the quantity of organic fertiliser that needs to be applied to the chard crop.

The grower estimates that despite the weed control regime the yield of the chard crop is reduced by 20 per cent (2,400 bunches in an average year compared to a yield of 12,000 bunches if full weed control could be achieved).

Budgeted impacts

A budget of the impacts discussed in the previous Section is presented in Table 6. The net reduction in whole farm operating profit due to weeds in the organic chard crop is seen to be $11,156, or $99,161 per hectare of organic chard grown. This net reduction in whole farm operating profit represents 37.2 per cent of the farm-gate value of crop gross revenue.

Costs added due to weeds account for a slightly greater share of the impact of weeds on whole farm operating profit than revenue lost due to weeds. Labour costs of diligent hand weeding are seen to account for most of the additional costs attributable to weeds.

Table 6. Impact of weeds in organic chard crop on whole farm operating profit of NSW Case 4

Item		Applications	Quantity	Rate	Area	Price	$	Subtotal	Total
Costs added by weeds									
Seed	Cover crop				0.1125 ha	$331.00 /ha	37	37	
Fertiliser	Organic fertiliser (Terra Firma)		11.25 rows	7.7 kg/row		$0.90 /kg	78	78	
Fuel	Cover crop - field operations	5	0.9375 hrs	10 L/hr		$1.50 /L	70		
	Cover crop - mow laneways						20	90	
Labour	Cover crop - field operations		11.25 rows	0.42 hrs/row		$36.00 /hr	169		
	Cover crop - mow laneways		11.25 rows	0.08 hrs/row		$36.00 /hr	34		
	Diligent hand weeding		11.25 rows	10 hrs/row		$36.00 /hr	4,050	4,253	
Machinery ownership and R&M							1,898	1,898	6,356
Revenue lost by weeds									
Yield loss from incomplete weed control			2,400 bunches			$2.50 /bunch	6,000	6,000	6,000
Costs avoided by weeds									
Costs of washing and packing produce			2,400 bunches			$0.50 /bunch	1,200	1,200	1,200
Net reduction in whole farm operating profit									*$11,156*
Net reduction in whole farm operating profit as % of crop gross revenue									*37.2%*
Per hectare net reduction in whole farm operating profit									*$99,161*

Impact of innovative weed control practice on whole farm operating profit

Details of the innovative weed control practice

The innovative practice for weed control in the organic chard crop that was chosen for evaluation was the combination of cover cropping and diligent hand weeding. This approach to hand weeding involves regularly monitoring the crop for weeds and removing as many weeds as possible by hand before they produce seed, to minimise the risk of increasing the weed seed bank and causing problems for future crops. Weed control in the organic chard crop in the absence of this practice would rely entirely on a more selective and occasional approach to hand weeding in which larger weeds are removed by hand when the opportunity arises and where they are expected to have an impact on quality of the final crop, or to interfere with harvesting (defined here as 'conventional hand weeding').

Description of impacts

The costs added by adopting cover cropping were discussed in Section 5 and are detailed in Table 6. The machinery ownership and R&M costs arising from cover cropping are detailed in Table A2-5 (Appendix 2).

The grower estimated that the number of hours of conventional hand weeding required to achieve acceptable weed control in the absence of both cover cropping and diligent hand weeding (the without-innovation scenario) would be four times greater than the number of hours required for diligent hand weeding when cover cropping is also practiced (the with-innovation scenario). Given that the latter number is 10 hours per row (see Table 6), the labour required for conventional hand weeding in without-innovation scenario would be 40 hours (four times 10) per row. It follows that 30 hours (40 minus 10) of labour is avoided per row when cover cropping and diligent hand weeding is adopted in place of conventional hand weeding.

The additional labour that that would be assigned to conventional hand weeding in the without-innovation scenario would nevertheless not deliver the same level of weed control, and thus yield, as gained when cover cropping and diligent hand weeding are both adopted. The grower estimated that the average crop yield with these innovations would be 3,600 bunches greater (at 9,600 bunches) than the 6,000 bunches that would be achieved if weed control were to rely instead on conventional hand weeding.

Associated with the additional yield available under the with-innovation scenario are additional packing and washing costs that vary directly with yield. The grower estimated these costs to be $0.50 per bunch of chard.

Budgeted impacts

A budget of the impacts discussed in the previous Section is presented in Table 7. Adopting cover cropping and diligent hand weeding in the organic chard crop, in place of conventional hand weeding, is seen to increase whole farm operating profit by $17,122, or by $152,199 per hectare of organic chard grown.

Table 7. Impact of innovative weed control practice (cover cropping and diligent hand weeding) on whole farm operating profit of NSW Case 4

Item		Applications	Quantity	Rate	Area	Price	$	Subtotal	Total
Costs added by innovative practice									
Seed	Cover crop		0.1125 ha			$331 /ha	37	37	
Fuel	Cover crop - field operations	5	0.9375 hrs	10 L/hr		$1.50 /L	70		
	Cover crop - mow laneways						20	90	
Labour	Cover crop - field operations		11.25 rows	0.42 hrs/row		$36 /hr	169		
	Cover crop - mow laneways		11.25 rows	0.08 hrs/row		$36 /hr	34	203	
Machinery ownership and R&M							1,898	1,898	
Costs of washing and packing produce			3,600 bunches			$0.50 /bunch	1,800	1,800	4,028
Costs avoided by innovative practice									
Labour	Diligent hand weeding		11.25 rows	30 hrs/row		$36 /hr	12,150	12,150	12,150
Revenue added by innovative practice									
Increased yield			3,600 bunches			$2.50 /bunch	9,000	9,000	9,000
Revenue lost by innovative practice									
	Nil						0	0	0
Net increase in whole farm operating profit									*$17,122*
Net increase in whole farm operating profit as % of crop gross revenue									*57.1%*
Per hectare net increase in whole farm operating profit									*$152,199*

The total costs added by adopting these practices are $4,028, while the costs avoided are considerably higher at $12,150. The revenue added by adopting these practices is $9,000. The single largest contributor to the higher whole farm operating profit under the with-innovation scenario is the $12,150 saving in (conventional) hand weeding costs arising from the innovation.

This increase in whole farm operating profit due to the innovation represents 57.1 per cent of the farm-gate value of crop gross revenue.

The grower observed that this evaluation most likely under-estimates the long-term increase in whole farm operating profit due to the innovation, since soil structure and health would deteriorate in the absence of cover cropping such that the crop yield of 6,000 bunches assumed under the without-innovation scenario could not be sustained into the long term.

Influence of neighbours on adoption of innovative weed control practice

Other landholders in the locality of this grower are not vegetable growers but use their land for grazing cattle. The grower answered that effective weed control in the organic chard crop using the innovative weed control practice (cover cropping and diligent hand weeding) depends 'weakly' on weed control efforts by other landholders in the locality. The grower explained that the dense growth of their cover crops makes the effectiveness of their innovative weed control practice fairly resilient to spread of weed seeds from neighbouring properties.

The grower said that their decision to adopt the innovative weed control practice was 'not at all' influenced by their level of confidence that other landholders in their locality would adequately control the weeds of concern to their business. They said that they would adopt the innovative practice regardless of what their neighbours were doing to control weeds on their properties.

The grower was 'moderately' confident that other landholders in their locality would adequately control the weed species of concern to their business, observing that one of their immediate neighbours exercises good weed control while the other is less diligent in this area.

4.2.5 NSW Case 5

Case overview

This case involves the same property as covered in NSW case 5, but with a different focal crop. Key details for this case are shown again below for convenience.

Type of operation	Business run as a trust
Area of property	58 hectares; 2 hectares is used per year for growing vegetables
Vegetable crops grown	Tomatoes, potatoes, cabbage, broccoli, rhubarb, leeks, lettuce, fennel, chards, Cavelo Nero
Staff for vegetable production	5 FTE permanent staff

Details of the particular vegetable crop chosen for the second of the case studies undertaken on this property are shown below.

Crop	Potatoes (organic)
Growing environment	Hilled rows
Annual crop area	0.81 hectares (2 acres)
Crop establishment	Seed potatoes planted mechanically
Sowing/planting period	September-January
Harvest period	January-July
Market	Mainly restaurants
Average annual gross revenue (farm-gate value)	$50,000

Weeds of key concern	Kikuyu (*Pennisetum clandestinum*), summer grass (*Digitaria* sp.)

Current weed management practices for the focal crop

An innovative procedure for hilling potatoes to better control weeds is followed by this grower. In the conventional hilling procedure, hilled rows are formed into which the seed potatoes are dropped as the planter moves across the potato bed. Hilling then occurs a further two times to smother weeds. The innovative hilling procedure involves levelling the hills with a mouldboard ridger ('tickler') 2-3 weeks after planting, such that planted potatoes are almost exposed. This provides the opportunity for a third hilling if necessary after planting to smother weeds that have emerged since the previous hilling, and may be considered operationally similar to inter-row tillage or even a false seed bed. This opportunity is precluded under the traditional procedure by lack of clearance between the underside of the tractor and the ground level after the second hilling post-planting.

Hand weeding occurs when there is a heavy weed load, as a result of delayed use of hilling operations, for example due to a prolonged wet period.

Impact of focal crop weeds on whole farm operating profit

Description of impacts

The costs of weed control by the innovative hilling procedure includes the fuel, labour, and machinery ownership and R&M costs of the four machinery passes undertaken for weed control – the mouldboard ridger pass and the three subsequent hilling passes. Refer to Table A2-6 (Appendix 2) for details of machinery ownership and R&M costs.

The grower estimated that 40 hours of hand weeding labour is required per hectare in years when a heavy weed load is experienced. Heavy-weed years occur on average once in every eight years (i.e. on 12.5 per cent of the crop area on an average annual basis) when the innovative hilling procedure is followed.

The grower stated that yield and revenue losses in the potato crop due to weed impacts are generally avoided when the foregoing methods of weed control are followed.

Budgeted impacts

A budget of the impacts discussed in the previous Section is presented in Table 8. The net reduction in whole farm operating profit due to weeds in the organic potato crop is seen to be $1,824, or $2,254 per hectare of organic potatoes grown. This net reduction in whole farm operating profit represents 3.6 per cent of the farm-gate value of crop gross revenue.

Costs added due to weeds account for the full impact of weeds on the operating profit of the organic potato crop. The machinery ownership and R&M costs of the innovative hilling procedure for weed control account for around two-thirds of the costs added due to weeds.

Table 8. Impact of weeds in organic potato crop on whole farm operating profit of NSW Case 5

Item		Applications	Quantity	Rate	Area	Price	$	Subtotal	Total
<u>Costs added by weeds</u>									
Fuel	Mouldboard ridger	1	1.24 hrs/ha	10 L/hr	0.81 ha	$1.50 /L	15		
	Hilling for weed control	3	1.24 hrs/ha	10 L/hr	0.81 ha	$1.50 /L	45	60	
Labour	Mouldboard ridger	1		1.2 hrs/ha	0.81 ha	$36.00 /hr	36		
	Hilling for weed control	3		1.2 hrs/ha	0.81 ha	$36.00 /hr	108		
	Hand weeding		12.5% of area	98.8 hrs/ha	0.81 ha	$36.00 /hr	360	504	
Machinery ownership and R&M							1,260	1,260	1,824
<u>Revenue lost by weeds</u>									
	Nil						0	0	0
<u>Costs avoided by weeds</u>									
	Nil						0	0	0
Net reduction in whole farm operating profit									*$1,824*
Net reduction in whole farm operating profit as % of crop gross revenue									*3.6%*
Per hectare net reduction in whole farm operating profit									*$2,254*

Impact of innovative weed control practice on whole farm operating profit

Details of the innovative weed control practice

The innovative practice for weed control in the organic potato crop that was chosen for evaluation was the modified hilling procedure described above. Weed control in this crop in the absence of this practice would rely on the conventional hilling procedure supplemented by more hand weeding than is required on average when the innovative hilling procedure is used.

Description of impacts

The costs added by adopting the innovative hilling procedure, compared with the conventional hilling procedure, were discussed in Section 5 and are detailed in Table 8. The machinery ownership and R&M costs added by adopting the innovative hilling procedure are detailed in Table A2-7 (Appendix 2).

The grower estimated that hand weeding at the rate of 40 hours labour per acre (98.8 hours per hectare) will be required once in every five years on average when the conventional hilling procedure is applied, compared with once in every eight years on average when the innovative hilling procedure is applied. Hence, adoption of the innovative procedure is expected on an average annual basis to reduce the proportion of the 0.81 hectares potato crop area in which hand weeding in required from one-fifth (0.16 hectares) to one-eighth (0.10 hectares); i.e. by 0.06 hectares.

The average annual yield of the potato crop with the current weed control regime was estimated by the grower to be 10 tonnes per acre (24.7 tonnes per hectare). They estimated further that this yield is 25 per cent higher than it would be (19.8 tonnes per hectare) if the current innovative hilling procedure were replaced by the conventional procedure. A revenue gain accrues accordingly from an estimated yield increase of 4.9 tonnes per hectare. The grower observed that this yield increase follows from the innovative procedure (and particularly the pass of the mouldboard ridger) reducing the volume of soil covering the seed potatoes around the time of germination, thus (given the transition from winter to spring) increasing the temperature of the soil surrounding the seed potatoes and promoting earlier germination. Earlier germination, in turn, lengthens the window for crop growth and reduces plant losses from potato rot. Earlier germination also enables faster ground coverage by the crop and thereby inhibits the emergence of weed problems that may reduce yield.

Packing costs of around $0.14 per kilogram[5] are assumed to be added as a result of this yield increase.

Budgeted impacts

A budget of the impacts discussed in the previous Section is presented in Table 9. Adopting the innovative hilling procedure in the organic potato crop, in place of the conventional hilling procedure, is seen to increase whole farm operating profit by $8,904, or by $11,001 per hectare of organic potatoes grown. This increase in whole farm operating profit represents 17.8 per cent of the farm-gate value of crop gross revenue.

Crop revenue added as a result of the yield increase expected from the innovative hilling procedure is seen to be the dominant driver of the increase in whole farm operating profit arising from the innovative procedure. The costs avoided by adopting this procedure (hand weeding labour costs) are outweighed by the added costs arising from this adoption.

[5] Based on figures in the gross margin budget for 'potato, unwashed, spring-summer' presented in Queensland Department of Primary Industries (2018b).

Table 9. Impact of innovative weed control practice (modified hilling procedure) on the whole farm operating profit of NSW Case 5

	Item	Applications	Quantity	Rate	Area	Price	$	Subtotal	Total
Costs added by innovative practice									
Fuel	Mouldboard ridger	1	1.2 hrs/ha	10 L/ha	0.81 ha	$1.50 /L	15		
	Hilling for weed control	1	1.2 hrs/ha	10 L/ha	0.81 ha	$1.50 /L	15	30	
Labour	Mouldboard ridger	1		1.2 hrs/ha	0.81 ha	$36 /hr	36		
	Hilling for weed control	1		1.2 hrs/ha	0.81 ha	$36 /hr	36	72	
Machinery ownership and R&M							650	650	
Packing				4.9 t/ha	0.81 ha	$0.14 /kg	560	560	1,312
Costs avoided by innovative practice									
Labour	Hand weeding			98.8 hrs/ha	0.06 ha	$36 /hr	216	216	216
Revenue added by innovative practice									
Yield increase				4.9 t/ha	0.81 ha	$2.50 /kg	10,000	10,000	10,000
Revenue lost by innovative practice									
	Nil						0	0	0
Net increase in whole farm operating profit									$8,904
Net increase in whole farm operating profit as % of crop gross revenue									17.8%
Per hectare net increase in whole farm operating profit									$11,001

Influence of neighbours on adoption of innovative weed control practice

As noted in Section 5 regarding this case study grower, other landholders in the same locality are not vegetable growers but use their land for grazing cattle. This grower answered 'not at all' when asked about the degree to which the effectiveness of the innovative weed control practice – the modified hilling procedure – in controlling weeds in their potato crop depends on weed control efforts by other landholders in the locality. They observed that the weeds in this crop come almost entirely from the seedbank on their own land, and that much the same weed problems would occur irrespective of how well their neighbours controlled weeds.

4.2.6 NSW Case 6

Case overview

Key details for this case are shown below.

Type of operation	Family business
Area of property	12.5 hectares; 100% used for vegetable production
Vegetable crops grown	Radish, coriander, spinach, parsley, carrots
Staff for vegetable production	1 FTE permanent staff, 64 FTE seasonal staff

Details of the particular vegetable crop chosen for the second of the case studies undertaken on this property are shown below.

Crop	Radish
Growing environment	Flat beds in green house
Annual crop area	9.6 hectares (eight crops of 1.2 hectares)
Crop establishment	Precision vacuum seeder
Sowing/planting period	Year-round (8 crops per year)
Harvest period	Year-round
Market	Supermarkets
Average annual gross revenue (farm-gate value)	Not provided
Weeds of key concern	Potato weed (*Galinsoga parviflora*), fat hen (*Chenopodium album*), fleabane (*Conyza* spp.), flickweed (*Cardamine hirsuta*), chickweed (*Stellaria media*), marshmallow (*Malva parviflora*), stinging nettle (*Urtica urens*)

Current weed management practices for the focal crop

Steam weeding occurs using a MSD (Möschle Seifert Dämpftechnik) sheet steamer. Two sheets are used for each steaming of 3-4 hours duration, with the sheets set up 25 times to steam-weed one hectare. Rotary hoeing to form beds facilitates entry of steam to the soil (although this practice is standard ground preparation and would occur in the absence of steam weeding). Roundup Ultra® MAX (glyphosate) is applied post-harvest by a tractor-drawn spray unit to control weeds for subsequent radish crops. The herbicide is also applied by backpack to areas within the greenhouse not reached by the tractor-drawn unit.

Impact of focal crop weeds on whole farm operating profit

Description of impacts

The costs of herbicide applications include chemical and labour and fuel costs, as well as machinery ownership and R&M costs for application by tractor and labour costs for application by backpack. Costs of steam weeding include fuel (heating diesel) costs for generating steam, labour for setting up and shifting the steam weeder, and the machinery ownership and R&M costs of the steam weeder. Machinery ownership and R&M costs added under the current weed control regime are detailed in Table A2-8 (Appendix 2).

The grower observed that labour costs in harvesting and packing the radish crop are increased by weeds slowing the harvesting process and contaminating the harvested radish bunches, thus lengthening the packing process. The cost of labour for harvest and packing was estimated to be increased by $0.015 per bunch as a result of weeds, with an average radish harvest summing to 700,000 bunches.

The grower observed that yield and revenue from the radish crop is not reduced by weeds under the weed control regime detailed above.

Budgeted impacts

A budget of the impacts discussed in the previous Section is presented in Table 10. The net reduction in the whole farm operating profit due to weeds in the radish crop is seen to be $107,371, or $11,185 per hectare of radish grown. This net reduction in whole farm operating profit as a percentage of the farm-gate value of crop gross revenue could not be calculated because the grower was reluctant to provide details of the crop gross revenue.

Costs added due to weeds account for the full impact of weeds on the operating profit of the radish crop. The fuel and labour costs of steam weeding account for most of these added costs, although the costs of the additional labour required in harvesting and packing the crop also contribute significantly.

Table 10. Impact of weeds in radish crop on whole farm operating profit of NSW Case 6

Item		Applications	Quantity	Rate	Area	Price	$	Subtotal	Total
Costs added by weeds									
Herbicides	Glyphosate (Roundup Ultra® MAX)	1		0.7 L/ha	9.6 ha	$9.90 /L	67	67	
Fuel	Herbicide application	1	533 L			$1.60 /L	853		
	Heating diesel for steam weeder	1	19,500 L			$1.60 /L	31,200	32,053	
Labour	Tractor-drawn application of herbicide	1		4.2 hrs/ha	9.6 ha	$32 /hr	1,290		
	Backpack application of herbicide		52 weeks	1 hr/week		$32 /hr	1,664		
	Steam weeding	1		182 hrs/ha	9.6 ha	$32 /hr	55,910		
	Harvest and packing		700,000 bunches			$0.015 /bunch	10,500	69,365	
Machinery ownership and R&M							5,888	5,888	107,371
Revenue lost by weeds									
	Nil						0	0	0
Costs avoided by weeds									
	Nil						0	0	0
Net reduction in whole farm operating profit									*$107,371*
Net reduction in whole farm operating profit as % of crop gross revenue									*n.a.*
Per hectare net reduction in whole farm operating profit									*$11,185*

Impact of innovative weed control practice on whole farm operating profit

Details of the innovative weed control practice

The innovative practice for weed control in the radish crop that was chosen for evaluation is use of the sheet steam weeder. In the absence of this innovative practice there would be a need for additional herbicide applications: the pre-emergent herbicide Ramrod® (Propachlor) would be applied to each of the eight radish crops of 1.2 hectares (i.e. 9.6 hectares in total); and nine hours of additional labour per week (10 hours per week, rather than the one hour per week required when steam weeding occurs) would be required for backpack application of glyphosate to greenhouse areas not reached by tractor spraying.

Description of impacts

The costs added by adopting the sheet steam weeder were discussed in Section 5 and are detailed in Table 10. The machinery ownership and R&M costs added by adopting this practice are detailed in Table A2-9 (Appendix 2).

Chemical and labour costs of applying the pre-emergent herbicide Ramrod® (Propachlor) are avoided when steam weeding occurs. The cost of nine hours of labour per week is avoided a result of steam weeding reducing the need for backpack application of glyphosate.

The grower observed that labour costs in harvesting and packing the radish crop are reduced by $0.185 per bunch because improved weed control with the steam weeder enables faster harvesting and reduces the need in the packing process to remove weed contaminants from radish bunches. The grower estimated the average radish harvest at 700,000 bunches.

The grower observed that crop yield and revenue is unaffected by adoption of steam weeding.

Budgeted impacts

A budget of the impacts discussed in the previous Section is presented in Table 11. Adopting the sheet steam weeder in the radish crop is seen to increase whole farm operating profit by $57,856, or by $6,027 per hectare of radish grown. This net reduction in whole farm operating profit as a percentage of the farm-gate value of crop gross revenue could not be calculated because the grower was not comfortable with providing details of the crop gross revenue.

Fuel and labour costs of steam weeding account for most of the costs added by this innovation, while the costs avoided by this innovation are accounted for predominantly by savings in harvest and packing costs due to improved weed control.

Table 11. Impact of innovative weed control practice (sheet steam weeding) on the whole farm operating profit of NSW Case 6

Item		Applications	Quantity		Rate		Area		Price		$	Subtotal	Total
Costs added by innovative practice													
Fuel	Steam weeding	1	19,500	L					$1.60	/L	31,200	31,200	
Labour	Steam weeding	1			182	hrs/ha	9.6	ha	$32.00	/hr	55,910	55,910	
Machinery ownership and R&M											5,888	5,888	92,998
Costs avoided by innovative practice													
Herbicides	Propachlor (pre-emergent herbicide) (Ramrod®)	1			7	L/ha	9.6	ha	$63.80	/L	4,287	4,287	
Fuel	Propachlor (Ramrod®) application	1	500	L					$1.60	/L	800	800	
Labour	Propachlor (Ramrod®) application	1			4.2	hrs/ha	9.6	ha	$32.00	/hr	1,290		
	Glyphosate (Roundup Ultra® MAX) application		52	weeks	9	hrs/week			$32.00	/hr	14,976	16,266	
	Harvest and packing		700,000	bunches					$0.185	/bunch	129,500	129,500	150,854
Revenue added by innovative practice													
	Nil										0	0	0
Revenue lost by innovative practice													
	Nil										0	0	0
Net increase in whole farm operating profit													*$57,856*
Net increase in whole farm operating profit as % of crop gross revenue													*n.a.*
Per hectare net increase in whole farm operating profit													*$6,027*

Influence of neighbours on adoption of innovative weed control practice

Other landholders in the locality of this grower are not vegetable growers but rather hobby farmers who use their land for grazing horses. The grower answered that effective weed control in the radish crop using the sheet steam weeder depends 'strongly' on weed control efforts by other landholders in the locality. They explained that spread of weed seeds from neighbouring properties reduces the effectiveness of the steam weeder in controlling weeds and requires it to be used more often.

The grower answered that their decision to adopt steam weeding in the radish crop was influenced 'not at all' by their confidence that other landholders in their locality would adequately control the weeds of concern to this crop. Moreover they were 'not at all' confident that other landholders in their locality would adequately control the weeds of concern for their radish crop. They explained that since other landholders in their locality are not vegetable growers they do not share their motivation in controlling the kinds of weeds affecting the radish crop. Nonetheless, the grower did not regard lack of weed control by surrounding landholders as a threat to the effectiveness and profitability of adopting steam weeding in their radish crop.

4.3 Victorian case studies

4.3.1 Victorian Case 1

Case overview

Key details for this case are shown below.

Type of operation	Family business
Area of property	500 hectares; 100% used for vegetable production
Vegetable crops grown	Lettuce, spinach, brassicas
Staff for vegetable production	80 full-time equivalent (FTE) permanent staff, and 80 FTE seasonal staff

Details of the particular vegetable crop chosen for the case study are shown below.

Crop	Iceberg lettuce
Growing environment	Raised beds
Annual crop area	150 hectares
Crop establishment	Transplanted seedlings
Sowing/planting period	Year-round
Harvest period	Year-round
Market	Processors
Average annual gross revenue (farm-gate value)	$7,761,000
Weeds of key concern	Groundsel (*Senecio vulgaris*), stinging nettle (*Urtica urens*), fat hen (*Chenopodium album*), shepherds purse (*Capsella bursa-pastoris*), pigweed (*Portulaca oleracea*), amaranth (*Amaranthus* spp.), marshmallow (*Malva parviflora*), milk (or sow) thistle (*Sonchus oleraceus*).

Current weed management practices for the focal crop

A stale seed bed is maintained for an average of six weeks prior to establishing the iceberg lettuce crop, for the purpose of depleting the soil weed seed bank. The field is irrigated once to germinate weeds and one application of Roundup Ultra® MAX (glyphosate) is applied to the weeds that emerge. Bed formation then follows.

Trickle tape fertigation is used once the crop plants are established (around four weeks after seedlings are transplanted) to limit access by weeds to the water and fertiliser applied to the crop by retaining these inputs as much as possible immediately within to the crop lines. This approach enables the crop to compete more successfully with weeds. The trickle tape is laid out when the seedlings are transplanted. Permanent risers are employed for irrigation until the trickle tape starts being used.

The pre-emergent herbicides Kerb® 500SC (propyzamide) and Dacthal® 900WG (chlorthal-dimethyl) are each typically applied once during a crop.

Impact of focal crop weeds on whole farm operating profit

Description of impacts

The stale seed bed uses land for six weeks on average that could otherwise be employed for cropping. The opportunity cost of this land was valued at the rate paid locally for leasing land of comparable quality; i.e. $1,400 per hectare per year, or $26.92 per hectare per week.

Irrigating the stale seed bed involves electricity costs for pumping water, as well as water costs.

Trickle tape is laid out on a single-use basis for each crop, at a cost of $946 per hectare. This operation occurs as part of the process of transplanting seedlings, and thus does not add significantly to fuel, labour, or machinery ownership and R&M costs.

Application of the herbicides (Roundup Ultra® MAX (glyphosate) in the stale seed bed, and Kerb® 500SC (propyzamide) and Dacthal® 900WG (chlorthal-dimethyl) in the crop) involves chemical, fuel, labour, and machinery ownership and R&M costs.

Harvesting time is doubled from 3 to 6 hours per hectare in the estimated 5 per cent of crops (i.e. 7.5 hectares on an average annual basis) that experience weed problems despite control efforts, thus adding to fuel, labour, and machinery ownership and R&M costs. These problems can include contamination of iceberg lettuces to be harvested with stinging nettle and pigweed.

With harvesting involving 20 people, this doubling of harvest time increases the labour requirement for harvesting from 60 to 120 hours per hectare.

The grower estimated that yield is reduced by 10 per cent in the 5 per cent of crops that experience weed problems despite control efforts; i.e. by 0.5 per cent on an average annual basis. Yield was estimated to be 40 tonnes per hectare on average for crops without weed problems. Yield is thus reduced on an average annual basis by 0.2 tonnes per hectare.

Packing costs of around $0.24 per kilogram[6] are avoided as a result of this yield reduction.

Impacts of weeds on machinery ownership and R&M costs are budgeted in Table A2-10 (Appendix 2).

Budgeted impacts

A budget of the impacts discussed in the previous Section is presented in Table 12. The net reduction in the whole farm operating profit due to weeds in the iceberg lettuce crop is seen to be $291,057, or $1,940 per hectare of iceberg lettuce grown. This net reduction in whole farm operating profit represents 3.8 per cent of the farm-gate value of crop gross revenue.

Costs added in controlling weeds are the dominant influence of weeds on whole farm operating profit. The cost of trickle irrigation tape accounts for the greatest proportion of these added costs. The opportunity cost of cropping land foregone to maintain a stale seed bed is another major contributor to these added costs.

[6] Based on figures in the lettuce gross margin published by NSW DPI (2013), as adjusted for subsequent inflation using the Consumer Price Index series for Australia (ABS 2019).

Table 12. Impact of weeds in iceberg lettuce crop on whole farm operating profit of Victorian Case 1

Item		Applications	Quantity	Rate	Area	Price	$	Subtotal	Total
Costs added by weeds									
Chemicals	Glyphosate (Roundup Ultra® MAX)	1		1.5 L/ha	150 ha	$8.80 /L	1,980		
	Pre-emergent herbicide (Dacthal® 900WG)	1		4 kg/ha	150 ha	$71.23 /kg	42,735		
	Pre-emergent herbicide (Kerb® 500SC)	1		2.3 L/ha	150 ha	$51.50 /L	17,768	62,483	
Fuel	Herbicide applications	3		5 L/ha	150 ha	$1.60 /L	3,600		
	Lengthened harvest due to weeds		3 hrs/ha	5 L/hr	7.5 ha	$1.60 /L	180	3,780	
Electricity	Irrigation pumping for stale seed bed			0.05 ML/ha	150 ha	$100 /ML	750	750	
Labour	Herbicide applications	3		0.33 hrs/ha	150 ha	$28.00 /hr	4,158		
	Lengthened harvest due to weeds			60 hrs/ha	7.5 ha	$28.00 /hr	12,600	16,758	
Land	Crop land foregone for stale seed bed		6 weeks		150 ha	$26.92 /ha/wk	24,231	24,231	
Water	Irrigation of stale seedbed			0.05 ML/ha	150 ha	$200 /ML	1,500	1,500	
Trickle tape					150 ha	$946 /ha	141,900	141,900	
Machinery ownership and R&M							7,825	7,825	259,226
Revenue lost by weeds									
Yield loss due to weeds				0.2 t/ha	150 ha	$1,300 /t	39,000	39,000	39,000
Costs avoided by weeds									
Packing costs				0.2 t/ha	150 ha	$0.24 /kg	7,169	7,169	7,169
Net reduction in whole farm operating profit									*$291,057*
Net reduction in whole farm operating profit as % of crop gross revenue									*3.8%*
Per hectare net reduction in whole farm operating profit									*$1,940*

Impact of innovative weed control practice on whole farm operating profit

Details of the innovative weed control practice

The innovative practice for weed control in the iceberg lettuce crop that was chosen for evaluation was a combination of stale seed bed and trickle tape fertigation practices described above. In the absence of the stale seed bed practice, the iceberg crop would on average be established six weeks earlier. In the absence of trickle tape fertigation, all fertigation during the crop would occur through permanent risers.

Description of impacts

The costs added by adopting the stale seed bed practice, compared with the practice of establishing the crop six weeks earlier, were discussed in Section 5 and are detailed in Table 12. The machinery ownership and R&M costs added by adopting the stale seed bed practice are detailed in Table A2-11 (Appendix 2).

Compared with the 5 per cent of iceberg lettuce crops that are estimated to experience significant weed problems despite the current weed control regime, the grower estimated that 25 per cent of these crops would experience such problems if stale seed bed and trickle tape fertigation practices were dis-adopted from this regime. Yields of crops with significant weed problems were estimated to be 10 per cent (i.e. 4 tonnes per hectare) lower than crops without such problems. Adoption of stale seed bed and trickle tape fertigation practices avoids this yield loss in 20 per cent (25 per cent less 5 per cent) of crops; i.e. on 30 hectares (20% of 150 hectares) of the crop area on an average annual basis. Crop revenue is increased by avoiding these yield losses.

As a result of the yield increase arising from adopting these practices, additional costs in packing the harvested produce (identified as $0.24 per kilogram in Section 5) are incurred.

Reducing the frequency of crops with significant weed problems means also that some of the additional costs arising from weed-affected crops lengthening of harvesting operations (discussed in Section 5) will be avoided.

Budgeted impacts

A budget of the impacts discussed in the previous Section is presented in Table 13. Adopting the innovative practice – stale seed beds and trickle tape fertigation – in the iceberg lettuce crop is seen to increase whole farm operating profit by $33,276, or by $222 per hectare of iceberg lettuce grown. This increase in whole farm operating profit represents 0.4 per cent of the farm-gate value of crop gross revenue.

The costs added by adopting the innovative practice ($173,844, dominated by the $141,900 cost of the trickle tape) exceed by a large margin the costs avoided by this adoption ($56,120, arising from reducing the frequency of weed-slowed harvests). The revenue added as a result of this adoption improving weed control and thereby crop yield ($156,000) was nevertheless sufficient for the innovation to deliver a net increase in whole farm operating profit.

Table 13. Impact of innovative weed control practice (stale seed bed and trickle tape fertigation) on the whole farm operating profit of Victorian Case 1

	Item	Applications	Quantity	Rate	Area	Price	$	Subtotal	Total
Costs added by innovative practice									
Chemicals	Glyphosate (Roundup Ultra® MAX)	1		1.5 L/ha	150 ha	$8.80 /L	1,980	1,980	
Fuel	Glyphosate application	1		5 L/ha	150 ha	$1.60 /L	1,200	1,200	
Electricity	Irrigation pumping for stale seed bed			0.05 ML/ha	150 ha	$100 /ML	750	750	
Labour	Glyphosate application	1		0.33 hrs/ha	150 ha	$28 /hr	1,386	1,386	
Land	Crop land foregone for stale seed bed		6 weeks		150 ha	$26.92 /ha/wk	24,231	24,231	
Water	Irrigation of stale seed bed			0.05 ML/ha	150 ha	$200 /ML	1,500	1,500	
Trickle tape					150 ha	$946 /ha	141,900	141,900	
Machinery ownership and R&M							898	898	173,844
Costs avoided by innovative practice									
Fuel	Harvest		3 hrs/ha	5 L/hr	30 ha	$1.60 /L	720	720	
Labour	Harvest			60 hrs/ha	30 ha	$28.00 /hr	50,400	50,400	51,120
Revenue added by innovative practice									
Yield increase				4 t/ha	30 ha	$1,300 /t	156,000	156,000	156,000
Revenue lost by innovative practice									
	Nil						0	0	0
Net increase in whole farm operating profit									*$33,276*
Net increase in whole farm operating profit as % of crop gross revenue									*0.4%*
Per hectare net increase in whole farm operating profit									*$222*

Influence of neighbours on adoption of innovative weed control practice

Most other landholders in the locality of this case study are also vegetable growers. The grower responded that effective weed control in the iceberg lettuce crop using the innovative weed control practice depends 'weakly' of the weed control efforts of other landholders in their locality. They observed that there is some spread of weeds onto their property due to wind dispersal from neighbours and flood dispersal from upstream landholders (their property is located on a floodplain), but that the effects of such cross-boundary dispersal are minor compared with the contribution to their weed problems from the weed seedbank within their own property.

This grower indicated that their decision to adopt the innovative weed control practice in the iceberg lettuce crop was 'not at all' influenced by their level of confidence that other local landholders would adequately control the weeds of concern to this crop. They explained that they 'fight their own battles' rather than depend on others to do the right thing. They were 'not at all' confident that other landholders in their locality would adequately control the weeds of concern to this crop.

4.3.2 Victorian Case 2

Case overview

Key details for this case are shown below.

Type of operation	Family business
Area of property	170 hectares; 100% used for vegetable production
Vegetable crops grown	Leeks, baby cos lettuce, radicchio, kohlrabi, endive, Chinese cabbage
Staff for vegetable production	50 FTE permanent staff, 15 FTE seasonal staff

Details of the particular vegetable crop chosen for the case study are shown below.

Crop	Leeks
Growing environment	Raised beds
Annual crop area	90 hectares
Crop establishment	Transplanted seedlings
Sowing/planting period	Year-round
Harvest period	Year-round
Market	Agents distribute to various markets including supermarkets and export
Average annual gross revenue (farm-gate value)	$7,750,000
Weeds of key concern	Stinging nettle (*Urtica urens*), mallow (*Malva parviflora*), wireweed (*Polygonum aviculare*), shepherd's purse (*Capsella bursa-pastoris*), winter grass (*Poa annua*)

Current weed management practices for the focal crop

Cereal rye (*Secale cereale*) is grown prior to the leek crop as a winter cover crop. Although cereal rye is not grown primarily for weed control but rather for soil health, it does provide an opportunity to apply selective herbicide for broadleaf control (Hammer® 400EC (carfentrazone-ethyl) with the wetting agent Hasten) that cannot be applied during the leek crop itself.

A pre-emergent herbicide mix (Stomp® Xtra (pendimethalin) and Outlook® (dimethenamid-p)) is applied after leek seedlings are transplanted.

Two applications of post-emergent herbicide (Tribunil® (methabenzthiazuron)) are applied to established weeds. Application of Hammer® 400EC (carfentrazone-ethyl) during the cereal rye cover crop generally improves control of broadleaf weeds in the leek crop sufficiently that a third application of Tribunal can be avoided. The grower has found a third application of this herbicide to burn and warp the leeks, thus affecting marketability.

Inter-row tillage is avoided since it can cause leeks to lean rather than grow vertically, thus affecting their marketability (given that the leeks are flat-packed once harvested).

Hand weeding is performed to the minimum extent necessary given its high labour costs.

Impact of focal crop weeds on whole farm operating profit

Description of impacts

Weeds add to the costs of leek production through the chemical, fuel, labour, and machinery ownership and R&M costs of herbicide applications, and the labour costs of hand weeding. The herbicide applications involve four spray passes in total, given that Stomp® Xtra (pendimethalin) and Outlook® (dimethenamid-p) are applied as a mix and Hasten is applied together with Hammer® 400EC (carfentrazone-ethyl). Except for the second Tribunil® (methabenzthiazuron) application which is performed using a tractor-driven boom-spray, all other herbicide applications are performed with a self-driven boom-spray. Impacts of weeds on machinery ownership and R&M costs are budgeted in Table A2-12 (Appendix 2).

The grower estimated that good weed control is achieved in 80 per cent of leek crops, when an average yield of 35.64 tonnes per hectare is achieved. In the remaining 20 per cent of crops that experience weed problems, the average yield was estimated to be 90 per cent of that achieved with good weed control (i.e. 32.08 tonnes per hectare). It follows that a yield loss of 3.56 tonnes per hectare is experienced in 20 per cent of the crop area (i.e. 18 hectares) on an average annual basis.

Washing and packing costs of around $0.28 per kilogram[7] are avoided as a result of this yield reduction.

Budgeted impacts

A budget of the impacts discussed in the previous Section is presented in Table 14. The net reduction in the whole farm operating profit due to weeds in the leek crop is seen to be $202,576, or $2,251 per hectare of leek grown. This net reduction in whole farm operating profit represents 2.9 per cent of the farm-gate value of crop gross revenue.

Loss of revenue to the value of $142,417 following from reduced yields was the major reason for the decline in whole farm operating profit due to weeds, followed by costs added in controlling weeds ($78,121) to which machinery ownership and R&M costs and herbicide costs were the major contributors.

[7] Based on figures in the gross margin budget for production of spring onions presented in Queensland Department of Primary Industries (2018b). Since a gross margin budget for leeks had not been developed, spring onions were selected as the most closely related proxy.

Table 14. Impact of weeds in leek crop on whole farm operating profit of Victorian Case 2

Item		Applications	Quantity	Rate	Area	Price	$	Subtotal	Total
Costs added by weeds									
Chemicals	Selective broadleaf herbicide (Hammer® 400EC)	1			90 ha	$10.80 /ha	972		
	Wetting agent (Hasten)	1			90 ha	$2.70 /ha	243		
	Pre-emergent herbicide (Stomp® Xtra)	1		1.0 L/ha	90 ha	$14.60 /L	1,314		
	Pre-emergent herbicide (Outlook®)	1		1.1 L/ha	90 ha	$57.20 /L	5,663		
	Post-emergent herbicide (Tribunil®)	1		1.0 kg/ha	90 ha	$70.00 /kg	6,300		
	Post-emergent herbicide (Tribunil®)	1		1.5 kg/ha	90 ha	$70.00 /kg	9,450	23,942	
Fuel	Herbicide application, self-driven	3		12 L/ha	90 ha	$1.60 /L	5,184		
	Herbicide application, tractor-driven	1		9 L/ha	90 ha	$1.60 /L	1,296	6,480	
Labour	Herbicide application, self-driven	3		0.17 hrs/ha	90 ha	$29.00 /hr	1,305		
	Herbicide application, tractor-driven	1		0.33 hrs/ha	90 ha	$29.00 /hr	870		
	Hand weeding		50 people	0.11 hrs/ha	90 ha	$29.00 /hr	14,500	16,675	
Machinery ownership and R&M							31,024	31,024	78,121
Revenue lost by weeds									
Average annual yield loss from weed problems				3.56 t/ha	18 ha	$2.22 /kg	142,417	142,417	142,417
Costs avoided by weeds									
Washing and packing costs				3.56 t/ha	18 ha	$0.28 /kg	17,963	17,963	17,963
Net reduction in whole farm operating profit									*$202,576*
Net reduction in whole farm operating profit as % of crop gross revenue									*2.9%*
Per hectare net reduction in whole farm operating profit									*$2,251*

Influence of neighbours on adoption of innovative weed control practice

As none of the weed control practices applied by this grower were identified as innovative, data were not collected in respect of this research focus.

4.3.3 Victorian Case 3

Case overview

Key details for this case are shown below.

Type of operation	Family business
Area of property	324 hectares; 100% used for vegetable production
Vegetable crops grown	Celery, leeks, baby spinach leaves, rocket, snowpeas
Staff for vegetable production	150 FTE permanent staff, 20 FTE seasonal staff

Details of the particular vegetable crop chosen for the case study are shown below.

Crop	Celery
Growing environment	Raised beds, controlled traffic
Annual crop area	200 hectares
Crop establishment	Transplanted seedlings
Sowing/planting period	Year-round
Harvest period	Year-round
Market	30 per cent to supermarket chains, 25 per cent to export, 10 per cent to independent supermarkets, and 35 per cent to wholesalers
Average annual gross revenue (farm-gate value)	$16,575,000
Weeds of key concern	Oxalis (*Oxalis* spp.), stinging nettle (*Urtica urens*), shepherd's purse (*Capsella bursa-pastoris*), chickweed (*Stellaria media*), common groundsel (*Senecio vulgaris*), wireweed (*Polygonum aviculare*), marshmallow (*Malva parviflora*), nutgrass (*Cyperus rotundus*; in patches).

Current weed management practices for the focal crop

A stale seed bed is maintained, typically for six weeks, after raised beds have been formed in preparation for planting the celery crop. The seed bed is normally irrigated once to germinate weed seeds, with glyphosate applied with the penetrant Pulse about four weeks later to control the weeds that emerge.

The pre-emergent herbicides Dual Gold® (s-metolachlor) and Gesagard® (prometryn) are each typically applied once, primarily to control broadleaf weeds: the former at the time of transplanting celery seedlings and the latter one week later. The broad-spectrum herbicide Linuron DF (linuron) is on average applied 1.5 times to control weeds that survive the pre-emergent herbicides. The herbicide Select® (clethodim) is applied once to control grass weeds.

One pass of a Weedfix cultivator (Figure 2) is typically undertaken to control inter-row weeds.

Figure 2. A Weedfix inter-row cultivator similar to the one used on the Victorian Case 3 farm

Hand weeding is normally required to control weeds that survive inter-row tillage. Weeds are carried off the field if they have produced seed.

Impact of focal crop weeds on whole farm operating profit

Description of impacts

Weeds add to the costs of celery production through: the electricity costs of irrigation pumping for the stale seed bed; the chemical, fuel, labour, and machinery ownership and R&M costs of herbicide applications; the fuel, labour and machinery costs of inter-row tillage; and the labour costs of hand weeding. Added machinery ownership and R&M costs are detailed in Table A2-13 (Appendix 2).

Weeds also add to the costs of fertilising the celery crop through competing for soil nutrients. The grower estimated that weeds consume the nutrients from fertilisers applied to 10 per cent of the crop area once in every five years (i.e. 2 per cent, or 4 hectares, of the crop area on an average annual basis). Expenditure on NPK fertilisers for the crop is typically $700 per hectare per year, while the expenditure on manure for the crop is typically $56 per hectare per year (the manure is applied to cover crops earlier in the rotation).

Irrigating the stale seed bed involves 0.33 hours of labour to set up the pump to water 10 hectares; i.e. 0.033 hours of labour per hectare.

Hand weeding involving 5 hours of labour per hectare is required on average in one of every 10 crops; i.e. in 10 per cent, or 20 hectares, of the crop area on an average annual basis.

Harvesting of celery was estimated to be slowed by 12.5 per cent in the crop area with weed problems at the time of harvest. With harvesting estimated to require 450 hours of labour per hectare in areas without weed problems, it follows that 56.25 additional hours of labour per hectare are required for harvesting in areas with such problems. The area with such problems was estimated at 4 hectares on an average annual basis.

The average marketable yield of the celery crop was estimated at 63,750 bunches per hectare. The grower estimated that within the 4 hectares of celery crop affected by weed competition on an average annual basis, the size of celery bunches is reduced such that 25 per cent more bunches are required to fill a carton. With the grower paid a fixed price per carton, the price received per bunch is 20 per cent lower in such crops than would be received in the absence of weed competition. With the gross farm-gate price received in crops without weed competition estimated at $1.30 per bunch, the price reduction experienced in crop areas experiencing weed competition is thus $1.04 per bunch ($0.26 per bunch lower).

Packing costs are avoided as a result of the smaller size of celery bunches grown in weed-affected areas, since the harvested crop of 63,750 bunches can be packed in 20 per cent fewer cartons (with a cost each of around $2.74[8]). The number of cartons packed under conditions of good weed control is 6,375 cartons per hectare when 10 bunches are packed per carton, while the number of cartons packed in areas with weed problems (where 25 per cent more bunches can be packed per carton) is 1,275 (20 per cent) less at 5,100 cartons per hectare.

Budgeted impacts

A budget of the impacts discussed in the previous Section is presented in Table 15. The net reduction in the whole farm operating profit due to weeds in the celery crop is seen to be $152,507, or $763 per hectare of celery grown. This net reduction in whole farm operating profit represents 0.9 per cent of the farm-gate value of crop gross revenue.

[8] Based on the cost for celery cartons in the gross margin budget for celery production presented in Queensland Department of Primary Industries (2018b).

Table 15. Impact of weeds in celery crop on whole farm operating profit of Victorian Case 3

Item		Applications	Quantity	Rate	Area	Price	$	Subtotal	Total
<u>Costs added by weeds</u>									
Herbicides	Glyphosate	1		2 L/ha	200 ha	$5.55 /L	2,220		
	Pulse (penetrant for glyphosate)	1		0.4 L/ha	200 ha	$24.80 /L	1,984		
	Pre-emergent herbicide (Dual Gold®)	1		1 L/ha	200 ha	$11.50 /L	2,300		
	Pre-emergent herbicide (Gesagard®)	1		2.5 L/ha	200 ha	$11.90 /L	5,950		
	Broad-spectrum herbicide (Linuron DF)	1.5		0.35 L/ha	200 ha	$35.70 /L	3,749		
	Select®	1		0.375 L/ha	200 ha	$15.00 /L	1,125	17,328	
Fertilisers	NPK fertilisers				4 ha	$700 /ha	2,800		
	Manure				4 ha	$56 /ha	224	3,024	
Fuel	Herbicide applications	5.5	0.5 hr/ha	15 L/hr	200 ha	$1.60 /L	13,200		
	Inter-row tillage (Weedfix cultivator)	1	1.5 hr/ha	15 L/hr	200 ha	$1.60 /L	7,200	20,400	
Electricity	Irrigation pumping for stale seed bed			0.05 ML/ha	200 ha	$100 /ML	1,000	1,000	
Labour	Herbicide applications	5.5		0.5 hrs/ha	200 ha	$30 /hr	16,500		
	Inter-row tillage	1		1.5 hrs/ha	200 ha	$30 /hr	9,000		
	Hand weeding			5 hrs/ha	20 ha	$30 /hr	3,000		
	Irrigation pumping for stale seed bed			0.03 hrs/ha	200 ha	$30 /hr	198		
	Harvest			56.25 hrs/ha	4 ha	$30 /hr	6,750	35,448	
Machinery ownership and R&M							12,501	12,501	89,700
<u>Revenue lost by weeds</u>									
Price reduction for bunches made smaller by weeds			63,750 bunches/ha		4 ha	$0.26 /bunch	66,300	66,300	66,300
<u>Costs avoided by weeds</u>									
Packing			1,275 cartons			$2.74 /carton	3,494	3,494	3,494
Net reduction in whole farm operating profit									$152,507
Net reduction in whole farm operating profit as % of crop gross revenue									0.9%
Per hectare net reduction in whole farm operating profit									$763

Added costs to the value of $89,700 due to weeds accounted for the majority of the decline in whole farm operating profit due to weeds, although revenue lost due to competition from weeds reducing the size of celery bunches also contributed significantly to this decline in whole farm operating profit. Labour costs accounted for the largest share of the costs added due to weeds, followed by fuel costs and herbicide costs.

Impact of innovative weed control practice on whole farm operating profit: Innovative practice 1 (stale seed bed)

Stale seeds beds and inter-row tillage using a Weedfix cultivator were both identified as innovative weed control practices for the celery crop, and economic evaluations of these practices were conducted separately. The evaluation of the stale seed bed practice is reported in this Section, while the evaluation of inter-row tillage is reported in Section 5.

Details of the innovative weed control practice

The stale seed bed practice adopted for weed control in the celery crop that was chosen for evaluation was described above as part of this crop's current weed control regime. In the absence of this practice the grower would be forced to rely more on hand weeding.

Description of impacts

The costs added by adopting the stale seed bed practice were discussed in Section 5 and are detailed in Table 15. Machinery ownership and R&M costs added by the innovation are detailed in Table A2-14 (Appendix 2).

The grower estimated that three times as much hand weeding labour would be required in the absence of this practice to achieve a comparable level of weed control. Without this practice, therefore, it would be necessary to apply 5 hours of hand weeding labour per hectare to an additional 40 hectares, of the crop area on an average annual basis. The yield and revenue from the crop with this increased level of hand weeding would in the grower's judgement be equivalent to that achieved when the innovative practices are adopted.

Budgeted impacts

A budget of the impacts discussed in the previous Section is presented in Table 16. Adopting this innovative practice – stale seed beds – in the celery crop is seen to reduce whole farm operating profit by $10,532, or by $52 per hectare of celery grown. This reduction in whole farm operating profit represents -0.06 per cent of the farm-gate value of celery crop gross revenue.

The hand weeding costs of $6,000 avoided by adoption of these practices are not sufficient to outweigh the costs of $16,532 added by this adoption. The chemical costs of the herbicide (glyphosate) application for the stale seed bed account for the largest share of the costs added by this practice, followed by the fuel and labour costs of this application.

The grower indicated that an important motivation for adopting this practice, and also inter-row tillage, is concerns regarding increasing resistance of weeds to herbicides. These practices enable less herbicide application than would otherwise be possible, and thereby help to minimise the risk of herbicide resistance developing. The grower is also considering shifting some land into organic celery production, so values the opportunities that these practices offer to learn about less herbicide-intensive approaches to weed control. These longer-term benefits might explain why these practices have been adopted despite their estimated negative impact on whole farm operating profit in the shorter term. The reduction in whole farm operating profit of $52 per hectare might be considered as a price paid by the grower to inhibit the onset of herbicide resistance in their celery crop while also exploring possibilities for organic production.

Table 16. Impact of innovative weed control practice (stale seed bed) on the whole farm operating profit of Victorian Case 3

Item		Applications	Quantity	Rate	Area	Price	$	Subtotal	Total
Costs added by innovative practice									
Herbicides	Glyphosate	1		0.4 L/ha	200 ha	$5.55 /L	444		
	Pulse (penetrant for glyphosate)	1		1 L/ha	200 ha	$24.80 /L	4,960	5,404	
Fuel	Herbicide application	1	0.5 L/hr	15 L/ha	200 ha	$1.60 /L	4,801	4,801	
Electricity	Irrigation pumping for stale seed bed			0.05 ML/ha	200 ha	$100.00 /ML	1,000	1,000	
Labour	Herbicide applications	1		0.5 hrs/ha	200 ha	$30.00 /hr	3,000		
	Irrigation pumping for stale seed bed			0.03 hrs/ha	200 ha	$30.00 /hr	198	3,198	
Machinery ownership and R&M							1,930	1,930	16,332
Costs avoided by innovative practice									
Labour	Hand weeding			5 hrs/ha	40 ha	$30.00 /hr	6,000	6,000	6,000
Revenue added by innovative practice									
	Nil						0	0	0
Revenue lost by innovative practice									
	Nil						0	0	0
Net increase in whole farm operating profit									*-$10,332*
Net increase in whole farm operating profit as % of crop gross revenue									*-0.06%*
Per hectare net increase in whole farm operating profit									*-$52*

Impact of innovative weed control practice on whole farm operating profit: Innovative practice 2 (inter-row tillage with a Weedfix cultivator)

Details of the innovative weed control practice

The inter-row tillage practice adopted for weed control in the celery crop that was chosen for evaluation was described above as part of this crop's current weed control regime. In the absence of this practice the grower would be forced to rely more on hand weeding.

Description of impacts

The costs added by adopting the inter-row tillage practice were discussed in Section 5 and are detailed in Table 15. The machinery ownership and R&M costs added by adopting this practice are detailed in Table A2-15 (Appendix 2).

As was the case in evaluating the stale seed bed practice, the grower estimated that three times as much hand weeding labour would be required in the absence of this practice to achieve a comparable level of weed control. Without this practice, therefore, it would be necessary to apply 5 hours of hand weeding labour per hectare to an additional 40 hectares of the crop area on an average annual basis. The yield and revenue from the crop with this increased level of hand weeding would in the grower's judgement be equivalent to that achieved when the innovative practices are adopted.

Budgeted impacts

A budget of the impacts discussed in the previous Section is presented in Table 17. Adopting this innovative practice – inter-row tillage with a Weedfix cultivator – in the celery crop is seen to reduce whole farm operating profit by $9,087, or by $45 per hectare of celery grown. This reduction in whole farm operating profit represents -0.01 per cent of the farm-gate value of celery crop gross revenue.

Table 17. Impact of innovative weed control practice (inter-row tillage with Weedfix cultivator) on the whole farm operating profit of Victorian Case 3

Item		Applications	Quantity	Rate	Area	Price	$	Subtotal	Total
Costs added by innovative practice									
Fuel	Inter-row tillage (Weedfix cultivator)	1	1.5 L/hr	15 L/ha	200 ha	$1.60 /L	4,802	4,802	
Labour	Inter-row tillage	1		1.5 hrs/ha	200 ha	$30.00 /hr	9,000	9,000	
Machinery ownership and R&M							1,286	1,286	15,087
Costs avoided by innovative practice									
Labour	Hand weeding			5 hrs/ha	40 ha	$30.00 /hr	6,000	6,000	6,000
Revenue added by innovative practice									
	Nil						0	0	0
Revenue lost by innovative practice									
	Nil						0	0	0
Net increase in whole farm operating profit									*-$9,087*
Net increase in whole farm operating profit as % of crop gross revenue									*-0.1%*
Per hectare net increase in whole farm operating profit									*-$45*

The hand weeding costs of $6,000 avoided by adoption of these practices are not sufficient to outweigh the costs of $15,087 added by this adoption. The labour costs of inter-row tillage account for the majority the costs added by this practice.

As was the case for the stale seed bed practice, the grower indicated that an important motivation for adopting inter-row tillage for weed control is concerns regarding increasing resistance of weeds to herbicides. These practices enable less herbicide application than would otherwise be possible, and thereby help to minimise the risk of herbicide resistance developing. The grower is also considering shifting some land into organic celery production, and values the opportunities that these practices offer to learn about less herbicide-intensive approaches to weed control. The reduction in whole farm operating profit of $45 per hectare might be considered as a price paid by the grower to inhibit the onset of herbicide resistance in their celery crop while also exploring possibilities for organic production.

Influence of neighbours on adoption of innovative weed control practice

Some of the other landholders in the locality of this grower are vegetable growers, while others graze cattle.

The grower answered that effective weed control in the celery crop depends 'not at all' on weed control efforts by other landholders in the locality. Although they observed that weed infestation from off-property sources is a significant issue for the celery crop, they argued that these sources are mainly manures, machinery, vehicles, and visiting professionals coming onto the property rather than neighbouring landholders.

4.3.4 Victorian Case 4

Case overview

Key details for this case are shown below.

Type of operation	Family business
Area of property	54.6 hectares; 100% used for vegetable production
Vegetable crops grown	Radish, spring onions, parsley, Dutch carrots, beetroot (i.e. 'bunch lines').
Staff for vegetable production	24 FTE permanent staff

Details of the particular vegetable crop chosen for the case study are shown below.

Crop	Continental (flatleaf) parsley
Growing environment	Raised beds
Annual crop area	5.7 hectares
Crop establishment	40% transplanted seedlings, 60% direct-seeded
Sowing/planting period	Year-round
Harvest period	Year-round
Market	Supermarket chain and produce market
Average annual gross revenue (farm-gate value)	$889,200
Weeds of key concern	Nutgrass (*Cyperus rotundus*)

Current weed management practices for the focal crop

The herbicide Linuron DF (linuron) is applied once as a pre-emergent herbicide, and once (at a lower rate) as a post-emergent herbicide.

Inter-row tillage using a small rotary hoe is performed for weed control after each of the three cuts of parsley typically undertaken during a crop.

Three passes with a furrow moulder are normally also undertaken for weed control. The sides of the beds are cut down in each pass, with the loosened soil pushed back up onto the beds to smother weeds.

Hand weeding of nutgrass is performed with knives in large teams. Although this is largely ineffectual in reducing ongoing nutgrass problems, it is typically required to achieve harvestable crops in order to fulfil contracts with buyers.

Impact of focal crop weeds on whole farm operating profit

Description of impacts

Weeds add to the cost of continental parsley production through: the chemical, fuel, labour, and machinery ownership and R&M costs incurred in herbicide applications; fuel, labour and machinery costs of inter-row tillage and passes with the furrow moulder; and labour costs of hand weeding. One pass of hand weeding involving 80 hours of labour per hectare is normally undertaken per crop. Machinery ownership and R&M costs added by weeds are detailed in Table A2-16 (Appendix 2).

Nutgrass contaminants in harvested parsley are removed during harvest, and are estimated to increase by an estimated 50 per cent the length of this process and its requirements for labour. With harvest of a crop estimated to involve 382 hours of labour per cut per hectare (for each of the three cuts per crop) when good weed control has been achieved, a 50 per increase in harvesting labour requirements amounts to 191 hours per cut per hectare.

The grower observed that revenue losses from weeds are generally avoided if the regime described above for controlling weeds and removing weed contaminants from harvested produce is followed.

Budgeted impacts

A budget of the impacts discussed in the previous Section is presented in Table 18. The net reduction in whole farm operating profit due to weeds in the continental parsley crop is seen to be $113,741 for the crop, or $19,955 per hectare of continental parsley grown. This net reduction in whole farm operating profit represents 12.8 per cent of the farm-gate value of crop gross revenue.

This net reduction in whole farm operating profit is wholly attributable to the costs added as a result of weeds. These added costs are largely accounted for by the labour required to remove weed contaminants from harvested produce (costing $91,451) and the labour required for hand weeding (costing $12,768).

Table 18. Impact of weeds in continental parsley crop on whole farm operating profit of Victorian Case 4

Item		Applications	Quantity	Rate		Area		Price		$	Subtotal	Total
Costs added by weeds												
Herbicides	Linuron DF: pre-emergent application	1				5.7	ha	$190.00	/ha	1,083		
	Linuron DF: post-emergent application	1				5.7	ha	$38.25	/ha	218	1,301	
Fuel	Herbicide (Linuron DF) applications	2		5	L/ha	5.7	ha	$1.60	/L	91		
	Inter-row tillage	3		6.7	L/ha	5.7	ha	$1.60	/L	182		
	Furrow moulding	3		6.7	L/ha	5.7	ha	$1.60	/L	182	456	
Labour	Herbicide applications	2		0.5	hr/ha	5.7	ha	$28.00	/hr	160		
	Inter-row tillage	3		1	hr/ha	5.7	ha	$28.00	/hr	479		
	Furrow moulding	3		1	hr/ha	5.7	ha	$28.00	/hr	479		
	Hand weeding	1		80	hrs/ha	5.7	ha	$28.00	/hr	12,768		
	Harvest	3		191	hrs/ha	5.7	ha	$28.00	/hr	91,451	105,336	
Machinery ownership and R&M										6,648	6,648	113,741
Revenue lost by weeds												
	Nil									0	0	0
Costs avoided by weeds												
	Nil									0	0	0
Net reduction in whole farm operating profit												*$113,741*
Net reduction in whole farm operating profit as % of crop gross revenue												*12.8%*
Per hectare net reduction in whole farm operating profit												*$19,955*

Impact of innovative weed control practice on whole farm operating profit

None of the weed control practices applied by this grower were identified as innovative.

Influence of neighbours on adoption of innovative weed control practice

As none of the weed control practices applied by this grower were identified as innovative, data were not collected in respect of this research focus.

4.3.5 Victorian Case 5

Case overview

Key details for this case are shown below.

Type of operation	Family business
Area of property	121 hectares; 100% used for vegetable production
Vegetable crops grown	Broccoli, beetroot, beans, sweet corn, parsnip, celery (all grown organically)
Staff for vegetable production	5 FTE permanent staff, 7 FTE seasonal staff

Details of the particular vegetable crop chosen for the case study are shown below.

Crop	Parsnip (organic)
Growing environment	Raised beds
Annual crop area	6.1 hectares
Crop establishment	Direct seeding
Sowing/planting period	July-January
Harvest period	January-August
Market	Wholesale markets
Average annual gross revenue (farm-gate value)	$218,600
Weeds of key concern	Johnson grass (*Sorghum halepense*), wireweed (*Polygonum aviculare*), shepherds purse (*Capsella bursa-pastoris)*, amaranth (*Amaranthus* spp.), thornapple (*Datura stramonium*), and stinging nettle (*Urtica urens*).

Current weed management practices for the focal crop

The area for growing parsnip is watered prior to ground preparation and bed formation in order to draw down the weed seed bank prior to establishing the crop. A shallow tillage pass is carried out prior to crop sowing to control weeds recently germinated by the fallow irrigation.

A tractor-pulled, five foot wide, LPG-fuelled flame weeder is applied to the surface of beds prior to emergence of the crop. This normally occurs once; a second application may be required (although rarely) if cold weather delays germination of the crop more than of weeds.

Tillage for weed control includes one pass with a disc scarifier, which scarifies the surface of the beds to matchbox width, and two passes of a small sweep scarifier (the second pass occurring 3-4 weeks after the first pass). The sweep scarifier hills-up soil around crop plants in order to smother the weeds surrounding them while also controlling weeds growing on the sides of beds and in the wheel tracks.

Hand weeding is undertaken after the pass of the disc scarifier and prior to the sweep scarifier passes.

Impact of focal crop weeds on whole farm operating profit

Description of impacts

Weeds add to the costs of organic parsnip production through: the electricity costs of pumping to water the crop area prior to ground preparation; the LPG, diesel, labour and machinery costs of flame weeding; the fuel, labour, and machinery ownership and R&M costs of tillage (disc and sweep scarifier) passes; and the labour costs of hand weeding. The machinery ownership and R&M costs added as a result of weeds are detailed in Table A2-17 (Appendix 2).

Hand weeding occurs in teams of eight people, involving a total of 224 hours of labour per hectare for the crop.

The grower estimated that one in ten organic parsnip crops need to be abandoned because weeds have 'got away'. The average annual yield when harvest occurs was estimated at 10 tonnes per hectare. The average annual yield loss resulting from abandoned crops is thus one tonne per hectare.

Costs of harvesting and packing the crop are avoided when crops are abandoned. The grower estimated these costs at $2 per kilogram.

Budgeted impacts

A budget of the impacts discussed in the previous Section is presented in Table 19. The net reduction in the whole farm operating profit due to weeds in the organic parsnip crop is seen to be $52,566 for the crop, or $8,656 per hectare of organic parsnip grown. This net reduction in whole farm operating profit represents 24.0 per cent of the farm-gate value of parsnip crop gross revenue.

The $40,420 of added costs due to weeds is the greatest contributor to the reduction in whole farm operating profit, although the $24,291 loss in revenue due to weeds also clearly has a major impact. The hand weeding costs of $36,729 account for most of the costs added due to weeds.

Table 19. Impact of weeds in organic parsnip crop on whole farm operating profit of Victorian Case 5

Item		Applications	Quantity	Rate		Area		Price		$	Subtotal	Total
Costs added by weeds												
Fuel	Tractor use for flame weeding	1		7.4	L/ha	6.1	ha	$1.60	/L	72		
	Flame weeder (LPG)	1		148	L/ha	6.1	ha	$0.90	/L	809		
	Disc scarifier	1		16.5	L/ha	6.1	ha	$1.60	/L	160		
	Small sweep scarifier	2		12.4	L/ha	6.1	ha	$1.60	/L	241	1,282	
Electricity	Pump water to pre-germinate weeds	1		0.05	ML/ha	6.1	ha	$100.00	/ML	30	30	
Labour	Flame weeding	1		1.7	hrs/ha	6.1	ha	$27.00	/hr	279		
	Disc scarifier	1		3.3	hrs/ha	6.1	ha	$27.00	/hr	541		
	Small sweep scarifier	2		1.7	hrs/ha	6.1	ha	$27.00	/hr	557		
	Hand weeding			224	hrs/ha	6.1	ha	$27.00	/hr	36,729	38,106	
Machinery ownership and R&M										1,002	1,002	40,420
Revenue lost by weeds												
Yield loss from abandoned crops				1	t/ha	6.1	ha	$4.00	/kg	24,291	24,291	24,291
Costs avoided by weeds												
Harvest and packing costs				1	t/ha	6.1	ha	$2.00	/kg	12,146	12,146	12,146
Net reduction in whole farm operating profit												*$52,566*
Net reduction in whole farm operating profit as % of crop gross revenue												*24.0%*
Per hectare net reduction in whole farm operating profit												*$8,656*

Impact of innovative weed control practice on whole farm operating profit

Details of the innovative weed control practice

The innovative practice for weed control in the organic parsnip crop that was chosen for evaluation was the flame weeder that was described above as part of this crop's current weed control regime. Adoption of this practice enables the grower to avoid a third pass with the small sweep scarifier as well as the additional hand weeding that would be required to compensate for the absence of flame weeding.

Description of impacts

The costs added by adopting the flame weeder for weed control in the organic parsnip crop were discussed in Section 5 and are detailed in Table 19. The machinery ownership and R&M costs added by adopting this innovative practice in the organic parsnip crop are detailed in Table A2-18 (Appendix 2).

The cost saving from flame weeding enabling one pass of the small sweep scarifier to be avoided was also calculated using the details for this technology discussed in Section 5 and detailed in Table 19.

The grower estimated that flame weeding avoids 40 per cent greater use of labour in hand weeding. With 224 hours of labour employed for hand weeding per hectare when flame weeding has been applied, a 40 per cent increase in labour use represents an additional 89.6 hours per hectare.

Budgeted impacts

A budget of the impacts discussed in the previous Section is presented in Table 20. Adopting the innovative practice – flame weeding – in the organic parsnip crop is found to increase whole farm operating profit by $13,438, or by $2,213 per hectare of organic parsnip grown. This increase in whole farm operating profit represents 6.1 per cent of the farm-gate value of crop gross revenue.

The increase in whole farm operating profit results from the costs avoided by the innovation ($15,091) exceeding the costs added by the innovation ($1,652). The saving in hand weeding costs arising from flame weeding accounts for most of the costs avoided due to this innovation.

Aside from the financial benefit of adopting flame weeding for weed control, the grower indicated that they were committed to organic methods that avoid any need to apply synthetic chemicals to their crop.

Table 20. Impact of innovative weed control practice (flame weeding) on the whole farm operating profit of Victorian Case 5

	Item	Applications	Quantity	Rate	Area	Price	$	Subtotal	Total
Costs added by innovative practice									
Fuel	Tractor use for flame weeder (petrol	1		7.4 L/ha	6.1 ha	$1.60 /L	72		
	Flame weeder (LPG)	1		148 L/ha	6.1 ha	$0.90 /L	809	881	
Labour	Flame weeding	1		1.7 hrs/ha	6.1 ha	$27.00 /hr	279	279	
Machinery ownership and R&M							493	493	1,652
Cost avoided by innovative practice									
Fuel	Small sweep scarifier	1		12.4 L/ha	6.1 ha	$1.60 /L	120	120	
Labour	Small sweep scarifier	1		1.7 hrs/ha	6.1 ha	$27.00 /hr	279		
	Hand weeding			89.6 hrs/ha	6.1 ha	$27.00 /hr	14,691	14,970	15,091
Revenue added by innovative practice									
	Nil						0	0	0
Revenue foregone by innovative practice									
	Nil						0	0	0
Net increase in whole farm operating profit									*$13,438*
Net increase in whole farm operating profit as % of crop gross revenue									*6.1%*
Per hectare net increase in whole farm operating profit									*$2,213*

Influence of neighbours on adoption of innovative weed control practice

Some other landholders in the locality of this grower are vegetable growers, while others graze cattle.

The grower answered that effective weed control in the organic parsnip crop using the innovative weed control practice (flame weeding) depends 'not at all' on weed control efforts by other landholders in the locality. They explained that their property is located on a floodplain, so that flood events bring in weed seeds from beyond the local area. While wind also delivers some weed seeds onto the property from local landholders, this effect is minor effect compared to the effect of floods.

4.4 Tasmanian case studies

4.4.1 Tasmanian Case 1

Case overview

Key details for this case are shown below.

Type of operation	Family business
Area of property	5.3 hectares; 100% used for vegetable production
Vegetable crops grown	Rhubarb, zucchini and curly parsley
Staff for vegetable production	2 FTE permanent staff

Details of the particular vegetable crop chosen for the case study are shown below.

Crop	Curly parsley
Growing environment	Flat beds, black plastic mulch
Annual crop area	0.4 hectares
Crop establishment	Transplanted seedlings
Sowing/planting period	Early Spring to mid-Autumn, with a single planting in mid-Winter to enable year-round supply
Harvest period	Year-round
Market	Mostly sold under contract to a supermarket chain
Average annual gross revenue (farm-gate value)	$82,973
Weeds of key concern	Fat hen (*Chenopodium album*), wild radish (*Raphanus raphanistrum*), nightshade (*Solanum nigrum*)

Current weed management practices for the focal crop

Black plastic is used as a mulch to control weeds in the crop. Despite this mulch, fat hen and wild radish can still create weed problems given their capacity to pierce the plastic, and nightshade can become established in the holes made in the plastic for transplanting seedlings. The plastic is normally used for one crop.

Glyphosate is applied for inter-row weed control using a manually-operated shielded controlled droplet applicator (CDA) with two low-volume nozzles (Figure 3). On average 2.5 applications occur over the crop area.

A tractor-drawn implement referred to by the grower as a customised 'skimmer' is on average applied 2.5 times as a scarifier over the crop area, also for inter-row weed control. This implement was purchased to remove the black plastic after completion of a crop. When adapted for inter-row weed control, the two steel feet of the implement are aligned with the wheels of the tractor.

Hand weeding (with Dutch hoes) is used for intra-row weeding, particularly for fat hen which pierces the plastic mulch.

Figure 3. Mankar shielded CDA used for glyphosate application in the parsley crop

Description of impacts

Weeds add to the costs of curly parsley production through: the costs of the black plastic mulch and the fuel, labour, and machinery ownership and R&M costs to lay it out after completion of ground preparation out and pull it off after harvest; chemical, labour and machinery costs of glyphosate applications with the CDA and inter-row tillage with the customised 'skimmer'; and labour costs of hand weeding. Machinery ownership and R&M costs added due to weeds are detailed in Table A2-19 (Appendix 2).

The grower observed that there are no yield or revenue losses in the curly parsley crop due to weeds under the current weed control regime.

Budgeted impacts

A budget of the impacts discussed in the previous Section is presented in Table 21. The net reduction in the whole farm operating profit due to weeds in the curly parsley crop is seen to be $1,041 for the crop, or $2,572 per hectare of curly parsley grown. This net reduction in whole farm operating profit represents 1.3 per cent of the farm-gate value of crop gross revenue.

Table 21. Impact of weeds in curly parsley crop on whole farm operating profit of Tasmanian Case 1

Item		Applications	Quantity	Rate	Area	Price	$	Subtotal	Total
Costs added by weeds									
Herbicides	Glyphosate	2.5		1.75 L/ha	0.4 ha	$4.15 /L	7	7	
Fuel	Lay out black plastic		20 hrs/ha	2.5 L/hr	0.4 ha	$1.60 /L	32		
	Inter-row tillage (skimmer)	2.5		0.8 hrs/ha	0.4 ha	$1.60 /L	1		
	Pull off black plastic		12 hrs/ha	2.5 L/hr	0.4 ha	$1.60 /L	19	53	
Labour	Lay out black plastic			20 hrs/ha	0.4 ha	$30.00 /hr	243		
	Glyphosate application (CDA)	2.5		1.5 hrs/ha	0.4 ha	$30.00 /hr	46		
	Inter-row tillage (skimmer)	2.5		0.8 hrs/ha	0.4 ha	$30.00 /hr	24		
	Hand weeding			8.7 hrs/ha	0.4 ha	$30.00 /hr	106		
	Pull off black plastic			12 hrs/ha	0.4 ha	$30.00 /hr	146	564	
Machinery ownership and R&M							416	416	1,041
Revenue lost by weeds									
	Nil						0	0	0
Costs avoided by weeds									
	Nil						0	0	0
Net reduction in whole farm operating profit									*$1,041*
Net reduction in whole farm operating profit as % of crop gross revenue									*1.3%*
Per hectare net reduction in whole farm operating profit									*$2,572*

The net reduction in whole farm operating profit derives entirely from costs added as a result of weeds. Added labour costs account for more than half of the added costs overall. These added labour costs are accounted for largely by the labour required in laying out and pulling off the black plastic mulch and in hand weeding.

Impact of innovative weed control practice on operating profit of the focal crop

Details of the innovative weed control practice

The innovative practice for weed control in the curly parsley crop that was chosen for evaluation was use of the CDA for inter-row glyphosate application. This practice was adopted in place of applying glyphosate with a backpack sprayer.

Description of impacts

The costs added by adopting the CDA for glyphosate application in the curly parsley crop were discussed in Section 5 and are detailed in Table 21. The machinery ownership and R&M costs added by adopting this innovative practice are detailed in Table A2-20 (Appendix 2).

Adopting the CDA avoids the additional glyphosate and labour costs of using a backpack sprayer. The glyphosate costs of using a backpack sprayer are lower than those of using the CDA due to the higher application rate required by the latter. The labour costs of using a backpack sprayer are double those of using a CDA sprayer since the former requires two passes of any inter-row area (down one side and back up the other side) while the latter requires only a single pass.

Budgeted impacts

A budget of the impacts discussed in the previous Section is presented in Table 22. Adopting the innovative practice – use of a CDA for glyphosate application – in the curly parsley crop is seen to increase whole farm operating profit by $73, or by $180 per hectare of curly parsley grown. This increase in whole farm operating profit represents 0.1 per cent of the farm-gate value of crop gross revenue.

The net saving in labour costs as a result of applying glyphosate by a CDA rather than a backpack sprayer contributes most significantly to the increase in whole farm operating profit. This net saving considerably outweighs the increase in herbicide costs due to this change in herbicide application technology.

In addition to the economic advantages of using a CDA rather than a backpack sprayer, the grower remarked on the advantage of this change avoiding the weight of carrying a 20 litre capacity backpack for extended periods. Pushing the CDA requires little effort as it travels on tyred wheels (similar to bicycle wheels; Figure 3).

Table 22. Impact of innovative weed control practice (CDA) on the whole farm operating profit of Tasmanian Case 1

Item		Applications	Quantity	Rate	Area	Price	$	Subtotal	Total
<u>Costs added by innovative practice</u>									
Herbicides	Glyphosate	2.5		4.3 L/ha	0.4 ha	$4.15 /L	18	18	
Labour	Glyphosate application with CDA	2.5		3.7 hrs/ha	0.4 ha	$30.00 /hr	112	112	
Machinery ownership and R&M							29	29	160
<u>Costs avoided by innovative practice</u>									
Herbicides	Glyphosate	2.5		1.9 L/ha	0.4 ha	$4.15 /L	8	8	
Labour	Glyphosate application with backpack sprayer	2.5		7.4 hrs/ha	0.4 ha	$30.00 /hr	225	225	233
<u>Revenue added by innovative practice</u>									
	Nil						0	0	0
<u>Revenue lost by innovative practice</u>									
	Nil						0	0	0
Net increase in whole farm operating profit									*$73*
Net increase in whole farm operating profit as % of crop gross revenue									*0.1%*
Per hectare net increase in whole farm operating profit									*$180*

Influence of neighbours on adoption of innovative weed control practice

Other landholders in the locality of this grower are vegetable growers, while some of these also graze cattle.

The grower answered that effective weed control in their curly parsley crop using the CDA for glyphosate application depends 'weakly' on weed control efforts by other landholders in their locality. They explained that weed populations on their property are affected largely by weed management within their property rather than by the weed control efforts of neighbouring landholders.

This grower answered that their decision to adopt the CDA for glyphosate application in the curly parsley crop was influenced 'not at all' by their confidence that other landholders in the locality would adequately control the weeds of concern to this crop. They were 'very strongly' confident that other landholders in the locality would adequately control the weeds of concern to this crop.

4.4.2 Tasmanian Case 2

Case overview

Key details for this case are shown below.

Type of operation	Family business
Area of property	242 hectares; 99% used for vegetable production
Vegetable crops grown	Carrots, onions, broccoli, Brussel sprouts, beetroot, swede, turnips, rhubarb, fresh peas, pyrethrum
Staff for vegetable production	20 FTE permanent staff, 75 FTE seasonal staff

Details of the particular vegetable crop chosen for the case study are shown below.

Crop	Broccoli
Growing environment	Strip-tilled field
Annual crop area	100 hectares
Crop establishment	Transplanted seedlings
Sowing/planting period	September-January
Harvest period	November-April/May
Market	Mostly to supermarkets
Average annual gross revenue (farm-gate value)	$2,475,000
Weeds of key concern	Wild radish (*Raphanus raphanistrum*), fat hen (*Chenopodium album*), amaranth (*Amaranthus* spp.), couch grass (*Cynodon dactylon*), various other grasses, previous crops (volunteer plants)

Current weed management practices for the focal crop

Strip tillage is used for ground preparation to minimise the weed emergence that otherwise results from conventional cultivation, and also for its soil condition and soil health benefits. Two strip tillage passes are normally conducted.

The selective herbicide Baron® 400 WG (oxyfluorfen) is applied once, after seedlings have been transplanted and weeds have just emerged. Two passes of inter-row cultivation are subsequently conducted for weed control, and hand weeding (normally in a team of 7-8 people for a day) is undertaken for further weed control as required.

Description of impacts

Weeds add to the costs of broccoli production through: the fuel, labour and machinery costs of strip tillage; chemical, fuel, labour and machinery costs of herbicide application; and labour costs of hand weeding. Machinery costs added due to weeds are detailed in Table A2-21 (Appendix 2).

The grower observed that there are no yield or revenue losses in the broccoli crop due to weeds under the current weed control regime.

Budgeted impacts

A budget of the impacts discussed in the previous Section is presented in Table 23. The net reduction in the whole farm operating profit due to weeds in the broccoli crop is seen to be $60,815, or $608 per hectare of broccoli grown. This net reduction in whole farm operating profit represents 2.5 per cent of the farm-gate value of crop gross revenue.

The net reduction in whole farm operating profit derives entirely from costs added as a result of weeds. Added machinery costs account for the largest share of total added costs, followed by the chemical costs of herbicide (Baron® 400 WG (oxyfluorfen)) application.

Table 23. Impact of weeds in broccoli crop on whole farm operating profit of Tasmanian Case 2

Item		Applications	Quantity	Rate	Area	Price	$	Subtotal	Total
Costs added by weeds									
Herbicides	Selective herbicide (Baron® 400 WG)	1			100 ha	$198.00 /ha	19,800	19,800	
Fuel	Strip tillage	2		15 L/ha	100 ha	$1.50 /L	4,500		
	Herbicide application	1		5 L/ha	100 ha	$1.50 /L	750		
	Inter-row cultivation	2		7 L/ha	100 ha	$1.50 /L	2,100	7,350	
Labour	Strip tillage	2		0.5 hrs/ha	100 ha	$32.50 /hr	3,250		
	Herbicide application	1		0.5 hrs/ha	100 ha	$32.50 /hr	1,625		
	Inter-row cultivation	2		0.5 hrs/ha	100 ha	$32.50 /hr	3,250		
	Hand weeding			1 hr/ha	100 ha	$32.50 /hr	3,250	11,375	
Machinery ownership and R&M							22,290	22,290	60,815
Revenue lost by weeds									
	Nil						0	0	0
Costs avoided by weeds									
	Nil						0	0	0
Net reduction in whole farm operating profit									*$60,815*
Net reduction in whole farm operating profit as % of crop gross revenue									*2.5%*
Per hectare net reduction in whole farm operating profit									*$608*

Impact of innovative weed control practice on whole farm operating profit

Details of the innovative weed control practice

The innovative practice for weed control in the broccoli crop that was chosen for evaluation was use of strip tillage (or zone tillage in the USA) to minimise disruption of soil in ground preparation for the crop. This practice was adopted in place of a conventional approach to ground preparation, including cultivation and formation of beds.

Strip tillage combines no till and standard tillage to allow row crops to be produced. Only the planting rows are disturbed in strip tillage, commonly by vertical implements not horizontal or shallow-angled implements. Outside the planting rows the ground remains untilled, thus retaining surface residues, preserving soil moisture, maintaining soil structure, and reducing the risk of erosion. The untilled area can be used to grow green manure or cover crops.

Description of impacts

Costs added by adopting strip tillage in the broccoli crop were discussed in Section 5 and are detailed in Table 23.

The conventional approach to ground preparation that has been displaced by strip tillage would have involved two passes of a disc plough, one pass of a mouldboard plough, and one pass of a bed former. These costs are avoided in the strip tillage approach. Although are replaced by two strip till passes.

The grower observed that herbicide and hand weeding regimes regime after conventional ground preparation would be the same as those implemented following strip tillage.

Aside from the added costs noted above, use of strip tillage results in a need to apply slug bait to control the slug populations that feed on the grass residues left behind by this form of cultivation. This would not be required subsequent to conventional ground preparation.

The net effect of shifting from conventional ground preparation to strip tillage is a reduction in machinery costs. This net effect is shown in the 'costs avoided by innovative practice' Section of Table 24, and calculation of this amount is detailed in Table A2-22 (Appendix 2).

The grower stated that the level of weed control achieved by strip tillage is equivalent to that achieved with conventional cultivation (with the same herbicide and hand weeding regime). Hence crop yield and revenue is unaffected by adoption of strip tillage.

Budgeted impacts

A budget of the impacts discussed in the previous Section is presented in Table 24. Adopting the innovative weed control practice – strip tillage – in the broccoli crop is seen to increase whole farm operating profit by $35,312, or by $353 per hectare of broccoli grown. This increase in whole farm operating profit represents 1.4 per cent of the farm-gate value of crop gross revenue.

Since adoption of the innovative practice has no effect on crop yield and revenue, the increase in whole farm operating profit derives entirely from the costs avoided by this adoption exceeding the costs added. The net saving in machinery ownership and R&M costs is the largest contributor to the costs avoided by adopting strip tillage, followed by fuel savings associated with reduced reliance on machinery operations.

Table 24. Impact of innovative weed control practice (strip tillage) on the whole farm operating profit of Tasmanian Case 2

Item		Applications	Quantity	Rate	Area	Price	$	Subtotal	Total
Costs added by innovative practice									
Chemicals	Slug bait				100 ha	$95.00 /ha	9,500	9,500	
Fuel	Strip tillage	2		15 L/ha	100 ha	$1.50 /L	4,500		
	Slug bait application	1		10 L/ha	100 ha	$1.50 /L	1,500	6,000	
Labour	Strip tillage	2		0.50 hr/ha	100 ha	$32.50 /hr	3,250		
	Slug bait application	1		0.25 hr/ha	100 ha	$32.50 /hr	813	4,063	19,563
Costs avoided by innovative practice									
Fuel	Disc plough	2		15 L/ha	100 ha	$1.50 /hr	4,500		
	Mouldboard plough	1		35 L/ha	100 ha	$1.50 /hr	5,250		
	Bed former	1		35 L/ha	100 ha	$1.50 /hr	5,250	15,000	
Labour	Disc plough	2		0.5 hr/ha	100 ha	$32.50 /hr	3,250		
	Mouldboard plough	1			100 ha	$40.00 /ha	4,000		
	Bed former	1			100 ha	$40.00 /ha	4,000	11,250	
Machinery ownership and R&M							28,624	28,624	54,874
Revenue added by innovative practice									
	Nil						0	0	0
Revenue lost by innovative practice									
	Nil						0	0	0
Net increase in whole farm operating profit									*$35,312*
Net increase in whole farm operating profit as % of crop gross revenue									*1.4%*
Per hectare net increase in whole farm operating profit									*$353*

Aside from the direct economic advantages of strip tillage accounted for by the increase in whole farm operating profit, the grower observed there are further practical advantages. Compared with conventional ground preparation, strip tillage leaves a firmer (mulched) soil surface between rows of the crop which makes it easier for workers to traverse the crop by foot, and also reduces the risk of machinery becoming bogged thus compromising the timeliness of operations.

Influence of neighbours on adoption of innovative weed control practice

Other landholders in the locality of this grower are vegetable growers.

The growers answered that effective weed control in the broccoli crop using strip tillage depend 'not at all' on weed control efforts by other landholders in the locality. They observed that many other vegetable growers had adopted strip tillage in the surrounding area.

4.4.3 Tasmanian Case 3

Case overview

Key details for this case are shown below.

Type of operation	Family business
Area of property	550 hectares; 50% used for vegetable production
Vegetable crops grown	Potatoes, onions, carrots, peas, broadbeans, broccoli
Staff for vegetable production	3 FTE permanent, 1 FTE seasonal

Details of the particular vegetable crop chosen for the case study are shown below.

Crop	Green beans
Growing environment	Flat harrowed ground
Annual crop area	20 hectares
Crop establishment	Direct seeded
Sowing/planting period	November
Harvest period	February
Market	Processor (for frozen product)
Average annual gross revenue (farm-gate value)	$115,900
Weeds of key concern	Volunteer potatoes, fat hen (*Chenopodium album*), wild radish (*Raphanus raphanistrum*), spring grasses (various unidentified), summer grass *(Digitaria* spp.)*,* amaranth *(Amaranthus* spp.)*,* wild turnip (*Brassica tournefortii*), black bindweed (*Fallopia convolvulus*), fumitory (pinkweed; *Fumaria* spp.), wild poppies (*Papaver somniferum*), sow thistle (*Sonchus oleraceus*)

Current weed management practices for the focal crop

Following a cover crop, a stale seed bed is established 3-4 weeks prior to bean sowing. Roundup Ultra® MAX (glyphosate) is used earlier than would otherwise be the case to close off the cover crop, and a light irrigation is applied to get a weed strike. Roundup Ultra® MAX (glyphosate) is applied a second time to clean up the weeds that emerge.

Pre-emergent herbicides (a mix of Stomp® Xtra (pendimethalin) and Frontier-P® (dimethenamid-p) are applied together with the second glyphosate application. A post-emergent broadleaf herbicide (Basagran® (bentazone)) is applied twice, and a selective herbicide (Blazer® (acifluorfen)) is applied to control for nightshade, fat hen and amaranth. A post-emergent grass herbicide (Fusilade® (fluazifop-p)) is applied once to control spring and summer grasses.

Hand weeding of volunteer potatoes occurs to reduce competition for soil moisture and contamination of the bean crop.

Machinery and equipment used for ground preparation is washed down in dedicated bays to reduce risks of spreading weeds around the property.

Impact of focal crop weeds on whole farm operating profit

Description of impacts

Weeds add to the costs of bean production through the chemical, fuel, labour and machinery costs of herbicide applications for the stale seed bed and the crop, and the labour costs of hand weeding and washing down machinery and equipment. Note that the application of Roundup Ultra® MAX (glyphosate)to close off the cover crop preceding the bean crop is not specifically for weed control and is thus not included as a cost impact of weeds. Machinery costs added due to weeds are detailed in Table A2-23 (Appendix 2).

Costs are added also by the water, electricity and labour required for the light irrigation of the stale seed bed, and for an additional irrigation of the bean crop (compared with the irrigation regime for a weed-free crop) that is required to compensate for the competition for soil moisture caused by emergence of volunteer potato plants in this crop.

Weeds add to the costs of the bean crop also through increasing the need for agronomic consultancy services.

The grower observed that weeds reduce revenue from the bean crop through herbicide applications setting back crop growth, weeds competing for sunlight and soil moisture, and contamination of the harvest (particularly by stems of volunteer potato plants) causing loss of harvested beans in the process of fan-powered removal of weed contaminants. They estimated that the combined yield loss due to these factors is 4.5 tonnes per hectare on an average annual basis.

With harvest and post-harvest activities performed by the processor, there are no on-farm cost savings associated with the yield reduction due to weeds.

Budgeted impacts

A budget of the impacts discussed in the previous Section is presented in Table 25. The net reduction in whole farm operating profit due to weeds in the green bean crop is seen to be $57,143, or $2,857 per hectare of green beans grown. This net reduction in whole farm operating profit represents 49.3 per cent of the farm-gate value of crop gross revenue.

Costs added due to weeds ($29,693) contribute marginally more to the net reduction of whole farm operating profit than the revenue foregone as a result of weeds ($27,450). Labour costs contribute to the majority of the costs added due to weeds, with the added labour costs largely accounted for by hand weeding labour.

Table 25. Impact of weeds in green bean crop on whole farm operating profit of Tasmanian Case 3

Item		Applications	Quantity	Rate	Area	Price	$	Subtotal	Total
Costs added by weeds									
Herbicides	Glyphosate (Roundup Ultra® MAX)	1			20 ha	$23.00 /ha	460		
	Pre-emergent herbicide (Stomp® Xtra/Frontier-P® mix)	1			20 ha	$70.00 /ha	1,400		
	Basagran®	2			20 ha	$87.00 /ha	3,480		
	Blazer®	1			20 ha	$20.00 /ha	400		
	Fusilade®	1			20 ha	$70.00 /ha	1,400	7,140	
Fuel	Herbicide applications	5			20 ha	$14.00 /ha	1,400	1,400	
Electricity	Irrigation pumping: stale seed bed	1			20 ha	$20.00 /ha	400		
	Irrigation pumping: added crop irrigation	1			20 ha	$40.00 /ha	800	1,200	
Labour	Herbicide applications	5			20 ha	$28.00 /ha	2,800		
	Hand weeding				20 ha	$750.00 /ha	15,000		
	Irrigation of stale seed bed	1			20 ha	$10.00 /ha	200		
	Wash-down of machinery and equipment	1		0.25 hr/ha	20 ha	$30.00 /hr	150	18,150	
Water	Irrigation of stale seed bed	1			20 ha	$3.00 /hr	60		
	Added crop irrigation	1			20 ha	$10.00 /hr	200	260	
Agronomic consulting fees					20 ha	$8.00 /hr	160	160	
Machinery							1,383	1,383	29,693
Revenue lost by weeds									
Yield loss from herbicide setback, weed competition, and weed contamination				4.5 t/ha	20 ha	$305 /t	27,450	27,450	27,450
Costs avoided by weeds									
	Nil						0	0	0
Net reduction in whole farm operating profit									*$57,143*
Net reduction in whole farm operating profit as % of crop gross revenue									*49.3%*
Per hectare net reduction in whole farm operating profit									*$2,857*

Impact of innovative weed control practice on whole farm operating profit

Although the stale seed bed approach to weed control had been identified as an innovative practice adopted by this grower, it was not possible to perform an economic evaluation of this adoption. While the grower was able to estimate the costs added by adoption of this practice, they were unable to estimate its benefits (avoided costs and added revenue) with any confidence given that they had to date adopted it only in one bean crop. Although they expect fewer herbicide applications and less hand weeding will ultimately be required as the weed seed bank depletes due to this practice, they have to date maintained the herbicide and hand weeding regimes that existed prior to adopting this practice.

Influence of neighbours on adoption of innovative weed control practice

The neighbours of this grower are also vegetable growers.

The grower answered that effective weed control in the bean crop using the stale seed bed practice depends 'not at all' on weed control efforts by other landholders in the locality. They observed that the source of weed problems in their bean crop is mainly from within their own operations. Hence they regarded the weed control efforts of neighbouring landholders as having little bearing on the effectiveness of the stale seed bed approach on their own property.

4.4.4 Tasmanian Case 4

Case overview

Key details for this case are shown below.

Type of operation	Family business
Area of property	155 hectares; 100% used for vegetable production
Vegetable crops grown	Potatoes
Staff for vegetable production	5 FTE permanent, 0.5 FTE seasonal

Details of the particular vegetable crop chosen for the case study are shown below.

Crop	Potatoes for fresh market
Growing environment	Moulded beds
Annual crop area	37.5 hectares
Crop establishment	Seed potatoes
Sowing/planting period	December
Harvest period	March
Market	Supermarket chains
Average annual gross revenue (farm-gate value)	$474,375
Weeds of key concern	Volunteer (self-sown) potatoes, wild radish (*Raphanus raphanistrum*), blackberry nightshade (*Solanum nigrum*).

Current weed management practices for the focal crop

Potatoes are grown in a three-year rotation. A potato crop is followed by a fallow period during which an average of 3.5 applications of Roundup Ultra® MAX (glyphosate), with the wetter/penetrant Pulse®, occur to control volunteer potatoes.

Following the fallow period a cover crop of high-performance ryegrass varieties is sown. The ryegrass cover crop would be included in the rotation in any case for soil health reasons, but it is sown at 5 kilograms per hectare higher than the standard rate in order to more effectively smother weeds. The ryegrass cover crop is cut three times for silage.

After the third cut for silage, a blended brassica (Caliente; *Brassica juncea* and Nemat; *Eruca sativa*) seed mix is sown into the field to establish a biofumigant cover crop. A cross-slot drill is used for sowing to minimise soil disturbance and thereby germination of weeds. The field is sprayed with glyphosate prior to, or soon after, sowing. The biofumigant cover crop grows vigorously (to 5-6 feet high), thereby providing weeds with minimal opportunities to compete.

At flowering, the biofumigant cover crop is terminated with a high-speed mulcher, and the mulch is promptly incorporated into the soil using a high-speed disc plough. Incorporating the mulch in this way is intended to generate a biofumigant effect in the soil that helps to kill weed seed.

The potato crop is sown following incorporation of the biofumigant into the soil. The grower observes that the overall impact of the biofumigant cover crop is to reduce weeds in the potato crop by 85 per cent compared to a fallow.

The herbicide regime within the potato crop involves one application of (Reglone® (diquat)) mixed with Metribuzin. Weed control for the potato crop also involves spraying the boundaries of the crop area with Roundup Ultra® MAX (glyphosate) six times per year.

Impact of focal crop weeds on whole farm operating profit

Description of impacts

Weeds add to the costs of potato production through:

- the chemical, fuel, labour and machinery costs of the Roundup Ultra® MAX (glyphosate; with Pulse®) applications during the fallow phase in the rotation;
- the additional grass seed sown into the grass cover crop to outcompete weeds; the seed, fertiliser, fuel, labour and machinery costs of sowing the biofumigant cover crop;
- the fuel, labour and machinery costs of mulching and incorporating the cover crop;
- the chemical, fuel, labour and machinery costs of herbicide (Reglone® (diquat) mixed with Metribuzin) application within the potato crop; and
- the chemical, fuel, labour and machinery costs of spraying the crop area boundaries with Roundup Ultra® MAX (glyphosate).

Machinery costs added due to weeds are detailed in Table A2-24 (Appendix 2).

The grower observed that there are no yield or revenue reductions in the potato crop due to weeds when the weed control regime described above is followed.

Budgeted impacts

A budget of the impacts discussed in the previous Section is presented in Table 26. The net reduction in whole farm operating profit due to weeds in the potato crop is seen to be $38,652, or $1,031 per hectare of potatoes grown. This net reduction in whole farm operating profit represents 8.1 per cent of the farm-gate value of crop gross revenue.

This net reduction in whole farm operating profit is accounted for entirely by the costs added due to weeds. Contractor costs of herbicide application (excluding chemical costs) account for the largest share of these added costs, followed by the seed and fertiliser costs of the biofumigant cover crop.

Table 26. Impact of weeds in potato crop on whole farm operating profit of Tasmanian Case 4.

Costs added by weeds									
Seed & fertiliser	Ryegrass cover crop (seed only)			5 kg/ha	37.5 ha	$18.00 /kg	3,375		
	Biofumigant cover crop (cost includes fertiliser)				37.5 ha	$220.00 /ha	8,250	11,625	
Labour & fuel	Sow & fertilise biofumigant cover crop				37.5 ha	$60.00 /ha	2,250	2,250	
Chemicals	Glyphosate (Roundup Ultra® MAX, fallow phase)	3.5		2.75 L/ha	37.5 ha	$8.54 /L	3,082		
	Pulse (applied with glyphosate, fallow phase)	3.5		100 mL/ha	37.5 ha	$40.00 /L	525		
	Diquat (Reglone®, potato crop)	1		0.5 L/ha	37.5 ha	$31.58 /L	592		
	Metribuzin (potato crop)	1		150 g/ha	37.5 ha	$50.70 /kg	285		
	Glyphosate (Roundup Ultra® MAX, boundaries)	6	12 L			$8.54 /L	615	5,100	
Herbicide application	Fallow, cover crops and potato crop (contractor cost - covers fuel, labour, machinery)	4.5			37.5 ha	$60.00 /ha	10,125		
	Boundaries (fuel and labour)	6	6 hrs			$40.00 /hr	1,440	11,565	
Biofumigant mulching & incorporation	Fuel, labour & machinery R&M costs of mulcher				37.5 ha	$80.00 /ha	3,000		
	Fuel, labour & machinery R&M costs of disc plough (incorporation)				37.5 ha	$80.00 /ha	3,000	6,000	
Machinery ownership and R&M (costs not otherwise accounted for)							2,112	2,112	38,652
Revenue lost by weeds									
	Nil						0	0	0
Costs avoided by weeds									
	Nil						0	0	0
Net reduction in whole farm operating profit									*$38,652*
Net reduction in whole farm operating profit as % of crop gross revenue									*8.1%*
Per hectare net reduction in whole farm operating profit									*$1,031*

Impact of innovative weed control practice on whole farm operating profit

Details of the innovative weed control practice

The innovative practice for weed control in potato production that was chosen for evaluation was the cover cropping strategy for weed control, including a biofumigant cover crop (Caliente and Nemat) and a more densely sown ryegrass cover crop. A ryegrass cover crop would be established under the 'without-innovation' cover cropping strategy, although sown less densely. A biofumigant cover crop would not be included in this strategy – the ryegrass cover crop would instead remain in place until termination with a Roundup Ultra® MAX (glyphosate) application to enable ground preparation for a potato crop sown when it would have been under the innovative strategy.

Description of impacts

Costs added by adopting the biofumigant-based innovative cover cropping strategy for potato production were discussed in Section 5 and are detailed in Table 26. Machinery costs added due to adopting this innovative strategy are detailed in Table A2-25 (Appendix 2).

The grower observed from their experience prior to adoption of the innovative strategy that the herbicide regime within the potato crop under the without-innovation scenario would require one application of Reglone® (diquat), two applications of Metribuzin for broadleaf weeds (one of which is applied in a mix with diquat), and one application of Boxer Gold® (prosulfocarb/s-metolachlor) for control of blackberry nightshade. Reglone® (diquat) and Metribuzin would need to be applied at higher rates than under the innovative strategy. The costs of this without-innovation regime would be avoided under the innovative cover cropping strategy.

The grower observed that the herbicide application regime under the without-innovation scenario 'knocks back' the potato crop so that 3-4 weeks of crop growth is lost, resulting on average in a 3 tonne per hectare loss in pack-out yield. They observed further that this yield loss is avoided under the less intensive herbicide regime that is followed under the innovative cover cropping strategy, thus increasing yield and revenue.

Potato washing and packing costs of around $0.08 per kilogram[9] are added as a result of this increase in yield.

Budgeted impacts

A budget of the impacts discussed in the previous Section is presented in Table 27. Adopting the innovative weed control practice – a cover cropping strategy including a biofumigant cover crop – in the potato crop is seen to increase whole farm operating profit by $71,874, or by $1,917 per hectare of potatoes grown. This increase in whole farm operating profit represents 15.2 per cent of the farm-gate value of crop gross revenue.

[9] Based on figures in the gross margin budget for production of spring-summer potatoes presented in Queensland Department of Primary Industries (2018b).

Table 27. Impact of innovative weed control practice (biofumigant-based cover cropping) on the whole farm operating profit of Tasmanian Case 4

Item		Applications	Quantity	Rate	Area	Price	$	Subtotal	Total
Costs added by innovative practice									
Seed & fertiliser	Ryegrass cover crop (seed only)			5 kg/ha	37.5 ha	$18.00 /kg	3,375		
	Biofumigant cover crop (cost includes fertiliser)				37.5 ha	$220.00 /ha	8,250	11,625	
Fuel & labour	Sow & fertilise biofumigant cover crop				37.5 ha	$60.00 /ha	2,250	2,250	
Chemicals	Diquat (Reglone®, potato crop)	1		0.5 L/ha	37.5 ha	$31.58 /L	592		
	Metribuzin (potato crop)	1		150 g/ha	37.5 ha	$50.70 /kg	285	877	
Herbicide application	Diquat/metribuzin mix (contractor cost: covers fuel, labour, machinery)	1			37.5 ha	$60.00 /ha	2,250	2,250	
Biofumigant mulching & incorporation	Fuel, labour & machinery R&M costs of mulcher				37.5 ha	$80.00 /ha	3,000		
	Fuel, labour & machinery R&M costs of disc plough (incorporation)				37.5 ha	$80.00 /ha	3,000	6,000	
Machinery ownership and R&M (costs not otherwise accounted for)							1,702	1,702	
Washing & packing of added crop yield				3 t/ha	37.5 ha	$0.08 /kg	8,550	8,550	33,254
Costs avoided by innovative practice									
Chemicals	Diquat (Reglone®, potato crop)	1		2 L/ha	37.5 ha	$31.58 /L	2,369		
	Metribuzin (potato crop)	2		350 g/ha	37.5 ha	$50.70 /kg	1,331		
	Boxer Gold®			4 L/ha	37.5 ha	$12.00 /L	1,800	5,499	
Herbicide applications	Fuel, labour and machinery (covered by contractor rate)	2			37.5 ha	$60.00 /L	4,500	4,500	9,999
Revenue added by innovative practice									
Yield increase by avoiding herbicide 'knock-back' of crop				3 t/ha	37.5 ha	$0.55 /kg	61,875	61,875	61,875
Revenue lost by innovative practice									
	Nil						0	0	0
Net increase in whole farm operating profit									*$71,874*
Net increase in whole farm operating profit as % of crop gross revenue									*15.2%*
Per hectare net increase in whole farm operating profit									*$1,917*

The increase in revenue arising from the greater crop yield achieved with the innovative cover cropping regime ($61,875) contributes most to the impact on whole farm operating profit, followed by the costs added due to this innovation ($33,254), and finally the costs avoided as a result of this innovation ($9,999).

Not accounted for in the foregoing evaluation of the innovative cover cropping strategy are benefits other than those directly related to weed management. Such other kinds of benefits identified by the grower are the benefits for worker health of reducing herbicide applications, the soil health benefits of the innovative cover cropping strategy (from both reduced herbicide use and increased soil organic matter), and reduced risks of exceeding herbicide residue limits in produce and thereby losing supermarket contracts. A further benefit identified by the grower is an approximate 50 per cent reduction in harvesting time for potatoes as a result of improvements in soil structure arising from the innovative strategy.

Influence of neighbours on adoption of innovative weed control practice

The neighbours of this grower are also vegetable growers.

The grower answered that effective weed control in the potato crop using the innovative cover cropping strategy depends 'strongly' on weed control efforts by other landholders in the locality. The grower observed that the weed control practices of two of their neighbouring landholders are a source of weed dispersal onto their property by wind or birds; while they spray weeds within their vegetable crops where they have uncontrolled weed populations along their boundaries. Uncontrolled volunteer potatoes on neighbouring blocks also provide habitat for potato moths which disperse into their potato crops.

They answered that their decision to adopt the innovative cover cropping strategy was influenced 'not at all' by their level of confidence that other landholders in the locality would adequately control the weeds of concern to their potato crop. They were 'not at all' confident that other landholders in the locality would adequately control the weeds of concern to this crop. Although the effectiveness of this strategy was compromised somewhat by lack of weed control by neighbouring growers, their assessment was that the strategy was more than effective enough for it to be profitable on their property.

4.4.5 Tasmanian Case 5

Case overview

Key details for this case are shown below.

Type of operation	Public (research station)
Area of property	54 hectares, of which 40 hectares used for vegetable production
Vegetable crops grown	Potatoes, carrots, onions, peas, beans, broccoli
Staff for vegetable production	2 FTE permanent

Details of the particular vegetable crop chosen for the case study are shown below.

Crop	Carrots
Growing environment	Beds
Annual crop area	1.152 hectares for each of three different experimental autumn-sown treatments prior to establishing the carrot crop: (i) fallow; (ii) Caliente (*Brassica juncea*) cover crop; and (iii) ryegrass (*Lolium multiflorum*) cover crop.
Crop establishment	Direct seeded
Sowing/planting period	November
Harvest period	May
Market	Supplies under contract to a commercial vegetable growing operation

Average annual gross revenue (farm-gate value)	$19,865 (for crop after fallow treatment)
Weeds of key concern	Wireweed (*Polygonum aviculare*), wild radish (*Raphanus raphanistrum*), volunteer potatoes, grasses (various not identified)

This case study was concerned with field experiments run on the research station that were designed to compare three alternative rotation phases prior to a carrot crop. The alternative rotation phases involved a Caliente (brassica biofumigant) cover crop, a ryegrass cover crop, and herbicide-controlled fallow. These rotation phases had been grown for 13 consecutive prior years representing a long-term trial. The specific focus was on an economic comparison of the Caliente and ryegrass cover cropping treatments as alternatives to the fallow treatment. The Caliente cover cropping treatment had been identified as an innovative weed control practice of particular interest to the present research. Each of the three treatments was replicated four times on 12 individual plots. The area for each treatment summed to 1.152 hectares.

As the field experiments did not generate data relating to the impact of weeds on the carrot crop, an evaluation of the impact of weeds in this crop on whole farm operating profit was not undertaken as part of the present research. Our account of this case study thus proceeds directly to reporting on the economic impact of the innovative weed control practice that was chosen for evaluation; i.e. Caliente cover cropping.

Impact of innovative weed control practice on whole farm operating profit

Details of the innovative weed control practice

The innovative practice for weed control in carrot production that was chosen for evaluation was Caliente cover cropping. This practice was compared to the more conventional practice of ryegrass cover cropping. The economics of each of these cover cropping practices were evaluated against the common benchmark of fallowing instead of cover cropping. A partial budget was thus developed for each of the two cover cropping practices. These two budgets were then compared to identify the economic performance of the Caliente cover cropping practice relative to that of ryegrass cover cropping.

Ground preparation for all three treatments involves deep ripping, but for the cover cropping treatments it also involves a pass of a Rotera power harrow.

The fallow treatment involves two applications of Argo® (glyphosate). Since the fallow occurs during winter when there is normally good soil moisture, irrigation of the fallow to germinate weeds is not required prior to the Argo® (glyphosate) applications.

The Caliente and ryegrass cover crops are each sown with a seed drill. Irrigation of the cover crops is normally not required.

The ryegrass cover crop is terminated by spraying with Argo® (glyphosate) at the same rate as applied in the applications to the fallow treatment.

Standing vegetation within both cover crop treatments is mulched when the Caliente cover crop flowers.

Shallow rotary hoeing of all treatment plots occurs within an hour of the cover crops having been mulched, to incorporate the mulch into the soil (in the case of the cover crop treatments), and (for all treatments including the fallow) to prepare the ground for the subsequent carrot crop. The grower observed that the cost of rotary hoeing to prepare ground for the carrot crop after the fallow treatment fallow is no greater than that of the rotary hoeing undertaken for mulch incorporation and ground preparation after the cover crop treatments.

Beds are then formed for all treatments. Seed-drilling the carrot crop occurs three weeks later, in late November, to allow time for 'trash' which may impede crop germination to rot or be blown away.

Description of impacts

The cover cropping treatments add to the costs of carrot production through: the costs of preparing the ground for these treatments (involving a power harrow pass in addition to deep ripping); the costs of sowing the cover crops (including seed); the costs of spraying off the ryegrass cover crop; the costs of mulching the cover crops; and the costs of rotary hoeing to incorporate the mulch and prepare ground for the carrot crop.

The cover cropping treatments avoid the costs of the fallow treatment, which include: ground preparation for the fallow treatment (involving only deep ripping); glyphosate applications for weed control; and rotary hoeing to prepare ground for the carrot crop.

The grower used relevant contractor rates in costing out the various field operations identified above. The grower charges these rates when undertaking equivalent field operations on other properties. These rates include fuel and labour costs as well as allowances for machinery-related costs including depreciation, opportunity cost of capital, and repairs and maintenance.

The cover cropping treatments add to revenue through the carrot yields achieved following the cover crops. The treatments forego the revenue that would accrue from the carrot yields achieved following a fallow phase.

Carrot crop revenues following the three treatments were calculated by the grower for use in developing partial budgets for the cover crop treatments. Their estimates are based on yields recorded, and farm-gate prices received.

Budgeted impacts

A partial budget of the economic impacts of the Caliente cover crop treatment (relative to the fallow treatment) is presented in Table 28. The Caliente cover crop treatment is seen to increase whole farm operating profit by $7 for the area assessed, or by $7 per hectare of the treatment. This decrease in whole farm operating profit represents 0.04% of the farm-gate value of crop gross revenue under the fallow treatment.

The Caliente cover crop treatment is seen to add $1,475 to carrot production costs while avoiding costs of $662 that would be incurred under a fallow treatment. Adopting this cover crop treatment thus causes an $813 net increase in carrot production costs.

Meanwhile the Caliente cover crop treatment is seen to result in carrot crop revenue of $20,685 while foregoing revenue of $19,865 that would follow from a fallow treatment. Adopting the Caliente treatment thus causes an $820 increase in carrot crop revenue.

The $8 increase in whole farm operating profit from adopting the Caliente cover crop arises because the costs added by this adoption exceed by this amount the revenue added as a result of this adoption.

Table 28. Impact of Caliente cover crop (compared with fallow) on the whole farm operating profit of Tasmanian Case 5

Item		Applications	Quantity	Rate	Area	Price	$	Subtotal	Total
Costs added by innovative practice									
Ground preparation for treatment	Deep ripping (contractor rate)	1		1.3 hrs/ha	1.152 ha	$170 /hr	245		
	Power harrow (contractor rate)	1		1.7 hrs/ha	1.152 ha	$150 /hr	300	545	
Seed & seed drilling	(Contractor rate)	1		1.7 hrs/ha	1.152 ha	$150 /hr	300	300	
Mulch & incorporate cover crop	Mulch (contractor rate)	1		1.7 hrs/ha	1.152 ha	$190 /hr	361		
	Incorporate mulch and prepare ground for next crop (contractor rate)	1		1.2 hrs/ha	1.152 ha	$200 /hr	269	630	1,475
Costs avoided by innovative practice									
Ground preparation	Deep ripping (contractor rate)	1		1.3 hrs/ha	1.152 ha	$170 /hr	245	245	
Herbicides	Glyphosate (Argo®)	2		3.0 L/ha	1.152 ha	$7.50 /L	52	52	
Herbicide application	Glyphosate (Argo®) (contractor rate)	2			1.152 ha	$42 /ha	97	97	
Ground preparation: carrot crop	(contractor rate)	1		1.2 hrs/ha	1.152 ha	$200 /hr	269	269	662
Revenue added by innovative practice									
Crop farm-gate revenue after Caliente cover crop treatment					1.152 ha	$17,956 /ha	20,685	20,685	20,685
Revenue lost by innovative practice									
Crop farm-gate revenue after fallow treatment					1.152 ha	$17,244 /ha	19,865	19,865	19,865
Net increase in whole farm operating profit									*$8*
Net increase in whole farm operating profit as % of crop gross revenue									*0.04%*
Per hectare net increase in whole farm operating profit									*$7*

A partial budget of the economic impacts of the ryegrass cover crop treatment (relative to the fallow treatment) is presented in Table 29. The ryegrass cover crop treatment is seen to reduce whole farm operating profit by $1,091 for the area assessed, or by $947 per hectare of this treatment. This decrease in whole farm operating profit represents -5.5% of the farm-gate value of crop gross revenue under the fallow treatment.

The ryegrass cover crop treatment is seen to add $1,549 to carrot production costs while avoiding costs of $662 that would be incurred under a fallow treatment. Adopting this cover crop treatment thus causes an $887 net increase in carrot production costs.

Meanwhile the ryegrass cover crop is seen to result in carrot crop revenue of $19,661 while foregoing revenue of $19,865 that would follow from a fallow treatment. Adopting this cover crop treatment thus causes a $204 decrease in carrot crop revenue.

The $1,091 decrease in whole farm operating profit from adopting the ryegrass cover crop treatment arises because the costs added by this adoption exceed by this amount the revenue added as a result of this adoption.

The partial budgets presented in Table 28 and Table 29 reveal that the Caliente cover crop treatment results in (marginally) greater whole farm operating profit than achieved with the fallow treatment, while the ryegrass cover crop treatment resulted in less whole farm operating profit than that available following the fallow treatment.

Table 29. Impact of ryegrass cover crop (compared with fallow) on the whole farm operating profit of Tasmanian Case 5

Item		Applications	Quantity	Rate	Area	Price	$	Subtotal	Total
Costs added by innovative practice									
Ground preparation for treatment	Deep ripping (contractor rate)	1		1.3 hrs/ha	1.152 ha	$170 /hr	245		
	Power harrow (contractor rate)	1		1.7 hrs/ha	1.152 ha	$150 /hr	300	545	
Seed & seed drilling	(Contractor rate)	1		1.7 hrs/ha	1.152 ha	$150 /hr	300	300	
Herbicides	Glyphosate (Argo®)	1		3.0 L/ha	1.152 ha	$7.50 /L	26	26	
Herbicide application	Glyphosate (Argo®) (contractor rate)	1			1.152 ha	$42 /ha	48	48	
Mulch & incorporate cover crop	Mulch (contractor rate)	1		1.7 hrs/ha	1.152 ha	$190 /hr	361		
	Incorporate mulch and prepare ground for next crop (contractor	1		1.2 hrs/ha	1.152 ha	$200 /hr	269	630	1,549
Costs avoided by innovative practice									
Ground preparation	Deep ripping (contractor rate)	1		1.3 hrs/ha	1.152 ha	$170 /hr	245	245	
Herbicides	Glyphosate (Argo®)	2		3.0 L/ha	1.152 ha	$7.50 /L	52	52	
Herbicide application	Glyphosate (Argo®) (contractor rate)	2			1.152 ha	$42 /ha	97	97	
Ground preparation: carrot crop	(contractor rate)	1		1.2 hrs/ha	1.152 ha	$200 /hr	269	269	662
Revenue added by innovative practice									
Crop farm-gate revenue after ryegrass cover crop treatment					1.152 ha	$17,067 /ha	19,661	19,661	19,661
Revenue lost by innovative practice									
Crop farm-gate revenue after fallow treatment					1.152 ha	$17,244 /ha	19,865	19,865	19,865
Net increase in whole farm operating profit									*-$1,091*
Net increase in whole farm operating profit as % of crop gross revenue									*-5.5%*
Per hectare net increase in whole farm operating profit									*-$947*

Influence of neighbours on adoption of innovative weed control practice

The neighbours of this grower are also vegetable growers. The grower answered that effective weed control using the Caliente and ryegrass cover crops depends 'not at all' on weed control efforts by other landholders in the locality.

4.5 Western Australian case studies

4.5.1 Western Australian Case 1

Case overview

Key details for this case are shown below.

Type of operation	Family trust
Area of property	12 hectares, of which 9.5 hectares used for vegetable production
Vegetable crops grown	Spinach, Asian salad greens, rocket, chard
Staff for vegetable production	3 FTE permanent, 0.25 FTE seasonal

Details of the particular vegetable crop chosen for the case study are shown below.

Crop	Rocket
Growing environment	Hilled rows
Annual crop area	18 hectares
Crop establishment	Direct seeded
Sowing/planting period	Year-round
Harvest period	Year-round
Market	Food service industry
Average annual gross revenue (farm-gate value)	$352,800
Weeds of key concern	Pigweed (*Portulaca oleracea*), stinging nettle (*Urtica urens*), winter grass (*Poa annua*), wild lupin (*Lupinus* spp.), wireweed (*Polygonum aviculare*)

Current weed management practices for the focal crop

Weeds (particularly pigweed) serve as hosts for insects which can contaminate the rocket when harvested and thereby threaten future sales. Diligent hand weeding is practised in implementing a zero-tolerance strategy of weed control for rocket production. The strategy extends from cropped areas to permanent irrigation lines which have been a major source of weed problems. Weeds are removed diligently whenever noticed during all field activities, as well as opportunistically when staff have few other activities to complete at a given time. On average three hours of labour is devoted per week to diligent hand weeding in and around fields where rocket is grown.

A non-selective herbicide for broadleaf and grass weeds (Spray.Seed®250 (paraquat/diquat)) is applied after completion of each rocket crop, including along permanent irrigation lines, while glyphosate is applied when the need arises (in a minority of rocket crops). The diligent hand weeding strategy avoids the need for further herbicide applications, which the grower believes stunt crop growth and thereby reduce yield.

Impact of focal crop weeds on whole farm operating profit

Description of impacts

Weeds add to the costs of rocket production through: the labour costs of diligent hand weeding; and the chemical, fuel, labour and machinery costs of herbicide (Spray.Seed®250 (paraquat/diquat) and glyphosate) applications. The grower estimated that the time spent on herbicide applications for rocket production averages out at 0.5 hours per hectare on a year-round basis. Machinery costs added due to weeds are detailed in Table A2-26 (Appendix 2).

The strategy of diligent hand weeding ensures there are no yield or revenue losses in rocket production due to weeds.

Budgeted impacts

A budget of the impacts discussed in the previous Section is presented in Table 30. The net reduction in whole farm operating profit due to weeds in the rocket crop is seen to be $7,233, or $402 per hectare of rocket grown. This net reduction in whole farm operating profit represents 2.1 per cent of the farm-gate value of crop gross revenue.

This net reduction in the whole farm operating profit is accounted for entirely by the costs added due to weeds. Labour costs account for the majority these added costs, and labour for hand weeding accounts for most of the added labour costs.

Table 30. Impact of weeds in rocket crop on whole farm operating profit of Western Australian Case 1

Item		Applications	Quantity	Rate	Area	Price	$	Subtotal	Total
Costs added by weeds									
Herbicides	Spray.Seed®250	1			18 ha	$41.67 /ha	750		
	Glyphosate				18 ha	$4.17 /ha	75	825	
Fuel	Herbicide applications		26 hrs/yr	10 L/hr		$1.50 /L	390	390	
Labour	Herbicide applications		52 weeks	0.5 hrs/wk		$30.00 /hr	780		
	Hand weeding		52 weeks	3 hrs/wk		$30.00 /hr	4,680	5,460	
Machinery ownership and R&M							558	558	7,233
Revenue lost by weeds									
	Nil						0	0	0
Costs avoided by weeds									
	Nil						0	0	0
Net reduction in whole farm operating profit									*$7,233*
Net reduction in whole farm operating profit as % of crop gross revenue									*2.1%*
Per hectare net reduction in whole farm operating profit									*$402*

Impact of innovative weed control practice on whole farm operating profit

Details of the innovative weed control practice

The innovative practice for weed control in rocket production that was chosen for evaluation was the diligent hand weeding strategy. The grower observed that in the absence of this strategy there would be a need to apply a pre-emergent herbicide (Dacthal® 900WG (chlorthal-dimethyl)) at the commencement of each rocket crop in order to achieve satisfactory in-crop weed control; and that weeds along the permanent irrigation lines would nevertheless continue to serve as hosts for insects and potentially contaminate harvested rocket.

Description of impacts

Costs added by adopting the diligent hand weeding strategy for rocket production were discussed in Section 5 and are detailed in Table 30. Machinery costs added due to adopting this strategy are detailed in Table A2-27 (Appendix 2).

Chemical, fuel, labour and machinery costs of applying the pre-emergent herbicide Dacthal® 900WG (chlorthal-dimethyl) within the rocket crop are avoided as a result of adopting the diligent hand weeding strategy.

It was estimated by the grower that long-term use of the pre-emergent herbicide would stunt growth of the rocket crop such that yield would be reduced by 5 per cent on average. Diligent hand weeding avoids the need for such herbicide use and thereby contributes a revenue increase associated with its positive effect on crop yield.

The grower observed that the diligent hand weeding strategy allows risks of insect contamination of harvested rocket to be avoided. It was estimated that in the absence of this strategy there would be a 50 per cent yield loss due to insect contamination in two of the twelve months during which rocket is grown; i.e. a 50 per cent yield loss over three hectares (two-twelfths of the crop area). The grower explained that the yield gain due to avoiding this contamination would be additional to the yield gain achieved by avoiding use of the pre-emergent herbicide.

These yield gains arising from diligent hand weeding sum to 3.08 tonnes per hectare. Packing costs of around $0.24 per kilogram[10] are added as a result of these yield increases.

Budgeted impacts

A budget of the impacts discussed in the previous Section is presented in Table 31. Adopting the innovative weed control practice – diligent hand weeding – in the rocket crop is seen to increase whole farm operating profit by $32,032, or by $1,780 per hectare of rocket grown. This increase in whole farm operating profit represents 9.1 per cent of the farm-gate value of crop gross revenue.

[10] Based on figures in the lettuce gross margin budget published by NSW DPI (2013), as adjusted for subsequent inflation using the Consumer Price Index series for Australia (ABS 2019). Given the lack of a gross margin budget for rocket production, the budget for lettuce was chosen as a proxy for rocket given their commonality as salad greens.

Table 31. Impact of innovative weed control practice (diligent hand weeding) on the whole farm operating profit of Western Australian Case 1

	Item	Applications	Quantity	Rate	Area	Price	$	Subtotal	Total
<u>Costs added by innovative practice</u>									
Labour	Hand weeding		52 weeks	3 hrs/wk		$30.00 /hr	4,680	4,680	
Packing	Costs of packing the increase in yield due to the innovation			3.08 t/ha	18 ha	$0.24 /kg	13,306	13,306	17,986
<u>Costs avoided by innovative practice</u>									
Chemicals	Pre-emergent herbicide (Dacthal® 900WG)	1			18 ha	$69.44 /ha	1,250	1,250	
Fuel	Pre-emergent herbicide application		26 hrs/yr	10 L/hr		$1.50 /L	390	390	
Labour	Pre-emergent herbicide application		26 hrs/yr			$30.00 /hr	780	780	
Machinery ownership and R&M							558	558	2,978
<u>Revenue added by innovative practice</u>									
Yield increase	Avoided crop stunting by pre-emergent herbicide			0.28 t/ha	18 ha	$3.50 /kg	17,640		
	Avoided insect contamination			2.8 t/ha	3 ha	$3.50 /kg	29,400	47,040	47,040
<u>Revenue lost by innovative practice</u>									
	Nil						0	0	0
Net increase in whole farm operating profit									*$32,032*
Net increase in whole farm operating profit as % of crop gross revenue									*9.1%*
Per hectare net increase in whole farm operating profit									*$1,780*

Revenue added as a result of diligent hand weeding sums to $47,040, and the costs avoided by this innovative practice sum to $2,978. These two effects combine to increase whole farm operating profit by $50,018. The overall impact of adoption on whole farm operating profit ($32,032, as noted above) is obtained by deducting from this amount the costs added as a result of adopting diligent hand weeding ($17,986).

Aside from the weed control benefits of the diligent hand weeding strategy, the grower also valued highly the advantages that this strategy provides for soil and worker health by enabling reduced use of herbicides.

Influence of neighbours on adoption of innovative weed control practice

One of the grower's three neighbours is a vegetable grower. Of the other two neighbouring landholders, one lives in Perth and visits occasionally and the other is a retiree who runs cattle.

The grower answered that effective weed control in the rocket crop using the diligent hand weeding strategy depends 'not at all' on weed control efforts by other landholders in their locality, despite their observation that weed control by one or more of their neighbours is poor.

4.5.2 Western Australian Case 2

Case overview

Key details for this case are shown below.

Type of operation	Family trust
Area of property	324 hectares, of which 48.5 hectares is used for vegetable production
Vegetable crops grown	Baby leaf lettuce, spinach, rocket
Staff for vegetable production	3 FTE permanent, 4 FTE seasonal

Details of the particular vegetable crop chosen for the case study are shown below.

Crop	Baby leaf lettuce
Growing environment	Beds
Annual crop area	26 hectares (0.5 hectares planted per week)
Crop establishment	Direct seeded
Sowing/planting period	Year-round
Harvest period	Year-round
Market	Food service industry
Average annual gross revenue (farm-gate value)	$783,650
Weeds of key concern	Capeweed (*Arctotheca calendula*), sow thistle (*Sonchus oleraceus*), pigweed (*Portulaca oleracea*), mint weed (*Salvia reflexa*)

Current weed management practices for the focal crop

One pass of a rotary hoe occurs primarily for weed control prior to forming beds for the baby leaf lettuce crop.

Metham is applied once as a soil fumigant for weed control, five days before direct seeding of the crop.

The non-selective herbicide Spray.Seed®250 (paraquat/diquat) is applied the day before direct seeding is to occur if germination of weeds has commenced. The grower estimates this is the case for 10 per cent of crops sown through the year; i.e. for 2.6 hectares of the annual crop area.

Hand weeding is relied upon for weed control between sowing and harvest. Given that all baby leaf lettuce is machine-cut, contamination of the harvest will occur unless sufficient hand weeding is undertaken to remove all weeds. The grower estimated that 600 person-hours of hand weeding is required on average per year to achieve this level of weed control in the baby leaf lettuce crop.

Impact of focal crop weeds on whole farm operating profit

Description of impacts

Weeds add to the costs of baby leaf lettuce production through: the fuel, labour and machinery costs of the rotary hoeing pass; the chemical, fuel, labour and machinery costs of applying Metham and Spray.Seed®250 (paraquat/diquat); and the labour costs of hand weeding. Machinery costs added due to weeds are detailed in Table A2-28 (Appendix 2).

The grower estimated that one per cent of the crop area is abandoned due to excessive weed load on an average annual basis. Weeds thus reduce crop yield (and hence revenue) by reducing the crop area harvested in an average year.

Packing costs of around $0.24 per kilogram[11] are avoided as a result of this reduction in crop yield.

Budgeted impacts

A budget of the impacts discussed in the previous Section is presented in Table 32. The net reduction in whole farm operating profit due to weeds in the baby leaf lettuce crop is $62,667, or $2,410 per hectare of baby leaf lettuce grown. This net reduction in whole farm operating profit represents 8.0 per cent of the farm-gate value of crop gross revenue.

The major contributor to this decline in the whole farm operating profit is the costs added in weed control efforts. The chemical costs of applying Metham account for the largest share of these added costs, followed by the labour costs of hand weeding.

[11] Based on figures in the lettuce gross margin budget published by NSW DPI (2013), as adjusted for subsequent inflation using the Consumer Price Index series for Australia (ABS 2019).

Table 32. Impact of weeds in baby leaf lettuce crop on whole farm operating profit of Western Australian Case 2

Item		Applications	Quantity	Rate	Area	Price	$	Subtotal	Total
Costs added by weeds									
Chemicals	Metham	1			26 ha	$800 /ha	20,800		
	Spray.Seed®250	1			2.6 ha	$20 /ha	52	20,852	
Fuel	Tillage (rotary hoe)	1	0.5 hr/ha	50 L/hr	26 ha	$1.50 /L	975		
	Metham	1	0.17 hr/ha	10 L/hr	26 ha	$1.50 /L	65		
	Spray.Seed®250 application	1	0.17 hr/ha	10 L/hr	2.6 ha	$1.50 /L	7	1,047	
Labour	Tillage (rotary hoe)	1		0.5 hr/ha	26 ha	$30 /hr	390		
	Metham application	1		0.5 hr/ha	26 ha	$30 /hr	390		
	Spray.Seed®250 application	1		0.5 hr/ha	2.6 ha	$30 /hr	39		
	Hand weeding			600 hrs/yr		$30 /hr	18,000	18,819	
Machinery ownership and R&M							14,650	14,650	55,368
Revenue lost by weeds									
Yield loss from crops abandoned to weeds				8.6 t/ha	0.26 ha	$3.50 /kg	7,837	7,837	7,837
Costs avoided by weeds									
Packing costs				8.6 t/ha	0.26 ha	$0.24 /kg	537	537	537
Net reduction in whole farm operating profit									*$62,667*
Net reduction in whole farm operating profit as % of crop gross revenue									*8.0%*
Per hectare net reduction in whole farm operating profit									*$2,410*

Impact of innovative weed control practice on whole farm operating profit

None of the weed control practices applied by this grower were identified as innovative.

In the past, the grower was completing inter-row tillage using a Weedfix cultivator. However, this weed control practice ceased when the grower changed from cos lettuce to baby leaf lettuce production. The baby leaf lettuce crop involves a markedly different planting system to the former cos lettuce crop, characterised by closer plant spacing. This makes Weedfix-style inter-row tillage impractical without excessive crop damage.

Influence of neighbours on adoption of innovative weed control practice

As none of the weed control practices applied by this grower were identified as innovative, data were not collected in respect of this research focus.

4.5.3 Western Australian Case 3

Case overview

Key details for this case are shown below.

Type of operation	Family business
Area of property	16 hectares; 100% used for vegetable production
Vegetable crops grown	Kale, carrots, broccoli, lettuce (cos and oakleaf), celery, cauliflower, cabbage (all grown organically)
Staff for vegetable production	6 FTE permanent

Details of the particular vegetable crop chosen for the case study are shown below.

Crop	Carrots (organic)
Growing environment	Beds
Annual crop area	6.24 hectares (52 weekly plantings of 0.12 ha)
Crop establishment	Direct seeded
Sowing/planting period	Year-round
Harvest period	Year-round
Market	Supermarkets
Average annual gross revenue (farm-gate value)	$489,840 ($78,500/ha)
Weeds of key concern	Pigweed (*Portulaca oleracea*); chickweed (*Stellaria media*); winter grass (*Poa annua*)

Current weed management practices for the focal crop

A stale seed bed is maintained on average for 4.5 weeks prior to sowing the carrot crop. The stale seed bed is irrigated to germinate weeds. This irrigation substitutes for one that would occur in the absence of the stale seed bed practice, so does not add to costs. The organic herbicide Slasher® (nonanoic acid) is applied 1.5 times on average to control weeds germinated by the irrigation.

A small rotary hoe is used for inter-row weed control once the carrot crop has germinated, with 2.5 passes per crop undertaken on average.

A finger weeder tillage implement (with plastic rotating fingers) is used for inter-row weed control, but cannot be used until carrot plants are sufficiently established (5-6 weeks old) so that they will not be pulled out with the weeds during the tillage pass. Two passes per crop with this implement are undertaken on average.

Hand weeding occurs when weeds 'get away', in support of the foregoing weed control regime. The weeds removed from the soil are thrown into the wheel ruts between the beds (provided they haven't seeded) rather than taken from the field.

Mechanical path hoeing is performed to incorporate the weeds thrown into the wheel ruts during hand weeding. Two passes of path hoeing normally occur when hand weeding is performed.

Impact of focal crop weeds on whole farm operating profit

Description of impacts

The grower estimated that during a year the stale seed bed practice adopted for carrot production uses land for 4.5 weeks on average that could otherwise be employed for cropping. The opportunity cost of this land was valued at the rate paid locally for leasing land of comparable quality; i.e. $1,500 per hectare per year, or $28.85 per hectare per week.

Weeds also add to the costs of organic carrot production through: the chemical, fuel, labour and machinery costs of applying the organic weedicide; the fuel, labour and machinery costs of inter-row weeding with a rotary hoe and inter-row weeding with a finger weeder, and of incorporation of hand-removed weeds with a mechanical path hoe; and the labour costs of hand weeding. Machinery costs added due to weeds are detailed in Table A2-29 (Appendix 2).

Hand weeding occurs in carrot plantings with a heavy or moderate weed load. Of the 52 plantings per year, the growers estimate that in an average year a heavy weed load is experienced in eight of the plantings and a moderate weed load in 30 of the plantings. The hand weeding labour cost in a heavily weed-affected planting was estimated to be $3,000, and in a moderately weed-affected planting it was estimated to be $750.

Path hoeing to incorporate weeds removed during hand weeding occurs only in the estimated 38 plantings per year in which hand weeding is required; i.e. on 4.56 hectares of the annual area planted (38 plantings @ 0.12 hectares per planting).

The growers estimated that under the current weed control regime, as described above, weeds 'get away' in five per cent of plantings to the extent that harvest becomes uneconomic and the plantings are abandoned. A revenue loss thus results from five per cent of the crop area of 6.24 hectares (i.e. 0.31 hectares) not being harvested. The average crop yield was estimated to be 40 tonnes per hectare, and the average farm-gate price was estimated to be $1.96 per kilogram.

Packing costs of around $0.09 per kilogram[12] are avoided as a result of the five per cent reduction in crop yield, relative to an average crop yield of 40 tonnes per hectare, that results from abandoning five per cent of plantings due to excessive weed load.

Budgeted impacts

A budget of the impacts discussed in the previous Section is presented in Table 33. The net reduction in whole farm operating profit due to weeds in the organic carrot crop is seen to be $81,251, or $13,021 per hectare of organic carrots grown. This net reduction in whole farm operating profit represents 16.6 per cent of the farm-gate value of crop gross revenue.

[12] Based on figures in the gross margin budget for production of carrots (bags and cartons) presented in Queensland Department of Primary Industries (2018b).

Table 33. Impact of weeds in organic carrot crop on whole farm operating profit of Western Australian Case 3

Item		Applications	Quantity	Rate	Area	Price	$	Subtotal	Total
Costs added by weeds									
Chemicals	Organic weedicide (Slasher®)	1.5		28.0 L/ha	6.24 ha	$12 /L	3,145	3,145	
Fuel	Weedicide (Slasher®) application	1.5	3.5 L/hr	2.75 hrs/ha	6.24 ha	$1.50 /L	135		
	Rotary hoe	2.5	3.5 L/hr	4.2 hrs/ha	6.24 ha	$1.50 /L	344		
	Finger weeder	2	3.5 L/hr	2.1 hrs/ha	6.24 ha	$1.50 /L	138		
	Path hoeing	2	3.5 L/hr	2.1 hrs/ha	4.56 ha	$1.50 /L	101	717	
Labour	Weedicide (Slasher®)application	1.5		2.75 hrs/ha	6.24 ha	$40 /hr	1,030		
	Rotary hoe	2.5		4.2 hrs/ha	6.24 ha	$40 /hr	2,621		
	Finger weeder	2		2.1 hrs/ha	6.24 ha	$40 /hr	1,048		
	Path hoeing	2		2.1 hrs/ha	4.56 ha	$40 /hr	766		
	Hand weeding - heavy weed load		8 plantings			$3,000 /plantin	24,000		
	Hand weeding - moderate weed load		30 plantings			$750 /plantin	22,500	51,965	
Land	Crop land foregone for stale seedbed		4.5 weeks		6.24 ha	$28.85 /ha/wk	810	810	
Machinery ownership and R&M							1,245	1,245	57,882
Revenue lost by weeds									
Yield loss from crop area abandoned due to excessive weed load				40 t/ha	0.31 ha	$1.96 /kg	24,492	24,492	24,492
Costs avoided by weeds									
Packing costs avoided due to yield loss				40 t/ha	0.31 ha	$0.09 /kg	1,123	1,123	1,123
Net reduction in whole farm operating profit									*$81,251*
Net reduction in whole farm operating profit as % of crop gross revenue									*16.6%*
Per hectare net reduction in whole farm operating profit									*$13,021*

The costs added by weed control efforts account for the majority of the decline in whole farm operating profit due to weeds, and labour costs incurred in hand weeding account for a large proportion of these added costs.

Impact of innovative weed control practice on whole farm operating profit

Details of the innovative weed control practice

The innovative practice for weed control in organic carrot production that was chosen for evaluation was the stale seed bed practice as described in Section 5. In the absence of the stale seed bed practice, organic carrot crops would on average be established 4.5 weeks earlier, and additional hand weeding would be required.

Description of impacts

Costs added by adopting the stale seed bed practice were discussed in Section 5 and are detailed in Table 33.

Adopting the stale seed bed practice avoids the costs of additional hand weeding labour that would be required in its absence. The growers estimated that in the absence of this practice the proportion of plantings experiencing a heavy weed load (entailing a hand weeding labour cost of $3,000 per hectare) would increase to 90 per cent, with all remaining plantings experiencing a moderate weed load (entailing a hand weeding labour cost of $750 per hectare). The average number of plantings experiencing a heavy weed load would be 46.8 (90 per cent of 52 plantings), and the hand weeding labour cost for these plantings would be $140,400 (19 plantings x $3,000/planting). The average number of plantings experiencing a moderate weed load would be 5.2 (10 per cent of 52 plantings), and the hand weeding labour cost for these plantings would be $3,900 (5.2 plantings x $750/planting). Summing these amounts gives a total of $144,300 of hand weeding labour costs that would be incurred in the absence of the stale seed bed practice. The hand weeding labour requirements with the stale seed bed practice adopted were costed in Table 33, and these costs sum to $46,500. Hence the costs of hand weeding labour avoided by adopting this practice are $97,800.

The growers found that revenue from organic carrot production is increased by the stale seed bed practice. They stated that adoption of this practice does not affect the overall yield, but that it does increase the average farm-gate price received for carrots by $0.49 per kilogram by up-grading a proportion of this yield. This up-grading results from better control of weeds reducing their negative impacts on carrot shape. The growers estimated that in the absence of this practice 50 per cent, 30 per cent and 20 per cent of total yield would be graded into the premium, juicing and waste grades, respectively, and that these proportions would shift to 75 per cent, 20 per cent and five per cent with adoption of this practice.

Adopting the stale seed bed practice thus increases pack-out (i.e. excluding waste-grade) yield from 80 per cent of the overall yield of 40 tonnes (i.e. 32 tonnes) to 95 per cent of this yield (i.e. 38 tonnes). Hence packing costs are incurred for an additional six tonnes of produce. As noted in Section 5, packing costs for this crop were estimated at $0.09 per kilogram.

Budgeted impacts

A budget of the impacts discussed in the previous Section is presented in Table 34. Adopting the innovative weed control practice – stale seed beds – in the organic carrot crop increases whole farm operating profit by $115,950, or by $18,582 per hectare. This increase in whole farm operating profit represents 23.7 per cent of the farm-gate value of crop gross revenue.

The large increase in whole farm operating profit follows from the positive economic impacts from this practice of $117,300 – obtained by summing the costs it avoids ($97,500) and the revenue it adds ($19,500) – greatly exceeding the negative impacts comprising the costs added by the stale seed bed practice ($1,350). The costs avoided, which account for most of the positive economic impacts of the innovative practice, are wholly accounted for by the costs of hand weeding labour avoided as a result of this practice.

Table 34. Impact of innovative weed control practice (stale seed beds) on the whole farm operating profit of Western Australian Case 3

Item		Applications	Quantity	Rate	Area	Price	$	Subtotal	Total
Costs added by innovative practice									
Land	Opportunity cost of land used for stale seed beds		4.5 weeks		6.24 ha	$28.85 /ha/wk	810	810	
Packing	Increase in pack-out yield		6 tonnes			$0.09 /kg		540	1,350
Costs avoided by innovative practice									
Labour	Hand weeding						97,800	97,800	97,800
Revenue added by innovative practice									
Increased returns from up-grading of produce			40 tonnes			$0.49 /kg	19,500	19,500	19,500
Revenue lost by innovative practice									
	Nil						0	0	0
Net increase in whole farm operating profit									*$115,950*
Net increase in whole farm operating profit as % of crop gross revenue									*23.7%*
Per hectare net increase in whole farm operating profit									*$18,582*

Influence of neighbours on adoption of innovative weed control practice

One of the four neighbours of this property is a vegetable (potato) grower. One of the other neighbours grows citrus, and the two others are hobby farmers who graze some livestock.

The growers answered that effective weed control in the organic carrot crop using the stale seed bed practice depends 'not at all' on weed control efforts by other landholders in their locality. They explained that they maintain buffer zones around and within their property which minimise spread of weeds from neighbouring properties.

4.5.4 Western Australian Case 4

Case overview

Key details for this case are shown below.

Type of operation	Family business
Area of property	270 hectares, of which 25 hectares used for vegetable production
Vegetable crops grown	Cabbage, cauliflower, broccoli, kale
Staff for vegetable production	1 FTE permanent, 8 FTE seasonal

Details of the particular vegetable crop chosen for the case study are shown below.

Crop	Cabbage
Growing environment	Grown on flat, with 30 cm row spacing
Annual crop area	10 hectares
Crop establishment	Transplanted seedlings
Sowing/planting period	Autumn-winter
Harvest period	Spring-summer
Market	Processors (for coleslaw)
Average annual gross revenue (farm-gate value)	\$550,000
Weeds of key concern	Doublegee (three-cornered jack; *Rumex hypogaeus*), wireweed (*Polygonum aviculare*), fat hen (*Chenopodium album*)

Current weed management practices for the focal crop

The herbicide regime for the cabbage crop includes: one application of the knock-down herbicide Basta® (glufosinate-ammonium) (required in 90 per cent of crops on average, or nine hectares per year), one application of Spray.Seed®250 (paraquat/diquat) on the day of transplanting seedlings (90 per cent of crops, or nine hectares per year), one application of pre-emergent herbicide (Dual Gold® (s-metolachlor), 100 per cent of crops or 10 hectares per year), one application of grass herbicide (Fusilade® (fluazifop-p), one per cent of crops or 0.1 hectares per year), and one application of Lontrel® (clopyralid; for doublegee and wireweed in 20 per cent of crops or 2 hectares per year).

None of the tillage operations are conducted primarily for weed control.

Hand weeding is performed as required to remove doublegee and/or wireweed that would otherwise slow the harvest (by becoming entangled in the harvester) or contaminate the harvest (through doublegee seeds adhering to cabbage leaves).

Impact of focal crop weeds on whole farm operating profit

Description of impacts

Weeds add to the costs of cabbage production through: the chemical, fuel, labour and machinery costs of herbicide (Basta® (glufosinate-ammonium), Spray.Seed®250 (paraquat/diquat), Dual Gold® (s-metolachlor), Fusilade® (fluazifop-p) and Lontrel® (clopyralid)) applications; and the labour costs of hand weeding. Machinery costs added due to weeds are detailed in Table A2-30 (Appendix 2).

The grower estimated that hand weeding is required during 15 of the 30 weeks over which the cabbage cropping season normally extends, and in each of these weeks involves a team of five people spending 10 minutes on this activity (i.e. a total of 50 minutes or 0.83 hours per week).

Budgeted impacts

A budget of the impacts discussed in the previous Section is presented in Table 35. The net reduction in whole farm operating profit due to weeds in the cabbage crop is seen to be $3,468, or $347 per hectare of cabbage grown. This net reduction in whole farm operating profit represents 0.6 per cent of the farm-gate value of crop gross revenue.

The net reduction in whole farm operating profit is wholly due to the costs added by weed control efforts. Machinery ownership and R&M costs account for the largest proportion of these added costs, followed by the costs of the herbicides applied.

Impact of innovative weed control practice on whole farm operating profit

None of the weed control practices applied by this grower were identified as innovative.

Influence of neighbours on adoption of innovative weed control practice

As none of the weed control practices applied by this grower were identified as innovative, data were not collected in respect of this research focus.

Table 35. Impact of weeds in cabbage crop on whole farm operating profit of Western Australian Case 4

	Item	Applications	Quantity	Rate	Area	Price	$	Subtotal	Total
Costs added by weeds									
Herbicides	Knock-down herbicide (Basta®)	1		3 L/ha	9 ha	$16.75 /L	452		
	Spray.Seed®250	1		2.5 L/ha	9 ha	$10.00 /L	225		
	Pre-emergent herbicide (Dual Gold®)	1		4 L/ha	10 ha	$16.00 /L	640		
	Grass herbicide (Fusilade®)	1		1 L/ha	0.1 ha	$58.50 /L	6		
	Lontrel®	1		0.6 L/ha	2 ha	$59.00 /L	71	1,394	
Fuel	Herbicide application - Basta®	1	0.08 hrs/ha	10 L/hr	9 ha	$1.50 /L	11		
	Herbicide application - Spray.Seed®250	1	0.08 hrs/ha	10 L/hr	9 ha	$1.50 /L	11		
	Herbicide application - Dual Gold®	1	0.08 hrs/ha	10 L/hr	10 ha	$1.50 /L	12		
	Herbicide application - Fusilade®	1	0.08 hrs/ha	10 L/hr	0.1 ha	$1.50 /L	0		
	Herbicide application - Lontrel®	1	0.08 hrs/ha	10 L/hr	2 ha	$1.50 /L	2	36	
Labour	Herbicide application - Basta®	1		0.08 hrs/ha	9 ha	$28 /hr	20		
	Herbicide application - Spray.Seed®250	1		0.08 hrs/ha	9 ha	$28 /hr	20		
	Herbicide application - Dual Gold®	1		0.08 hrs/ha	10 ha	$28 /hr	22		
	Herbicide application - Fusilade®	1		0.08 hrs/ha	0.1 ha	$28 /hr	0		
	Herbicide application - Lontrel®	1		0.08 hrs/ha	2 ha	$28 /hr	4		
	Hand weeding		15 weeks	0.83 hrs/wk		$28 /hr	350	417	
Machinery ownership and R&M							1,620	1,620	3,468
Revenue lost by weeds									
	Nil						0	0	0
Costs avoided by weeds									
	Nil						0	0	0
Net reduction in whole farm operating profit									*$3,468*
Net reduction in whole farm operating profit as % of crop gross revenue									*0.6%*
Per hectare net reduction in whole farm operating profit									*$347*

5 SUMMARY OF CASE STUDY FINDINGS, AND SUGGESTIONS FOR FURTHER RESEARCH

In this concluding Section of the report the findings of the various case studies documented in Section 4 are summarised, and some areas for further research are discussed.

5.1 Summary of case study findings

Research objective 1: Evaluate the farm-level economic impacts of weeds in vegetable production

The case study findings in respect of this research objective are summarised in Table 36. These impacts were calculated for 19 of the 20 cases studied. In four of these cases the focal vegetable crops were grown organically, and in the remaining 15 cases the crops were grown conventionally. The focal crops included: lettuce, cabbage, chard (organic), potato (organic), potato (conventional), radish, iceberg lettuce, leek, celery, continental parsley, parsnip (organic), curly parsley, broccoli, green bean, rocket, baby leaf lettuce, and carrot (organic). The annual area of the focal crops ranged across the cases from 0.0486 hectares to 200 hectares. The areas of the organic crops were at the lower end of this range, along with a case involving a demonstration site.

Weeds added to the costs of vegetable production in all 19 cases. Despite the weed control practices adopted in all cases, weeds reduced revenue from vegetable production in 10 of the cases. In two of these 10 cases (both conventional) the revenue reduction due to weeds exceeded the costs added. Three of the four organic cases (75 per cent) experience weed-induced revenue reductions, compared with seven of the 15 conventional cases (47 per cent).

Table 36. Farm-level economic impacts of weeds: summary of findings across the cases

Case	Focal crop	Crop area per year (ha)	Crop farm-gate revenue ($)	Economic impact of weeds						Comments
				Costs added ($)	Revenue lost ($)	Costs avoided ($)	Reduction in whole farm operating profit ($)	Reduction as % of crop farm-gate revenue	Reduction in whole farm operating profit per ha ($)	
NSW Case 1	Lettuce	15	675,000	19,817	67,500	17,922	69,395	10.3%	4,626	
NSW Case 2	Cabbage	40	500,000	135,795	99,936	13,880	221,851	44.4%	5,546	
NSW Case 3	Cabbage	0.0486	n.a.	805	0	0	805	n.a.	16,572	Demonstration site. Revenue data unavailable since crop not harvested.
NSW Case 4	Chard (organic)	0.1125	30,000	6,356	6,000	1,200	11,156	37.2%	99,161	
NSW Case 5	Potato (organic)	0.81	50,000	1,824	0	0	1,824	3.6%	2,254	Same property as NSW Case 4.
NSW Case 6	Radish	9.6	n.a.	107,371	0	0	107,371	n.a.	11,185	Crop revenue data unavailable.
Victorian Case 1	Iceberg lettuce	150	7,761,000	259,226	39,000	7,169	291,057	3.8%	1,940	
Victorian Case 2	Leek	90	7,750,000	78,121	142,417	17,963	202,576	2.9%	2,251	
Victorian Case 3	Celery	200	16,575,000	89,700	66,300	3,494	152,507	0.9%	763	
Victorian Case 4	Continental parsle	5.7	889,200	113,741	0	0	113,741	12.8%	19,955	
Victorian Case 5	Parsnip (organic)	6.1	218,600	40,420	24,291	12,146	52,566	24.0%	8,656	
Tasmanian Case 1	Curly parsley	0.4	82,973	1,041	0	0	1,041	1.3%	2,572	
Tasmanian Case 2	Brocolli	100	2,475,000	60,815	0	0	60,815	2.5%	608	
Tasmanian Case 3	Green bean	20	115,900	29,693	27,450	0	57,143	49.3%	2,857	
Tasmanian Case 4	Potato	37.5	474,375	38,652	0	0	38,652	8.1%	1,031	
Tasmanian Case 5	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	Research site. Data on impacts of weeds unavailable.
WA Case 1	Rocket	18	352,800	7,233	0	0	7,233	2.1%	402	
WA Case 2	Baby leaf lettuce	26	783,650	55,368	7,837	537	62,667	8.0%	2,410	
WA Case 3	Carrot (organic)	6.24	489,840	57,882	24,492	1,123	81,251	16.6%	13,021	
WA Case 4	Cabbage	10	550,000	3,468	0	0	3,468	0.6%	347	
*Weighted average: all cases**								*3.6%*	*2,090*	
*Weighted average: organic crops**								*18.6%*	*11,069*	
*Weighted average: conventional crops**								*3.3%*	*1,925*	

* Values of annual crop farm-gate revenue were used as weights when calculating the weighted average reduction in whole farm operating profit due to weeds as a percentage of crop farm-gate revenue. Annual crop areas were used as weights when calculating the weighted average per-hectare reduction in whole farm operating profit

Reduction in whole farm operating profit

The per-hectare reduction in whole farm operating profit due to weeds in the respective focal crops ranges across all cases from $347/ha to $99,161/ha. Across all cases, the weighted average per-hectare reduction in whole farm operating profit due to weeds in the respective focal crops (with annual crop areas used as weights) is $2,090/ha (Table 36). A frequency distribution for this performance measure is presented in Figure 4. The per-hectare reduction in whole farm operating profit due to weeds is seen to be less than $2,500/ha for almost half (nine) of the 19 applicable cases, and less than $5,000/ha for 12 of these cases.

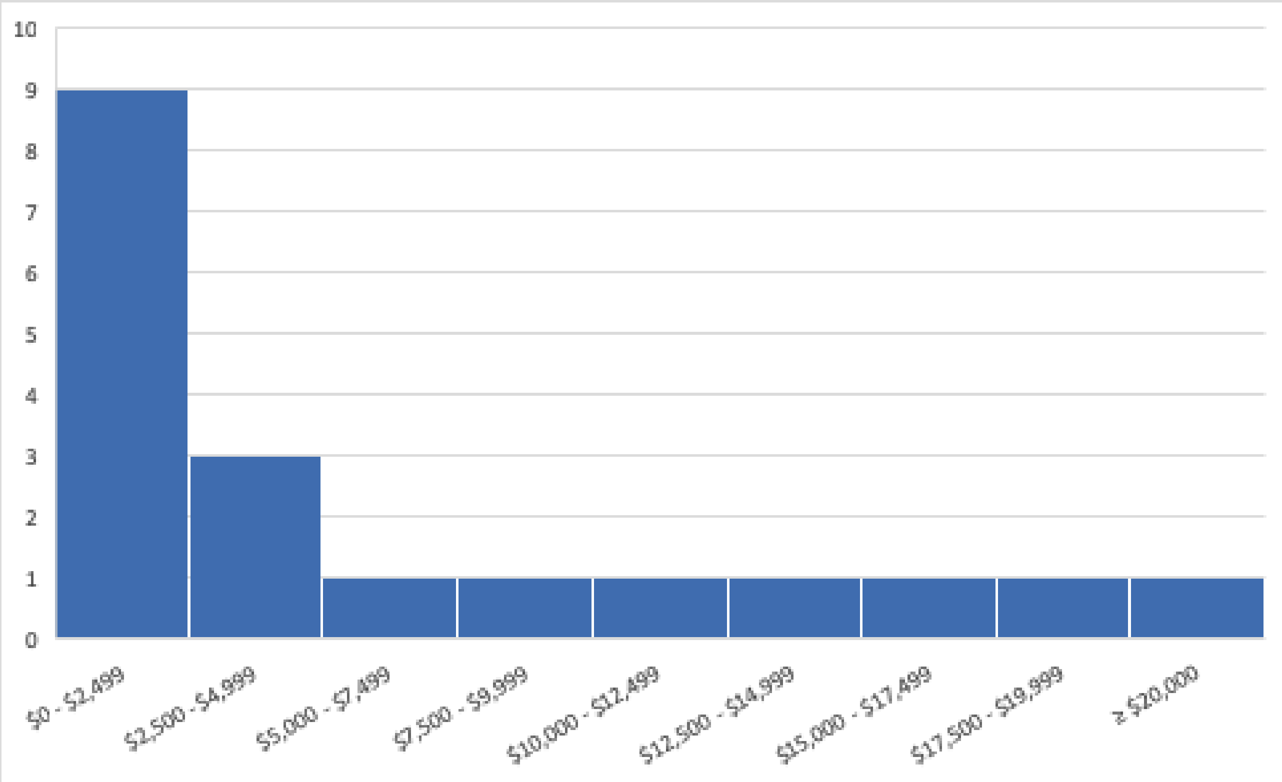

Figure 4. Frequency distribution for per-hectare reduction in whole farm operating profit due to weeds in the focal crop

The proportion of crop farm-gate revenue represented by the reduction in whole farm operating profit due to weeds in the respective focal crop ranges across all cases from 0.6 per cent to 49.3 per cent. The weighted average of such proportions across all cases (with values of annual crop farm-gate revenue used as weights) is 3.6 per cent (Table 36). A frequency distribution for this performance measure is presented in Figure 5. The proportion of crop farm-gate revenue represented by the reduction in whole farm operating profit due to weeds in the respective focal crop is seen to be less than 5 per cent for eight of the 17 applicable cases[13], less than 10 per cent for ten of these cases, and less than 15 per cent for 12 of these cases.

[13] Data on crop farm-gate revenue could not be obtained for two of the cases accounted for in Figure 5.

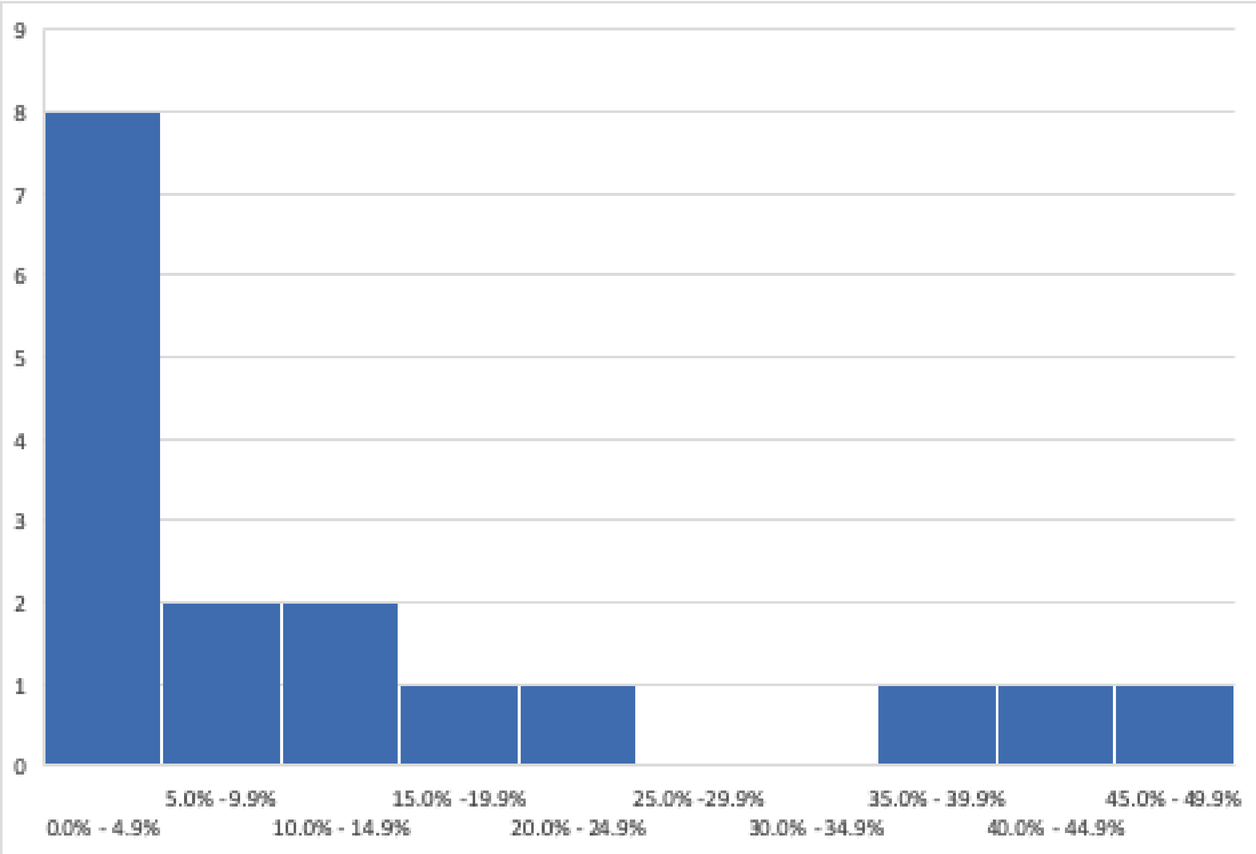

Figure 5. Frequency distribution for the proportion of crop farm-gate revenue represented by reduction in whole farm operating profit due to weeds in the focal crop

Comparing conventional and organic production

Across the four cases involving organic vegetable production, the per-hectare reduction in whole farm operating profit due to weeds in the respective focal crops ranges from $2,254/ha to $99,161/ha. Across these cases, the weighted average per-hectare reduction in whole farm operating profit due to weeds in the respective focal crops is $11,069/ha. The proportion of crop farm-gate revenue represented by the reduction in whole farm operating profit due to weeds in the respective focal crops ranges across these four cases from 3.6 per cent to 37.2 per cent. The weighted average of such proportions across all cases is 18.6 per cent (Table 36).

Across the 15 cases involving conventional vegetable production, the per-hectare reduction in whole farm operating profit due to weeds in the respective focal crops ranges from $347/ha to $19,955/ha. Across these cases, the weighted average per-hectare reduction in whole farm operating profit due to weeds in the respective focal crops is $1,925/ha. The proportion of crop farm-gate revenue represented by the reduction in whole farm operating profit due to weeds in the respective focal crops ranges across these 15 cases from 0.6 per cent to 44.4 per cent. The weighted average of such proportions across all cases is 3.3 per cent (Table 36).

The weighted average per-hectare reduction in whole farm operating profit due to weeds in the respective focal crops is thus almost six times higher for the organic cases than for the conventional cases. The weighted average of proportion of crop farm-gate revenue represented by weed-induced reductions in whole farm operating profit is similarly almost six times greater for the organic cases for the conventional cases. Even so, two of the conventional cases have the highest such proportions (49.3 per cent and 44.4 per cent).

Comparison of findings with those of McLeod (2018)

A number of findings from the present research regarding the farm-level economic impacts of weeds across the cases studied can be compared with equivalent measures derived from the national evaluation of economic impacts of weeds reported in McLeod (2018). Selected statistics[14] and findings[15] from McLeod (2018), and metrics calculated on the basis of those statistics and findings, are presented in Table 37.

Comparable metrics calculated from the case study data collected in the present research are presented in Table 38. Metrics are presented in this table for the full set of crops studied as cases, and also for the subsets of cases involving organically and conventionally grown crops. The metric of 'net costs added due to weeds' reported in Table 38 was calculated by subtracting the sum of costs avoided due to weeds across all cases from the sum of costs added due to weeds across all cases. This metric is comparable to the metric of 'total weed control expenditure' estimated by McLeod (2018).

Table 37. Selected statistics and findings from McLeod (2008), and metrics calculated from these

Measure	
Vegetable industry	
Mean area cropped 2013-2017 (ha)	119,854
Chemical expenditure for weed control, 2018 (mean value, $m)	5.6
Non-chemical expenditure for weed control, 2018 (mean value, $m)	3.4
Total weed control expenditure (mean value, $m)	9
Revenue loss due to weeds (mean value, $m)	35
Total economic impact of weeds (mean value, $m)	44
Per hectare	
Total weed control expenditure per hectare (mean value, $)	75
Revenue loss per hectare due to weeds (mean value, $)	292
Total economic impact of weeds per hectare (mean value, $)	367
Percentage contribution to total economic impact of weeds	
Total weed control expenditure (mean value, %)	20.5
Revenue loss due to weeds (mean value, %)	79.5

[14] The figures for 'mean area cropped 2013-17', 'chemical expenditure for weed control, 2018' and 'non-chemical expenditure for weed control, 2018' were sourced from Tables 4, 5 and 6 in McLeod (2018), respectively.

[15] The figures for 'total expenditure for weed control, 2018', 'revenue loss due to weeds' and 'total economic impact of weeds' were sourced from Table 13 in McLeod (2018).

Table 38. Selected findings from the present research

Measure	All crops	Organic crops	Conventional crops
All cases			
Total area (ha)	735.5	13.3	722.2
Net costs added due to weeds ($)	1,031,894	92,013	939,881
Revenue lost due to weeds ($)	505,223	54,783	450,440
Reduction in WFOP[16] due to weeds ($)	1,537,117	146,796	1,390,321
Per hectare (weighted average across cases)			
Net costs added per hectare due to weeds ($)	1,403	6,938	1,301
Revenue lost per hectare due to weeds ($)	687	4,131	624
Reduction in WFOP per hectare due to weeds ($)	2,090	11,069	1,925
Percentage contribution to reduction in whole farm operating profit			
Net costs added due to weeds (%)	67.1	62.7	67.6
Revenue lost due to weeds (%)	32.9	37.3	32.4

An estimate of total economic impact of weeds per hectare calculated from figures in McLeod (2018) is shown in Table 37 to be $367. This estimate is comparable with the $2,090 reduction in whole farm operating profit per hectare due to weeds that, as shown in Table 38 (and also Table 36), was estimated for the full set of cases studied in the present research. It is evident that the estimate of total economic impact of weeds per hectare calculated from the full set of case studies is almost six times higher than the national-level estimate derived from the work of McLeod (2018). The method followed by McLeod (2018) in deriving this national-level estimate was discussed in Section 2.1 and its limitations reviewed. Briefly, the method involved the loss-expenditure approach applied earlier by Sinden et al. (2004). The 'expenditure' focus in this approach refers to the direct costs of weed control, which were distinguished as herbicide and non-chemical control costs. The 'loss' focus in this approach accounts for revenue losses across an industry arising from reductions in production experienced despite weed control efforts. The expenditure and loss estimates for an industry were calculated on a per hectare basis, then aggregated to the national level using ABARES estimates of farm numbers and operating areas.

The proportion of the McLeod (2018) estimate of the total economic impact of weeds accounted for by total weed control expenditure is shown in Table 37 to be 20.5 per cent. The remaining proportion accounted for by revenue loss due to weeds is seen to be 79.5 per cent. In contrast, the proportion of the estimated weed-induced reduction in whole farm operating profit across the full set of cases studied in the present research that is accounted for by net costs added due to weeds is shown in Table 38 to be 67.1 per cent. The equivalent proportions for 'organic' and 'conventional' subsets of cases are seen from this table to be 62.7 per cent and 67.6 per cent, respectively. Hence while the figures based on McLeod's (2018) work indicate that about one-fifth of the total economic impact of weeds in Australian vegetable production is accounted for by weed control expenditure, in the present research we found that approximately two-thirds of the total reduction in WFOP across the full set of cases studied was accounted for by the net costs added due to weeds (equivalent to weed control expenditures). The estimate of the proportion of the total economic impact of weeds across the

[16] Whole farm operating profit.

cases studied in the present research that is accounted for by net costs added due to weeds is clearly much higher than the estimate for the national industry derived from the work of McLeod (2018).

The focus of the McLeod (2018) evaluation of the economic impacts of weeds on Australian vegetable industry was explicitly on the industry as a whole, whereas the focus of the present research was on a small set of cases of vegetable production that was not selected to be representative of the whole industry. The quality of the data utilised in the two evaluations should also be considered, however. Limitations of the data used by McLeod (2018) for evaluating the economic impact of weeds on the Australian vegetable industry have been discussed previously in Section 2.1. In presenting estimates of economic impacts for different Australian agricultural industries (including the vegetable industry), McLeod (2018 p. 30) cautioned that "there is a high level of uncertainty around these estimates as many production loss and control loss assumptions, with the exception of the grains industry, are based on limited data". The uncertainty around the estimate of the economic impact of weeds for the vegetable industry is arguably greater than for most of the other industries for which evaluations were undertaken, given that the estimate of production loss in the vegetable industry due to weeds was merely assumed[17] rather than (as was the case for most other industries evaluated) informed by the scientific literature or at least by documented 'personal communication' with an industry expert. From this perspective the present research – in which data on farm-level economic impacts of weeds were sourced directly from case study vegetable growers – offers a superior basis for estimating the impacts of weeds on this industry. However, the methods of McLeod (2018) and the present research each have benefits and limitations for estimating the economic impact of weeds on the Australian vegetable industry. An alternative to these methods will be required for this impact to be estimated with a reasonable level of confidence, and such an alternative is suggested for consideration in Section 5.2.

Research objective 2: Evaluate the farm-level economic impacts of adopting innovative weed control practices in vegetable production

The farm-level economic impacts of adopting innovative weed control practices were calculated for the 15 cases in which at least one such innovative practice was identified. With two innovative practices identified, and evaluated separately, for one of the cases (Victorian Case 3), 16 evaluations of innovative weed control practices were conducted in total.

The range of innovative weed control practices that were evaluated is revealed in Table 39. The crops within which these practices were adopted were: cabbage, chard (organic), potato (organic), potato (conventional), radish, iceberg lettuce, celery, parsnip (organic), curly parsley, broccoli, carrot, rocket, and carrot (organic). The annual area of these crops ranged from 0.0486 hectares to 200 hectares. The areas of the organic crops were at the lower end of this range, along with a case involving a demonstration site. Four of the full set of 16 evaluations were of practices adopted in organic crops.

The impact of adopting the innovative weed control practices on WFOP per hectare ranges across all evaluations from -$5,586 to $152,199. The impact is negative in five of the evaluations, with all of these evaluations focused on conventional vegetable production. Across the evaluations concerned with organic vegetable production, the impact on WFOP of adopting innovative weed control practices ranges from $2,213 to $152,199. Four of the five greatest positive impacts on WFOP per hectare (ranging from $2,213 to $152,199) are found to come from innovative weed control practices adopted in organic crops.

The proportion of crop farm-gate revenue represented by the impact of innovative weed control practices on WFOP ranges across all evaluations from -13.2 per cent to 57.1 per cent. Across the evaluations concerned with organic vegetable production, this proportion ranges from 6.1 per cent to 57.1 per cent. The larger this proportion, the more crucial is the innovative weed control practice in question for the profitability of the crop within which it is practised.

The findings that the impact on WFOP is negative in respect of five of the innovative weed control practices evaluated serves as a caution against presuming that innovation in weed control is necessarily of on-farm

[17] McLeod (2018, Table 7) noted that the estimate of percentage production loss he used in evaluating the economic impact of weeds in the vegetable industry had been "assumed from Sinden et al. (2004)", while Sinden et al. (2004, Table 3.5) identified the data source for their estimate of percentage production loss in the vegetable industry due to weeds as "assumed".

economic benefit. Whether this impact is positive or negative depends on multiple factors including the type of innovation, the crop within which it is adopted, the weed problems experienced in that crop, and the efficacy of existing weed control measures in solving those problems.

Table 39. Farm-level economic impacts of innovative weed control practices: summary of findings across the cases

Case	Focal crop	Innovative weed control practice/s	Crop area per year (ha)	Crop farm-gate revenue ($)	Economic impact of innovative weed control practice			Comments
					Impact on whole farm operating profit ($)	Impact as % of crop farm-gate revenue	Impact on whole farm operating profit per ha ($)	
NSW Case 2	Cabbage	Oats cover crop	40	500,000	-22,800	-4.6%	-570	Soil health benefits not accounted for
NSW Case 3	Cabbage	Diligent hand-weeding and inter-row scuffling	0.0486	n.a.	-271	n.a.	-5,586	Demonstration site. Crop is not harvested, so crop revenue and revenue impacts of innovation could not be
NSW Case 4	Chard (organic)	Cover cropping and diligent hand-weeding	0.1125	30,000	17,122	57.1%	152,199	
NSW Case 5	Potato (organic)	Modified hilling process	0.81	50,000	8,904	17.8%	11,001	Same property as NSW Case 4
NSW Case 6	Radish	Sheet steam weeding	9.6	n.a.	57,856	n.a.	6,027	Revenue data unavailable
Victorian Case 1	Iceberg lettuce	Stale seed bed and trickle tape fertigation	150	7,761,000	33,276	0.4%	222	
Victorian Case 3	Celery	Stale seed bed	200	16,575,000	-10,332	-0.1%	-52	Benefits from stalling herbicide resistance, and for possible transition to organic production, not accounted for
Victorian Case 3	Celery	Inter-row tillage with Weedfix cultivator	200	16,575,000	-9,087	-0.1%	-45	Benefits from stalling herbicide resistance, and for possible transition to organic production, not accounted for
Victorian Case 5	Parsnip (organic)	Flame weeding	6.1	218,600	13,438	6.1%	2,213	
Tasmanian Case 1	Curly parsley	Inter-row push sprayer for glyphosate	0.4	82,973	73	0.1%	180	
Tasmanian Case 2	Brocolli	Strip tillage	100	2,475,000	35,312	1.4%	353	
Tasmanian Case 4	Potato	Biofumigant-based cover cropping strategy	37.5	474,375	71,874	15.2%	1,917	Benefits for soil health, herbicide residues, and harvesting time not
Tasmanian Case 5	Carrot	Caliente cover crop	1.15	20,685	8	0.04%	7	
Tasmanian Case 5	Carrot	Ryegrass cover crop	1.15	19,661	-1,091	-5.5%	-947	
WA Case 1	Rocket	Diligent hand-weeding	18	352,800	32,032	9.1%	1,780	
WA Case 3	Carrot (organic)	Stale seed bed	6.24	489,840	115,950	23.7%	18,582	

For four of the six innovative weed control practices evaluated as having a negative economic impact, at least some of the benefits of these practices other than for weed control were unable to be accounted for. It is possible then that the economic impact of some of these practices might be positive if it were possible to value all of their benefits. Consider for instance the stale seed bed innovation adopted in the celery crop of Victorian Case 3. Although the economic impact of this innovation was estimated at -$52 per hectare, this estimate does not account for benefits that the grower identified (but could not assign a dollar value to) by way of slowing onset of herbicide resistance and providing lessons that may prove useful in transitioning to organic production methods for this crop.

Break-even analysis could be used by this grower to assess whether adoption of this innovation in fact has a positive economic impact from their perspective when all of its benefits are considered. This step involves the grower considering whether the total value for their operations of the innovation's unaccounted-for benefits is sufficient to outweigh the $52 per hectare negative economic impact that was estimated without accounting for these benefits.

Research objective 3: **Explore vegetable growers' perceptions of** collective action problems in benefiting from innovative weed control practices

The case study findings in respect of this research objective are summarised in Table 40. Only growers who had adopted at least one innovative weed control practice were questioned for this part of the research.

Table 40. Growers' perceptions of collective action problems in benefiting from innovative weed control practice: Summary of responses from relevant cases

Question	No. of responses from relevant cases					
	Very strongly	Strongly	Moderately	Weakly	Not at all	Total
Effective weed control in focal crop using innovative practice depends on weed control efforts by other local landholders?	1	2	1	3	9	16
Adoption of innovation influenced by confidence that other local landholders would exercise adequate weed control?	0	0	0	0	7	7
Confident that other local landholders would exercise adequate weed control on their properties?	1	1	1	0	4	7

In all 16 cases where an innovative weed control practice had been adopted, the grower interviewed was asked about the extent to which effective weed control in the focal crop using that practice depends on weed control efforts by other landholders in their locality. 'Not at all' was answered in a majority (nine) of the cases, and the next most frequent response (for three cases) was 'weakly'. The level of dependence was thus perceived to be at most weak for 75 per cent of the cases. In contrast, as noted in Section 2.3, a survey of graziers in two regions of NSW affected by the pasture weed serrated tussock found that 63 per cent of respondents identified "neighbouring private landholders who don't attempt to control [this weed]" as causing difficulty in controlling it on their properties (Marshall et al. 2016 p. 106).

Explaining this marked difference in the patterns of response from graziers and vegetable growers may be a productive focus for future research. Qualitative responses from the vegetable growers interviewed in the present research indicate that the difference may follow from vegetable growing typically being conducted much more intensively than livestock production due to the considerably higher value of its output per hectare. This tendency is reflected in an observation by Sinden et al. (2004) that vegetable growers and other horticultural producers tend to spend more on weed control per hectare than is the case for livestock grazing operations. The greater intensity of vegetable production relative to grazing may create a tendency for vegetable growers to seek self-reliance in managing their weed problems rather than expose themselves to the vulnerability of depending on cooperation from other landholders. Many of the most important weeds of vegetable production also appear to be relatively less likely to spread long distances by wind. This suggests that vegetable growers may be less vulnerable to significant weed invasion from neighbouring properties than their livestock grazing counterparts.

Growers other than those answering 'not at all' to the question about dependence on weed control efforts by other local landholders were asked a further two questions. Seven of the cases were in this category. They could choose between 'very strongly', 'strongly', 'moderately', 'weakly' and 'not at all' in answering each of these questions.

The first of the additional questions enquired about the extent to which the grower's decision to adopt the innovative weed control practice under consideration was influenced by their level of confidence that other local landholders would exercise adequate weed control. The answer given in all seven cases was 'not at all'. In contrast, the aforementioned pasture landholder survey found that the serrated tussock control efforts of 65 per cent of the graziers interviewed were strongly motivated by their confidence that their neighbours would reciprocate their own control efforts (Sindel et al. 2013). Reasons for this marked difference in patterns of response from vegetable growers and graziers could be explored in further research. Previous research has found that adoption of agricultural innovations tends to be inhibited when the innovations are: overly complex or inflexible; not divisible into manageable parts; incompatible with personal or farm objectives; not profitable or require high capital outlay; uncertain in their outcomes; intensive in their learning requirements; and subject to conflicting information from multiple sources (Vanclay 2004).

The second of the additional questions asked respondents how confident they were that other local landholders would exercise adequate weed control on their properties. 'Not at all' was answered in a majority (four) of the cases to which the question applied, and 'very strongly', 'strongly' and 'moderately' were answered for one case each. Based on the responses to the previous question, however, this dominant pattern of lack of confidence in other local landholders' weed control efforts appears not to have affected respondents' decisions to adopt innovative weed control practices on their own properties.

5.2 Areas for further research

Two areas in which further research would strengthen the knowledge base available to guide future decision making around weed management in the Australian vegetable industry were identified in Section 5.1. The first of these areas concerns estimation of the economic impact of weeds on this industry. The quality of data on which previous evaluations of this economic impact have relied has been low given the degree of reliance on assumptions. Moreover, results from the case studies conducted in the present research give some reason to suspect that the previous evaluations may have under-estimated the economic impact of weeds on the Australian vegetable industry.

The method followed by Llewellyn et al. (2016) in estimating the economic impact of weeds on Australian grain growing industry utilised data obtained in respect of a randomly selected sample of 600 grain growers who represented approximately two million hectares of Australian cropping land. Data sourced directly from grain growers through phone interviews were combined with yield loss coefficients for each identified weed that were based on prior research, and with estimates from industry experts of costs of weed control practices and grain contamination, in calculating the economic impact of weeds on each interviewed grain grower. The economic impacts of weeds calculated across all interviewed growers were then used to estimate the impact for the Australian grain growing industry as a whole. The random sampling procedure followed in selecting the growers to be interviewed ensured that the industry-level economic impact of weeds could be estimated in a statistically valid manner from the impacts calculated for interviewed growers.

This method applied in estimating the economic impact of weeds on the Australian grain growing industry may be transferable to the Australian vegetable growing industry, although further investigation would be required to confirm this. Questions of key relevance to such an investigation concern the feasibility of translating the method to the vegetable industry given (a) the greater diversity of crops to be accounted for in this industry; and (b) the less extensive body of weeds research in this industry to draw from in specifying the yield loss coefficients which the method requires to be combined with data directly sourced from vegetable growers.

The second of the areas identified in Section 5.1 for potential further research concerns the influence of collective action challenges in controlling weeds on vegetable growers' adoption of innovative weed control practices. As noted in Section 5.1.3 in respect of this issue, the pattern of responses from vegetable growers that was identified in the present research differs markedly from the pattern found by Sindel et al. (2013) from a survey of the practices and motivations of graziers in controlling weeds in two regions of NSW.

This survey involved telephone interviews with one hundred graziers in each of these regions. Aside from the focus on collective action challenges in controlling weeds, the interviews sought information more broadly on respondents' perceptions of the barriers to, and incentives for, adoption of weed control practices. The quantitative data collected through the survey was complemented by qualitative data obtained from community workshops held in each of the two regions. Workshop attendees included landholders, Landcare group members, and staff from various government bodies responsible for weed control in those regions.

Applying to the vegetable industry a survey method similar to that followed by Sindel et al. (2013) would provide a check of whether the differences in response patterns from the two industries is explained by the differences in the research methods by which these patterns were identified. Application of this survey method to the vegetable industry (or part of this industry), would also allow further greater examination of (a) the factors contributing to vegetable growers' perceptions of collective action challenges in managing weeds, (b) the extent to which, and how, these perceptions influence their decisions about weed control, and (c) potential solutions to any identified collective action challenges, than was possible in the present research given that challenges of this kind were not its sole concern. It would add also to our understanding of vegetable growers' perceptions more broadly of the barriers to, and incentives for, controlling weeds on their properties. Complementing the survey approach with community workshops, as in the Sindel et al. (2013) study, would assist in translating the quantitative survey results into practical strategies for strengthening weed control in the vegetable industry.

6 REFERENCES

ABS. 2019 *6401.0 Consumer Price Index Australia, March 2019*. Australian Bureau of Statistics, Canberra.

Aftab, M., Freeman, A. and Henry, F. 2011 *Agnote AG1207: Temperate Pulse Viruses: Cucumber Mosaic Virus (CMV)*. Department of Primary Industries Victoria, Melbourne.

AUSVEG. 2012. *VegTool Version 1.1 Workbook: Gross Margin Comparison Tool for Vegetables*. AUSVEG, Melbourne. https://ausveg.com.au/resources/economics-statistics/gross-margin-tool/.

Bailey, W.A., Wilson, H.P. and Hines, T.E. 2001. Influence of cultivation and herbicide programs on weed control and net returns in potato (*Solanum tuberosum*). *Weed Technology.* 15(4): 654-659.

Bangarwa, S.K., Norsworthy, J.K., Rainey, R.L. and Gbur, E.E. 2010. Economic returns in plasticulture tomato production from crucifer cover crops as a methyl bromide alternative for weed management. *HortTechnology.* 20(4): 764-771.

Brown, B., Hoshide, A.K. and Gallandt, E.R. 2019. An economic comparison of weed management systems used in small-scale organic vegetable production. *Organic Agriculture.* 9: 53-63.

Cho, A.H., Hodges, A.W. and Chase, C.A. 2012. Partial budget analysis of summer fallows for organic nutrient and weed management in Florida. *HortTechnology.* 22(2): 258-262.

Coutts, B. 2006 *Farmnote: Virus Diseases of Cucurbit Crops*. Agriculture WA, Perth.

Coutts, S.R., Yokomizo, H. and Buckley, Y.M. 2013. The behavior of multiple independent managers and ecological traits interact to determine prevalence of weeds. *Ecological Applications.* 23(3): 523-536.

Davidson, B.R. and Martin, B.R. 1965. The relationship between yield on farms and in experiments. *Australian Journal of Agricultural Economics.* 9(2): 129-140.

Delate, K., Cwach, D. and Chase, C.A. 2011. Organic no-tillage system effects on soybean, corn and irrigated tomato production and economic performance in Iowa, USA. *Renewable Agriculture and Food Systems.* 27(1): 49-59.

Department of Resources (Northern Territory). 2012 *Vegetable Growing Manual*. Department of Resources, Darwin.

Devkota, P., Norsworthy, J.K. and Rainey, R. 2013. Efficacy and economcs of herbicide programs compared to methyl bromide for weed control in polyethylene-mulched tommato. *Weed Technology.* 27(3): 580-589.

Engindeniz, S. 2008. Economic analysis of agrochemical use for weed control in field-grown celery: A case study for Turkey. *Crop Protection.* 27: 377-384.

Epanchin-Niell, R.S., Hufford, M.B., Aslan, C.E., Sexton, J.P., Port, J.D. and Waring, T.M. 2010. Controlling invasive species in complex social landscapes. *Frontiers in Ecology and the Environment.* 8(4): 210-216.

Eure, P.M., Culpepper, A.S., Merchant, R.M., Roberts, P.M. and Collins, G.C. 2015. Weed control, crop response, and profitability when intercropping can. *Weed Technology.* 29(2): 217-225.

Fennimore, S.A., Smith, R.F., Tourte, L., LeStrange, M. and Rachuy, J.S. 2014. Evaluation and economics of a rotating cultivator in bok choy, celery, lettuce and radicchio. *Weed Technology.* 28: 176-188.

Fennimore, S.A., Tourte, L., Rachuy, J.S., Smith, R.F. and George, C. 2010. Evaluation and economics of a machine-vision guided cultivation program in brocolli and lettuce. *Weed Technology.* 24(1): 33-38.

Fontanelli, M., Frasconi, C., Martelloni, L., Pirchio, M., Raffaelli, M. and Peruzzi, A. 2015. Innovative strategies and machines for physical weed control in organic and integrated vegetable crops. *Chemical Engineering Transactions.* 44: 211-216.

Graham, S. 2013. Three cooperative pathways to solving a collective weed management problem. *Australasian Journal of Environmental Management.* 20(2): 116-129.

Graham, S. 2014. A new perspective on the trust power nexus from rural Australia. *Journal of Rural Studies.* 36: 87-98.

Graham, S. and Rogers, S. 2017. How local landholder groups collectively manage weeds in south-eastern Australia. *Environmental Management.* 60(3): 396-408.

Height, K.M. 2018. *The Role of Social Norms for Weed Management Across Rural Private Property*. Doctor of Philosophy thesis. University of Melbourne, Melbourne.

Henderson, C. 2000 *Integrated Weed Management, Cover Crop, Mulch and Rotation Management in Vegetable Production Systems*. Horticultural Research and Development Corporation, Sydney.

Henderson, C. 2001 *Weed Management in Lettuce*. Queensland Department of Primary Industries, Brisbane.

Henderson, C.W.L. and Bishop, A.C. 2000 Vegetable Weed Management Systems. In: Sindel, B.M. (ed.) *Australian Weed Management Systems*. R.G. and F.J. Richardson, Melbourne. pp. 355-372.

Johnson, H.J., Colqhhoun, J.B., Bussan, A.J. and Rittmeyer, R.A. 2010. Feasibility of organic weed management in sweet corn and snap bean for processing. *Weed Technology.* 24(4): 544-550.

Khokkar, K.M., Mahmoud, T., Shakeel, M. and Chaudry, M.F. 2006. Evaluation of integrated weed management practices for onion in Pakistan. *Crop Protection.* 25: 968-972.

Kristiansen, P., Coleman, M., Fyfe, C. and Sindel, B. 2014a *Weed Management for the Australian Vegetable Industry: Final Report (HAL Project No. VG13079)*. Horticulture Australia Limited, Sydney.

Kristiansen, P., Coleman, M., Fyfe, C. and Sindel, B. 2014b *Weed Management for the Vegetable Industry - Scoping Study*. Horticulture Innovation Australia, Sydney.

Kristiansen, P., Sindel, B.M. and Jessop, R.S. 2008. Weed management in organic echinacea (Echinacea purpurea) and lettuce (Lactuca sativa) production. *Renewable Agriculture and Food Systems.* 23: 120-135.

Leela, D. 1987. Weed control by herbicides in knol khol and radish. *International Journal of Pest Management.* 33(3): 214-219.

Liu, L.C., Antoni-Padilla, M., Goyal, M.R. and Gonzalez-Ibanez, J. 1987. Integrated weed management in transplanted tomatoes and peppers under drip irrigation. *Journal of Agriculture of the University of Puerto Rico.* 71(4): 349-358.

Llewellyn, R.S., Ronning, D., Ouzman, J., Walker, S., Mayfield, A. and Clark, M. 2016 *Impact of Weeds on Australian Grain Production: The Cost of Weeds to Australian Grain Growers and The Adoption of Weed Management and Tillage Practices. Report for the Grains Research and Development Corporation*. CSIRO, Australia.

Lubeck, A.A., Metcalf, A.L., Beckman, C.L., Yung, L. and Angle, J.W. 2019. Collective factors drive individual invasive species control behaviors: Evidence from private lands in Montana, USA *Ecology and Society.* 24(2): 32.

Ma, Z., Clarke, M. and Church, S.P. 2018. Insights into individual and cooperative invasive plant management on family forestlands. *Land Use Policy.* 75: 682-693.

Makeham, J.P. and Malcolm, L.R. 1993 *The Farming Game Now*. Cambridge University Press, Cambridge.

Marinan-Arroyuelo, E., Marchi, A., Marchal-Rubio, F., Bozoglou, C., Servis, D. and Giannopolitis, C.N. 2014. Weed control benefit to cost ratio and labour return value in crops of southern European countries with the use of herbicide pendimethalin. *Hellenic Plant Protection Journal.* 7: 61-72.

Marshall, G.R. 2009. Polycentricity, reciprocity, and farmer adoption of conservation practices under community-based governance. *Ecological Economics.* 68(5): 1507-1520.

Marshall, G.R., Coleman, M.J., Sindel, B.M., Reeve, I.J. and Berney, P.J. 2016. Collective action in invasive species control, and prospects for community-based governance: The case of serrated tussock (*Nassella trichotoma*) in New South Wales, Australia. *Land Use Policy.* 56: 100-111.

McLeod, R. 2018 *Annual Costs of Weeds in Australia*. Centre for Invasive Species Solutions, Canberra.

Melander, B. 1998 Economic aspects of physical inter-row weed control in seeded onions. In: Foguelman, D. and Lockeretz, W. (eds.) *12th International IFOAM Scientific Conference* IFOAM, Mar Del Plata, Argentina. pp. 180-185.

Melander, B., Rasmussen, I.A. and Barberi, P. 2005. Integrating physical and cultural methods of weed control – examples from European research. *Weed Science.* 53(3): 369-381.

Niemiec, R.M., Ardoin, N.M., Wharton, C.B. and Asner, G.P. 2016. Motivating residents to combat invasive species on private lands: Social norms and community reciprocity. *Ecology and Society.* 21(2): 30.

NSW DPI. 2013. *Horticulture Gross Margin Budgets*. NSW Department of Primary Industries, Orange. https://www.dpi.nsw.gov.au/agriculture/budgets/vegetable.

Ogbuchiekwe, E.J. and McGiffen, M.E. 2001. Efficacy and economic value of weed control for drip and sprinkler irrigated celery. *HortScience.* 36(7): 1278-1282.

Pannell, D.J., Marshall, G.R., Barr, N., Curtis, A., Vanclay, F. and Wilkinson, R. 2006. Understanding and promoting adoption of conservation practices by rural landholders. *Australian Journal of Experimental Agriculture.* 46: 1407-1424.

Patel, T.U., Patel, C.L., Patel, D.D., Thanki, J.D., Patel, P.S. and Jat, R.A. 2011. Effect of weed and fertiliser management on weed control and productivity of onion (*Allium cepa*). *Indian Journal of Agronomy.* 56: 267-272.

Queensland Government. 2018a. *Agbiz tools - Plants - Vegetables*. Queensland Government, Brisbane. https://publications.qld.gov.au/dataset/agbiz-tools-plants-vegetables.

Queensland Government. 2018b. *Gross Margin Assessment for Producing Cartons of Cabbage in Southern Queensland*. Queensland Government, Brisbane. https://www.publications.qld.gov.au/dataset/agbiz-tools-plants-vegetables/resource/d34b5017-23d2-445d-b65f-2bc8e9b43b8c.

Rae, A.N. 1977 *Crop Management Economics*. Granada, St Albans, UK.

Ramachandraiah, B., Rao, N.H. and Madavi, M. 2016. Integrated weed management practices and their effect on yield and economics of onion. *Ecology, Environment and Conservation.* 22(3): 1449-1451.

Sindel, B., Berney, P., Coleman, M., Marshall, G. and Reeve, I. 2013 *Improving Regional Adoption of Weed Control: A Case Study in the NSW Northern and Southern Tablelands*. Rural Industries Research and Development Corporation, Barton.

Sindel, B., Coleman, M., Kristiansen, P. and Reeve, I. 2012 *Scoping Study for Sustainable Broadleaf Weed Control in Cucurbit Crops*. Horticulture Australia Limited, Sydney.

Sinden, J., Jones, R., Hester, S., Odom, D., Kalisch, C., James, R.F. and Cacho, O. 2004 *The Economic Impact of Weeds in Australia*. CRC for Australian Weed Management, Adelaide.

Sloane Cook and King Pty Ltd. 1988 *The Economic Impact of Pasture Weeds, Pests and Diseases on the Australian Wool Industry*. Australian Wool Corporation, Melbourne.

Sullivan, A., York, A.M., White, D.D., Hall, S.J. and Yabiku, S.T. 2017. De jure versus de facto institutions: Trust, information, and collective efforts to manage the invasive mile-a-minute weed (Mikania micrantha). *International Journal of the Commons.* 11(1): 171-199.

van den Berg, F., Gilligan, C.A., Gerdessen, J.C., Gregoire, L.A.H. and van den Bosch, F. 2010. Optimal weed management in crop rotations: Incorporating economics is crucial. *Weed Research.* 50: 413-424.

Vanclay, F. 2004. Social principles for agricultural extension to assist in the promotion of natural resource management. *Australian Journal of Experimental Agriculture.* 44(3): 213-222.

Wang, G., McGiffen, M.E., Ogbuchiekwe, E.J. and Butler, L. 2009. Economic return of purple and yelow nutsedge management in vegetable production in southern California. *Crop Protection.* 28: 319-326.

Wilcut, J.W., Wehtje, G.R. and Walker, R.H. 1987. Economics of weed control in peanuts (*Arachis hypogea*) with herbicides and cultivations. *Weed Science.* 35(5): 711-715.

Wortman, S.E., Forcella, F., Lambe, D., Clay, S.A. and Humberg, D. 2018. Profitability of abrasive weeding in organic grain and vegetable crops. *Renewable Agriculture and Food Systems.* online: 1-6.

Yung, L., Chandler, J. and Haverhals, M. 2015. Effective weed management, collective action, and landownership change in western Montana. *Invasive Plant Science and Management.* 8(2): 193-202.

7 APPENDICES

Appendix 1. Summary of literature documenting evaluations of on-farm economics of weed control practices in vegetable crops

Reference	Vegetable crop/s	Geographic focus	Focal weed control practice/s	Economic focus / method	Data source/s	Economic findings	Notes
Leela, 1987	Kohl rabi, and radish	Bangalore, India	Herbicides (butachlor, fluchloralin, alachlor), compared with hand weeding	Cost comparison between herbicide and hand weeding treatments	Field experiments; market prices of outputs and inputs	Cost of weed control by herbicides is lower than by hand weeding	Details of how cost of weed control by herbicides was calculated were not provided
Liu et al., 1987	Tomatoes and peppers	Juana Díaz, Puerto Rico	Mulching and chemical weed control, alone and integrated with either hand weeding or mechanical cultivation. Mulching options were plastic and rice straw. Chemical options were metribuzin and napropamide for tomatoes, and diphenamid and napropamide for peppers, and paraquat with mulching.	Perform partial budget analyses for the production of tomatoes and peppers with the different weed control treatments.	Field experiments; market prices of outputs and inputs	For tomatoes, net return (as estimated by partial budgeting) was highest for the treatment involving plastic mulching plus hand weeding. For peppers, the highest net return was obtained with plastic mulching plus paraquat application, followed by plastic mulching plus hand weeding.	Time required for herbicide application, mechanical cultivation, installation of plastic and rice straw mulching, hand weeding and harvesting was either recorded or estimated for the different treatments. Details of how costs were calculated were not provided.
Wilcut et al., 1987	Peanuts	Headland, Alabama, USA	Comparison of weed control treatments for Texas panicum including mechanical cultivation alone and various combinations of mechanical cultivation with selected herbicide treatments	To determine which weed control treatment for Texas panicum yields the highest net return to the producer.	Field experiments. Production costs were used to prepare an enterprise budget for each treatment, using the Oklahoma State University crop budget estimator as modified for Alabama. Crop returns and other costs were based on market prices.	Neither cultivations alone or herbicides alone consistently yielded the highest net returns. Generally, herbicides plus cultivation provided more consistent net returns.	
Henderson, 1996	Lettuce and cabbage	Gatton, Queensland, Australia	Comparison of four weed management treatments: (i) short-term practices based on single-crop economic considerations, which ignore seed-set consequences for ensuing crops; (ii) practices aimed at long-term weed	For each of lettuce and cabbage, compare the costs of the four treatments.	Field experiments	Although the cost of the eradication treatment for lettuce was found to be $35/ha greater than for the short-term treatment, it was judged that this additional cost would be recouped through easier weed	Details of how treatments cost were calculated were not provided.

Reference	Vegetable crop/s	Geographic focus	Focal weed control practice/s	Economic focus / method	Data source/s	Economic findings	Notes
			suppression (e.g., more expensive herbicides, or more cultivation or hand weeding); (iii) eradication (combining herbicides, cultivation and hand weeding conducted throughout the year); and (iv) unproven future practices (including oxyfluorfen which was yet to be registered).			management in ensuing years. The cost of the future strategy for cabbage was found to be lowest, although one of its components (oxyfluorfen) had yet to be registered.	
Melander, 1998	Organic seeded onions	Europe	A system of preemergence flaming, post-emergence brush weeding and hand weeding for intra-row weeds was compared with a system of pure hand weeding for intra-row weeds. Both treatments used conventional hoeing for inter-row weeds, although the first system required fewer passes since the intra-row methods also control inter-row weeds.	Compare the economics of the two systems by comparing their costs	Field experiments; market prices of outputs and inputs	The economic benefits of the physical intra-row weed control system, compared with a pure hand weeding intra-row system, are great in situation where wages are high, the annual area of onions sown is relatively large, and the weed infestation level is high. The first system becomes uneconomical when wages and the area treated annually are low, unless weed density is very high.	
Bailey et al., 2001	Potatoes	Painter, Virginia, USA	Single versus multiple cultivations (up to 3) for weed control, with and without various combinations of pre- and post- emergent herbicides. Twelve treatments were compared in total.	Determine the effect of single and multiple cultivations, with and without herbicides, on weed control and net returns. An enterprise budget was calculated for each treatment.	Field experiments. Output price was estimated from market prices, and herbicide and cultivation costs were estimated by the authors. All other input costs were based on existing potato production budgets.	When averaged over all weed control treatments (herbicide and cultivation-only treatments), multiple cultivations significantly increased net returns.	No details provided on how herbicide and cultivation costs were estimated.
Ogbuchiekwe et al., 2001	Drip and sprinkler irrigated celery	Irvine, California, USA	Hand weeding versus herbicides	Comparison of net returns from hand weeding and herbicides in both sprinkler and drip irrigated celery. All production costs were accounted for in calculating net returns, not only those	Field experiments; market prices of outputs and inputs	The herbicides prometryn and linuron were identified as the most valuable treatments for weed control in both drip and sprinkler irrigated celery	Although the economic comparison was described as involving partial budgeting, this was not actually the case since cost impacts common to all treatments were accounted for in calculation of net returns.

Reference	Vegetable crop/s	Geographic focus	Focal weed control practice/s	Economic focus / method	Data source/s	Economic findings	Notes
				that differed between the treatments.			
Kristiansen et al., 2003	Organic lettuce and echinacea	Northern Tablelands, NSW, Australia	Five weed control treatments were compared: control (unweeded), hand weeding, tillage, hay mulch, and paper mulch.	Comparison of the adjusted crop value (ACV) of the treatments, where ACV accounts for both cost and revenue impacts of the treatments.	Field experiments; market prices of outputs and inputs	Averaged across all lettuce trials, the tillage, control and hand weeding treatments yielded the highest ACVs. Averaged across echinacea trials, hand weeding and hay mulch had the highest ACVs.	Only costs that differed between treatments were accounted for; hence the implicit method was partial budgeting.
Khokhar et al. 2006	Onion	Islamabad, Pakistan	Ten weed management treatments were compared, including a weed-free control and applications of pendimethalin or oxadiazon (either alone or in combination with hand weeding)	Determine the most economical method (i.e., with highest net income/ha) of weed control in transplanted onion	Field experiments; market prices of outputs and inputs	Pendimethalin in combination with hand weeding recorded the highest net return of all the treatments	
Engindeniz, 2007	Field-grown celery	Izmir, Turkey	Herbicides	Identify break-even yield increase from herbicide use. All production costs with herbicide options were accounted for, regardless of whether differing between options	Survey of 24 randomly selected farmers; market prices of outputs and inputs	Yield increase has to be 252 kg/ha for herbicide use to be economic	
Wang et al., 2009	Rotation of cantaloupe (spring), fallow (summer) and brocolli (winter)	Southern California, USA	Comparison of seven treatments for control of purple and yellow nutsedge: (i) weed-free control; (ii) uncontrolled nutsedge; (iii) cultivation; (iv) smother crop; (v) Halosufuron application; (vi) non-solarisation; and (vii) solarisation.	Economic performance of treatments was compared on the basis of their net return above variable costs ('net return').	Field experiments; market prices of outputs and inputs	The cultivation treatment was found to yield positive net returns for both purple and yellow nutsedge. For yellow nutsedge, the non-solarisation and solarisation treatments were also found to yield positive net returns.	The method of comparing treatment net returns was incorrectly referred to as partial budgeting analysis.
Johnson et al., 2010	Snap bean for processing	Wisconsin, USA	A range of organic and conventional weed management treatments were compared: non-treated control; stale seedbed; inter-row cultivations (1, 2 and 3 cultivations); 1 rotary hoe and	Comparison of the net profit from different weed management strategies.	Field experiments; costs obtained from extension materials, public sources, and market prices; revenue calculated from contract prices.	When the organic price premium was used in calculating net profit from organic weed management treatments, the net profit from organic treatments was consistently as high as, and	Net profit was calculated by subtracting total weed management costs from gross revenue.

Reference	Vegetable crop/s	Geographic focus	Focal weed control practice/s	Economic focus / method	Data source/s	Economic findings	Notes
			1 inter-row cultivation; stale seedbed and 2 inter-row cultivations; stale seedbed, 1 inter-row cultivation and 1 hand weeding; 2 inter-row cultivations and 1 hand weeding; conventional herbicide program; and conventional herbicide program and 1 inter-row cultivation. The last two treatments were labelled conventional, and all others as organic.			often higher than, conventional weed management strategies.	
Fennimore et al., 2010	Brocolli and lettuce	Salinas, California, USA	Machine-guided cultivator for weed control using DCPA or pronamide	Determine the herbicide band width and non-cultivated band width with the highest net returns in broccoli and lettuce using a machine-guided cultivator. Net returns were calculated by partial budgeting, which was performed using Budget Planner software.	On-farm trials; market prices for inputs and outputs	Net returns for brocolli were highest in the DCPA band widths of 7.6 and 12.7 cm. Although pronamide applied in lettuce in 7.6 and 12.7 cm wide bands improved weed control and reduced hand weeding times, net returns from lettuce were not improved.	
van den Berg et al., 2010	Organic carrot production	Fucino Plateau, Abruzzo, Italy	Comparison of innovative organic cropping system with the traditional organic system. Innovative system involved (a) false seedbed followed by pre-sowing weed removal with a spring-tine harrow; (b) sowing in 10 individual rows within 2 m wide beds; (c) one pass with flame weeder prior to crop emergence; (d) one or more passes with a precision hoe following crop emergence; and (e) hand weeding. Traditional system involved: (a) sowing within 2 m wide bands, but in 5 bands; (b) spring tine harrowing and	Economic comparison of innovative and traditional systems. Gross margins were calculated for each treatment in each year of the trial.	Field trials on two organic farms; market prices for inputs and outputs.	The innovative system was found to have a significantly higher gross margin than the traditional system in 2 years of the trial, while it was not significantly different in the other year of the trial.	

Reference	Vegetable crop/s	Geographic focus	Focal weed control practice/s	Economic focus / method	Data source/s	Economic findings	Notes
			flame weeding post crop emergence; and (c) hand weeding.				
Delate et al., 2011	Organic tomatoes	Iowa, USA	Comparison of an organic no-tillage system of weed control (and soil quality enhancement) with a tilled organic system. The no-tillage system used a roller/crimper and two cover crop combinations.	Comparison of return to management (RTM) from the treatments. RTM calculated through enterprise budgets; i.e., as enterprise gross revenue minus enterprise total (fixed and variable) costs.	Field experiments on land certified as organic; market prices of inputs and outputs	Return to management was greatest for the tilled treatment.	
Patel et al., 2011	Onion	Navsari, India	Comparison of 10 weed management treatments, including: weed-free control; sole reliance on herbicides (pendimethalin, oxyfluorfen, and/or fluazipop-p-butyl); and herbicide in combination with hand weeding.	Comparison of the net profit and benefit/cost ratio from the different treatments	Field experiments; market prices of outputs and inputs	Highest net profit was obtained from the treatment involving pendimethalin application followed by hand weeding,	The metrics of net return and benefit/cost ratio were left undefined. Treatment costs were not presented.
Cho et al., 2012	Summer squash	Florida, USA	Five organic summer treatments, including 4 cover crops (sunn hemp; velvet bean; cowpea and sorghum-sudangrass) and tillage	Conduct economic (partial budgeting) analyses of the summer treatments, including by accounting for the nutrient accumulation and weed suppression effects of treatments on costs of the ensuing cash crop	Existing literature and squash production budgets	When the costs of both the summer treatment and the ensuing cash crop were accounted for, velvet bean was the least-cost summer treatment, followed by sunn hemp, cowpea, sorghum-sudangrass, and tillage.	Benefits of cover crops were calculated in terms of contributions to the following cash crop of summer squash in the form of biologically fixed nitrogen and reduced weed pressure. These contributions were assumed to reduce the costs of cash crops rather than increase their yields.
Devkota et al., 2013	Polyethylene-mulched tomato	Fayetteville, Arizona	Comparison of herbicide programs versus fumigant (methyl bromide) for weed control	Economic evaluation of various herbicide treatments compared with standard methyl bromide application for control of Palmer amaranth, large crabgrass, and yellow nutsedge control. Net returns compared using a method similar to Bangarwa et al. (2010, see above). Net return per treatment was	Field experiments; existing tomato production budgets; market prices for inputs and outputs	Net returns from all herbicide treatments were less than than that of the methyl bromide treatment.	

Reference	Vegetable crop/s	Geographic focus	Focal weed control practice/s	Economic focus / method	Data source/s	Economic findings	Notes
				calculated by subtracting the total costs of the treatment from its gross returns.			
Marinan-Arroyuelo et al., 2014	Processing tomatoes, onions and broccoli	Larissa, Greece; Bologna, Italy	Pre-emergent herbicide (pendimethalin), other herbicides, and hand weeding, compared with an untreated control	Identify the benefit/cost ratio (BCR) when using a pre-emergence herbicide (pendimethalin) versus hand weeding and alternative herbicides.	Field experiments; market prices of outputs and inputs	Pendimethalin can in many cases be sufficiently effective as a single weed treatment to provide the highest benefit/cost ratio in weed control.	The benefit-cost ratio for each treatment was calculated by taking the difference in yield value between a treatment and the untreated control and dividing it by the respective weed control cost.
Fennimore et al., 2014	Seeded lettuce, and transplanted celery, lettuce and radicchio	Salinas, Santa Maria and San Juan valleys, California, USA	Inter-row rotating cultivator, as an alternative to a standard inter-row cultivator	Measure the cost effectiveness of the inter-row rotating cultivator for intra-row weed removal in celery and lettuce. Economic analyses were performed using the Budget Planner Software. Data collected from trials on a per hectare basis were entered into the software for analysis. Net returns were calculated by subtracting total production costs from gross returns.	Field experiments, and commercial trials with cooperating growers; market prices for inputs and outputs; machinery lubricant and repair costs based on formulas from the American Society of Agricultural Engineers.	In seeded lettuce, the inter-row rotating cultivator reduced net returns relative to the standard inter-row cultivator. In transplanted celery, lettuce and raddicchio, net returns were similar from the two types of inter-row cultivator.	Although the economic method was described as partial budgeting, it accounted for costs that were incurred equally by the different treatments
Eure et al., 2015	Cantaloupe intercropped with cotton	Ty Ty, Georgia, USA	Compare 4 cantaloupe-cotton intercropping systems and 3 monoculture systems for managing Palmer amaranth	Compare the profitability (measured as return over variable costs) of cantaloupe-cotton intercropping systems and monoculture systems for managing Palmer amaranth	Field experiments; market prices of outputs and inputs	Returns over variable costs per hectare from intercropping systems that controlled Palmer amaranth using fomesefan were at least $USD3,600 greater than the cantaloupe monoculture system.	
Fontanelli et al., 2015	Organically grown carrot, garlic and fennel	Sicily (carrot trial), Avezzano (fennel trial), and Vessalico (garlic trial), all in Italy	Comparison of innovative strategies for non-chemical weed control with traditional strategies, where strategies of each differed according to the local context. The innovations included preventative methods (stale seed beds), crop spatial arrangement to	Comparison of gross income under the innovative and traditional systems	On-farm experiments; other sources not specified	Use of the innovative weed management systems always resulted in significant increases of farmers' gross incomes	Unclear how this finding was drawn from the results presented. Gross incomes under the different systems for the three regions were not reported.

Reference	Vegetable crop/s	Geographic focus	Focal weed control practice/s	Economic focus / method	Data source/s	Economic findings	Notes
			improve machine effectiveness, and direct control measures (flaming, precision hoeing, etc.)				
Ramachandraiah et al., 2016	Onion	Rajendranagar, Hyderabad, India	The IWM treatments compared included: pre-emergence herbicides (pendimethalin, oxyfluorfen oxadiagyl) integrated with hand weeding at 30 days after transplanting (DAT), post-emergence herbicide (quizalofop ethyl) and mulching with ground shells; hand weeding at 30 and 45 DAT, 30 and 60 DAT, and one treatment of unweeded control.	Comparison of the treatments on the basis of net returns and benefit/cost ratio	Field experiments	Net returns and benefit/cost ratio were highest with the treatment using oxadiargyl and quizalofop ethyl.	Details of how net returns were calculated were not provided
Wortman et al., 2018	Organic tomatoes and bell peppers (green & red)	USA (various locations)	Comparison of abrasive weeding with hand weeding	Use partial budgeting to compare the profitability of abrasive weeding compared with hand weeding	Data from previously-reported field experiments; extension materials; market prices of inputs and outputs	Hand weeding was marginally more profitable than abrasive weeding for tomatoes and sweet green bell peppers, and more than twice as profitable for sweet red bell peppers	Partial budgets were constructed in each case relative to a scenario where neither weed control technology was adopted
Gheshm et al., 2018	High tunnel lettuce production	Kingston, Rhode Island, USA	Compost mulch	Determine how using compost as an organic mulch for weed suppression affected profitability of high tunnel lettuce production.	Field experiments; market prices of outputs and inputs	Mulched plots of lettuce yielded enough additional lettuce to cover the costs of the treatment (for mulch and labour for spreading it)	Although not referred to as such, partial budgeting was used to assess profitability
Brown et al., 2019	Organically grown yellow onion	Old Town, Maine, USA	Comparison of four weed control systems: critical period (I.e., hoeing every 14 days for 56 days after crop emergence); zero seed rain (hoeing every 14 days until harvest); polyethylene mulch; and hay mulch.	Use enterprise budgets to compare profitability (net farm income) from the different weed control systems	Field experiments; assumptions based on extension materials; market prices of input and outputs; activity labour timed with stopwatch	The zero seed rain system was most profitable, followed by the hay mulch system.	

References

Bailey, W. A., Wilson, H. P., and Hines, T. E. (2001). Influence of cultivation and herbicide programs on weed control and net returns in potato (Solanum tuberosum). *Weed Technology* 15, 654-659.

Bangarwa, S. K., Norsworthy, J. K., Rainey, R. L., and Gbur, E. E. (2010). Economic returns in plasticulture tomato production from crucifer cover crops as a methyl bromide alternative for weed management. *HortTechnology* 20, 764-771.

Brown, B., Hoshide, A. K., and Gallandt, E. R. (2019). An economic comparison of weed management systems used in small-scale organic vegetable production. *Organic Agriculture* 9, 53-63.

Cho, A. H., Hodges, A. W., and Chase, C. A. (2012). Partial budget analysis of summer fallows for organic nutrient and weed management in Florida. *HortTechnology* 22, 258-262.

Delate, K., Cwach, D., and Chase, C. A. (2011). Organic no-tillage system effects on soybean, corn and irrigated tomato production and economic performance in Iowa, USA. *Renewable Agriculture and Food Systems* 27, 49-59.

Devkota, P., Norsworthy, J. K., and Rainey, R. (2013). Efficacy and economcs of herbicide programs compared to methyl bromide for weed control in polyethylene-mulched tommato. *Weed Technology* 27, 580-589.

Engindeniz, S. (2008). Economic analysis of agrochemical use for weed control in field-grown celery: A case study for Turkey. *Crop Protection* 27, 377-384.

Eure, P. M., Culpepper, A. S., Merchant, R. M., Roberts, P. M., and Collins, G. C. (2015). Weed control, crop response, and profitability when intercropping can. *Weed Technology* 29, 217-225.

Fennimore, S. A., Smith, R. F., Tourte, L., LeStrange, M., and Rachuy, J. S. (2014). Evaluation and economics of a rotating cultivator in bok choy, celery, lettuce and radicchio. *Weed Technology* 28, 176-188.

Fennimore, S. A., Tourte, L., Rachuy, J. S., Smith, R. F., and George, C. (2010). Evaluation and economics of a machine-vision guided cultivation program in brocolli and lettuce. *Weed Technology* 24, 33-38.

Fontanelli, M., Frasconi, C., Martelloni, L., Pirchio, M., Raffaelli, M., and Peruzzi, A. (2015). Innovative strategies and machines for physical weed control in organic and integrated vegetable crops. *Chemical Engineering Transactions* 44, 211-216.

Gheshm, R., and Brown, R. N. (2018). Organic mulch effects on high tunnel lettuce in southern New England *HortTechnology* 28, 485-491.

Henderson, C. W. L. (1996). Weed management strategies in vegetable production and their agronomic, environmental and economic implications. *In* "Proceedings of the 11th Australian Weeds Conference, Melbourne, Australia, 30 September - 3 October 1996 1996 pp.78-81" (R. C. H. Shepherd, ed.), pp. 78-81, Melbourne, Australia, .

Johnson, H. J., Colqhhoun, J. B., Bussan, A. J., and Rittmeyer, R. A. (2010). Feasibility of organic weed management in sweet corn and snap bean for processing. *Weed Technology* 24, 544-550.

Khokkar, K. M., Mahmoud, T., Shakeel, M., and Chaudry, M. F. (2006). Evaluation of integrated weed management practices for onion in Pakistan. *Crop Protection* 25, 968-972.

Kristiansen, P., Sindel, B., and Jessop, R. (2003). Agronomic and economic evaluation of weed management methods in organic herb and vegetable production systems. *In* "Proceedings of the 11th Australian Agronomy Conference". Australian Society of Agronomy, Geelong.

Leela, D. (1987). Weed control by herbicides in knol khol and radish. *International Journal of Pest Management* 33, 214-219.

Liu, L. C., Antoni-Padilla, M., Goyal, M. R., and Gonzalez-Ibanez, J. (1987). Integrated weed management in transplanted tomatoes and peppers under drip irrigation. *Journal of Agriculture of the University of Puerto Rico* 71, 349-358.

Marinan-Arroyuelo, E., Marchi, A., Marchal-Rubio, F., Bozoglou, C., Servis, D., and Giannopolitis, C. N. (2014). Weed control benefit to cost ratio and labour return value in crops of southern European countries with the use of herbicide pendimethalin. *Hellenic Plant Protection Journal* 7, 61-72.

Melander, B. (1998). Economic aspects of physical inter-row weed control in seeded onions. *In* "12th International IFOAM Scientific Conference " (D. Foguelman and W. Lockeretz, eds.), pp. 180-185. IFOAM, Mar Del Plata, Argentina.

Ogbuchiekwe, E. J., and McGiffen Jr, M. E. (2001). Efficacy and economic value of weed control for drip and sprinkler irrigated celery. *HortScience* 36, 1278-1282.

Patel, T. U., Patel, C. L., Patel, D. D., Thanki, J. D., Patel, P. S., and Jat, R. A. (2011). Effect of weed and fertiliser management on weed control and productivity of onion (*Allium cepa*). *Indian Journal of Agronomy* 56, 267-272.

Ramachandraiah, B., Rao, N. H., and Madavi, M. (2016). Integrated weed management practices and their effect on yield and economics of onion. *Ecology, Environment and Conservation* 22, 1449-1451.

van den Berg, F., Gilligan, C. A., Gerdessen, J. C., Gregoire, L. A. H., and van den Bosch, F. (2010). Optimal weed management in crop rotations: Incorporating economics is crucial. *Weed Research* 50, 413-424.

Wang, G., McGiffen, M. E., Ogbuchiekwe, E. J., and Butler, L. (2009). Economic return of purple and yelow nutsedge management in vegetable production in southern California. *Crop Protection* 28, 319-326.

Wilcut, J. W., Wehtje, G. R., and Walker, R. H. (1987). Economics of weed control in peanuts (Arachis hypogea) with herbicides and cultivations. *Weed Science* 35, 711-715.

Wortman, S. E., Forcella, F., Lambe, D., Clay, S. A., and Humberg, D. (2018). Profitability of abrasive weeding in organic grain and vegetable crops. *Renewable Agriculture and Food Systems*, Online: https://doi.org/10.1017/S1742170518000479. 1-6.

Appendix 2. Machinery cost calculations

Table A2-1. Impact of weeds on machinery costs: NSW Case 1

Machinery	Current price ($)	Economic life (yrs)	Salvage value ($)	Average annual depreciation ($)	Annual opportunity cost of capital ($)	Annual repair & maintenance cost ($)	Total annual cost ($)	% of annual use in focal crop weed control	Total annual cost due to focal crop weed control ($)
Tractor - 60 hp	40,000	10	20,000	2,000	1,200	2,000	5,200	2%	104
Boomspray	12,000	10	4,000	800	320	500	1,620	20%	324
Total annual machinery cost due to focal crop weed control									*428*

Table A2-2. Impact of weeds on machinery costs: NSW Case 2

Machinery	Current price ($)	Economic life (yrs)	Salvage value ($)	Average annual depreciation ($)	Annual opportunity cost of capital ($)	Annual repair & maintenance cost ($)	Total annual cost ($)	% of annual use in focal crop weed control	Total annual cost due to focal crop weed control ($)
Tractor, 270 hp	350,000	5	100,000	50,000	9,000	8,000	67,000	13%	8,710
Boomspray, 30 m	600,000	7	180,000	60,000	15,600	8,000	83,600	25%	20,900
Mulcher	80,000	7	15,000	9,286	1,900	5,000	16,186	0%	0
Rotary hoe	80,000	7	15,000	9,286	1,900	5,000	16,186	38%	6,151
In-crop cultivator	100,000	20	5,000	4,750	2,100	2,000	8,850	25%	2,213
Total annual machinery cost due to focal crop weed control									*37,973*

Table A2-3. Impact of innovative weed control practice on machinery costs: NSW Case 2

Machinery	Current price ($)	Economic life (yrs)	Salvage value ($)	Average annual depreciation ($)	Annual opportunity cost of capital ($)	Annual repair & maintenance cost ($)	Total annual cost ($)	% of annual use in focal crop weed control *without* innovation	% of annual use in focal crop weed control *with* innovation	Total added annual cost due to innovation ($)
Tractor, 270 hp	350,000	5	100,000	50,000	9,000	8,000	67,000	10%	12%	1,340
Boomspray, 30 m	600,000	7	180,000	60,000	15,600	8,000	83,600	25%	0%	-20,900
Mulcher	80,000	7	15,000	9,286	1,900	5,000	16,186	0%	50%	8,093
Rotary hoe	80,000	7	15,000	9,286	1,900	5,000	16,186	0%	12%	1,942
Total added annual machinery cost due to adoption of innovative weed control practice										*-9,525*

Table A2-4. Impact of weeds on machinery costs: NSW Case 3

Machinery	Current price ($)	Economic life (yrs)	Salvage value ($)	Average annual depreciation ($)	Annual opportunity cost of capital ($)	Annual repair & maintenance cost ($)	Total annual cost ($)	% of annual use in focal crop weed control	Total annual cost due to focal crop weed control ($)
Tractor, 70 hp	80,000	10	20,000	6,000	2,000	1,000	9,000	2.5%	225
Boomspray, 6 m	6,789	10	1,500	529	166	500	1,195	2.5%	30
Scuffler	2,000	15	500	100	50	100	250	5.0%	13
Total annual machinery costs due to focal crop weed control									*267*

Table A2-5. Impact of weeds on machinery costs: NSW Case 4

Machinery	Current price ($)	Economic life (yrs)	Salvage value ($)	Average annual depreciation ($)	Annual opportunity cost of capital ($)	Annual repair & maintenance cost ($)	Total annual cost ($)	% of annual use in focal crop weed control	Total annual cost due to focal crop weed control ($)
Tractor, 80 hp	80,000	20	20000	3,000	2,000	5,000	10,000	12%	1,200
Mulcher	20,000	10	8000	1,200	560	400	2,160	10%	216
Rotary hoe	16,000	10	6000	1,000	440	400	1,840	10%	184
Harrow	15,000	15	5000	667	400	350	1,417	10%	142
Roller	12,000	15	5000	467	340	200	1,007	15%	151
Lawn mower	400	10	0	40	8	50	98	5%	5
Total annual machinery costs due to focal crop weed control									*1,898*

Table A2-6. Impact of weeds on machinery costs: NSW Case 5

Machinery	Current price ($)	Economic life (yrs)	Salvage value ($)	Average annual depreciation ($)	Annual opportunity cost of capital ($)	Annual repair & maintenance cost ($)	Total annual cost ($)	% of annual use in focal crop weed control	Total annual cost due to focal crop weed control ($)
Tractor, 90 hp	80,000	20	20,000	3,000	2,000	5,000	10,000	3%	300
Potato hilling plough	3,000	20	0	150	60	200	410	100%	410
Moldboard ridger	5,000	20	0	250	100	200	550	100%	550
Total annual machinery costs due to focal crop weed control									*1,260*

Table A2-7. Impact of innovative weed control practice on machinery costs: NSW Case 5

Machinery	Current price ($)	Economic life (yrs)	Salvage value ($)	Average annual depreciation ($)	Annual opportunity cost of capital ($)	Annual repair & maintenance cost ($)	Total annual cost ($)	% of annual use in focal crop weed control *without* innovation	% of annual use in focal crop weed control *with* innovation	Total added annual cost due to innovation ($)
Tractor, 90 hp	80,000	20	20,000	3,000	2,000	5,000	10,000	2%	3%	100
Potato hilling plough	3,000	20	0	150	60	200	410	100%	100%	0
Moldboard ridger	5,000	20	0	250	100	200	550	0%	100%	550
Total added annual machinery cost due to adoption of innovative weed control practice										*650*

Table A2-8. Impact of weeds on machinery costs: NSW Case 6

Machinery	Current price ($)	Economic life (yrs)	Salvage value ($)	Average annual depreciation ($)	Annual opportunity cost of capital ($)	Annual repair & maintenance cost ($)	Total annual cost ($)	% of annual use in focal crop weed control	Total annual cost due to focal crop weed control ($)
Sheet steam weeder	144,000	30	0	4,800	2,880	3,600	11,280	50%	5,640
Steaming blankets (2)	6,000	16	0	375	120	0	495	50%	248
Total annual machinery costs due to focal crop weed control									*5,888*

Table A2-9. Impact of innovative weed control practice on machinery costs: NSW Case 6

Machinery	Current price ($)	Economic life (yrs)	Salvage value ($)	Average annual depreciation ($)	Annual opportunity cost of capital ($)	Annual repair & maintenance cost ($)	Total annual cost ($)	% of annual use in focal crop weed control	Total annual cost due to focal crop weed control ($)
Sheet steam weeder	144,000	30	0	4,800	2,880	3,600	11,280	50%	5,640
Steaming blankets (2)	6,000	16	0	375	120	0	495	50%	248
Total annual machinery costs due to focal crop weed control									*5,888*

Table A2-10. Impact of weeds on machinery costs: Victorian Case 1

Machinery	Current price ($)	Economic life (yrs)	Salvage value ($)	Average annual depreciation ($)	Annual opportunity cost of capital ($)	Annual repair & maintenance cost ($)	Total annual cost ($)	% of annual use in focal crop weed control	Total annual cost due to focal crop weed control ($)
Tractor, 125 hp	110,000	4	50,000	15,000	3,200	2,500	20,700	15%	3,105
Boomspray 1	40,000	10	0	4,000	800	1,000	5,800	15%	870
Tractor, 135 hp	100,000	4	30,000	17,500	2,600	2,500	22,600	15%	3,390
Boomspray 2	30,000	10	0	3,000	600	1,000	4,600	10%	460
Total annual machinery costs due to focal crop weed control									*7,825*

Table A2-11. Impact of innovative weed control practice on machinery costs: Victorian Case 1

Machinery	Current price ($)	Economic life (yrs)	Salvage value ($)	Average annual depreciation ($)	Annual opportunity cost of capital ($)	Annual repair & maintenance cost ($)	Total annual cost ($)	% of annual use in focal crop weed control due to innovation	Total added annual cost due to innovation ($)
Tractor, 135 hp	100,000	4	30,000	17,500	2,600	2,500	22,600	3.3%	746
Boomspray 2	30,000	10	0	3,000	600	1,000	4,600	3.3%	152
Total added annual machinery cost due to adoption of innovative weed control practice									*898*

Table A2-12: Impact of weeds on machinery costs: Victorian Case 2

Machinery	Current price ($)	Economic life (yrs)	Salvage value ($)	Average annual depreciation ($)	Annual opportunity cost of capital ($)	Annual repair & maintenance cost ($)	Total annual cost ($)	% of annual use in focal crop weed control	Total annual cost due to focal crop weed control ($)
Tractor, 110 hp	130,000	10	45,000	8,500	3,500	200	12,200	80%	9,760
Tractor-driven boomspray	20,000	10	2,000	1,800	440	200	2,440	60%	1,464
Self-driven boomspray, 200 hp	400,000	10	200,000	20,000	12,000	1,000	33,000	60%	19,800
Total annual machinery costs due to focal crop weed control									*31,024*

Table A2-13. Impact of weeds on machinery costs: Victorian Case 3

Machinery	Current price ($)	Economic life (yrs)	Salvage value ($)	Average annual depreciation ($)	Annual opportunity cost of capital ($)	Annual repair & maintenance cost ($)	Total annual cost ($)	% of annual use in focal crop weed control	Total annual cost due to focal crop weed control ($)
Tractor, 80 hp	80,000	10	15,000	6,500	1,900	1,500	9,900	15%	1,485
Self-driven boomspray	450,000	10	30,000	42,000	9,600	2,000	53,600	20%	10,720
Weedfix cultivator	15,000	10	1,000	1,400	320	250	1,970	15%	296
Total annual machinery costs due to focal crop weed control									*12,501*

Table A2-14. Impact of innovative weed control practice 1 on machinery costs: Victorian Case 3

Machinery	Current price ($)	Economic life (yrs)	Salvage value ($)	Average annual depreciation ($)	Annual opportunity cost of capital ($)	Annual repair & maintenance cost ($)	Total annual cost ($)	% of annual use in focal crop weed control	Total annual cost due to focal crop weed control ($)
Self-driven boomspray	450,000	10	30,000	42,000	9,600	2,000	53,600	3.6%	1,930
Total annual machinery costs due to adoption of innovative weed control practice									*1,930*

Table A2-15. Impact of innovative weed control practice 2 on machinery costs: Victorian Case 3

Machinery	Current price ($)	Economic life (yrs)	Salvage value ($)	Average annual depreciation ($)	Annual opportunity cost of capital ($)	Annual repair & maintenance cost ($)	Total annual cost ($)	% of annual use in focal crop weed control	Total annual cost due to focal crop weed control ($)
Tractor, 80 hp	80,000	10	15,000	6,500	1,900	1,500	9,900	10%	990
Weedfix cultivator	15,000	10	1,000	1,400	320	250	1,970	15%	296
Total annual machinery costs due to adoption of innovative weed control practice									*1,286*

Table A2-16. Impact of weeds on machinery costs: Victorian Case 4

Machinery	Current price ($)	Economic life (yrs)	Salvage value ($)	Average annual depreciation ($)	Annual opportunity cost of capital ($)	Annual repair & maintenance cost ($)	Total annual cost ($)	% of annual use in focal crop weed control	Total annual cost due to focal crop weed control ($)
Boomspray unit	7,500	10	2,500	500	200	250	950	25%	238
Tractor, 110 hp	150,000	4	65,000	21,250	4,300	6,000	31,550	10%	3,155
Tractor 85 hp	90,000	10	25,000	6,500	2,300	2,000	10,800	25%	2,700
Rotary hoe	12,000	15	3,000	600	300	200	1,100	35%	385
Furrow molder	5,000	15	1,000	267	120	100	487	35%	170
Total annual machinery costs due to focal crop weed control									*6,648*

Table A2-17. Impact of weeds on machinery costs: Victorian Case 5

Machinery	Current price ($)	Economic life (yrs)	Salvage value ($)	Average annual depreciation ($)	Annual opportunity cost of capital ($)	Annual repair & maintenance cost ($)	Total annual cost ($)	% of annual use in focal crop weed control	Total annual cost due to focal crop weed control ($)
Tractor with built-in disc scarifier, 23 hp	10,000	25	0	400	200	500	1,100	23%	254
Tractor with built-in small sweep scarifier, 23 hp	10,000	25	0	400	200	500	1,100	23%	254
Tractor for flame weeder, 60 hp	15,000	12	0	1,250	300	1,500	3,050	5%	153
Flame weeder	8,000	25	0	320	160	1,000	1,480	23%	342
Total annual machinery costs due to focal crop weed control									*1,002*

Table A2-18. Impact of innovative weed control practice on machinery costs: Victorian Case 5

Machinery	Current price ($)	Economic life (yrs)	Salvage value ($)	Average annual depreciation ($)	Annual opportunity cost of capital ($)	Annual repair & maintenance cost ($)	Total annual cost ($)	% of annual use in target enterprise flame weeding	Total annual cost due to flame weeding in target enterprise ($)
Tractor for flame weeder, 60 hp	15,000	12	0	1,250	300	1,500	3,050	5%	153
Flame weeder	8,000	25	0	320	160	1,000	1,480	23%	340
Total annual machinery costs due to adoption of innovative weed control practice									*493*

Table A2-19. Impact of weeds on machinery costs: Tasmanian Case 1

Machinery	Current price ($)	Economic life (yrs)	Salvage value ($)	Average annual depreciation ($)	Annual opportunity cost of capital ($)	Annual repair & maintenance cost ($)	Total annual cost ($)	% of annual use in focal crop weed control	Total annual cost due to focal crop weed control ($)
CDA sprayer	500	15	100	27	12	20	59	70%	41
Tractor, 55 hp	20,000	30	7,000	433	540	300	1,273	25%	318
Skimmer	8,000	20	3,000	250	220	100	570	10%	57
Total annual machinery costs due to focal crop weed control									*416*

Table A2-20. Impact of innovative weed control practice on machinery costs: Tasmanian Case 1

Machinery	Current price ($)	Economic life (yrs)	Salvage value ($)	Average annual depreciation ($)	Annual opportunity cost of capital ($)	Annual repair & maintenance cost ($)	Total annual cost ($)	% of annual use in focal crop weed control *with* innovation	% of annual use in focal crop weed control *without* innovation	Total added annual cost due to innovation ($)
CDA sprayer	500	15	100	27	12	20	59	70%	0%	41
Backpack sprayer	80	15	0	5	2	10	17	0%	70%	-12
Total annual machinery costs due to adoption of innovative weed control practice										*29*

Table A2-21. Impact of weeds on machinery costs: Tasmanian Case 2

Machinery	Current price ($)	Economic life (yrs)	Salvage value ($)	Average annual depreciation ($)	Annual opportunity cost of capital ($)	Annual repair & maintenance cost ($)	Total annual cost ($)	% of annual use in focal crop weed control	Total annual cost due to focal crop weed control ($)
Tractor, 155 hp	230,000	10	45,000	18,500	5,500	5,000	29,000	10%	2,900
Strip tiller (Sly Stripcat 2)	55,000	15	10,000	3,000	1,300	3,000	7,300	95%	6,935
Tractor, 150 hp	150,000	8	25,000	15,625	3,500	5,000	24,125	1%	241
Boom spray unit	60,000	6	15,000	7,500	1,500	2,750	11,750	1%	118
Tractor, 105 hp	135,000	10	40,000	9,500	3,500	5,000	18,000	20%	3,600
Inter-row cultivator (Garford)	70,000	10	12,000	5,800	1,640	2,000	9,440	90%	8,496
Total annual machinery costs due to focal crop weed control									*22,290*

Table A2-22. Impact of innovative weed control practice on machinery costs: Tasmanian Case 2

Machinery	Current price ($)	Economic life (yrs)	Salvage value ($)	Average annual depreciation ($)	Annual opportunity cost of capital ($)	Annual repair & maintenance cost ($)	Total annual cost ($)	% of annual use in focal crop weed control *with* innovation	% of annual use in focal crop weed control *without* innovation	Total added annual cost due to innovation ($)
Tractor, 155 hp	230,000	10	45,000	18,500	5,500	5,000	29,000	10%	80%	-20,300
Strip tiller (Sly Stripcat 2)	55,000	15	10,000	3,000	1,300	3,000	7,300	95%	0%	6,935
Tractor, 150 hp	150,000	8	25,000	15,625	3,500	5,000	24,125	1%	0%	241
Disc plough	30,000	10	7,500	2,250	750	6,000	9,000	0%	60%	-5,400
Mouldboard plough	60,000	15	14,000	3,067	1,480	2,500	7,047	0%	70%	-4,933
Bed former	40,000	10	7,000	3,300	940	1,200	5,440	0%	95%	-5,168
Total annual machinery costs due to adoption of innovative weed control practice										*-28,624*

Table A2-23. Impact of weeds on machinery costs: Tasmanian Case 3

Machinery	Current price ($)	Economic life (yrs)	Salvage value ($)	Average annual depreciation ($)	Annual opportunity cost of capital ($)	Annual repair & maintenance cost ($)	Total annual cost ($)	% of annual use in focal crop weed control	Total annual cost due to focal crop weed control ($)
Tractor, 190 hp	150,000	12	30,000	10,000	3,600	4,000	17,600	5%	880
Boom spray unit	100,000	12	20,000	6,667	2,400	1,000	10,067	5%	503
Total annual machinery costs due to focal crop weed control									*1,383*

Table A2-24. Impact of weeds on machinery costs: Tasmanian Case 4

Machinery	Current price ($)	Economic life (yrs)	Salvage value ($)	Average annual depreciation ($)	Annual opportunity cost of capital ($)	Annual repair & maintenance cost ($)	Total annual cost ($)	% of annual use in focal crop weed control	Total annual cost due to focal crop weed control ($)
Tractor, 135 hp	250,000	8	85,000	20,625	6,700	8,500	35,825	5%	1,612
Tractor (boundary spraying)	10,000	20	0	500	200	200	900	20%	180
Spray unit (boundary spraying)	1,500	10	0	150	30	50	230	100%	230
Fertiliser spreader	15,000	10	0	1,500	300	400	2,200	1%	22
High-speed mulcher	20,000	10	6,000	1,400	520	500	2,420	2%	36
Disc plough	20,000	10	10,000	1,000	600	500	2,100	2%	32
Total annual machinery costs due to focal crop weed control									*2,112*

Table A2-25. Impact of innovative weed control practice on machinery costs: Tasmanian Case 4

Machinery	Current price ($)	Economic life (yrs)	Salvage value ($)	Average annual depreciation ($)	Annual opportunity cost of capital ($)	Annual repair & maintenance cost ($)	Total annual cost ($)	% of annual use in focal crop weed control *with* innovation	% of annual use in focal crop weed control *without* innovation	Total added annual cost due to innovation ($)
Tractor, 135 hp	250,000	8	85,000	20,625	6,700	8,500	35,825	4.5%	0%	1,612
Fertiliser spreader	15,000	10	0	1,500	300	400	2,200	1.0%	0%	22
High-speed mulcher	20,000	10	6,000	1,400	520	500	2,420	1.5%	0%	36
Disc plough	20,000	10	10,000	1,000	600	500	2,100	1.5%	0%	32
Total annual machinery costs due to adoption of innovative weed control practice										*1,702*

Table A2-26. Impact of weeds on machinery costs: Western Australian Case 1

Machinery	Current price ($)	Economic life (yrs)	Salvage value ($)	Average annual depreciation ($)	Annual opportunity cost of capital ($)	Annual repair & maintenance cost ($)	Total annual cost ($)	% of annual use in focal crop weed control	Total annual cost due to focal crop weed control ($)
Tractor, 70 hp	120,000	10	7,000	11,300	2,540	2,200	16,040	2.6%	417
Boomspray	15,000	20	100	745	302	360	1,407	10.0%	141
Total annual machinery costs due to focal crop weed control									*558*

Table A2-27. Impact of innovative weed control practice on machinery costs: Western Australian Case 1

Machinery	Current price ($)	Economic life (yrs)	Salvage value ($)	Average annual depreciation ($)	Annual opportunity cost of capital ($)	Annual repair & maintenance cost ($)	Total annual cost ($)	% of annual use in focal crop weed avoided by innovation	Total annual cost due to focal crop weed control avoided by innovation ($)
Tractor, 70 hp	120,000	10	7,000	11,300	2,540	2,200	16,040	2.6%	417
Boomspray	15,000	20	100	745	302	360	1,407	10.0%	141
Total annual machinery costs avoided due to adoption of innovative weed control practice									*558*

Table A2-28. Impact of weeds on machinery costs: Western Australian Case 2

Machinery	Current price ($)	Economic life (yrs)	Salvage value ($)	Average annual depreciation ($)	Annual opportunity cost of capital ($)	Annual repair & maintenance cost ($)	Total annual cost ($)	% of annual use in focal crop weed control	Total annual cost due to focal crop weed control ($)
Tractor, 100 hp	150,000	10	0	15,000	3,000	5,000	23,000	10%	2,300
Tractor, 230 hp	250,000	12	40,000	17,500	5,800	10,000	33,300	25%	8,325
Rotary hoe	90,000	10	5,000	8,500	1,900	2,000	12,400	25%	3,100
Boomspray	25,000	20	0	1,250	500	100	1,850	50%	925
Total annual machinery costs due to focal crop weed control									*14,650*

Table A2-29. Impact of weeds on machinery costs: Western Australian Case 3

Machinery	Current price ($)	Economic life (yrs)	Salvage value ($)	Average annual depreciation ($)	Annual opportunity cost of capital ($)	Annual repair & maintenance cost ($)	Total annual cost ($)	% of annual use in focal crop weed control	Total annual cost due to focal crop weed control ($)
Tractor, 100 hp	100,000	20	25,000	3,750	2,500	1,000	7,250	0	906
Inter-row rotary hoe	20,000	20	2,000	900	440	800	2,140	0	101
Finger weeder	12,000	10	1,000	1,100	260	200	1,560	0	73
Boomspray	15,000	12	1,000	1,167	320	1,000	2,487	0	77
Path (rotary) hoe	12,000	15	2,000	667	280	1,000	1,947	0	88
Total annual machinery costs due to focal crop weed control									*1,245*

Table A2-30. Impact of weeds on machinery costs: Western Australian Case 4

Machinery	Current price ($)	Economic life (yrs)	Salvage value ($)	Average annual depreciation ($)	Annual opportunity cost of capital ($)	Annual repair & maintenance cost ($)	Total annual cost ($)	% of annual use in focal crop weed control	Total annual cost due to focal crop weed control ($)
Tractor 1	140,000	10	40,000	10,000	3,600	1,000	14,600	0	584
Tractor 2	100,000	8	30,000	8,750	2,600	400	11,750	0	470
Tractor 3	85,000	8	25,000	7,500	2,200	400	10,100	0	404
Tractor 4	40,000	30	10,000	1,000	1,000	200	2,200	0	88
Boomspray	40,000	18	10,000	1,714	1,000	1,000	3,714	0	74
Total annual machinery costs due to focal crop weed control									*1,620*