An Evaluation of the Economic, Environmental and Social Impacts of NSW DPI Investments in IPM Research in Lettuce

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Economic Research Report No. 40

August 2008

NSW DEPARTMENT OF
PRIMARY INDUSTRIES

Abstract

Research into IPM technologies has been conducted by NSW DPI for over 20 years. Evaluating the returns from investment in specific research and development projects is an important component of the NSW DPI science and research program. An economic evaluation has been conducted of IPM in managing invertebrate pests in lettuce in NSW. We found that there has been widespread adoption of IPM practices amongst NSW lettuce growers leading to a flow of economic benefits to the lettuce industry and the community. Important environmental and human health benefits were also identified. A benefit-cost ratio of 2 was calculated for the return to NSW DPI investment in lettuce IPM research which while satisfactory, is lower than returns calculated for other agricultural R&D. It does not include 'spillover' benefits to other States nor have human health or environmental benefits been valued.

Keywords: research; benefit-cost; evaluation; IPM (Integrated Pest Management); lettuce

JEL code: Q160

ISSN 1442-9764

ISBN 978 0 7347 1902 7

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Citation:
Orr, L.M., McDougall, S., and Mullen, J.D (2008), *An Evaluation of the Economic, Environmental and Social Impacts of NSW DPI Investments in IPM Research in Lettuce,* Economic Research Report No 40, NSW Department of Primary Industries, Orange.

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Acronyms and Abbreviations Used in This Report

ABS	Australian Bureau of Statistics
BCR	Benefit cost ratio
BMO	Best Management Options
Bt	*Bacillus thuringiensis*
CLA	Currant lettuce aphid
DPI	Department of Primary Industries
GRDC	Grains Research and Development Corporation
GVP	Gross value of production
HAL	Horticulture Australia Limited
IPM	Integrated pest management
IRR	Internal rate of return
NPV	Net present value
NSW	New South Wales
NSW DPI	New South Wales Department of Primary Industries
R&D	Research and Development
SB/CW	Sydney basin and central western area
UC	University of California
WFT	Western flower thrips
YAI	Yanco Agricultural Institute

Acknowledgements

The authors would like to acknowledge Tony Napier (District Horticulturalist, NSW DPI, Yanco, NSW), Helen Scott-Orr (Director Health Science, Strategic Alliances and Evaluation, NSW DPI, Orange, NSW) and Dr David Hall (Research Leader Plant Health Sciences, NSW DPI, Gosford, NSW) for their valuable contributions to this report.

The authors would also like thank Dr Grant Herron (Senior Research Scientist, NSW DPI, Camden, NSW) and Robyn Hean (Economist, Farm Forestry, NSW DPI, Armidale, NSW) for their valuable comments on the final report.

Executive Summary

Evaluating the returns from investment in specific research and development (R&D) projects is an important component within New South Wales Department of Primary Industries (NSW DPI) Science and Research Division. In 2006 the NSW DPI invested an estimated $5.6m in pest management research activities related to plants. An important component has been the development and extension of Integrated Pest Management (IPM) programs. Research into IPM strategies has been carried out by NSW DPI for over 20 years. In that time, a flow of recommendations from this research for adoption by NSW primary producers have been released.

In this evaluation we have attempted to assess some of the important benefits to industry, consumers and the wider community in NSW resulting from NSW DPI research in lettuce IPM. Insect pests and diseases can cause major crop losses and create unacceptable contamination problems for the lettuce industry. The lettuce industry has largely been dependant on insecticides and other costly chemicals, which can have adverse environmental and social effects, to control these pests.

Since 1999, NSW DPI has committed significant resources to research relating to developing IPM strategies for lettuce production, with research focussed on developing recommendations for IPM practices and determining chemical efficacy. This evaluation looks at NSW DPI cash and in-kind expenditure (some of which is industry funded) on a suite of projects focussing on lettuce IPM. The research is based at the Yanco Agricultural Institute and has been primarily carried out by Dr Sandra McDougall, Research Leader, Leafy Vegetables.

Approach to the evaluation

In the analysis reported here the investments by NSW DPI in research relating to lettuce IPM from 1990 to 2006 were evaluated in an economic framework. An estimation of the increased profits from using IPM practices and new chemical controls is the basis for the analysis of economic benefits. Estimated welfare gains also depend on the level of adoption of the technology.

Two sets of results are presented in this report. The first is a comparison of industry benefits and costs of these investments by NSW DPI up to 2006; the second extends the evaluation to 2020, where the benefits from research are measured from the commencement of the initial research project to 2020 to allow for the flow of benefits into the future from research already undertaken. Projected research costs to 2020 are included to protect the stream of benefits arising from research already completed.

The on-farm benefits of the research program are measured as the difference in the economic return from the research (the 'with' research scenario) and those which would have resulted had the projects not been initiated (the 'without' research scenario).

Funding sources

Four research projects were identified for evaluation in this cluster of IPM research. Research costs up to 2006 were estimated to have a present value of $2.26million, and when research costs were projected to 2020 the total was $5.28million. Of the funds invested in lettuce research to 2007, 54% was provided by NSW DPI and 46% was from industry. The main industry funding source was Horticulture Australia Limited (HAL).

Economic, social and environmental effects

The benefit-cost ratio (BCR) of NSW DPI lettuce IPM research up to 2006 was 1.7. The net present value (NPV) of the benefits from this research up to 2006 was $1.63million. The internal rate of return (IRR) up to 2006 was 46%. When research benefits and costs were extended to 2020 the BCR was 2, the NPV was $5.4million and the IRR was 48%.

These financial criteria suggest that while still profitable, the investment in IPM research in lettuce has not delivered the same level of returns as other investments in R&D by NSW DPI. However in our judgement these results may understate actual returns by a considerable margin. We made no attempt to value reduced risks to human and environmental health and we focussed on benefits to NSW, as in other evaluations in this series, knowing that the lettuce industry in other States has benefited strongly from research in NSW. Furthermore we have adopted a conservative approach in only recognising benefits to IPM technologies developed by NSW DPI as distinct from the benefits of new chemicals more properly attributed to chemical firms

These economic benefits from lettuce IPM research flow to the lettuce industry and are shared by producers, input suppliers, processors and consumers. Social benefits have arisen from the networking and education activities supporting lettuce growers. Social support networks have been developed and fostered, growers and consultants are better informed and have greater access to technical and professional assistance. Improved prosperity of the lettuce industry from reduced levels of crop damage from pests and reductions in pest control costs has also been a positive social outcome.

Environmental benefits from lettuce IPM research are both farm specific (some of which are reflected in estimated economic benefits) and community wide in nature. Adoption of recommendations from lettuce IPM research has led to increased usage of generally more pest specific, efficacious and less toxic insecticides with lower rates of active ingredient used. This has resulted in outcomes such as potential for increased farm biodiversity and reduced off-farm environmental contamination. Most of the environmental impacts of lettuce IPM research, especially off-farm impacts, have not been valued in this analysis.

1. Introduction

Integrated Pest Management (IPM) as part of wider pest management, is an important issue for agricultural producers, consumers and government in NSW. On-farm pest management impacts on the quantity and quality of produce and on costs of production. Producers benefit from potentially reduced costs of production and reduced crop damage, whereas consumers benefit from better quality and potentially lower priced produce. There may also be reduced risks to human and environmental health.

The distinguishing features of an IPM strategy are: the use of knowledge about the biology of pests and their interaction with their natural enemies, and about cultural and chemical control strategies, along with the monitoring of pest and beneficial populations, to allow growers to make profitable pest management decisions. The term IPM, is often misused to encompass all pest management technologies. While new scientific information has enabled farmers to make more profitable pest management decisions particularly with respect to pesticides, it has also been a valuable input into the management of externalities associated with pests and the use of pesticides and into the public regulation of pest management. It is appropriate for a public institution such as NSW DPI to conduct research and extension activities to generate information of this nature, which has characteristics of a public good and is, to some degree, unique to the agricultural ecosystem of NSW.

Evaluating the returns from investment in R&D is an important activity within NSW DPI Science and Research Division. The findings from these evaluations are reported in DPI's Economics Research Report series available at http://www.dpi.nsw.gov.au/ research/areas/health-science/ economics-research#Economic-Research-Reports. Early evaluations are summarised in Mullen (2004).

NSW DPI has invested in R&D into IPM technologies for over 20 years. In 2006, NSW DPI invested an estimated $5.6million in pest management research activities related to plants. These research activities encompassed a wide variety of pests that affect NSW plant industries – including insects, diseases and weeds – and a wide range of control strategies. Research has been carried out not only at the farm level (including chemical efficacy) but also at the post-harvest level, often involving market access issues. In 2007, economic evaluations were conducted of IPM research clusters in three areas: invertebrate pests in rice, lettuce IPM and fruit fly disinfestation of citrus.

The focus of this paper is the evaluation of the lettuce IPM research cluster. The size and nature of the lettuce industry in NSW is described and the significant pest issues facing lettuce producers in NSW are outlined. We summarise the nature of IPM technologies arising from this lettuce IPM research, their rate of adoption and the economic, environmental and social impacts. The results of a benefit-cost analysis are presented for NSW DPI R&D into lettuce IPM.

There are two components to this evaluation. First, we report what is an essentially ex-post evaluation of the flow of benefits and costs from lettuce IPM research to 2006. Second, we assess the likely flow of benefits and costs to 2020 in a more speculative ex-ante component. Because of differences in climate, pest problems and management responses, our analysis has been conducted for two regions of NSW – the Hay region and a region comprising the Sydney basin (including surrounding coastal areas) and the central west referred to as the SB/CW region.

2. The NSW lettuce industry

Lettuce is a short-season crop produced under irrigation in rotation with other vegetable crops. The bulk of lettuce production in NSW is centred in three main growing regions, the Sydney Basin, the Murrumbidgee and the Central West.

Around 520 hectares (ha) of lettuce are harvested all year round in the Sydney Basin and coastal region using both field and hydroponic systems. Production declines through summer due to the warm conditions. Lettuce producers in the Sydney Basin and on the coast primarily supply fresh markets with a small percentage going to processors. Around 320 ha are sown in the Murrumbidgee region from early February through to late July for harvesting from April to the end of October, using field production systems only. Production through summer is not possible due to high temperatures. All lettuce producers in this region supply the fresh market with a small number also supplying processors. In the central west of NSW, lettuce is only produced for harvest during spring and autumn as production outside these times is difficult due to extremes of hot and cold climatic conditions. Around 180 ha of field lettuce are harvested each year in the central west.

NSW accounts for roughly 20 percent (%) of harvested area of lettuce in Australia. It is the third largest lettuce producing state with an average of around 23 kilo tonnes (kt) of lettuce produced in the past eight years from around 950 ha. Data on key parameters such as harvested area, yield, production, price and value of production are presented in Table 1.

Table 1: NSW lettuce production and prices, 1998-2006.

Year	**Area Sown**	**Yield**	**Production**	**Price**	**Value of Production**	**Real Price**	**Value of Production**
				(nominal dollars)		(year-2006 dollars)	
	(ha)	(t/ha)	(kt)	($/t)	($m)	($/t)	($m)
1998	929	23.6	21.9	744	16.3	962	21.1
1999	1,223	22.7	27.7	675	18.7	873	24.2
2000	611	19.3	11.8	851	10.1	1,064	12.6
2001	1,046	24.2	25.3	1,000	25.3	1,190	30.1
2002	1,011	26.9	27.2	978	26.6	1,138	30.9
2003	935	21.8	20.4	889	18.1	1,013	20.6
2004	787	23.0	18.1	913	16.5	1,002	18.1
2005	773	20.1	15.6	747	11.6	782	12.1
2006	1,235	33.1	40.9	914	37.4	914	37.4

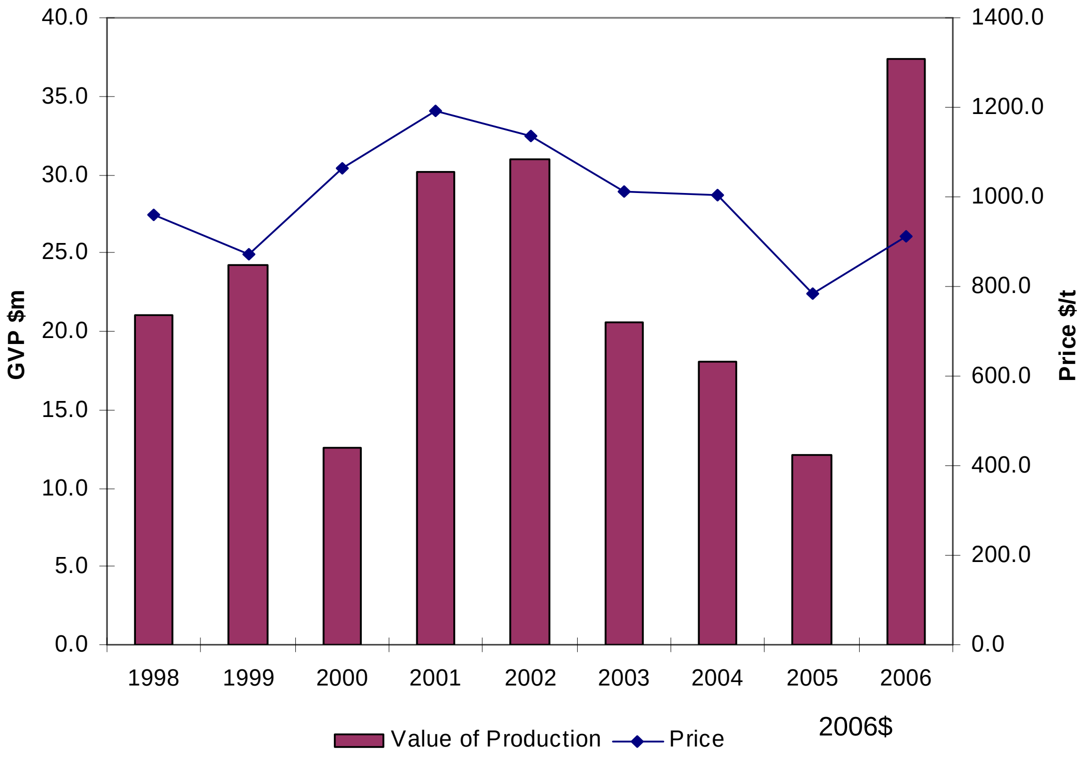
Source: ABS various catalogues

NSW lettuce production peaked at an estimated 41kt in 2006 from an area of 1235ha sown, whereas in 2000 production was less than a third of this with only 11.8kt of lettuce produced from around 600ha sown (ABS 7121.0). Area sown is not always an accurate guide to area harvested because of pest and disease damage.

Average yields in NSW are around 23.9 tonnes (t) of lettuce harvested per ha sown, equating to an average of approximately 1700 cartons of lettuce produced per ha (ABS 7121.0). However researchers and industry experts estimate that average yields are in the order of 2200 carton per ha for NSW growers using furrow irrigation. The industry estimate of average yield was used in this analysis. The difference in yields is largely accounted for by the difference between the area of lettuce sown as recorded by the ABS and the actual area harvested by growers, which is reduced by the area of crops damaged or abandoned.

Lettuce prices, in nominal terms, were around $740/t ($10 per 18kg carton) in 1998 and rose to around $1000/t ($13 per carton) in 2001/02 before falling back to around $740/t in 2005. In real (year 2006) dollars, lettuce prices rose from around $960/t ($13 per carton) in 1998 to almost $1200/t ($16 per carton) in 2001 before falling to $780/t in 2005. NSW lettuce prices were around $900/t ($12 per carton) in 2006. In real (year 2006) dollars, the lettuce industry contributed an estimated $37.4 m to the NSW economy in 2006 (ABS, 7502.0) growing from just over $20 m in 1998. The large rise from cash receipts of around $15 m between 2005 and 2006 is largely due to increased area and higher yields in the 2006 season.

Figure 1: Value of lettuce production and lettuce price, NSW, 1998-2006



2.1 Significant pests in lettuce

Information about pests in lettuce in NSW and their management can be obtained from a number of sources including McDougall and Creek (2003) and various NSW DPI PrimeFacts and industry notes. Pests and diseases reduce both the yield and quality of lettuce. Most pests of lettuce are common pests of other vegetable and field crops (PrimeFact 154, 2006). Pest insects either physically damage the plants or transmit diseases. Significant pests of lettuce have historically included pests such as Heliothis caterpillars, cutworms, thrips and a number of aphid species.

Helicoverpa (Heliothis) species are by far the most serious insect pests found attacking lettuce throughout NSW. The most problematic species being *Helicoverpa armigera* (Tobacco Budworm) which has developed resistance to the key insecticide groups used for its control. In the Hay region of NSW, *H. armigera* is most commonly a problem over the summer and autumn months while another species of Heliothis, *H. punctigera* (Native Budworm), is more commonly a problem in spring. In the Sydney Basin region crop damage from Heliothis is most severe during the spring growing season.

Insects such as thrips and aphids are the next most significant pests affecting lettuce growers in NSW. As recently as early 2006, a significant new pest emerged as a threat to lettuce production in NSW. The currant lettuce aphid (CLA) *Nasonovia ribis-nigri* was first detected in Tasmania in 2004 and is believed to have spread from New Zealand by wind. CLA is a potentially devastating pest for the lettuce industry with the aphid preferring to be sheltered within the lettuce head and hence difficult to reach with foliar insecticides. CLA contaminates the lettuce to such a degree that it cannot be sold.

In some areas, particularly for hydroponic producers in the Sydney basin, western flower thrips, *Franklinella occidentalis* (WFT), is a major problem as a vector of tomato spotted wilt virus. Other thrips can also vector this disease but WFT is highly resistant to most insecticides.

The most common diseases in lettuce are fungal, bacterial and viral. Fungal diseases affecting lettuce include downy mildew, sclerotinia, grey mould, anthracnose and septoria spot. Bacterial diseases of lettuce include leaf spot, varnish spot and soft rot. Virus' affecting lettuce include nectrotic yellows virus, big vein virus, tomato spotted wilt virus and lettuce mosaic virus. Diseases such as these can cause production losses of around 10% for affected growers (McDougall *et al.*, 2002).

3. Integrated pest management in lettuce

Decisions about pest control strategies are complex because of the mobility of pests and their ability to respond to control strategies. Many control strategies, particularly those of a chemical nature, have adverse impacts, sometimes distant in time, on non-target species and non-target sites. These non-target impacts, sometimes referred to as externalities, come in many forms. Externalities include the loss of natural enemies of target species, secondary pest outbreaks, and the emergence of resistant pest strains. Externalities also include health risks to farm labour and the consumers of farm produce, as well as risks to environmental resources such as air and water quality.

In the decades immediately following the development of synthetic pesticides, lettuce growers developed almost total reliance on these chemicals for pest control. Right from these early years there were 'spillover' impacts of consequence to human and environmental health, although not all of these were immediately recognised or thought to be significant at the time. On the farm, however, pests began to develop resistance to the chemicals used for their control requiring ever more chemical applications and the search for alternative chemicals – a pesticide 'treadmill'.

Much of the early research into IPM was conducted within the University of California (UC) system. The key elements of IPM programs seem to have been first brought together in a classic paper by Stern et al. (1959). Stern et al (1959) discussed the management of arthropod pests and recognized that pests had to be managed in ways profitable to farmers. Their paper began with a discussion of why arthropods had increased in significance as pests of agriculture. They identified the recent development of agriculture and the sometime indiscriminate use of pesticides as the main causes for the increased problems with arthropods. They spoke in terms of 'general equilibrium' populations of pests and suggested that, in general, pesticides provided only a temporary lowering of the equilibrium population, whereas biological controls held the potential of a permanent lowering. The objective of pest management was to lower the pest population below an economic threshold, but the problem was complex because the threshold was not fixed, varying with economic, biological and physical parameters. They called for the integration of biological and chemical control strategies based on greater knowledge of the ecosystem, science-based monitoring and prediction of pest populations, the augmentation of natural enemies, and the use of selective insecticides. All of these have become important components of IPM programs. A component they did not foresee was the use of gene technology, although they did talk about traditional breeding for resistance.

Initially very few pesticides were registered for use in lettuce, but the few pesticides available were highly successful at controlling the major pests and diseases. In the 1980s and 1990s Heliothis management relied heavily on synthetic pyrethroid and carbamate insecticides for control with most growers routinely using these insecticides whether caterpillar pests were present or not. As the key caterpillar pest *H. armigera* developed resistance to both these chemical groups, control became less effective. The insecticides available for Heliothis control included methomyl, endosulfan, diazinon, synthetic pyrethroids and carbaryl. Sucking insect pests were generally controlled by dimethoate and endosulfan. A typical pest management regime for lettuce growers in this era would involve the use of 'hard' insecticides such as Lannate®, Fastac®, Endosulfan and Dimethoate®. Fungicides such as Sumisclex® and Rovral® were used to control sclerotinia, and Ridomil®, mancozeb and copper oxychloride were used on downey mildew.

Prior to research into strategies for IPM, and due to the low tolerance by consumers of insect or disease damage, growers largely used pesticides in a preventative manner. All but a few growers were spraying on a routine calendar basis with some modification depending on weather conditions or casual observations in the crop. In autumn most growers sprayed for insects every 7-10 days and in spring every 7-21 days. Few growers could identify their key pests, and even fewer knew what other insects or diseases could help manage these pests (McDougall *et al*, 2002). The majority of lettuce growers in NSW applied pesticides using a conventional boom sprayer which does not provide good coverage of the chemical over the whole plant (McDougall *et al*, 2002). Most growers did not calibrate their spray equipment regularly.

Emerging pest resistance problems in the 1990s eventually required solutions including an IPM component. As a result of a strong research program in the late 1990s by NSW DPI staff supported by funds from HAL and industry, initial recommendations forming an IPM program for the control of pests and diseases in lettuce were developed by 1999. Elements of this research program included studying the life cycle of pests and diseases and their predators, the impact of pesticides and other management technologies on pests, diseases and predators and the development of monitoring tools to identify threshold pest populations. The aim was to develop IPM strategies profitable for farmers to use with fewer environmental and human health risks.

'Soft' insecticides such as Success® (spinosad) and Avatar® (indoxicarb) and the biological insecticide Gemstar® (Nuclear Polyhedrosis Virus) were registered for use in controlling Heliothis. Success® was registered for use in lettuce in spring 1999. In 2001 Avatar® and in 2002 Gemstar® were also registered for use in lettuce. In 1998 a permit for the use of a biological control, *Bacillus thuringiensis* (Bt) for Heliothis control was granted. These insecticides are thought less harmful to beneficial insects than other broad-spectrum insecticides.

The elements of an IPM program for control of pests and diseases in lettuce include adoption of cultural practices (monitoring and recording, spray management and timing and improved knowledge about pest and diseases and their life cycles), and use of 'soft' pesticides and biological controls. Research and extension conducted between 2002 and 2005 was designed to improve the understanding of IPM by growers. A field identification guide was produced and distributed as a reference for all lettuce growers. The efficacy of a further 23 products were screened and best management options (BMO) trials were conducted. Foliar, soil drench and seedling drench insecticide trials evaluated the efficacy of different chemicals on sap sucking insect pests and Lepidopteran pests. Data generated in these trials were passed onto the chemical companies to assist them in seeking registration, minor use or emergency permits.

Insecticide use in lettuce has declined significantly since recommendations regarding IPM strategies were released. Figure 3 shows the estimated amount of active ingredient required per hectare for Heliothis control in the Hay region in autumn falling by over 80% from around 2450g/ha active ingredient for a typical grower in 1998 to around 435g/ha active ingredient in 2006 for an IPM grower.

The environmental and human health impacts of the chemicals used in 2006 are likely to be reduced due to the active ingredients being more pest specific, as opposed to the broad spectrum chemicals used in 1998. Success® acts on the nervous system of the target insect; has low toxicity to predatory beetles and other beneficial insects and humans; and it is rapidly broken down in soil and water leaving no toxic residues (McDougall *et al.*, 2002). Avatar® is 'soft' on aquatic species, has low mammalian toxicity and little impact on beneficial insects or mites. Bt produces excitotoxins which are ingested by the target pest as they feed on the crop, and exhibits little or no toxicity to beneficial terrestrial invertebrates, birds, mammals or aquatic organisms. Gemstar® attacks only Heliothis caterpillars and does not affect beneficial invertebrates or vertebrates and leaves no toxic residues (McDougall *et al.*, 2002).

Figure 2: Estimated active ingredient for Heliothis control, Hay region (g/ha)

4. Lettuce IPM research in NSW DPI

Since 1998 NSW DPI has been involved with HAL in conducting research into IPM strategies for lettuce production. Vegetable growers pay a levy for research, which is largely matched on a dollar for dollar basis by the Commonwealth Government. In addition, there are significant contributions provided by other research organisations both cash and in kind, such as those contributions identified in this evaluation by NSW DPI.

In this evaluation we focus on a suite of activities at the Yanco Agricultural Institute (YAI) and the research led by Dr Sandra McDougall, Research Leader, Leafy Vegetables, referred to as the researcher in the following sections of this report. The objectives of this research have been:

- To build a knowledge base of what pests, diseases and beneficials are in the lettuce crop system.
- To understand the interactions and impacts of pests, diseases and beneficials on the lettuce crop.
- To develop and determine efficacy of more specific pesticides that are 'softer' on beneficial insects.
- To identify lettuce varieties which are resistant to pests or disease.
- To develop crop monitoring techniques and strategies which are time and cost effective.
- To develop action thresholds and information to determine when intervention is required.
- To disseminate this information to allow lettuce producers to make more profitable pest management decisions.
- To collaborate with growers to develop pest management systems that they will adopt using IPM principles.

- To train or assist as necessary, crop consultants or growers in adopting IPM strategies for lettuce.

The ex-post component of our analysis focused on two projects, VG98048 and VG01028. Information about their objectives and level of investment can be found in Tables 2 and 3.

Table 2: Summary of lettuce IPM projects evaluated

Project	Summary
VG98048 Adapting to change: enhancing change skills through collaboratively developing an integrated pest and disease management strategy for lettuce	This project conducted between July 1998 and June 2001, developed key management recommendations for implementing an IPM system for lettuce production. The project also investigated and determined efficacy for a number of insecticides and biological control agents.
VG01028 Improving lettuce insect pest management	This project conducted between March 2002 and October 2005, aimed to further develop an IPM strategy for lettuce production. The project also aimed to increase the tools available to support IPM in lettuce and increase lettuce grower awareness about IPM in lettuce production.

The total investment in these two projects from all funding sources over the period 1999 – 2006 has been $2.26m in real (year 2006) dollars. The NSW DPI share of annual funding has varied from 24% to 89%; the variation is due to funds from HAL being paid in subsequent years. On average, NSW DPI has provided 54% of the funds for lettuce IPM research and HAL has supported the research by providing 46% of the research funds. Small amounts of HAL funding have also been provided to other State government agencies through NSW DPI, for specific trial work which has also required an in-kind level of funding from those agencies.

Table 3: Project financial data, 1999-2006

Year	VG98048 Nominal $	VG01028 Nominal $	NSW DPI share of funding %	Deflator 2006=100	VG98048 Real $	VG01028 Real $
1999	202,460		53	77.4	261,705	
2000	214,093		58	80.0	267,678	
2001	234,933		55	84.0	279,670	
2002	14,052	114,063	89	86.0	16,346	132,680
2003	11,000	402,306	24	87.7	12,536	458,492
2004	28,829	173,708	57	91.1	31,641	190,650
2005		273,094	38	95.5		285,932
2006		11,696		100.0		11,696
Present value in 2006[a]						2,257,901

[a] real dollars have been compounded to present values in 2006 and totalled.

A third ongoing project VG 05044, currently funded by HAL aims to develop IPM strategies to manage CLA and other lettuce pests. This will be achieved through increasing knowledge of CLA seasonal population trends, weed hosts and important beneficial insects. Regional barriers to IPM adoption will be identified and addressed. An additional aim is to encourage crop consultants and growers to access extension resources for implementing biological IPM resulting in a reduction in use of old chemistry. There have been no quantifiable benefits from the project at this stage. Project VG05044 has been extended through funding of project VG07076 to 2010.

The ex-ante analysis conducted to 2020 includes the costs of all four projects as well as a projected level of maintenance expenditure of $260,000 each year beyond 2011 to 2020. The actual level of funding for lettuce IPM research in the future is dependant on the emergence of new pests and new pesticide resistance problems.

Research costs into the future are included to protect the stream of benefits arising from research already completed. A level of maintenance expenditure on lettuce IPM research into the future will safeguard the stream of benefits for lettuce producers.

Table 4 shows the level of funding committed for projects VG05044 and VG07076 and the estimated level of funding beyond these projects to 2020. The total investment in lettuce IPM research over the period 1999 – 2020 is estimated at $5.28m in real (year 2006) dollars. It is estimated that the NSW DPI share of funding for projects VG05044 and VG07076, and further maintenance investment to 2020, will average around 30%, with HAL providing around 70% of funds.

Table 4: Project financial data (2006-2010) and estimated maintenance expenditure (2011-2020)

Year	VG05044 (Real $)	VG07076 (Real $)	Maintenance ($)
2006	399,837		
2007	231,980		
2008	116,245		
2009		280,497	
2010		280,497	
2011-20			260,000
Present Value in 2006 [a]			5,280,408

[a] real dollars have been compounded to present values in 2006 and totalled.

A series of other projects have been funded over the past four years focussing on the WFT. WFT is a serious pest of numerous vegetable crops including hydroponic lettuce, cucumber, potato, tomato and capsicum. Projects concerning WFT have been focussed on the growing chemical resistance problem, resistance monitoring and chemical efficacy against WFT in all affected vegetable crops. This information is likely to prove of benefit to adjusting lettuce IPM strategies in the future .These potential benefits were not included in the ex-post analysis to 2006 but implicitly are part of the flow of benefits post 2006. It is likely that some of the estimated maintenance expenditure included in the analysis to 2020 will be for projects focussed on WFT and lettuce IPM strategies.

4.1 Outputs from lettuce IPM research

The key outputs of the NSW DPI research program in lettuce IPM are;

- Development of key recommendations for an IPM system for lettuce production.
- Publication of Primefact 154, ‘Lettuce IPM’.
- Publication of a ‘Pests, Diseases, Disorders and Beneficials in Lettuce: Field Identification Guide’.
- Publication of ‘Integrated Pest Management in Lettuce: Information Guide’.
- Recognition and evaluation of biological controls: ‘Gemstar®’ (NPV) 2002, ‘Vivus®’ and ‘Vivus Gold®’ and *Bacillus thuringiensis* (Bt) for Heliothis control and *trichoderma spp* for sclerotinia control.
- Recognition and evaluation of new chemistry, such as the ‘soft’ insecticides Success® (1999) and Avatar® (2001).
- Publication of a bimonthly newsletter, ‘Lettuce Leaf’.
- Conduct of national lettuce conferences and IPM workshops.
- Conduct of a lettuce IPM survey in 2006 and preparation of a report, ‘Lettuce Integrated Pest Management (IPM) Survey 2006’.
- Efficacy of 23 new products and alternative applications of old chemistry were screened against various sap suckers and/or lepidoptera.
- Conduct of best management options (BMO) trials, practice plots and pest specific trials.
- Publication of Primefact 155, ‘Current Lettuce Aphid’.
- Publication of, ‘Insect Pests of Lettuce’ and ‘Diseases of Lettuce’ posters.
- Publication of quick notes, ‘Current Lettuce Aphid’ and ‘Current Lettuce Aphid resistant varieties in Australia’.

4.2 Outcomes from lettuce IPM research

Economic outcomes
There have been two areas of benefit for lettuce producers from NSW DPI lettuce IPM research. These have been a reduction in levels of crop damage and savings in chemical application costs.

Lettuce producers in NSW have experienced a reduction in levels of crop damage resulting from adoption of effective IPM practices enabling better understanding, management and control of lettuce pests and diseases. Crop damage has also been reduced through better control of resistant *H. armigera* resulting from the development and registration of new ‘soft’ insecticides and biological controls for use against this pest.

Lower levels of crop damage have also been experienced from a reduction in the impact of CLA. The initial impact of this pest was significantly lessened due to effective and timely communication and dissemination of information to IPM growers resulting in greater adoption of CLA control methods amongst this group.

Changes to the on-farm cost of chemicals are an outcome of the lettuce IPM program. Chemical application costs have been reduced due to better crop monitoring. This results in more targeted, less frequent spray applications for those adopting IPM strategies. Whilst there are savings in a reduced number of spray applications, the newer chemical and biological controls tend to be more expensive than the old chemicals. Consequently, use of new chemicals can lead to an increase in cost for the lettuce producer.

The direct outcome of these economic benefits is a more profitable and productive lettuce industry in NSW. The resultant community effect is an increase in industry and community incomes that flow from increased productivity. There are also benefits flowing from this research to other States in Australia, including recommendations about IPM strategies and new chemical and biological controls registered for use by their lettuce producers. No attempt has been made to quantify these benefits. However, the other big lettuce producing States are Victoria and Queensland. Together they account for around 65% of total Australian lettuce production.

Environmental and social outcomes

The NSW lettuce industry operates in an environment which exerts conflicting pressures on lettuce growers. On one hand there is considerable market pressure for insect-free (pest or beneficial) cheap produce in an environment where pesticide resistance problems also threaten industry profitability. On the other hand there is pressure for the lettuce industry to use technologies with lower risk to human and environmental health. The dimensions of human health include the risks from pesticide use to farm workers and families and the risks to consumers from chemical residues. Environmental risks include threats to biodiversity and on- and off-site soil and water contamination. To these ends, the lettuce industry is moving towards the adoption of growing practices which while still being profitable, use fewer pesticides and leave the minimum possible chemical residues on lettuce.

The environmental outcomes of relevance to this evaluation are those that can be attributed to the lettuce IPM research program over and above those that would have arisen from other sources. There are a number of on-farm and broader community environmental outcomes from this research. On-farm environmental outcomes of lettuce IPM research include: reduced usage of broad-spectrum insecticides which can lead to an increase in farm biodiversity; and reduced exposure of farm owners and workers to harmful effects of broad-spectrum insecticides. On the whole, the more selective insecticides have fewer harmful effects on mammals. The newer chemistries generally require less active ingredient to be applied, hence the total quantity of insecticide applied is greatly reduced than when older chemistry is used.

Broader community environmental outcomes of lettuce IPM research include: reduced spray drift as improved crop management practices mean more targeted spray applications and allow use of beneficial insects, therefore resulting in the possibility of less frequent chemical sprays; and reduced risk of chemicals moving off-site as a result of lower chemical application. Although this risk is relatively small, the perception of lettuce production as an environmentally friendly activity is very important. There is also opportunity for increased regional biodiversity associated with replacement of broad-spectrum chemicals with more selective chemicals. We have not attempted to value these environmental outcomes.

An integral part of each of the lettuce IPM research projects has been the social, networking and education activities supporting lettuce growers in their understanding and adoption of IPM systems. Key social benefits of lettuce IPM research are the development of social support networks in the industry, greater access to information, a more educated industry with greater access to technical and professional assistance and improved communication in the industry between government, consultants and lettuce producers. This build up of social capital gives farm families and communities greater capacity to adapt to the range of economic and social change confronting them.

Social outcomes also arise from the improved prosperity of the lettuce industry as a result of the improvements to yield and reductions in cost of production associated with lettuce IPM research.

4.3 Community versus industry outcomes from lettuce IPM research and extension

There is considerable community pressure for the Australian vegetable industry to adopt growing practices with less risk to human and environmental health. An increasing number of growers are adopting IPM strategies in their crop management. However some farmers still find broad spectrum pesticides useful in some scenarios. Further, some ‘softer’ pesticides are not registered in Australia for use in lettuce. Since the Australian pesticide market is relatively small on the global scene, trans-national chemical companies seem reluctant to invest in the research that is needed to generate the data required by our pesticide regulatory body, the Australian Pesticides and Veterinary Medicines Authority (APVMA).

In Australia, data are required on the efficacy of a pesticide to control the target pest/s on each crop for which registration is being sought. Residue data are also required for the pesticide on the crop and an extensive toxicology package is needed. If the pesticide has been registered in another crop in Australia it must already have generated a toxicology package so will only require the efficacy and residue data for the pest-crop combination. At the project planning stage, when chemical companies were approached by NSW DPI researchers about new chemical registrations in lettuce, they were concerned about the potential cost of generating the efficacy data but they readily agreed to participate by supplying chemical samples for the trials when pointed out that the project (VG98048) would fund the trials and the generation of efficacy data for chemical registration.

The extent to which the benefits from the lettuce IPM research program are shared between the lettuce industry and the NSW community has implications for public support for lettuce IPM research. The economic benefits from lettuce IPM research flow to the lettuce industry and are shared by producers, input suppliers, processors and consumers. In addition it seems highly likely that the new technologies and recommendations which arise from the lettuce IPM research program have generated significant benefits for the community in terms of reduced risks to human and environmental health. Lettuce industry R&D is facilitated primarily through HAL and NSW DPI. On average, from 1999 to 2005 around half the funds for IPM research have come from industry and half have come from public sources. It is estimated that from 2006 to 2020, 30% of funds for IPM research will come from public sources and 70% from industry. In our judgement, given the likely way in which benefits are shared between the community and industry, these funding arrangements are appropriate.

4.4 Adoption of recommendations

Identifying the pathways to adoption, time to adoption and the level of adoption are critical components in determining impacts and the consequent benefits of investments in a lettuce IPM program. The pathways to adoption of recommendations have been embedded in the project planning for lettuce IPM research. The main pathway to adoption has been through a strong extension program, the second, minor pathway is through registration of new chemicals.

Adoption of lettuce IPM research recommendations is dependent on a number of factors. A range of factors, discussed in some detail in papers such as Hayman *et al* (2007) and Pannell *et al* (2006), affect the adoption of technology. However a necessary condition from a lettuce grower's perspective is that the benefits from adoption must outweigh the costs of adoption. Here we try to focus the discussion more closely on the adoption of IPM technologies in lettuce where the broad components of the program are the use of soft chemicals or biological controls and the use of a variety of IPM practices. Farmers may not adopt these components to the same extent and, hence, it is difficult to precisely classify growers as adopters or not.

The factors influencing the use of new chemicals for the control of pests include: the cost of recommended chemicals versus benefits from more effective control, costs of monitoring predators and beneficials, costs of more information intensive management, present and expected levels of resistance associated with the 'calendar spraying' technology based on a small number of broad spectrum pesticides, the level of perceived risk posed by effectiveness of 'soft' or biological insecticides and the apparent success of current management practices. For CLA control, the risk of crop losses from CLA infestation and the existence of extension services to facilitate information transfer influence adoption.

Factors influencing the adoption of IPM practices such as crop monitoring, beneficials monitoring and modification of spray equipment include: the cost of crop monitoring services, the availability of trained crop scouts and crop consultants in lettuce growing areas, the additional time required by the lettuce producer to undertake training to enable them to monitor their own crops, the time required on a regular basis to carry out crop monitoring and the cost and time involved in modifying/calibrating spray units.

Adoption profiles have been developed from the results of surveys conducted in 1998, 2005 and 2006 in the Australian lettuce industry as part of the lettuce IPM projects as well as from estimates made by the researcher. The measure for adoption used in this evaluation is the percentage of the total area sown (Table 5).

IPM management involves a basket of technologies and in survey responses some growers who adopt only a limited number of these technologies still class themselves as IPM users. Classifying growers into IPM and non-IPM users is not straightforward but our litmus test is the use of crop monitoring to determine spray type and frequency. While adoption of crop monitoring appears to be as high as 100% in the Sydney Basin/Central West (SB/CW) region, the percentage of growers who state they monitor the population of beneficials and/or who modify their spray equipment is lower.

We have estimated from the surveys and from expert opinion the percentage of growers who we classify as IPM adopters. By 2005, we estimate that over half of all lettuce growers used IPM practices. This level of adoption of IPM practices may be understated as we are assuming all growers have the same magnitude of production where the case may be that the larger lettuce producers are IPM users. Information on the scale of production was not collected from the 2006 survey and the characteristics of lettuce producers classed as IPM users cannot be determined.

Table 5: Adoption profile IPM practices

	Region	
Year	Hay %	Sydney Basin/ Central West %
1999	8	8
2000	15	16
2001	25	23
2002	30	31
2003	40	38
2004	48	45
2005-20	56	53

Use of new ‘soft’ chemistries and biological controls for Heliothis has steadily risen since their respective registrations for use in lettuce. New chemicals have become readily available at farm supply outlets and are widely promoted and have other characteristics likely to lead to high rates of adoption. New chemistries and biological controls are used by both those growers practicing IPM strategies and those who are not.

In this evaluation, we are focussing on the benefits derived from NSW DPI investment in lettuce IPM R&D. Many of the benefits from new chemicals can rightly be attribute to the companies who develop the chemicals. However, an important component of the lettuce IPM R&D program was to develop a strategy and make recommendations about the use of these new chemicals consistent with IPM principles and in a profitable manner. We have assumed that non-IPM growers would have used these new chemicals in a less efficient way than IPM growers and, hence, have recognised as a benefit from lettuce IPM R&D the efficiency gains IPM users experience over and above those enjoyed by non-IPM users. A further benefit recognised below is that non IPM growers adopt these new chemicals at a slower rate than IPM growers.

Usage rates amongst IPM growers have been estimated by the researcher and from the 2006 lettuce IPM survey for the new chemicals and biological controls and are shown in Table 6. While total adoption rates of new chemicals might approach 100 percent, here the adoption by IPM growers is limited to the estimated area of lettuce being produced using IPM practices. Hence, the benefits of using the new chemicals in an IPM consistent manner are limited to just over 50 percent from 2005.

Success® has proven to be the most popular newer generation insecticide due to its efficacy against the major insect pests, Heliothis and western flower thrips. Following the registration of Success® in 1999, usage had risen to around 50% of the IPM growers in 2002 in the SB/CW region and has since increased to around 80% of growers (Bechaz, 2006). Use of Success® by IPM growers is estimated to have risen to around 70% in 2002 in the Hay lettuce growing region and in 2006 was used by 100% of IPM growers in this region as part of their IPM strategy (Bechaz, 2006). Note that the use of Success® by non-IPM growers in 2006 was 100% in the Hay region and 67% in the SB/CW region as shown in Table 7.

Use of Avatar® by IPM growers has also steadily risen since its registration in 2001. In 2003, Avatar® was used by an estimated 20% of IPM growers in the Hay region and 30% in the SB/CW region. In 2006, Avatar® was used by 80% of these growers in the Hay region and around 40% of IPM growers in the SB/CW region (Bechaz, 2006). The use of Avatar amongst non-IPM growers in 2006 was around 70% in Hay and 20% in SB/CW (Table 7).

Use of the biological control Gemstar® by IPM growers has remained fairly static from initial levels after its registration in 2001. This reflects the unsuitability of growing conditions in most lettuce producing regions for the Nuclear Polyhydrosis Virus and the perceived risks growers associate with its use (Bechaz, 2006). Gemstar® is not used by any non-IPM growers in either growing region. The biological control Bt has proven more popular with IPM growers, particularly those classing themselves as 'organic' growers, with use amongst IPM growers rising steadily from registration in 2002 to around 40% in Hay and 50% in SB/CW. Bt was used by 20% of non-IPM growers in 2006 in the SB/CW but was not used by any non-IPM growers in the Hay region.

Table 6: IPM growers use of new Heliothis chemistries

	Success®		Avatar®		Bt		Gemstar®	
Year	**Hay** %	**SB/CW** %	**Hay** %	**SB/CW** %	**Hay** %	**SB/CW** %	**Hay** %	**SB/CW** %
2000	**50**	**40**						
2001	60	45						
2002	70	50		20			5	5
2003	80	55	20	30	10	20	5	7
2004	90	60	40	40	15	30	10	10
2005	95	70	80	40	22	40	10	10
2006	100	80	80	40	40	50	10	10

Table 7: Non-IPM growers use of new Heliothis chemistries

	Success®		Avatar®		Bt		NPV	
Year	**Hay** %	**SB/CW** %	**Hay** %	**SB/CW** %	**Hay** %	**SB/CW** %	**Hay** %	**SB/CW** %
2002	50	40						
2003	60	45						
2004	70	50		10				
2005	80	55	20	15		10		
2006	100	67	70	20	0	20	0	0

When CLA was identified as a potential threat to the NSW lettuce industry in 2005, over 90% of all IPM growers in the SB/CW region had adopted the use of the seedling drench Confidor® for CLA control (Bechaz, 2006). Utilising *Nasonovia* (Nas) sp.-resistant lettuce varieties is also a control measure which many lettuce growers have utilised against CLA with around 68% of growers in 2006 in the SB/CW region adopting this strategy (Bechaz, 2006).

5. Defining the 'with' and 'without' scenarios

In this analysis, we have attempted to value the economic outcomes of lettuce IPM research by NSW DPI, in terms of reduced crop damage and changes in pest management costs. However, no valuation has been placed on the environmental and social impacts not reflected in productivity gains. Nor have we valued benefits to growers outside NSW.

Not all the productivity gains in the NSW lettuce industry since 1999 can be attributed to the lettuce IPM research at YAI. Some productivity gains have come from better varieties, new chemicals, improved plant nutrition and irrigation techniques. We have tried to isolate those productivity gains that have arisen from the development and adoption of IPM principles, the 'with IPM research' scenario, from productivity gains that would have occurred in the industry anyway, the 'without IPM research' scenario. If environmental and social impacts were to be valued 'with' and 'without' scenarios would similarly have to be developed.

The defining difference between the 'with' and 'without' scenarios is whether growers adopt an IPM approach to the management of pests in lettuce. The difficulties of identifying an IPM grower when IPM involves a range of management practices were discussed above, but in essence we have classified IPM growers as those who monitor populations of pests and their predators and choose narrow spectrum pesticides where possible, applied in the most effective manner. Those who are not classified as IPM growers, may still experience some productivity gains from say, new chemicals but not to the same extent as IPM growers.

As explained more fully below the economic benefits from IPM research are estimated as the difference in net revenue per hectare between IPM growers and those who do not adopt IPM practices. Hence, the ex-post economic analysis requires changes in management practices for both IPM and non-IPM growers to be tracked through time and estimates of net revenue per hectare to be made. These differences in net revenue are then aggregated to give an estimate of industry benefit by applying the adoption profiles for IPM practices and new chemicals identified above.

Since 1999, two major changes in pest management technologies for lettuce have occurred. In 1999, an IPM strategy was released and between 1999 and 2002 new chemicals and biological controls were registered, which reduced the level of crop damage associated with Heliothis.

In addition, recommendations for the use of Confidor® as a preventative measure against an outbreak of CLA in lettuce growing regions in 2006 led to a reduced level of damage from this pest when it occurred in the SB/CW region in Autumn of 2006.

5.1 Cultural control recommendations

Recommendations were released in 1999 relating to the effectiveness of crop monitoring and recording, knowledge about pests and beneficials, targeting spray applications, timing and methods. Adoption of these IPM practices resulted in:

- reduced crop damage from pests and diseases from better understanding, management and control of lettuce pests and diseases, and
- reduced chemical application costs from more targeted, less frequent spray applications.

Adoption of these IPM practices are estimated to have reduced crop damage in both the Hay and SB/CW regions leading to a yield difference of 2% between IPM growers and non-IPM growers. This reduction in crop damage is valued at $328 per ha at 2006 prices.

Adoption of IPM practices also results in savings in chemical application costs and the number of chemicals used. The researcher and industry experts have estimated that in times of greatest pest pressure causing crop damage in Hay (autumn) and SB/CW (spring), adoption of IPM strategies has resulted in lettuce growers saving one Fastac® spray application (chemical cost and application cost) which equates to $24 per ha at 2006 prices. In times of lower pest pressure in Hay (spring) and SB/CW (autumn), the savings for those lettuce producers who adopt IPM strategies amount to three saved spray applications comprising the cost of four chemicals and their application costs, equating to a saving of $96 per ha at 2006 prices.

Hence, for those who adopt IPM practices whom we classify as IPM growers, the net change in revenue is in the order of $352 per ha in Hay in autumn and SB/CW region in spring and $424 per ha in the SB/CW region in autumn and Hay region in spring.

Lettuce is produced in all states of Australia. Prior to this suite of research projects commencing in 1998, no other State department of agriculture or industry body had undertaken any research into the area of IPM for lettuce. All States had issues with pests such as Heliothis and sap sucking insects to varying degrees, but they were not so significant at the time the first NSW DPI project was funded for any other State to take a lead.

Within a couple of years of research into lettuce IPM commencing in NSW, States such as Victoria and Queensland began to encounter increasing problems with *H. armigera* and its resistance to traditionally used insecticides. No doubt there would have been increasing pressure in other states for research into lettuce IPM strategies. It is perhaps unlikely that efficacy trials would have been undertaken by Victoria due to the nature of their chemical registration requirements, so Queensland would likely have undertaken this component of the research.

Whilst it is relatively easy for growers to become aware of some technologies, such as chemicals, used in other States and to acquire and use them, IPM technologies have a large knowledge-based component which farmers cannot so easily acquire by 'looking over the fence'. We have assumed that at least up to 2006, all those who are classified as IPM adopters have been influenced by the NSW DPI IPM program and that lettuce growers who have not adopted the NSW DPI program have not been able to develop IPM skills by observing practices in other States. Hence, the 'without' scenario we have assumed is that those who do not adopt IPM practices continue with pre-IPM pest control strategies and that the benefits to IPM users persist through to 2006 at least.

A summary of the impact of adoption of IPM practices by IPM growers in the two growing regions in NSW is shown in Table 8.

5.2 Registration of new insecticides and biological controls for Heliothis

Quantifiable benefits have risen through the registration of the new generation ‘soft’ insecticides Success® and Avatar® and biological insecticides using Bts and the Nuclear Polyhydrosis Virus (Gemstar®), which has resulted in a reduction in the level of crop damage from better control of resistant Heliothis. Use of these new chemical and biological controls for Heliothis by IPM growers has resulted in damage from Heliothis being reduced from 8.5% of crops damaged and 8% of crops abandoned in the Hay region in 1998 to 4% of crops damaged and 3% abandoned for IPM growers in 2006. Similar results were experienced by adopters of IPM practices in the SB/CW region with the percentage of crops damaged and abandoned falling from 7% and 5.5% respectively in 1998 to 4% and 3% respectively in 2006.

We have assumed that because non-IPM growers have ready access to these new chemicals, they also enjoy significant productivity gains. However, because they do not have the skills to apply these chemicals within an IPM strategy, they are unlikely to enjoy the same level of crop protection and/or they may apply the chemicals at inopportune times necessitating repeat treatments or at unnecessarily high rates.

It is assumed that without the NSW DPI research into lettuce IPM commencing with project VG98048 in July 1998, research would have been commenced by another State department of agriculture by 2000, with similar outcomes of registrations of new chemistries and biological controls flowing along a similar timeframe as the ‘with’ research scenario into the future. In this two year gap, lettuce producers in NSW would have continued to experience unacceptably high crop losses and crop damage from Heliothis due to the impact of increasing chemical resistance. Hence, the ‘without’ scenario has a two-year lag in adoption of the new chemicals by non-IPM users, as shown in Table 7.

Our approach to valuing these new chemistries may be highly conservative. NSW DPI conducted the trials that facilitated the registration of these chemicals for use in lettuce. Perhaps a less conservative approach would have been to attribute the full benefits of the chemistries to DPI initially and then curtail these benefits after a number of years on the grounds that if NSW DPI had not undertaken these trials, some other state eventually would have. The benefit to industry from the registration of new chemicals is very large but historically chemical companies have shown little interest in conducting the necessary trials in industries or markets which they seem to regard as being small.

5.3 CLA control recommendations

Quantifiable benefits have arisen from the release of recommendations and information from the efficacy trails conducted as part of project VG01028 for lettuce producers regarding control measures for CLA. Adoption of recommendations for the use of Confidor® as a preventative measure against an outbreak of CLA in lettuce growing regions led to a reduced level of crop damage amongst IPM growers when this pest appeared in the SB/CW region in autumn 2006.

The 'without' research scenario for CLA recommendations is centred on wider industry uptake of preventative measures for this pest. It is assumed that without the chemical trial work conducted on Confidor® as part of the second lettuce IPM project (VG01028) and the extension networks in place in NSW through lettuce IPM programs, lettuce producers in NSW would have had to rely on the transfer of information regarding CLA control measures from overseas or other States. The researcher has estimated for the 'without' research scenario that Confidor® would have been used by only 50% of IPM growers in the SB/CW region resulting in 50% of the area suffering damage from CLA and the subsequent abandonment of half the plantings in the ground at the time for each grower affected. This equates to a net revenue benefit to 40% of IPM growers in the SB/CW region reduced by the cost of controlling CLA.

Table 8 shows a summary of the impact of adoption of IPM practices, new chemistries and biological controls for Heliothis and use of Confidor® for IPM growers in NSW.

Table 8: Impact of adoption of IPM practices and use of new Heliothis and CLA controls for IPM growers in NSW

IPM growers	Cost Impact	Yield Impact	Non-IPM growers
IPM practices			
From 1999 Adoption of IPM strategies/cultural control recommendations	***Hay (autumn)*** ***SB/CW (spring)*** 1 x Fastac spray and application $24/ha cost saving ***Hay (spring)*** ***SB/CW (autumn)*** 3 x spray applications (2xFastac 1xDimethoate 1xLannate) $96/ha cost saving	Crop damage reduced for IPM adopters resulting in yield 2% higher for IPM-adopters than non IPM growers equating to $328/ha net benefit	***1999-2020*** No adoption of IPM strategies/cultural control recommendations
Heliothis control			
From 2000-2020 Use newer chemistries as they are developed (use specific chemical usage in Table 6) reducing % crop damaged and abandoned due to Heliothis in autumn (Hay) and spring (SB/CW)	Increase in chemical cost in Hay region of $110/ha in 2000 decreasing to $15/ha in 2006 Increase in chemical cost in SB/CW region of $70/ha in 2000 decreasing to $32/ha in 2006	Reduction to 4% crop damaged and 3 % crop abandoned from Heliothis damage; Hay region (autumn) benefit of $1917/ha in 2006; SB/CW region (spring) $1554/ha net benefit in 2006	***Up to 2001*** Use old chemistry 3 x Fastac 2 x Lannate experiencing high losses from Heliothis damage in autumn (Hay) and spring (SB/CW) ***From 2002-20*** Use new chemistries as they are developed with usage (Table 7) and crop damage benefit at lower levels

IPM growers	**Cost Impact**	**Yield Impact**	**Non-IPM growers**
Confidor® Use SB/CW autumn 2006			***SB/CW autumn 2006***
90% of growers use Confidor®	Increase in chemical cost of Confidor® treatment of $900/ha	10% growers suffer crop damage from CLA resulting in half plantings in ground (4 out of 8) abandoned	50% of growers use Confidor® with 50% suffering crop damage from CLA resulting half plantings in ground for each grower affected being abandoned

Table 9 shows the calculated benefit per hectare for IPM growers from reduced crop damage due to IPM practices, use of new chemistries and biological controls and use of Confidor®, and changes to chemical costs and chemical application costs using historical figures for lettuce prices and variable costs of production.

Table 9: Benefit per hectare for IPM growers 1999-2006

Year	IPM PRACTICES			HELIOTHIS CONTROL				CONFIDOR®	
		Chemicals & Application Cost Saving		Hay - autumn		SB/CW – spring		Central west/Sydney basin	
	Reduced Crop Damage ($/ha)	Autumn (SB/CW) Spring (Hay) ($/ha)	Spring (SB/CW) Autumn (Hay) ($/ha)	Reduced Crop Damage ($/ha)	Extra Chemical Cost ($/ha)	Reduced Crop Damage ($/ha)	Extra Chemical Cost ($/ha)	Reduced Crop Damage ($/ha)	Extra Chemical Cost ($/ha)
1999	190.2	88.0	25.9	0.0	0.0	0.0	0.0	n.a	n.a
2000	291.5	88.0	25.9	2,750.0	110.4	2,006.7	70.6	n.a	n.a
2001	377.2	99.9	25.9	3,750.9	122.6	2,789.1	74.7	n.a	n.a
2002	364.5	101.4	24.7	2,606.2	35.3	2,111.9	4.8	n.a	n.a
2003	313.3	101.7	22.7	2,122.4	53.5	1,719.9	23.3	n.a	n.a
2004	327.1	106.9	24.4	2,119.2	73.6	1,717.3	24.9	n.a	n.a
2005	231.6	100.0	24.2	1,307.9	69.1	1,059.9	33.5	n.a	n.a
2006	327.5	95.7	24.2	1,917.9	15.5	1,554.2	32.1	13,226	900

5.4 Benefits to 2020 from NSW DPI lettuce IPM R&D

The drawback of conducting only an ex-post evaluation of IPM R&D to 2006 is that the benefits from prior research continue well past 2006 as these benefits are in the form of long lasting productivity gains through reduced crop damage and chemical costs.

While these productivity gains from reduced crop damage are long lasting, the nature of IPM is such that there is an ongoing process of adaptation by pests to control measures. Hence, an IPM program needs ongoing maintenance R&D to preserve efficiency gains.

We have extended our analysis of the benefits and costs from DPI IPM R&D to 2020, in part to be consistent with the series of evaluations of investments in agricultural R&D being undertaken by research economists in NSW DPI.

We have assumed that the flow of annual expenditure associated with projects VG05044 and VG07076 of about $260,000 will continue to 2020. This level of maintenance R&D will likely be used to respond to new pest incursions, the development of new chemicals and/or the ongoing development of resistance within pest populations. We have assumed that the level of benefits from this maintenance research will be of a similar order to the recent flow of benefits of about $644,000 per year.

The benefit areas for lettuce IPM research to 2006 and then to 2020 are shown in Table 10.

Table 10: Benefit areas for IPM research

	IPM Practices and Heliothis Control			CLA Control	
	Hay		SB/CW	Additional area lost to CLA	Additional area treated with Confidor
Year	Autumn (ha)	Spring (ha)	Autumn & spring (ha)	Autumn (ha)	Autumn (ha)
1999	8.5	17.4	34.6	n.a	n.a
2000	8.5	17.3	34.6	n.a	n.a
2001	24.1	49.5	86.9	n.a	n.a
2002	28.0	57.4	110.7	n.a	n.a
2003	34.5	70.8	127.1	n.a	n.a
2004	35.0	71.7	127.8	n.a	n.a
2005	39.7	81.3	145.9	n.a	n.a
2006	64.6	132.4	237.7	23.8	47.5
2007 to 2020	55.6	111.1	205.3	n.a	n.a

6. Benefit-cost analysis

The economic surplus framework for modeling research-induced innovations as shifts in supply curves is well established (e.g., Alston *et al.* 1995). In that approach, *k*, the reduction in the marginal cost of supplying a product such as lettuce is estimated, applied as an exogenous shift in farm supply, and changes in consumer and producer surplus at the new market equilibrium are estimated.

This economic surplus modeling approach is more difficult to apply when there are several supply shifts (as a result of new technologies) over time and when adoption of the technologies also occurs over time. Here, we have used the incremental profit approach (GRDC, 1992) to estimate the change in profit per hectare as new technologies come on stream and as adoption rates change. This approach is equivalent to assuming that the demand curve is perfectly elastic and the supply curve is perfectly inelastic. Hence, it underestimates the total gain in economic surplus, although the error is generally not large. Despite the implications of these assumptions about demand and supply, the estimated change in profit or economic surplus should be interpreted as an estimate of gains to be shared by the industry – producers, processors and consumers – not just producers.

Benefit-cost analysis has been used to compare the value of benefits arising from the research with the costs of the research and development. The investment criteria used are the net present value (NPV) of the research, and the benefit-cost ratio (BCR). The NPV is the difference between the discounted benefits and the discounted costs of the research. The BCR is the ratio of the net present value of benefits to the present value of costs of the research. For the investment in research to be economically desirable, the NPV should be positive and the BCR should be greater than one.

6.1 Benefit-cost results to 2006

We used data from historical NSW DPI gross margin budgets, BMO information from lettuce IPM project final reports for the Hay region and the SB/CW region, and the views of researchers and industry experts to estimate the change in net revenue (profit) from the introduction of the new technologies for the IPM adopters (the 'with' R&D scenario) and those who do not adopt the technologies or, in the case of new chemicals, adopt them to a limited degree (the 'without' R&D scenario). ABS data on production levels and data on the adoption of technologies were then applied to the per hectare changes in net revenue to derive an estimate of the annual change in net profit for the industry for the period 1999 to 2006.

The regional Hay and SB/CW net benefits from research were aggregated to give an annual benefit for NSW as a whole. The aggregated benefits from lettuce IPM research for the Hay region and the SB/CW region and total benefit for NSW for the ex-post analysis from 1999-2006 are shown in Table 11.

Table 11: Benefits of lettuce IPM research by region, 1999-2006

Year	IPM Practices		Heliothis Control		CLA Control	Total Benefit
	Hay	SB/CW	Hay	SB/CW	SB/CW	NSW
	($'000)	*($'000)*	*($'000)*	*($'000)*	*($'000)*	*($'000)*
1999	6.7	17.1	0.0	0.0	0.0	23.7
2000	9.4	24.1	22.3	67.2	0.0	123.0
2001	33.3	76.6	87.6	236.5	0.0	434.0
2002	37.7	94.8	72.0	233.9	0.0	438.3
2003	41.0	95.6	71.4	216.2	0.0	424.3
2004	43.4	100.5	71.5	216.8	0.0	432.2
2005	37.0	85.8	49.1	150.2	0.0	322.1
2006	78.7	184.4	122.9	362.7	271.6	1,020.3

Nominal revenue flows from 1999 to 2006 were adjusted to real dollars using the GDP deflator with base=100 at 2006. Benefits and costs from 1998 until 2006 were compounded forward to 2006 at a real discount rate of 4% to convert benefit flows to a present value in 2006. The results of the analysis of the benefits and costs of NSW DPI lettuce IPM research to 2006 are shown in Table 12.

Table 12: Benefits and costs of lettuce IPM research for NSW

	Real		Discounted	
Year	Benefits *($'000)*	Costs *($'000)*	Benefits *($'000)*	Costs *($'000)*
1999	31	262	40	344
2000	154	268	195	339
2001	517	280	629	340
2002	510	133	596	155
2003	484	471	544	530
2004	474	222	513	240
2005	337	286	351	297
2006	1,020	12	1,020	12

The flows of costs and benefits from 1999 to 2006 are used to calculate investment criteria, presented in Table 13. The present value of the cost of research is $2.26 million and the present value of the benefits of research is $3.89 million. The NPV is $1.63 million; the BCR is 1.7; and the IRR is 46%.

Table 13: Results of benefit-cost analysis

Investment Criteria	Units	Value
Present Value of Costs	$’000	2,258
Present Value of Benefits	$’000	3,888
Net Present Value (NPV)	$’000	1,630
Benefit-Cost Ratio (BCR)		1.72
Internal Rate of Return (IRR)	%	46

These results indicate that the funds invested by NSW DPI and HAL in the joint research projects in lettuce IPM between 1999 and 2006 has returned $1.72 to the lettuce industry in NSW for every dollar invested in the research.

6.2 Benefit-cost results to 2020

In the analysis of costs and benefits of lettuce IPM research to 2020 industry projections are used from 2007 to 2020 for the ‘with’ research baseline.

For this evaluation, the costs and benefits flow from 1999 to 2020. The aggregated benefits for the Hay region and the SB/CW region for the period 2007 to 2020 are shown in Table 14.

Table 14: Benefits of lettuce IPM research, 2007-2020

Year	IPM Practices		Heliothis Control	
	Hay *($'000)*	SB/CW *($'000)*	Hay *($'000)*	SB/CW *($'000)*
2007-2020	66.6	159.0	105.7	312.4

The results of the analysis of the benefits and costs of NSW DPI lettuce IPM research to 2020 are shown in Table 15. It shows that research benefits peak in 2006 as a result of the contribution of lettuce IPM research to CLA control.

Table 15: Benefits and costs of lettuce IPM research for NSW

	Real		Discounted	
Year	Benefits *($'000)*	Costs *($'000)*	Benefits *($'000)*	Costs *($'000)*
1999	31	262	40	344
2000	154	268	195	339
2001	517	280	629	340
2002	510	133	596	155
2003	484	471	544	530
2004	474	222	513	240
2005	337	286	351	297
2006	1,020	412	1020	412
2007	644	232	619	223
2008	644	116	595	107
2009	644	280	572	249
2010	644	280	550	240
2011	644	260	529	214
2012	644	260	509	205
2013	644	260	489	198
2014	644	260	470	190
2015	644	260	452	183
2016	644	260	435	176
2017	644	260	418	169
2018	644	260	402	162
2019	644	260	387	156
2020	644	260	372	150

The flows of benefits and costs from 1999 to 2020 are used to calculate investment criteria, presented in Table 16. The present value of the cost of research is $5.28 million and the present value of the benefits of research is $10.7 million. The NPV is $5.4 million, the BCR is 2.02 and the IRR is 48%.

Table 16: Results of benefit-cost analysis

Investment Criteria	Units	Value
Present Value of Costs	$'000	5,280
Present Value of Benefits	$'000	10,688
Net Present Value (NPV)	$'000	5,408
Benefit-Cost Ratio (BCR)		2.02
Internal Rate of Return (IRR)	%	48

These results indicate that the funds invested by NSW DPI and HAL in the joint research projects in lettuce IPM between 1999 and 2020 has returned around $2 to the lettuce industry in NSW for every dollar invested in the research.

7. Conclusions

Since 1998, NSW DPI has been involved with Horticulture Australia Limited (HAL) in conducting research into IPM strategies for lettuce production. In that time, it has released a flow of recommendations and facilitated the registration of new chemicals and biological controls for lettuce growers in NSW. Adoption of these recommendations and use of the new chemistries and biological controls has led to a reduction in the level of crop damage experienced for lettuce growers, and changes to the on-farm cost of pest and disease control.

There have been two components to this analysis. An ex-post component focussed on estimating the actual flow of benefits and costs to 2006. The benefit-cost ratio found in the analysis was 1.7, with an internal rate of return of 46%. The net present value of the total resources invested in the research since 1999 was estimated at $1.6million. An economic benefit that we have not attempted to value is the knowledge gained about chemical efficacies from the research program that has 'spilled over' to other vegetable growing situations and to other States, enabling registration of new chemicals for use in lettuce in those States. A further economic benefit exists in the uptake of recommendations for IPM practices amongst lettuce growers in other States and the resulting productivity gains experienced by these growers.

The second component of the analysis was more ex-ante in nature speculating about the flow of benefits to 2020 arising from both investment in R&D to 2006 and a level of maintenance R&D through to 2020. In this analysis, the level of investment in the lettuce IPM program has been extended to include estimated investment in a further two lettuce IPM projects from 2006 to 2010. Beyond 2010, maintenance expenditure of $260,000 per year to 2020 is included. Benefits beyond 2006 are calculated by extending the current flow of benefits arising from adoption of IPM practices and the use of new Heliothis controls in 2006 through to 2020.

The benefit-cost ratio found in the ex-ante analysis was 2.0, with an internal rate of return of 48%. The net present value of the total resources invested in the research since 1999 was estimated at $5.4million. This ratio shows that although the benefits outweigh the costs of the research they do not do so to the same extent as that seen in other evaluations conducted by NSW DPI of areas of agricultural research where BCR has ranged from 4.5:1 to 22.2:1 (see Mullen, 2004). Note that Mullen et al (2003) were unable to identify any quantifiable benefits from UC lettuce IPM research due to the difficult nature of applying IPM practices to lettuce production.

We focussed on quantifying the industry benefits in NSW from a program in R&D investment funded jointly by NSW DPI and HAL. In addition to these industry-level economic benefits, there have been a flow of other benefits in the form of reduced risks to human and environmental health, which we have not quantified but which justify continued support from the public sector to ensure a level of investment closer to community expectations.

On-farm environmental and human health outcomes of lettuce IPM research include: reduced usage of broad-spectrum insecticides which can lead to an increase in farm biodiversity and reduced exposure of farm owners and workers to harmful effects of broad-spectrum insecticides. On the whole, the more selective insecticides have fewer harmful effects on mammals. The newer chemistries generally require less active ingredient to be applied, hence, the total quantity of insecticide used is greatly reduced when newer rather than older chemistry is used. Environmental human health outcomes which spill over to the community include: reduced spray drift from fewer spray applications and reduced risk of chemicals moving off-site as a result of lower chemical application. There is also opportunity for increased regional biodiversity associated with replacement of broad-spectrum chemicals with more selective chemicals.

In the period 1999-2005, about half of the funding has come from HAL; for the period 2006-2020, it is expected that around 70% of funding will come from industry. These funding arrangements seem appropriate given the way in which industry and the community share the flow of benefits from this program of research.

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