ANNUAL COSTS OF
WEEDS IN AUSTRALIA

ROSS MCLEOD, NOVEMBER 2018

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Executive Summary

Bottom line summary: Annual Costs of Weeds in Australia

Weeds are estimated to impose an overall average cost of nearly $5 billion across Australia. Chemical control across broad acre cropping enterprises and production loss costs among grain, beef and wool industries make up most of these impacts. Overall costs have increased by more than 20% over the 14 years since the Sinden et al (2004) study. The prevalence of weeds in the livestock industry was assumed to be the same, largely because no evidence has been accumulated in the last 14 years to gauge the degree of impacts weed cause of livestock carrying capacity and production losses. This information gap is important as weed competition in these animal industries contributes a quarter to overall national weed costs.

Weed control and production losses due to residual weeds in Australia are included in Table 1 for low, average and high weed impact scenarios. An average production loss cost of $4,823 million is estimated for winter and summer broad acre cropping, rice, cotton, horticulture and livestock industries, using the 'economic surplus' approach. As in previous studies, the difference between the loss-expenditure and economic surplus approaches to costing is small. Costs to agricultural industries comprise the majority of total costs, as public expenditures are less than $200m of the overall mean cost of $4,989 million in 2018. Table 1 includes details for low, average and high cost scenarios.

Table 1: Estimated annual costs of weeds in Australia, 2018 ($'million)

	Low	Average	High
Agriculture			
Loss-expenditure estimate	3,733.2	4,813.7	5,780.6
Economic surplus estimate	4,335.6	4,823.3	5,844.7
Expenditure/other non-agricultural			
Public	29.1	29.1	29.1
Private	132.3	132.3	132.3
Indigenous	4.5	4.5	4.5
Total*	**4,501.5**	**4,989.2**	**6,010.6**

nq: not quantified. * uses surplus estimate

Background

The cost of weeds has been estimated across a range of agricultural industries in Australia. Sinden et al (2004) included control and production loss estimates for winter crops (wheat, oats, barley, canola), legumes, summer crops, cotton, rice, horticulture and livestock industries (dairy, wool, sheep-meat and beef) using production and price data averaged over the five-year period from 1997–98 to 2001–02. A 'top-down' approach was employed where weed impacts for all species were aggregated into overall yield loss and control cost estimates. An overall annual cost of between $3,4442 to $4,420 million was calculated for agricultural industries, with an average cost of $3,927 million per year. Most costs were associated with livestock industries with $2,409 million being estimated for this sector, compared to $1,518 million for cropping.

An economic surplus approach was employed by the authors in which costs were attributed to farmers through lost income, and to consumers as a result of higher prices. Additionally, $112 million per year of taxpayer expenditure was allocated to weed control expenditures on public lands, indigenous lands and for research. The same approach was most recently used to estimate weed costs in NSW. Gordon (2014) estimated annual costs to be from

$1,671 million to $1,903 million per year. Like Sinden et al (2004), the overall cost included a relatively minor cost for non-agricultural industries – comprising $65 million in weed control expenditure by public agencies.

Prices for agricultural products have changed since the last major report on the national impact of weeds was released in 2004, as has the estimated coverage of weed control measures and associated residual production losses. Notably, the recent study by Llewellyn and colleagues in 2016 provides a comprehensive national analysis of the cost of weeds to Australian grain growers. It included the cost of yield losses due to in-crop and fallow weeds, along with control costs associated with herbicide and non-herbicide practices. The study involved interviews with 600 randomly selected grain growers (wheat, barley, oats, canola, pulses and grain sorghum) over two million hectares of cropping land from 13 major agro-ecological zones (AEZs) across the Western, Southern and Northern grain-growing regions. The annual financial cost of weeds was estimated to be $3,300 million across Australia.

Annual agricultural weed control and production loss costs are updated for 2018. Price and production data are sourced from ABARES for five year proceeding 2018 for base cost calculations. Many crop production loss and control assumptions are derived from Llewellyn et al (2016), while cotton, rice, and horticulture production loss assumptions are taken from Sinden et al (2004).

A large component of weed cost impacts in the NSW Grain-grower study by Gordon (2014) and national estimate of Sinden et al (2004) was associated with production losses in livestock industries. There is limited evidence on which to base production loss assumptions. Reductions in livestock output are taken from the previous two studies, however, applied to current average national flock and herd productivity. Given the high uncertainty associated with key assumptions, high, average and low impact scenarios are provided for guidance as to the likely range of weed cost impacts.

Government expenditures on weed control were not collected as part of this costing study. The estimates from Sinden et al (2004) were indexed to 2018 using consumer prices indexation. Correspondingly, there is a high degree of uncertainty around these estimates, however, they only comprise less than 5% of overall national weed costs. Overall national weed impact costs do not include estimates of non-market values associated with losses of biodiversity or environmental degradation as a result or weed infestation.

Method

Previous studies of the lost value due to weeds have used the loss-expenditure approach to measuring economic impact or the economic surplus approach. The loss-expenditure approach involves estimation of the yield losses using constant price for decrease agricultural output as a result of weeds, along with financial costs of control by land holders and the public sector. The aggregate cost impact of weeds is calculated by adding together production losses and expenditures on management at the farm and government levels.

Production loss valuation is the most difficult element of quantifying impact due to the vast range of agro-climates and industries across which weed competition is observed. Calculation involves estimation of the distribution and abundance of weeds, the degree to which the productivity in differing agricultural enterprises is hindered by weeds and the value of any declines in output or product quality. Output can be valued using fixed prices (as in the loss-expenditure approach), or assumptions can be made using economic modelling to capture any changes in prices following weeds impacting supply or demand conditions of a market. This latter approach is referred to as the 'economic surplus' method and was adopted by Sinden et al (2004) and Gordon (2014).

Gordon et al (2014) noted the valuation of weed impacts in NSW were in the same order of magnitude using both approaches, although the costs estimated using the economic surplus approach were marginally larger which was anticipated given that it incorporates price effects, that the loss-expenditure approach does not. Llewellyn et al (2016) noted “that as grain prices are largely determined by world export markets, the financial costs of weeds were virtually equivalent to the economic cost (loss in surplus) [in previous weed economic studies by Jones et al 2005]” (ibid, p. 11).

Residual weed-related production losses are valued using both fixed price (loss-expenditure) and economic surplus methods, along with farmer expenditure on control measures being calculated. Farm level control methods include herbicides, costs of herbicides application, cultivation and integrated weed management practices. Annual losses and weed control costs are estimated for winter crops (wheat, oats, barley, canola), legumes, summer crops, cotton, rice, horticulture and livestock industries (dairy, wool, sheep-meat and beef) using production and price data averaged over the five-year period to 2018. Weed control expenditures by state and commonwealth government were taken from Sinden et al (2004). These values were indexed to 2018 using the consumer price index. Farm and government expenditures and agricultural production losses are added together to estimate the national costs of weeds.

Agricultural control and product loss costs

Annual agricultural control and production loss costs are estimated at $4,823.3 million in this update using the economic surplus approach, which are more than 20% higher than those estimated by Sinden et al (2004). The increase in annual costs is largely driven by increases in crop weed control measures. The adoption of practices such as minimum tillage and other conservation practices have led to increases in herbicide usage, so chemical costs are far higher than those in the Sinden et al 2004 costing.

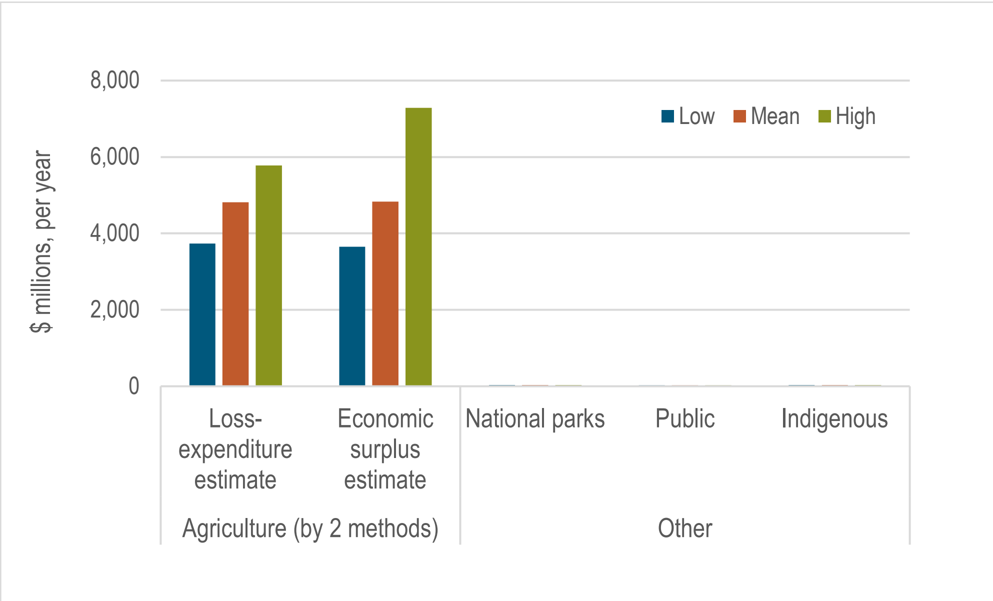

Figure 1: Annual costs of weeds in Australia, 2018

Source: This study

Broad acre (cereal cropping and livestock) farm expenditures on weed control were derived from ABARES Agsurf data chemical cost data and the Llewellyn et al (2016) survey of grain producers. The Llewellyn et al (2016) survey found some $2,573 million was spent on weed control on cereal farms, which is a large increase over the high control estimate of $720 million for the grain sector in Sinden et al (2004).

Residual production loss estimates vary across industries according to the degree of weed control. For wheat and other grain industries, control of weeds is widespread, with crop production loss accounting for less than 30% of total costs. Losses account for more 70% of overall costs in beef and sheep-beef livestock industries, as control is limited. Losses associated with weed competition in the beef industry contributed more than a quarter of overall national losses in the Sinden and Gordon studies. These studies assumed reductions in livestock production of 5% as a result of weed infestations.

A similar percentage reduction is assumed in this study to be attributable to weeds, however, a lower effective base carrying capacity is used to estimate losses (rather than NSW inland weaners) as this is more representative of the 'average' national production system. Beef-related weed costs are around 10% of total costs with the adoption of this approach.

In total, all industries are calculated to suffer control costs and losses of $4,814 million using the loss-expenditure approach. An average economic cost of $4,823 million is estimated using the economic surplus methodology. There is a high degree of uncertainty around these estimates. Variations in weed distribution, supply elasticity, yield loss and control cost assumptions have a substantial impact on production loss estimates which are summarised in Figure 1.

Public Expenditure on Weed Management

Government weed spending in 2002 was sourced by Sinden et al (2004) from state and commonwealth departments involved in weed control, surveys, research, maintenance of road and rail infrastructure, state forests, and reserves such as stock routes. Commonwealth authorities that conducted weed research were also surveyed. Weed control expenditure data in national parks was also collated, along with indigenous lands weed control costing information from the Central Land Council (CLC), Indigenous Land Corporation (ILC), Key Centre for Tropical Wildlife, National Native Title Tribunal, Northern Land Council (NLC) and relevant NT Departments. Sinden et al (2004) expenditures are used for the 2018 study, but indexed to 2018 using inflation. These estimates are included in the public expenditure section. They total $166 million in 2018 which is 3% of overall national weed costs.

List of Acronyms

ABARES	Australian Bureau of Agricultural and Resource Economics and Sciences
ABS	Australian Bureau of Statistics
CLC	Central Land Council
CRC	Cooperative Research Centre
CRDC	Cotton Research Development Corporation
CSIRO	Commonwealth Scientific Industrial Research Organisation
DPI	Department of Primary Industries and Fisheries
GRDC	Grains Research and Development Corporation
ILC	Indigenous Land Corporation
MLA	Meat and Livestock Australia
NHT	Natural Heritage Trust
NLC	Northern Land Council
PWC	Parks and Wildlife Commission of NT now in DIPE
QDPI	Queensland Department of Primary Industry
QDNRM	Queensland Department of Natural Resources and Mines
SRDC	Sugar Research and Development Corporation
WONS	Weeds of National Significance

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1 Introduction

Weeds impact on agricultural production, the environment, along with public and private infrastructure. Chemical, labour and mechanical control measures are implemented to mitigate these impacts. The overall cost of weeds is the sum of these control measure and the residual production losses associated with weeds that inflict yield, environmental and product quality damage. The spread of weeds across Australia, nature of impacts, economic studies quantifying these cost impacts and objectives of this report are outlined in this section

1.1 The weed problem

The areas infested by weeds across agricultural operating areas varies, along with the perceived impact of weeds and specific species. Llewellyn et al (2016) interviewed 600 randomly selected grain growers across 13 major agro-ecological zones (AEZs) in the Western, Southern and Northern grain-growing regions on Australia. They asked growers to provide information on density and area for their two main weeds for each crop category in the cropping season and fallow. The costliest weeds from a loss standpoint were ryegrass, wild radish and wild oats. Barnyard grass, feather-top Rhodes grass, fleabane and sweet summer grass were found to be most costly in sorghum.

There are few studies outlining the impact of weeds on livestock industries. MLA commissioned Grice et al (2014) to determine key species for grazing systems research. Grice et al (2014, p. 13) concluded there has not been a comprehensive national analysis of trends in abundance and distribution of weeds in Australia though several states maintain databases of weed occurrence. There is limited national data about the prevalence and impact of weeds on rice, cotton and horticultural producers which impedes accurate estimates of national weed cost impacts.

All agricultural industries are assumed to be affected be weeds in this costing study. This assumption was included in the Sinden et al (2004) and Gordon (2014) weed cost estimates. Given the paucity of weed impact data, losses and control costs are specified for all weeds in this costing study, which represents a 'top down' approach to calculating weed losses, rather than a 'bottom-up' perspective where weeds costs are estimated for individual species - then costs aggregated. Weed production losses for sugar, rice, fruit, vegetables, dairy cattle, beef cattle, grain-livestock, sheep-beef and sheep industries are taken from Sinden et al (2004).

In the case of grain industries, the overall production loss of 6% (in season residual and fallow) from Llewellyn et al (2016) was included to estimate losses for Wheat, Oats, Barley, Canola, Lupins, Field Peas, Chickpeas, Sorghum, Maize, Triticale, Sunflowers and Soybeans. The production loss derived from the Llewellyn et al (2016) survey was for the two main weeds for each crop category nominated by farmers in a survey. Weeds that may be widely present as the third or fourth most important weed were not 'costed' and production losses are potentially undervalued. A higher weed impact sensitivity analysis is included in this costing study, where weed-related production losses in broad acre grain crops are estimated to be 7.5%.

1.2 A range of economic impacts

The key production losses from weed infestations within livestock industries are that of decreasing carrying capacity. Some weeds downgrade product quality, such as burrs in wool, poisoning of livestock, or impede agricultural infrastructure. Sinden et al (2004) and Gordon (2014) focus on production losses and associated control costs, which is again followed in this study.

Since the Sinden et al (2004) study, the sizes of the national flock and cropping areas have stabilised, however, the beef herd and beef prices have increased – leading to a large increase in the gross value of production. ABARES (2018) livestock and cropping data averaged for the five years to 2018 are included for this 2018 update analysis on which weed yield losses are calculated. Horticulture, rice and cotton industry data are taken from 2017 using ABS value of agricultural commodities produced and agricultural area statistics. (See Appendix).

The impact of weeds on biodiversity has been described, although there is limited data on which to quantify this impact. Correspondingly, biodiversity impacts are not included in base cost estimates. Control costs on agricultural and public lands are taken from ABARES and Llewellyn et al (2016), along with 2004 public expenditures outlined in Sinden et al (2004) inflated to 2018. The range of impacts commonly quantified in previous economic impact studies are outlined in the brief review section.

1.3 A brief review of economic estimates

A number of economic studies have been undertaken to quantify the overall impact of weeds, or particular species. Grice et al (2014) undertook a systematic review[1] of studies using ISI Web of Science and the World Wide Web in September 2013, Proceedings of Australian Weeds Conferences, PhD and MSc theses completed since 2003, Final reports of MLA projects since 2003, and Weed CRC publications to identify studies that have considered the annual economic impact of weeds. They found 200 studies. Most examined the costs and losses that result from the presence and spread of a particular weed species.

Only five studies met the review inclusion criteria of being published during or after 2003, not a review article, having a major focus on Australian livestock industries and conducted at either the national or State level. They included the studies by the Department of Environment and Heritage 2003, Sinden et al. 2004, Page and Lacey 2006, and the AEC Group 2007. These studies are outlined in Table 2, along with other selected studies relevant to this cost assessment.

Table 2: Selected weed cost studies in Australia

Study	Notes	Cost
Combellack (1987)	The study by Combellack (1987) quantified the nationwide impact of weeds. The authors included weed control and losses in agriculture, management in national parks, railways, forestry establishment, aquatic areas and industrial buildings	The costs of weeds in 1981–82 were estimated to be $2,096 million.
Jones et al (2000)	The authors quantified the prevalence and impact of weeds in Australian winter crop production. They did not include costs for fallow weed management or a broad range of integrated weed management practices, that were covered by Llewellyn et al (2016).	A 1998 financial cost of weeds in winter crops of $1.2 billion was estimated. Llewellyn et al (2016) noted that the Jones study found the financial costs of weeds to be equivalent to the economic welfare (loss in surplus) as Australian grain producers are price takers on world markets.
Department of Environment and Heritage (2003)	This brief provides background about the species Serrated tussock being a Weed of National Significance. Its invasiveness, potential for spread, and infestations being associated with significant loss in livestock production are highlighted.	The cost in New South Wales of $40 million in lost production was outlined. No details about how the cost estimates were arrived at are provided, but presumably from NSW Agriculture studies.
Sinden et al (2004). The economic impact of weeds in Australia	The study includes direct financial costs of control (herbicide, etc), losses in production, changes in net money revenue, and changes in welfare – using the economic surplus approach. Production and price data cover the five-year period ending in 2001–02. In addition to production losses, public expenditure was estimated. A	Economic loss to Australian agriculture ranging from $3,4442m to $4,420m, with a mean loss of $3,927 million using the economic surplus method. With the addition of public control expenditures,

[1] Search terms combined several groups of key words — weed, Australia, pasture OR grazing, economic OR cost OR $, and cattle OR beef OR sheep OR goat

Study	Notes	Cost
	total of $112m per year of taxpayer expenditure was estimated to be directed at weed control. The cost included $81m for public expenditure, $20 for national parks, $3m for indigenous and $8m for research.	total costs varied from $3,554m to $4,532m.
Walker et al (2005)	The study focussed on dryland cotton cropping systems. It used a survey of 48 growers in Queensland and New South Wales, along with paddock monitoring. The economic impact of weeds was estimated using information collected in the survey and field observations.	Farm costs of weeds varied from $148 to $224/ha year. An annual economic cost of $19.6 million was estimated for dryland cotton producers. Farmers estimated weed-related yield losses were 4–9%
Page and Lacey (2006)	This study estimated the economic return from investment in biological control. It was undertaken by the Cooperative Research Centre for Australian Weed Management (Weeds CRC).	An overall benefit cost ratio (BCR) of 23.1 was estimated for biocontrol programs. This suggests every $1 of R&D will/has generated $23 in industry benefits from reduced weed pressure. An economic benefit of $95.3 million was calculated for the biocontrol investment.
AEC Group (2007)	The Economic Impact of Lantana on the Australian Grazing Industry study estimated 2.2 million hectares were infested with lantana and climatic modelling indicated the weed could spread across 34.5 million hectares. A literature review and survey was conducted to estimate costs.	The average cost per infested hectare was estimated to be $42.78/ha per year. In total the weed was estimated to cost $104 million per year in management and productivity costs in 2005/06. Queensland was estimated to account for $71 million of total costs.
AEC Group (2007)	AEC group estimated local government spending on weeds and pests in Queensland for the Department of Natural Resources and Mines	Local/Regional and State Government in Queensland were estimated to spend $46 million in 2005/06.
Ireson (2007).	The Tasmanian weed cost estimation study was supported by the Weed CRC. It included production losses and the cost of herbicides, but not labour.	The cost of weeds to Tasmania, included $48.9 million in production losses and $8.8 million in financial losses, or a total cost of $58 million per year.
Gordon (2014). The Economic cost of Weeds in NSW	The study estimated weed costs in NSW in 2014. The loss-expenditure and economic surplus approach were used. Weed costs were estimated to be similar for both approaches, with the economic surplus approach having a slightly bigger cost impact. Producers in the agriculture sector were calculated to bear 73% of weed costs in NSW, consumers 23% and 4% being public expenditures	The total annual cost of weeds in NSW was estimated to range from $1,671 million to $1,903 million per annum, with an average of $1,800 million. Public expenditures were estimated to be $64.59 million per year.
Llewellyn et al (2016). Impact of Weeds on Australian Grain Production	The study commissioned by The Grains R&D Corporation estimated weed costs in broad acre crops. It includes the cost of residual yield losses in season due to weeds, losses from fallow weeds (losses of moisture and nutrients translated into yield losses using a damage function) and grain contamination costs. Herbicide and application costs, along with integrated weed management costs were estimated. A survey of 600 wheat, barley, oats, canola, pulses and grain sorghum. farmers in 13 agro-ecological zones was used to derive control and production loss parameters.	Weeds were estimated to cost Australian grain growers $3,318 million, or $146/ha in expenditure and losses. Control costs were $113/ha.

Studies either use a ‘top down’ approach where an overall loss is attributed to weed competition, or a ‘bottom-up’ focus – where yield losses are estimated to individual species. The ‘top down’ focus is typically employed to quantify the collective presence of weeds across broad geographical areas. Nationally, it was first used by Combellack (1987), then by Jones et al (2000) and Sinden et al. (2005). State level ‘top down’ assessments were conducted in Tasmania by Ireson (2007) and Gordon (2014) for NSW.

Combellack (1987) estimated the national cost of weeds to be $2,096 million. The cost included farmer control costs, losses of production in agriculture, and control costs in national parks, railways, forestry establishment, aquatic areas and industrial buildings. The costs were estimated using the loss-expenditure approach. This method assumes commodity prices are not impacted by the presence, or not, of weeds. Production losses are calculated by multiplying a yield loss by a constant price. Jones et al (2000, 2005) estimated the overall cost weeds in Australia's winter cropping industry. Farmers were surveyed to calculate management expenditure and yield losses due to residual weeds. A loss-expenditure analysis and economic surplus approach were used in the study. A cost of $1,333 million per annum through lost economic surplus was calculated which was similar to the loss-expenditure estimate.

Sinden et al (2004) expanded the Jones et al (2000) analysis to include livestock industries. Both a loss-expenditure analysis and economic surplus cost analysis were undertaken. The surplus analysis resulted in economic costs to agriculture of between $3,554 million to $4,532 million, with an average of $3,927 million. Control costs on indigenous lands, in national parks and natural environments and on other public lands were also included. The overall mean national weed cost was estimated at $4,039 million.

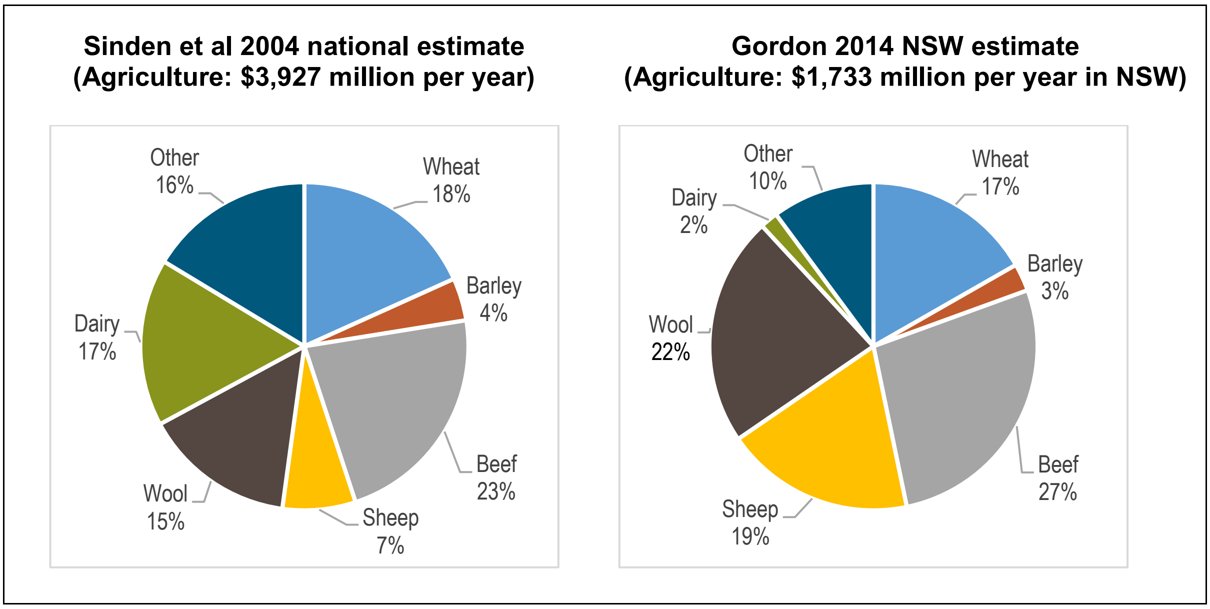

Figure 2: **Proportion of weed economic losses attributed to each industry in Sinden and NSW Gordon (2014) studies**

Source: Sinden et al 2004, Gordon 2014.

Since Sinden et al (2004), two state-level estimates have been undertaken using the top-down focus. Ireson et al (2007) estimated production losses and the cost of herbicides - but not associated labour - as the basis for an estimated annual cost of $58 million (2007) in Tasmania. In NSW, Gordon (2014) estimated annual costs to be from $1,671 million to $1,903 million per year. Like Sinden et al (2004), the overall cost included a relatively minor cost for non-agricultural industries – comprising $65 million in weed control expenditure by public agencies.

The contributions of livestock and grain industries to total weed agricultural sector costs for the Sinden and Gordon studies are presented in Figure 2. It is evident that livestock industries contribute the major share of costs to overall agricultural costs. In the case of Sinden - dairy, wool, sheep-meat and beef contributed 62% of total costs. Unlike the grain sector, most costs are associated with residual production losses as there are limited weed control measures employed by graziers across broad acre systems. The reduction in carrying capacity was assumed to be 5% across these industries. This assumption was derived from the study undertaken by Sloane et al (1988). Livestock industries also dominate the overall weed impact cost for agriculture in NSW calculated by Gordon (2014). They contributed 70% to overall agricultural costs, with beef and wool contributing half of the costs.

Large overall costs for weeds have been estimated in other countries. For example, Gordon (2014, p. 12) noted the "costs and production losses from plant invasions in agriculture in New Zealand were estimated to be $100 million in 2002 (Williams and Timmins, 2002), while more recently, the cost of pastoral weeds alone has been estimated to cost the New Zealand economy $NZ1,200 million per annum (Bourdôt, 2012). The total annual cost of weeds in the United States was estimated to approach $US15 to $US20 billion dollars (Ashton and Monaco, 1991) while a more recent, though still dated, study estimated the costs to be $US34.5 billion on the basis of direct costs and production losses from agriculture and some limited environmental losses".

There have been many estimates of the control costs and production losses for specific weeds. Most recently, Llewellyn et al (2016) estimated the impact of weeds on grain production, which included the cost of yield losses due to in-crop and fallow weeds and grain contamination costs as well as weed control. The analysis was based on the results of interviews with 600 grain growers. Weeds were estimated to cost $146/ha in expenditure and losses. Average expenditure on weed control, including herbicide and non-herbicide practices, was $113/ha. Weed costs were specified by species. The costliest weeds nationally were ryegrass, wild radish and wild oats.

The costs of serrated tussock infestation of the NSW tablelands were calculated by Vere and Campbell (1979). They estimated it would cost $24.4 million to eliminate the weed by improved pasture. Productions losses as a result of reduced wool income, was $11.8m. Paterson's curse across Australia was estimated cost $250 million (Lloyd, 2005) to sheep and cattle producers as a result of reduced carrying capacity, control costs, and wool contamination.

The loss-expenditure approach has been used for most of these studies. This involves estimating the expenditure on weed management and the residual losses from weeds. Most studies focus on agricultural losses. Sinden et al (2004) included control expenditures on public lands or on weeds which threaten environmental resources, however, Gordon (2014) noted no studies have incorporated losses in environmental values in a comprehensive way. This is due to a paucity of data surrounding biodiversity and other environmental cost impacts. Given this information gap, only agricultural production losses are quantified in this study. Control cost are specified for land holders and public authorities.

1.4 Economic concepts to measure the impacts

Estimating weed cost impacts is undertaken using the loss-expenditure and economic surplus approaches in this 2018 weed cost update. The loss-expenditure approach firstly involves estimating the per hectare cost of weed control by chemical and non-chemical measures, then aggregating costs to the national level using areas operated by cropping and livestock industries. Sinden et al (2004) estimated national costs by multiplying an average weed control expenditure per farm by the number of grazing and cropping farms.

ABARES Agsurf crop and pasture chemical cost data was used for broad acre crops and livestock industries. Proportions of overall chemical costs per average hectare farmed attributable to weed control were taken from Sinden et al (2014) and applied to Agsurf average costs for the 5-years till 2017. Agsurf data is derived from Australia-wide farmer surveys and relative standard errors provide an indication of how population values align with survey estimates[2]. For crop and pasture chemicals these are around 4%, therefore, cost estimates are subject to a degree of uncertainty. High and low control cost assumptions are included in

[2] http://www.agriculture.gov.au/abares/research-topics/surveys/farm-definitions-methods#calculating--confidence-intervals-using-relative-standard-errors

the 2018 costing update to gauge the sensitivity of control and production loss costs for each included agricultural industry.

The recent survey by Llewellyn et al (2016) found Australian grain growers are expending considerable resources on weed management ($2,573 million), particularly on herbicides. This differs to the costs calculated by Sinden et al (2004), where control was found to be around $720 million per year for the higher range estimate. The adoption of lower tillage intensity systems, greater herbicide inputs and inclusion of fallow weed control costs in the Llewellyn et al (2016) study underpin this result. The inclusion of 2013-2017 Agsurf data results in grain and grain-livestock control costs of $2,252 which are similar to those found by Llewellyn et al (2016). Gross margins by NSW DPI and others were used to estimate weed control expenditures for cotton, rice, vegetables and fruit. These industries accounted for around 11% of national weed costs.

The public sector directs resources to weed research and management at the Commonwealth and state levels. Commonwealth spending includes research centres, while state governments also provide resources to control weeds through national parks, relevant state agencies to maintain infrastructure and public lands. Indigenous agencies provide resources for weed control across indigenous lands. Public agencies were not contacted as part of this study to generate updated public expenditure data. Commonwealth and other state weed expenditure estimates are taken from Sinden et al (2004) and indexed up to 2018 using CPI inflation indices. Correspondingly, there is a high degree of uncertainty about the magnitude of current public expenditures. This cost represents less than 5% of the total cost of weeds (when agricultural control and production losses are considered).

Losses in production are valued using enterprise gross margins and prices for relevant commodities. Gross margins for wool, sheep-meet, cattle and broad acre production cropping were obtained from the New South Wales Department of Primary Industries[3], Queensland DPI and South Australian primary industries. Assumptions are provided in tables which accompany the impact assessment for the loss-expenditure analysis and in the Annex (See Table 22). These are estimated and aggregated across the relevant jurisdictions by the number of hectares operated by each industry in five years to 2017.

Losses can be valued using a fixed price loss-expenditure or economic surplus approaches. As noted, the loss-expenditure approach, involves quantifying the loss in production using constant pricing. Weeds or pests may have an impact on the price paid for commodities where weed prevalence is sufficiently high to reduce production and increase price. Sinden et al (2004) attempted to capture these price impacts using an economic surplus approach. The approach is summarised in in Table 3 below.

Table 3: Economic surplus approach

The economic surplus attempts to capture the impacts on producers and consumers, from increased commodity prices due to production being reduced from what it otherwise would be due to the impact of a weed. The impact of prices to changes in supply is captured using mathematical estimation of price elasticities. Consumer and producer impacts are calculated using 'surpluses' which reflect modelled changes in prices and quantities following reductions in supply as a result of a weed.

The overall economic surplus, is estimated by adding producer's surplus and consumer surplus. As noted by Sinden et al (2004, p 7). "The former is the profit to the producer, which is money revenue minus variable money costs. The latter is the net benefit to the consumer, which is the difference between the amount that the consumer is willing to pay

[3] http://www.dpi.nsw.gov.au

and the amount the consumer has to pay. Background information about the calculation method is outlined in Alston et al (1995)."

Jones et al (2005) estimated the impact of weeds on grain industries. As Australia is generally a 'price taker' on world markets increased Australian production as a result of no weeds was found to have non-significant impact on the price received for grain. Consequently, the difference between the fixed price loss-expenditure estimate of weed cost and that estimated using the economic surplus approach was small.

The outputs of some Australian livestock industries, such as wool, has been found to impact world prices. Increased productivity from the elimination of weeds could decrease world prices and consumers from overseas would benefit from the cost reduction.

This leakage has been modelled as part of R&D impact studies, however, both Gordon (2014) and Sinden et al (2004) use closed market models which capture costs to consumers whether they are in Australia or overseas. The same approach is used again, however, parameters developed by Australian Wool Innovation about the capture of costs and benefits between Australia and overseas are included in a sensitivity analysis.

The economic surplus approach and loss-expenditure approach are used to estimate production losses for grain, wool, horticulture, rice, cotton, sheep meat and beef markets in this costing study. Both methods were used to determine whether any differences in economic impact estimates exist using the two methods under current market conditions.

1.5 Objectives and plan of the report

In providing its investment of $20 million in the Centre for Invasive Species Solutions, the Federal Minister for Agriculture and Water Resources requested the Centre to develop a 10-year Investment Plan for Weed Research, Development and Extension that aims to improve weed management in Australia. While the planning process already includes a cursory summation of the economic dimensions of weeds using largely outdated references, there remains a need to complement this with deeper economic costing information of weeds to Australia

The broad goal of this report is to estimate the current economic impact of weeds across Australia. This includes estimating the financial costs of control and lost production in agriculture, the loss of economic surplus for producers and consumers of Australian agricultural products, and financial costs of control to government agencies. Specific objectives of the analysis include:

- Draw on the loss-expenditure and economic surplus weed costing approach adopted by Sinden et al (2004) to estimate weed-related production loss cost estimates;
- Calculate the costs of weed for winter crops (wheat, oats, barley, canola), legumes, summer crops, cotton, rice, horticulture and livestock industries (dairy, wool, sheep-meat and beef)- including descriptions of confidence in estimates; and
- Undertake cost sensitivity analysis to highlight robustness of results to key assumptions

These impacts are explored in a series of chapters following the structure outlined by Sinden et al (2004). Notes about the assumptions used are included in the summary of the report and a cost impact tables included in the Appendix.

2 Agricultural costs: Loss-expenditure approach

The impact of weeds on agricultural lands has been estimated firstly using the loss-expenditure approach. This involves estimating the direct cost of weed control, that is the cost of herbicide, application and non-chemical control. The value of lost production is referred to as the opportunity cost of weed infestations. Expenditure and loss costs are estimated on a per hectare basis for each industry, then aggregated to the national level using ABARES estimates of farm numbers and operating areas.

2.1 Numbers of farms and operational areas

Around 370 million hectares are used for agricultural production in Australia. The beef industry accounted for 70% of this area, largely the extensive operations in Queensland, NT and Western Australia. Specialist grain production (broad acre crops in chart) operates across 28 million hectares, although about half this area is cropped per year. Cropping areas within specialist cropping and mixed livestock operations averaged 21 million hectares over the last five years.

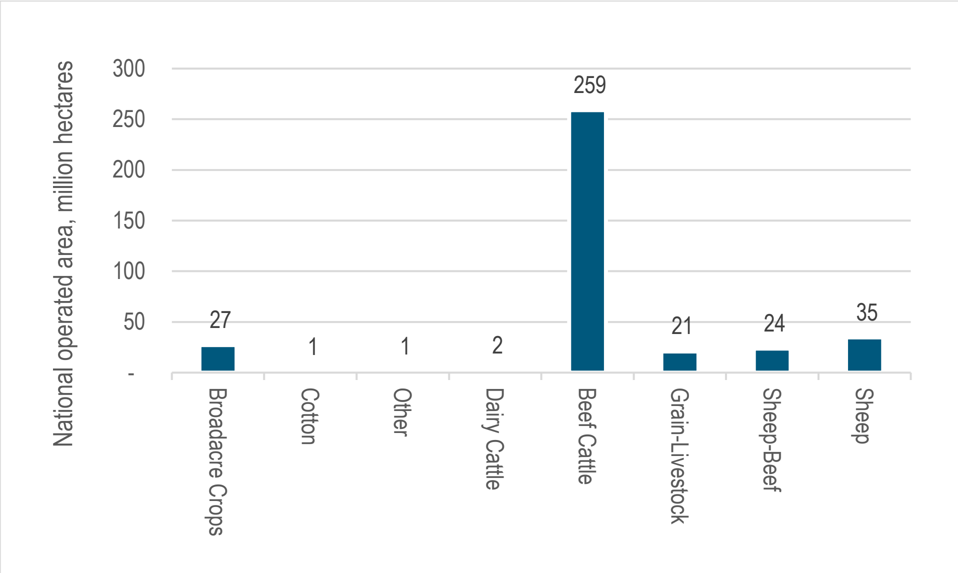

Figure 3: Australian agricultural land areas, average 2013-2017

Source: ABARES, Agsurf. https://apps.daff.gov.au/AGSURF/. Accessed August 2018.

ABARES and ABS farm numbers are provided in Table 4. It is evident that there are around 77 thousand farms across Australia. Two thirds of the farms are broad acre cropping and grazing (beef, sheep, wool) operations. Average farm size is highest for beef operations and smallest for fruit and vegetable production. The average operational area for beef was 13,592 hectares and less than 50 hectares for horticulture.

Table 4: Average number of Australian farms and operational areas, 2013-17

Industry	Number of farms	Assumed Proportion of industry impacted by weeds (%)	Area operated per farm (ha)	Area cropped per farm (ha)	Area cropped per industry (ha)	Area operated per industry (ha)
Wheat / other [a]	9,420	100%	2,897	1,605	15,119,742	27,292,783
Cotton [b]	1,009	100%	514	514	518,626	518,626
Sugar [c]	3,626	100%	125	115	416,990	453,250
Rice [d]	674	100%	123	123	82,902	82,902
Fruit [e]	8,850	100%	35	35	309,750	309,750
Vegetables [e]	3,737	100%	32	32	119,584	119,584
Dairy Cattle [a]	6,806	100%	309	125	852,061	2,102,930
Beef Cattle [a]	19,054	100%	13,592	40	758,365	258,987,405
Grain-Livestock [a]	10,884	100%	1,930	579	6,304,244	21,009,069
Sheep-Beef [a]	5,240	100%	4,508	67	348,971	23,621,018
Sheep [a]	7,917	100%	4,381	110	873,993	34,682,625
Total	**77,217**				**25,705,228**	**369,179,942**

Notes:
(a). Average 2013-2017, http://apps.daff.gov.au/agsurf/agsurf.asp, Accessed August 2018.
(b) Number of cotton businesses, and area (irrigated and non-irrigated) from ABS 2017, Agricultural Commodities, Australia- 2016-17, for the year 2016/17.
(c) Number of sugar cane businesses, total national area, and area for cane crushing from ABS 2017, Agricultural Commodities, Australia- 2016-17, for the year 2016/17
(d) Number of rice businesses, and area from ABS 2017, Agricultural Commodities, Australia- 2016-17, for the year 2016/17
(e, f) Number of fruit and vegetable businesses, and area from ABS 2017, Agricultural Commodities, Australia- 2016-17, for the year 2016/17

Since 2004, the number of farms in broad acre production has decreased for most industries. This trend in Figure 4 is notable for cropping and mixed livestock production. For example, the number of specialist grains producers has nearly halved since 1997 when the Sinden study was undertaken. In 1997 there were 14 thousand specialist cropping enterprises, while in 2017 there were around 8,773. Farm consolidation has been accompanied with the adoption of new tillage systems. Most growers surveyed in Llewellyn et al (2016) "believe[d] that weed costs will be higher under a no-till system that retains stubble compared to one based on cultivation, with only 17 per cent believing costs will be less. Overall, growers also believe that average crop disease and pest costs will increase under no-till stubble retention. The number of beef producers has remained relatively stable" (ibid, p. 59).

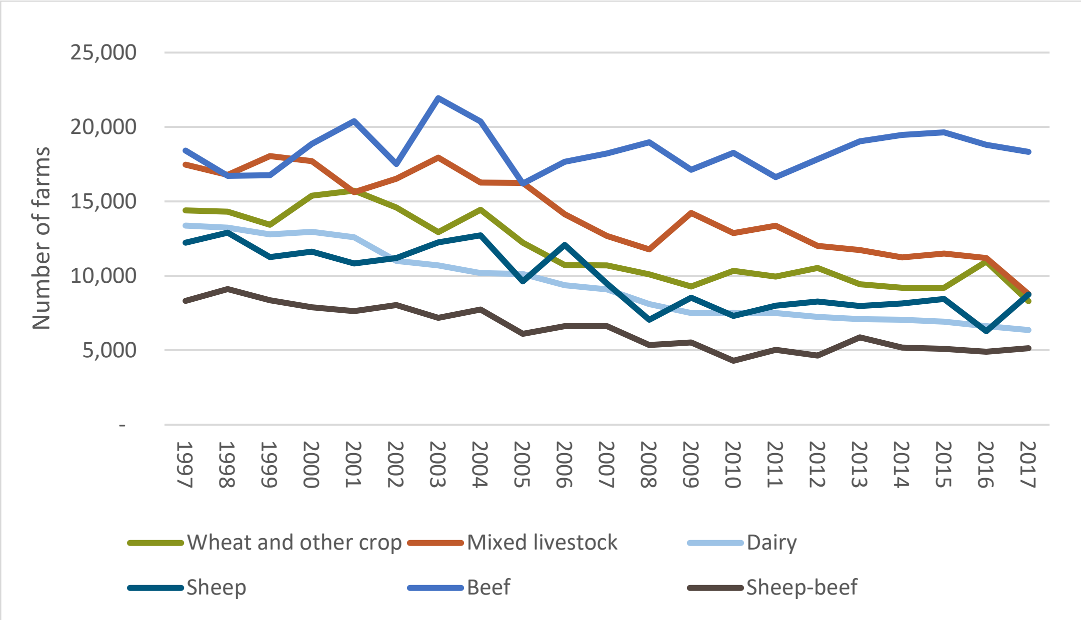

Figure 4: Number of Australian broad acre farms, 1997-2017

Source: ABARES, Agsurf. https://apps.daff.gov.au/AGSURF/. Accessed August 2018.

National weed control and loss estimates are calculated using the loss-expenditure approach by multiplying average weed control costs and production losses per farm by the number of farms and their average size. ABARES describe production using a classification based on beef, wheat/other cropping or sheep only, or mixed crop-livestock and sheep-beef production. The contribution of each system to wool, beef and cropping values of values of production are outlined in Figure 6..

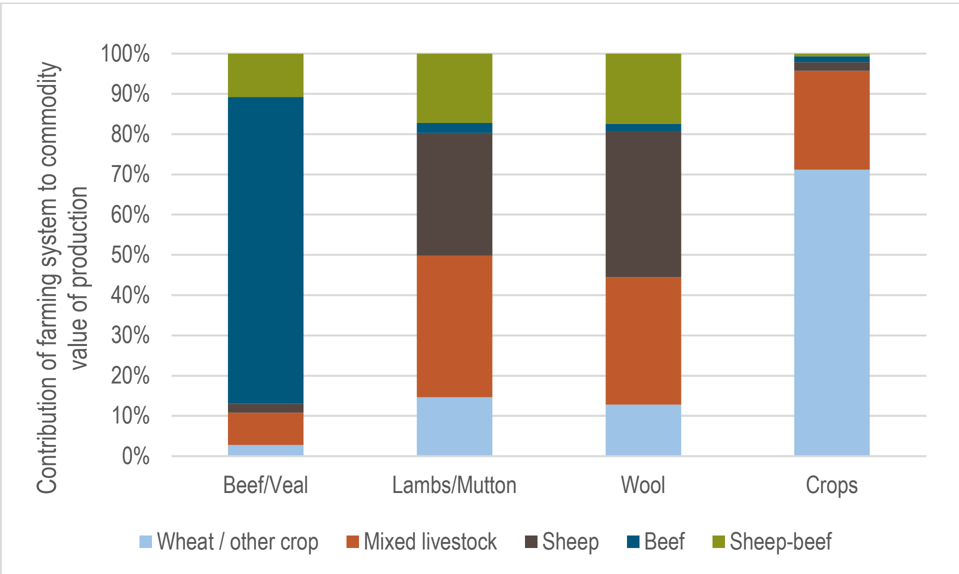

Figure 5: Contribution of ABARES farming systems to commodity values of production, 2017

Source: ABARES, Agsurf. https://apps.daff.gov.au/AGSURF/. Accessed August 2018.

Specialist beef farms contribute to around 75% of total beef values of farm production, while cropping specialists are the largest contributors to wheat/other crop receipts. Mixed livestock and sheep specialist producers account for around a third each of wool and sheep meat values of production. Production losses associated with grain crops, wool, beef and sheep meat are attributed back to each farming system in the loss-expenditure analysis using these proportions

The costs of weed control and gross margins for each of the industries are obtained from ABARES Agsurf, state departments of agriculture and industry reports. As in Sinden et al (2004), 'proxy' gross margins were used where an industry comprises a number of commodities groups. For example, oranges were used as a proxy for fruit production because citrus dominates Australia's fruit production. Potatoes were used for vegetable production. Weeds are prevalent across the geographic range of all industries. Most producers in the Llewellyn et al (2016) survey of 600 grain growers found weeds to be a problem. Correspondingly, all production areas are assumed to be impacted by weeds in this 2018 costing update.

2.2 Estimation of control financial costs

Sinden et al (2004) found the financial cost of weed control to Australian agriculture was between $1,365 to $1,519 million per annum. This cost included chemical costs, such as herbicides, and non-chemical cost associated with herbicide application and cultivation. The financial costs of farm-level weed control are again estimated as the sum of chemical and non-chemical control costs in the 2018 cost estimate.

Costs of herbicides

Deloitte Access Economics (2013) estimated that almost $2.5 billion was spent on 4,427 registered crop protection products in 2012. The ABARES Agsurf database reports on chemical cost in broad acre production. In 2017, it was estimated that $1.8 billion was spent on all chemicals. When chemical use costs are divided by operated areas across industries in the ABARES Agsurf database, the cost of chemicals used per hectare can be estimated. Chemical expenditure has been increasing on a per hectare basis since 1997. This trend is evident in Figure 6 and is most pronounced for cropping. The adoption of minimum tillage practices and farm consolidation underpins this trend. Since 1997 when the Sinden et al (2004) analysis was undertaken chemical costs per hectare have nearly doubled.

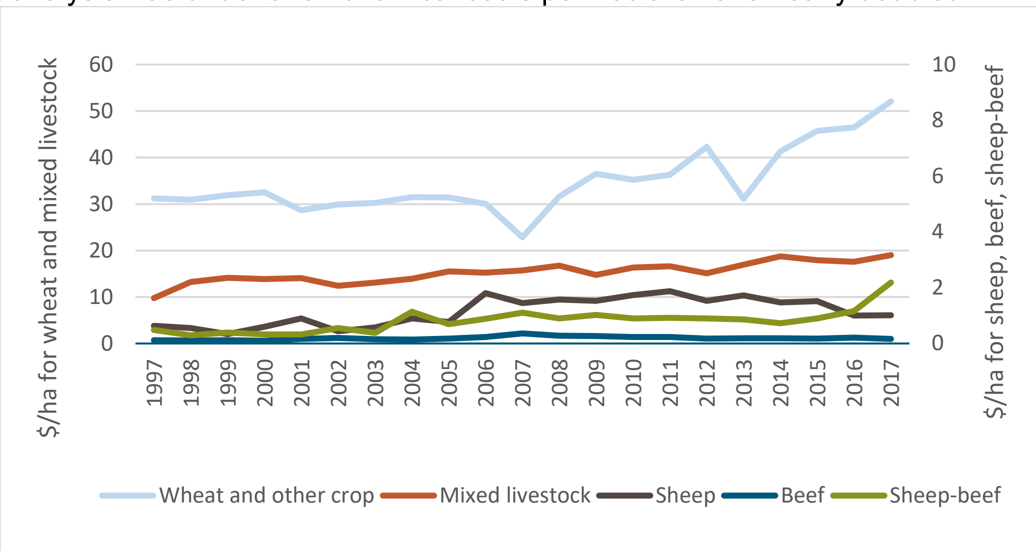

Figure 6: Broad acre chemical expenditure per hectare, 1997-2017
Source: ABARES, Agsurf. https://apps.daff.gov.au/AGSURF/. Accessed August 2018

Not all chemical costs relate to weed control. The proportion of this expenditure associated with herbicides was determined from Sinden et al (2004), NSW DPI gross margins (2012, 2013) and the recent grain grower survey by Llewellyn et al (2016). Gross margins are provided in Figure 7 and in Table 22 of the Annex. It is evident that chemical expenditures for weed control are highest for broad acre crops, sugar and horticulture, but low on a per hectare basis for livestock.

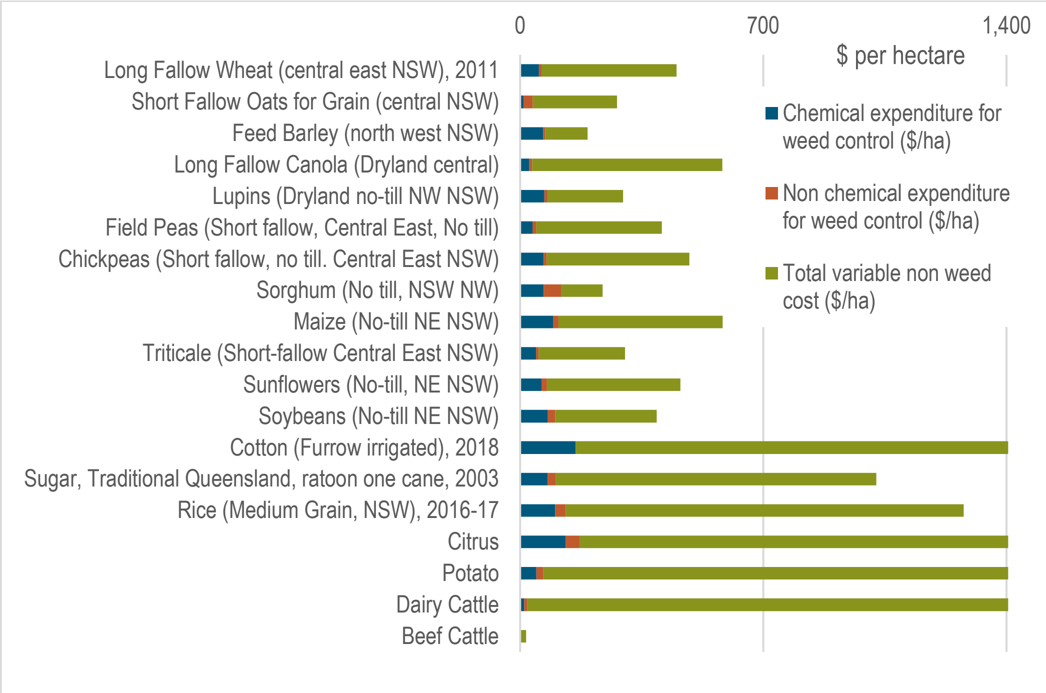

Figure 7: Variable costs per hectare, selected industries

Source: NSW Agriculture

Llewellyn et al (2016) surveyed grain farmers to determine control costs. Nationally, weed control expenditure makes up the majority of total weed costs at $2,573 million, or $113/ha. This cost includes chemical and applications costs, and is higher than many of the gross margins for cropping in NSW developed by NSW DPI. The higher cost includes allowances for weed resistance and integrated weed management practices

Annual chemical costs are outlined in Table 5 for broad acre cropping and livestock using ABARES Agsurf data 2013-2017. When the area cropped is considered, chemical costs per hectare are around $78.3 per hectare for wheat and other crops. Llewellyn et al (2016) estimated herbicide costs per hectare of $63/ha for in-season applications, plus fallow herbicide costs of between $14-46/ha. Correspondingly, most (90%) wheat-other broad acre crop chemical costs are attributed to herbicides in this costing update. A similar proportion was assumed by Sinden et al (2004).

Table 5: Annual chemical expenditure for weed control, 2018

Industry	Crop & pasture chemical costs	Percentage of crop and pasture chemicals used for weed control (%)			Crop and pasture chemical expenditure for weed control ($/ha)			Industry chemical expenditure for weed control ($ millions)		
	($/ha)	Low	Average	High	Low	Average	High	Low	Average	High
Wheat-other	78.3	75%	90%	100%	58.8	70.5	78.3	888.4	1,066.1	1,184.5
Cotton	741.0	10%	20%	25%	74.1	150.0	185.3	38.4	77.8	96.1
Sugar	100.0	90%	100%	100%	90.0	100.0	100.0	37.5	41.7	41.7
Rice	100.9	90%	100%	100%	90.8	100.9	100.9	7.5	8.4	8.4
Fruit	971.0	22%	29%	36%	212.3	283.0	353.8	65.7	87.7	109.6
Vegetables	374.0	8%	13%	30%	29.9	47.0	112.2	3.6	5.6	13.4
Dairy Cattle	13.3	80%	90%	90%	10.6	12.0	12.0	22.3	25.1	25.1
Beef Cattle	0.2	80%	90%	90%	0.1	0.2	0.2	38.1	42.9	42.9
Grain-Livestock	18.0	75%	90%	100%	13.5	16.2	18.0	284.3	341.2	379.1
Sheep-Beef	1.2	80%	90%	90%	0.9	1.1	1.1	22.1	24.8	24.8
Sheep	1.3	80%	90%	90%	1.1	1.2	1.2	37.3	42.0	42.0
Total								**1,445.3**	**1,763.2**	**1,967.5**

Source: This study

Llewellyn et al (2016), Sinden et al (2004) and gross margins were used to attribute overall crop and pasture chemical costs to herbicide costs for each industry. The cost per hectare is multiplied by cropped and operational areas to generate the overall cost of herbicides. It is evident the costs for specialist grain industries is $1,066 million and $341 million for mixed livestock-grain.

The costs of herbicides per hectare for livestock industries are relatively small. The same proportions of crop and pasture chemicals used for weed control (%) used by Sinden et al (2004) were applied to ABARES crop & pasture chemical costs for Dairy Cattle, Beef Cattle, Grain-Livestock, Sheep-Beef and Sheep production. Total herbicide control costs are estimated to be $1,763 million, with around 60% of control costs are associated with specialist grain producers. Specialist livestock industries contributed less than 8% to total herbicide costs.

Non-chemical costs of weed control

Expenditure on weed control also covers tillage, weed chipping, slashing, grazing strategies and herbicide application costs. Sinden et al (2004) used the Australian wool industry study of Sloane, Cook and King (1988) that found each $1.00 spent on weedicide, required $0.30 – $1.00 for application. When the costs of cutting, slashing and ploughing were considered each $1.00 of herbicide was assumed to have an additional $0.60 for non-chemical weed control.

Gordon (2014) further refined these costs by reviewing machinery use budgets in various NSW Department of Primary Industries gross margins. They included operating costs of $76.36/hour for fuel, repairs and maintenance, but not labour for operating the machinery, or any allowance for fixed costs. These costs, estimated on a per hectare basis, were also aggregated using the number of farms and average farm size per industry sub-sector. The combined expenditure on herbicides and cost of operating machinery for weed management activities to agriculture in NSW was estimated to be $696.14 million per annum

Llewellyn et al (2016) found application costs differ for across crops and regions when surveying grain growers across Australia. Costs ranged from $6/ha to $8/ha per application. Total cultivation costs for weed management was calculated as the sum of 'cultivation costs prior to seeding' and 'fallow cultivation costs'. Integrated weed management (IWM) practices contributed $475 million to the $2,573 million Australian grain growers spent on controlling weeds. Farmers spent the most on cultivation ($110 million), delayed seeding with knockdown ($99 million) and double knockdown ($97 million).

Application of herbicides using machinery or manually requires labour. Gordon (2014) identified that ABS had estimated 31 days of labour were consumed per 1,000 hectares for agricultural lands in NSW. When labour and machinery costs are added together in the Gordon study, they were similar to herbicide costs in the grain sector. Beef industry weed control labour costs were three times that of herbicide usage. It is not clear whether this level of labour intensity could be projected across other states such as Queensland, NT and Western Australia where management intensity per hectare is far less.

The additional $0.60 allowance for non-chemical weed control per $1 of herbicide is used for crop and livestock industries in this costing update study, except cotton and sugar industries where $0.1-0.2 was used. Gross margin analysis suggested non-chemical costs were lower for these industries, as in Sinden et al (2004). Non-chemical weed control costs are outlined in Table 6. Wheat / other specialist and grain-livestock enterprises account for $844 million in non-chemical control costs. These industries accounted for 85% of total non-chemical control costs.

Table 6: Annual non-chemical expenditure for weed control, 2018

Industry	Non chemical expenditure for weed control ($/ha)			Industry non-chemical expenditure for weed control ($ millions)			Expenditure for weed control ($ millions)		
	Low	Average	High	Low	Average	High	Low	Average	High
Wheat-other	31.7	42.3	52.9	479.7	639.6	799.5	1,368.1	1,705.7	1,984.0
Cotton	11.3	15.0	18.8	5.8	7.8	9.7	44.3	85.6	105.8
Sugar	15.0	20.0	25.0	6.3	8.3	10.4	43.8	50.0	52.1
Rice	45.4	60.5	75.7	3.8	5.0	6.3	11.3	13.4	14.6
Fruit	127.4	169.8	212.3	39.4	52.6	65.7	105.2	140.3	175.3
Vegetables	21.2	28.2	35.3	2.5	3.4	4.2	6.1	9.0	17.6
Dairy Cattle	5.4	7.2	9.0	4.6	6.1	7.6	26.9	31.2	32.8
Beef Cattle	0.1	0.1	0.1	19.3	25.7	32.1	57.4	68.6	75.0
Grain-Livestock	7.3	9.7	12.2	153.5	204.7	255.9	437.9	545.9	635.0
Sheep-Beef	0.5	0.6	0.8	11.2	14.9	18.6	33.2	39.7	43.4
Sheep	0.5	0.7	0.9	18.9	25.2	31.5	56.2	67.2	73.5
Total				**745.0**	**993.4**	**1,241.7**	**2,190.4**	**2,756.5**	**3,209.2**

Source: This study

The overall costs of weed control is estimated to be $2,756.5 million. This comprises $1,763.2 million on chemical costs plus $993 million of additional non-chemical costs. Changes in land management (such as widespread adoption of low or no till practices) over the last decade have created uncertainty about the exact magnitude of this cost. High and low estimates are included. The total financial cost for all agricultural industries lies between $2,190 million and $3,209.2 million per annum. Wheat-other broad acre and grain-livestock industries accounted for $2,252 million, which is similar to overall grain industry weed control estimate of $2,573 million, or $113/ha, by Llewellyn et al (2016).

2.3 Estimation of lost production

Residual production losses occur where land holders undertake control measures, or where no control is exercised. The 'top down' approach employed by Gordon (2014) and Sinden et al (2004) is applied to estimate overall production loss estimates for all weeds averaged for each industry included in the cost impact analysis. Production loss estimates using this approach are a function of the gross value of production and assumption used to calculate yield losses and reduced carrying capacities. Gross values of production for key agricultural industries between 1997 (when Sinden costs were estimated) and 2017 are presented in Figure 8.

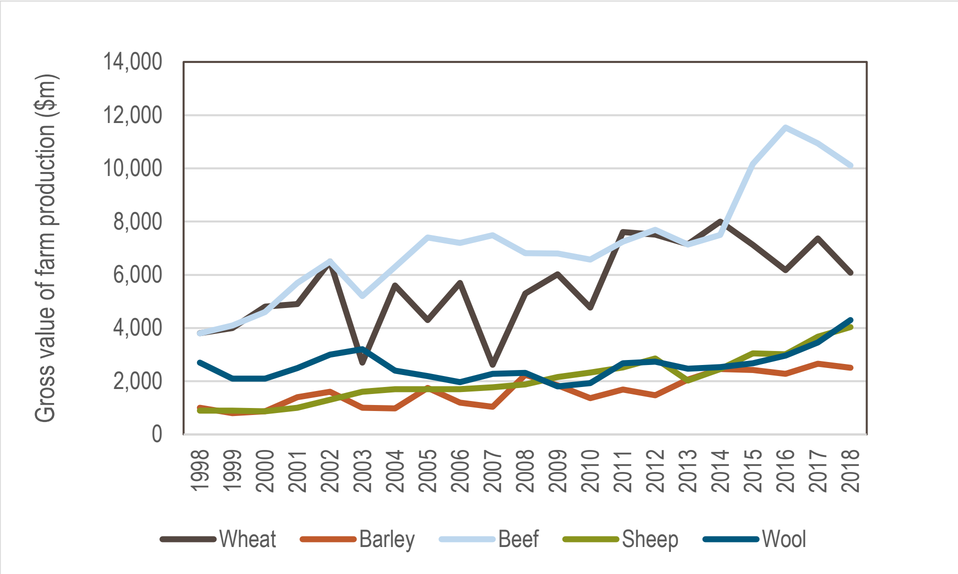

Figure 8: Gross value of production, 1997-2018

Source: ABARES, Australian Commodities.

Gross value production

Values of agricultural production have been increasing since 1997. ABARES forecast the overall value of farm production to be $61 billion in 2018–19, which is a large increase over the 10-year average of $55 billion. Much of the value increase is stemming from price increases, notably for livestock and livestock products. The increases in wheat and beef gross values are particularly evident in Figure 8.. The overall upward trend in prices for cattle has been apparent for 10 years from a combination of factors including lower domestic supply, and demand from exporters. The growth in the value of sheep-meat and wool values of production are not as pronounced as for beef and wheat.

Weed Production losses.

The costs associated with residual weeds are estimated by applying a production loss estimate to gross margins and industry values. This cost has been estimated using the same agricultural industry sub-sectors as Sinden et al (2004) and Gordon (2014). A range of lost yield/productivity percentages as a result of weeds has been estimated. Average, high and low productivity impacts are outlined in

Table 7: Estimated crop and pasture production lost to weed competition

Industry	Percentage of crop and livestock production lost to weed competition (%)			Notes
	Low	Average	High	
Wheat-other	4.5%	6.0%	7.5%	Llewellyn et al (2016) estimated yield losses of 2.76 million tonnes of grain due to residual weeds. An additional loss was also attributed to fallow weeds, using a damage relationship between observed weeds at end of fallow and consequent production losses. Overall yield loss was around 6% and this reduction is applied for Wheat, Oats, Barley, Canola, Lupins, Field Peas, Chickpeas, Sorghum, Maize, Triticale, Sunflowers and Soybeans in the costing update.
Cotton	4.5%	6.0%	7.5%	Sinden et al (2004) assumed a yield loss of 15%, however, this is likely to have reduced with new varieties. A yield loss of 6% (4-9% reported by farmers in survey of dryland cotton production by Walker et al 2005) is assumed.
Sugar	2.3%	3.0%	3.8%	McLeod et al (1996) estimated weed cost over the northern, Burdekin, central and southern production systems. All growers in each region, except those utilising no weed control, were assumed to employ the dominant farming system in their region. An average production loss of 3% was assumed.
Rice	1.9%	2.5%	3.1%	Assumed from Sinden et al (2004).
Fruit	0.8%	1.0%	1.3%	Assumed from Sinden et al (2004).
Vegetables	0.8%	1.0%	1.3%	Assumed from Sinden et al (2004).
Dairy Cattle	3.8%	5.0%	6.3%	Sloane, Cook & King (1988) was used in Sinden et al (2004) as the basis for these pasture based industries
Beef Cattle	3.8%	5.0%	6.3%	Sloane, Cook & King (1988) was used in Sinden et al (2004) as the basis for these pasture based industries
Grain-Livestock	3.8%	5.0%	6.3%	Averaged across livestock and grain losses.
Sheep-Beef	3.8%	5.0%	6.3%	Sloane, Cook & King (1988) was used in Sinden et al (2004) as the basis for these pasture based industries
Sheep	3.8%	5.0%	6.3%	Sloane, Cook & King (1988) was used in Sinden et al (2004) as the basis for these pasture based industries

Source: Assumptions used in this project

Broad acre crops
An average yield loss of 6% was derived from Llewellyn et al (2016), which includes residual and fallow weeds. Revenue losses caused from residual weeds in all crops (wheat, barley, oats, canola, pulses and sorghum) were estimated at $278 million or $12.21 per hectare. This was equivalent to yield losses of 2.6 per cent of production. Additional losses were also estimated for fallow weeds using estimates of weed density from the grower survey and a damage function. In total, yield losses for residual cropping season and fallow weeds were around 6%. A loss of 6% is applied to estimate losses in the 2018 cost update. An overall cost of $618 million for wheat-other cropping farms is estimated, while $340 million is estimated for mixed crop-livestock farms.

Beef cattle
Specialist beef producers contribute to around 75% of beef gross values of production, while mixed grain-livestock and sheep-beef producers are minor sources of beef production. Most specialist beef farms are in Queensland, where the beef herd per operated areas stands at 0.11 head/hectare and beef cattle sold receipts per hectare of $30/ha are similar to the national average.

Table 8: Number of beef farms, average receipts, costs and herd productivity, 2017

State	No. of beef farms	Beef herd at 30 June (no.)	Beef cattle sold (no.)	Area operated at 30 June (ha)	Beef cattle sold ($)	Total cash costs ($)	Beef cattle sold ($/ha)	Total cash costs ($/ha)	Beef herd / ha	Beef cattle sold / ha
Australia	18,325	952	283	14,580	368,432	265,968	25.27	18.24	0.08	0.02
New South Wales	4,628	496	193	890	269,075	204,635	302.33	229.93	0.77	0.22
Victoria	4,657	311	128	347	183,958	125,539	530.14	361.78	1.27	0.37
Queensland	6,988	1,359	386	16,441	496,796	348,915	30.22	21.22	0.11	0.02
South Australia	707	739	223	37,931	318,025	259,768	8.38	6.85	0.03	0.01
Western Australia	785	1,949	559	88,780	589,961	419,389	6.65	4.72	0.03	0.01
Tasmania	411	582	236	538	344,764	208,274	640.83	387.13	1.52	0.44
Northern Territory	149	12,822	2,113	334,180	2,335,829	2,048,452	6.99	6.13	0.04	0.01

Source: ABARES, Agsurf. https://apps.daff.gov.au/AGSURF/. Accessed August 2018

Sinden et al (2004) estimated weeds reduced beef enterprise productivity by 5% across the nation, which was taken from the weed productivity reduction estimates by Sloane et al (1988). There has not been a comprehensive national analysis of trends in abundance and distribution of weeds in Australia since this study. Grice et al (2014, p.52) noted “pasture weeds tend to be more difficult to evaluate economically than crop weeds for a number of reasons, including the complex interactions between livestock and weed species, lack of consistent biological properties that distinguish weeds from other pasture plants, and producers’ failure in identifying some as weeds due to their seasonal grazing value (Vere et al. 2004). For these reasons, there is usually a considerable level of uncertainty in quantifying the parameters (e.g. population density, impact on production, spread potential and life-cycle) that relate to weeds’ economic impacts, and again, the level of uncertainty is even more substantial when the potential consequences of invasion are of a long-term and large-scale nature.”

In the absence of data, the same beef industry productivity decline for weeds as that of Sinden et al (2004) is included in this 2018 costing study for livestock industries. The decrease in carrying capacity of 5% was applied to the inland weaner gross margin of NSW to generate a $6/ha financial loss in the Sinden et al (2004) study. This loss was then projected for cattle across the whole of Australia. The receipts per hectare and carrying capacity per hectare for NSW inland weaners is higher than many of the regions where the bulk of Australian cattle are grazed. The carrying capacities and gross margins for NSW, Queensland, WA and SA are presented in

Table 9: Cattle gross margins

State	Enterprise	Beef cattle sold ($/ha)	Total cash costs ($/ha)	Carrying capacity (AE/ha)	Carrying capacity (DSE/ha)	GM/ha	GM/DSE
New South Wales	Inland Weaners	229.74	40.60	0.44	4.00	189.14	47.29
	Coastal weaners – unimproved pasture					134.80	33.77
	Feeder steers					206.58	51.71
	Growing out steers 240-460 kg					279.42	34.97
	Japanese Ox					196.93	41.49
Queens-land	Southern Coastal	50.70	11.18	0.26	2.34	39.52	16.89
	Northern Coastal	30.60	8.80	0.20	1.80	21.80	12.11
	Eastern Downs	57.40	16.20	0.20	1.80	41.00	22.78
	Southern Inland	40.32	7.56	0.18	1.62	32.76	20.22
	Cape and Carpentaria	5.15	0.90	0.05	0.45	4.25	9.44
	West and South West	5.72	1.12	0.04	0.36	4.56	12.67
	Central North	14.10	3.00	0.10	0.90	11.10	12.33
	Central West	20.20	3.55	0.10	0.90	16.60	18.44
Northern Territory	Alice Springs	2.86	0.37	0.02	0.18	2.48	13.78
	Barkly Tablelands	3.39	0.45	0.03	0.27	2.94	10.89
	VRD & Katherine	7.14	1.38	0.06	0.54	5.76	10.67
	Darwin & Top-End	7.49	2.07	0.07	0.63	5.46	8.67
Western Australia	Kimberley	4.68	0.86	0.04	0.36	3.84	10.67
	Pilbara	3.54	0.50	0.03	0.27	3.03	11.22

Source: NSW DPI, Feb 2017, Mclean and Holmes (2015) for QLD, NT and WA

In this 2018 costing study, the five percent decrease in production is applied to national herd average productivity. Correspondingly, the 2018 update includes a beef weed-related loss cost of $493 million, which is around 5% of industry value. The Sinden et al (2004) study calculated a financial loss of $1,068 in 2002, equivalent to nearly 18% of the beef industry's $6.3 billion gross value in 2002.

Wool and sheep meat
Sheep specialist producers and mixed livestock farming systems contribute to more than two thirds of national wool and sheep meat production. Sheep carried per hectare in NSW and Australia are similar for specialist producers. Estimating productivity for mixed enterprises is confounded by grain and livestock production being rotated across the land area.

Table 10: Average number of sheep per farm and productivity, 2017

State	No. farms	Flock at 30 June (no.)	Sheep sold (no.)	Area (ha)	Total wool (kg)	Sheep carried / ha	Sheep sold / ha	Wool kg/ ha
Sheep only								
Australia	8,745	3,033	1,262	3,780	13,786	1.14	0.33	3.65
New South Wales	3,162	2,838	1,339	4,073	12,654	1.03	0.33	3.11
Victoria	2,415	3,226	1,073	713	13,323	6.03	1.50	18.69
Queensland	192	2,542	904	9,487	10,355	0.36	0.10	1.09
South Australia	1,560	2,798	1,358	9,107	15,378	0.46	0.15	1.69
Western Australia	1,110	3,518	1,416	1,777	16,315	2.78	0.80	9.18
Tasmania	306	3,270	1,148	1,485	14,003	2.98	0.77	9.43
Mixed-livestock *								
Australia	8,773	2,289	1,062	1,731	10,713	1.94	0.61	6.19
New South Wales	3,178	2,123	1,113	2,118	10,623	1.53	0.53	5.02
Victoria	2,563	1,816	829	533	7,470	4.96	1.56	14.02
Queensland	502	316	217	2,930	997	0.18	0.07	0.34
South Australia	1,161	2,760	1,164	3,006	12,013	1.31	0.39	4.00
Western Australia	1,281	3,832	1,585	1,509	19,654	3.59	1.05	13.02
Tasmania	88	4,677	1,874	2,235	16,586	2.93	0.84	7.42

Source: ABARES, Agsurf. https://apps.daff.gov.au/AGSURF/. Accessed August 2018. Operating area for mixed farms are net of cropping area. This may overstate averages.

The average wool and sheep receipts per hectare using ABARES Agsurf data are outlined in Table 11 using 2017 data. It is evident that wool receipts per hectare are similar for NSW and the national average in the case of sheep only producers. There is considerable variation across states and between sheep-only and mixed-livestock producers.

Table 11: Average sheep farm receipts and costs, 2017

State	No. farms	Area operated at 30 June (ha)	Sheep sold ($)	Total wool gross receipts ($)	Total cash costs ($)	Sheep sold ($/ha)	Wool gross receipts ($/ha)	Wool & sheep receipts ($/ha)	Total cash costs ($/ha)
Sheep only									
Australia	8,745	3,780	157,847	130,450	208,445	41.76	34.51	76.27	55.14
New South Wales	3,162	4,073	172,004	117,851	216,054	42.23	28.93	71.16	53.05
Victoria	2,415	713	138,902	130,126	199,474	194.81	182.50	377.32	279.77
Queensland	192	9,487	81,156	91,687	222,350	8.55	9.66	18.22	23.44
South Australia	1,560	9,107	169,029	130,716	190,679	18.56	14.35	32.91	20.94
Western Australia	1,110	1,777	164,863	163,828	230,066	92.78	92.19	184.97	129.47
Tasmania	306	1,485	126,733	165,062	204,042	85.34	111.15	196.49	137.40
Mixed-livestock									
Australia	8,773	1,731	142,990	95,082	na	82.61	55.54	137.53	na
New South Wales	3,178	2,118	159,068	88,874	na	75.10	42.49	117.06	na
Victoria	2,563	533	114,598	63,890	na	215.01	121.42	334.87	na
Queensland	502	2,930	30,335	8,142	na	10.35	2.85	13.13	na
South Australia	1,161	3,006	173,707	106,638	na	57.79	35.86	93.26	na
Western Australia	1,281	1,509	169,211	193,675	na	112.13	129.40	240.48	na
Tasmania	88	2,235	245,309	136,093	na	109.76	61.73	170.65	na

Source: ABARES, Agsurf. https://apps.daff.gov.au/AGSURF/. Accessed August 2018. Operating area for mixed farms are net of cropping area. This may overstate averages.

Sheep gross margins are provided in Table 12. It is evident that wool receipts per hectare vary from $90 in first cross ewes, $238 in SA wethers and $466 in fine wool merino ewes. When wool receipts per farm are divided by the operating areas of the ABARES Agsurf database, average wool recepts vary from $34-56 per hectare. These are less than receipts for gross margins as not all of farm areas are used for grazing. Correspondingly, average national wool and sheep meat production per hectare estimates are reduced by 5% to quantify weed-related production loss estimates in the 2018 weed cost update.

Table 12: Sheep gross margins

State	Enterprise	Sheep sold ($/ha)	Wool sold ($/ha)	Total cash costs ($/ha)	Carrying capacity (DSE/ha)	GM/ha	GM/DSE
New South Wales	Merino ewes (20mic)	363	229	291	10	302	30
	Merino wether (18 mic)	132	466	351	10	246	25
	Merino wether (20 mic)	132	413	326	10	219	22
	First cross ewes	644	90	393	10	341	34
South Australia	Wether (21 mic)	80	238	173	6	145	35
	Ewes (21 mic)	443	364	274	6	533	63

Source: NSW DPI, SA Agriculture

Sugar.
A wide range of cultivation practices are evident in the Australian sugar industry and a diversity of herbicides are used to control weeds. In the north, the majority of growers have adopted green cane trash blanketing systems, that utilise minimum tillage and incorporate herbicides to manage weeds. McLeod et al (1996) estimated weed cost over the northern, Burdekin, central and southern production systems. The annual value of herbicide usage (including application costs) was estimated to be around $28 million and cultivation $13 million.

To calculate the weed damage costs on the Australian sugar industry, McLeod et al (1996) assumed that most farmers (95%) efficiently control weeds using cultivation, chemical and cultural practices and only suffer a minor production loss of 1%. Around 5% of growers were assumed to manage weeds poorly and it was assumed that weed competition reduced yields by 22%. An average production loss of 2% was estimated across the industry, or $19 million. More recently, Sugar Research Australia estimated yield losses and cost of weeds exceeds $70 million is costs per year.[4] A yield loss of 3% is included in this costing study to generate sugar industry weed cost estimates of $83 million per year.

Cotton, Rice, Fruit, Vegetables
The production loss estimates assumed by Sinden et al (2004) and Gordon (2014) are included for these industries. The losses for vegetables and fruit were estimated at around 1%, so losses are relatively small compared to the overall gross value of the industry. A high production loss was included for cotton in the 2002 costs of Sinden. New cotton varieties that are resistant to herbicides have been adopted widely, therefore a production loss estimate of 6% is included in this cost update.

[4] https://sugarresearch.com.au/growers-and-millers/weeds/. Accessed August 2018

2.4 Results and discussion

Using the loss-expenditure approach, the costs of weeds to agriculture is estimated to be within 4,813.7 million. The annual cost is outlined in Figure 9. It is evident that the wheat and other broad-acre crops industry accounts for much of the loss-expenditure cost, largely as a result of high investment in herbicides. The combined weed control and production loss costs for wheat-other and grain-livestock sectors is estimated to be $3,209 million, which is similar to $3,318 million calculated by Llewellyn et al (2016). The beef sector is the next largest specialist sector impacted, with large estimated production losses from the assumed 5% decrease in productivity as a result of weed competition in pastures.

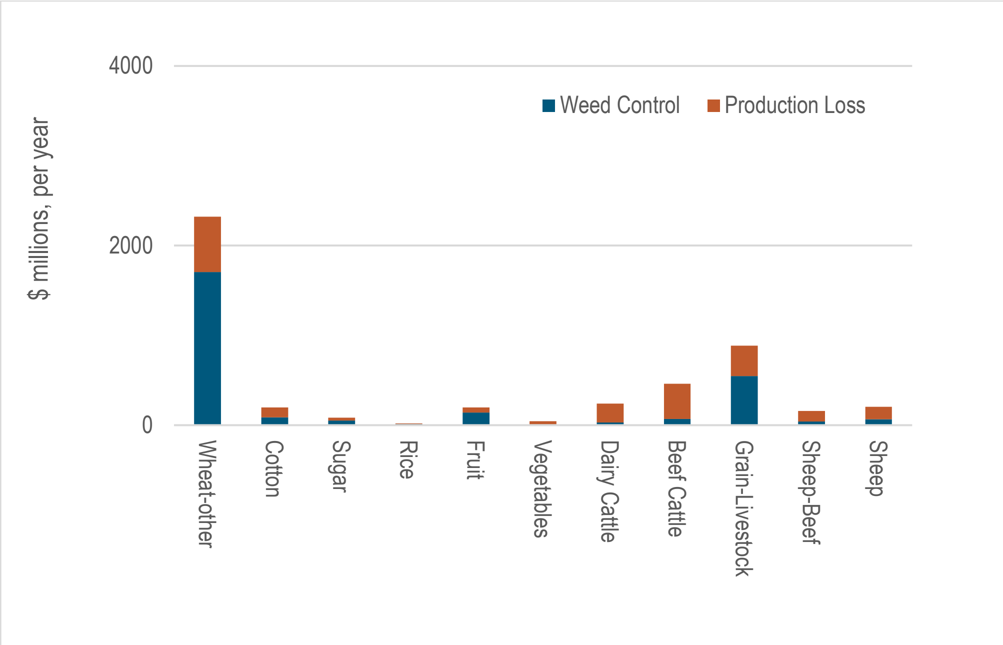

Figure 9: Annual cost of weeds, loss-expenditure estimate for 2018

Source: This study

There is a high degree 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. High and low cost scenarios were included to gauge how robust cost estimates are to changes in key assumptions. The control and production loss assumptions associated with these scenarios were provided in Table 5, Table 6 and Table 7. It is evident the overall combined control and loss costs vary from $3.7 billion to $5.8 billion when the low and high range parameters are included. Changes in the control cost assumptions for the grains sector have a large impact on the estimated overall costs of weeds in Australia.

Table 13: Annual weed costs, loss-expenditure approach, 2018

	Low			Mean			High		
	Control	**Loss**	**Total**	**Control**	**Loss**	**Total**	**Control**	**Loss**	**Total**
Wheat-other	1,368	463	1,831	1,706	618	2,323	1,984	772	2,756
Cotton	44	83	127	86	110	196	106	138	244
Sugar	44	24	68	50	33	83	52	41	93
Rice	11	5	16	13	6	19	15	8	22
Fruit	105	44	149	140	58	198	175	73	248
Vegetables	6	26	33	9	35	44	18	44	62
Dairy Cattle	27	158	185	31	210	242	33	263	296
Beef Cattle	57	295	352	69	393	462	75	491	566
Grain-Livestock	438	255	693	546	340	886	635	425	1,060
Sheep-Beef	33	89	122	40	118	158	43	148	191
Sheep	56	102	158	67	136	203	73	170	243
Total	**2,190**	**1,543**	**3,733**	**2,757**	**2,057**	**4,814**	**3,209**	**2,571**	**5,781**

Source: This study

The gross value of the beef industry has increased substantially since 2004. The national costs of weed for the beef industry in this study is less than that by Sinden in 2004 despite this increase. This is a result of production losses as a percentage of gross value of livestock production being less, due to use of average national beef herd productivity in the base calculations. The economic loss estimates for the Sinden et al (2004), Gordon (2014) and this 2018 study as a proportion of beef industry values are presented in Figure 10. Weed-related costs were estimated to be half of the gross value of the NSW beef industry in the Gordon (2014) study, and around 20% across Australia in Sinden et al (2004) study. Weed costs are 5% of the national beef industry value in the 2018 study.

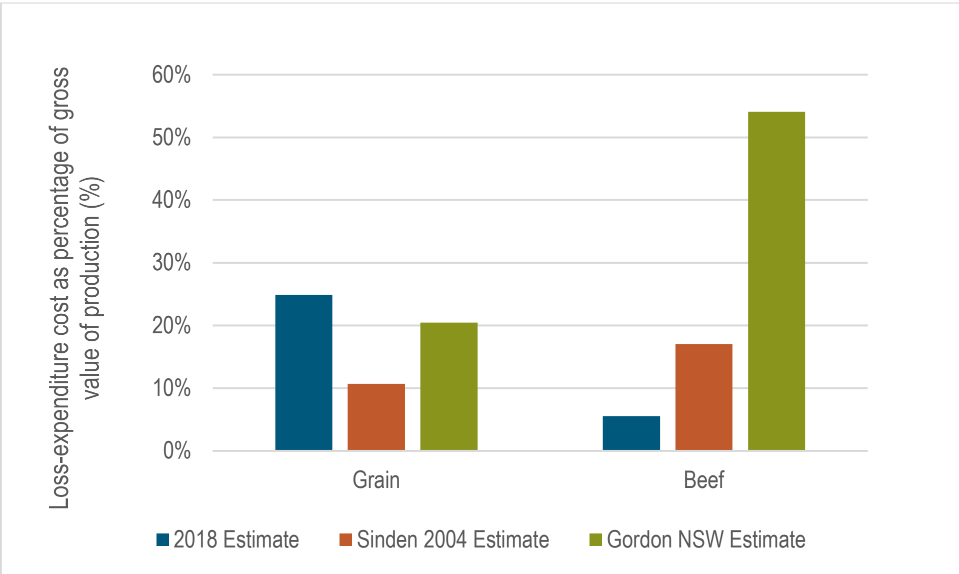

Figure 10: Economic-welfare estimate as a percentage of industry production for 2018, Gordon 2014 and Sinden 2004

Source: This study, Sinden et al 2004, Gordon 2014

Sinden et al (2004) noted “it is highly likely that losses to both the northern and southern Australian cattle industries will vary from the five per cent used in this study. Anecdotal evidence indicates that actual losses would exceed the five per cent that is adopted here. This provides further evidence that these estimates of total are lower bounds and also suggests the need for further assessment of losses in the grazing industries of Australia” (ibid, p.17). Grice et al (2014) also indicated there is limited data about the impact of weeds on grazing productivity. Given the very large absolute costs inflicted on this sector by weeds, gathering weed control cost and production loss data for grazing industries– such as in the grains sector by Llewellyn et al (2016), is critical.

3 Agricultural costs: economic surplus estimates

The economic surplus approach captures cost impacts on producers and consumers through a reduction in economic welfare. Unlike loss-expenditure methods, the economic surplus approach measures the impact of weeds on commodity supply and the resulting changed price consumers have to pay for livestock and crop products. As Sinden et al (2004) point out, the supply curve shift estimated as part of the approach includes direct and indirect financial costs within the calculations. Changes in prices and quantities as a result of this shift are quantified using demand and supply price elasticities – which are based on historical price-quantity relationships observed in relevant markets.

3.1 Basis for assessment

The weed cost impact quantified in the economic surplus framework is estimated as the change in total economic surplus (ΔES) that occurs across national markets in Wheat, Oats, Barley, Canola, Lupins, Field Peas, Chickpeas, Sorghum, Maize, Triticale, Sunflowers, Soybeans, Cotton, Sugar, Rice, Fruit, Vegetables, Dairy, Beef/Veal, Lambs/Mutton and Wool. Economic surplus comprises changes in consumer surplus and producer surplus or change in overall economic surplus is calculated as $\Delta ES = \Delta CS$ (change in consumer surplus) $+\Delta PS$ (change in producer surplus).

Producer surplus has been described as "being in the nature of a rent attributable ultimately to the specialised factors that actively confer differential advantage to the firm employing them" (Mishan, 1968, p.1270). An upward shift in the supply curve as a result of weed control and yield losses generates a decrease in producer surplus denoted by PS. Consumer surplus was described by Mishan (1968, p.416) as "the amount of money [someone] is willing to pay rather than go without the thing over that which he actually pays". Hence consumer surplus is graphically represented as the area under the demand curve and above the price of the commodity. With an upward shift in the supply curve as a result of weeds consumers lose consumer surplus.

Single market models were used in Gordon (2014) and Sinden et al (2004) to estimate changes in economics surplus as a result of weeds. Gordon (2014) estimated changes in the economic surplus from weeds using the equations from (Alston 1991), where ΔCS, ΔPS and ΔES are the changes or losses in consumer’s surplus, producer’s surplus and total economic surplus respectively, K is the vertical shift in the supply function expressed as a percentage of initial price (P1), Z is the percentage reduction in price arising from the supply shift, and 'Y and E are the absolute values for the elasticity of demand and the elasticity of supply, which are slopes that quantify the size of the price change resulting from supply changes. The equations specified by Gordon (2014) include:

$$\Delta CS = P_W Q_W Z(1+\frac{1}{2}Z\eta)$$

$$\Delta PS = P_W Q_W (K-Z)(1+\frac{1}{2}Z\eta)$$

$$and$$

$$Z = \frac{K\varepsilon}{(\varepsilon+\eta)}$$

where

P_W = equilibrium market price

Q_W = equilibrium market quantity

ε = absolute value of the elasticity of supply (slope of the supply function)

η = absolute value of the elasticity of demand (slope of the demand function)

K = vertical supply shift resulting from 'with' and 'without' weeds

Z = percentage change in price arising from a supply shift

3.2 Data collection

The input data used by Sinden et al (2004) is updated in this assessment for equilibrium quantities (Q) and prices (P). The equilibrium quantities and prices were obtained from ABARES (2018), averaged for the five years up to and including 2018. The prices and quantities underpinning estimates are provided in Table 14.

Table 14: Average commodity quantities and prices, 2014-1018

Industry	Price per Unit ($/tonne)	Relevant Quantity of Units (1000 tonnes)	Value of production ($ millions)
Wheat	274	25,320	6,931
Oats	248	1,428	354
Barley	248	9,651	2,392
Canola	522	3,427	1,791
Lupins	298	689	206
Field Peas	370	308	114
Chickpeas	656	1,046	687
Sorghum	279	1,700	474
Maize	308	428	132
Triticale	226	132	30
Sunflowers	478	24	12
Soybeans	648	40	26
Cotton	2,309	795	1,837
Sugar	32	33,500	1,089
Rice	374	644	241
Fruit	1,531	379	5,982
Vegetables	1,837	192	3,637
Dairy	0.45	9,382	4,207
Beef/Veal	4,185	2,357	9,865
Lambs/Mutton	4,468	706	3,153
Wool	7,689	429	3,297

Source: ABARES, Australian Commodities, Average 2014-2018.

Demand elasticities ('Y) and supply elasticities (E) were outlined in Sinden et al (2004). The authors sourced these parameters from ABARES (1999), Brennan and Bantilan (1999), Griffith et al. (2001), Hill, Piggott and Griffith (2001), Jones et al. (2000) and Myers, Piggott and MacAulay (1985). They are outlined in the Appendix.

The supply shift parameter for each industry (K) due to the presence of weeds is estimated as the cost increase (productivity loss) due to the weeds and includes the yield and cost per hectare impact. The yield and costs estimated 'with' and 'without' weeds are presented in Table 15, along with estimated cost saving if weeds were not prevalent. Many of the costs reap cost savings from the removal of herbicide application and chemical costs. It is evident that the K for livestock industries is less. The assumptions about changed carrying capacity were described in the loss-expenditure section and control costs are limited across broad acre production.

Table 15:Average net productivity loss from weeds

Industry	Yield with weeds (t/ha)	Costs of production with weeds ($/ha)	Cost of production with weeds ($/t)	Yield without weeds (t/ha)	Costs of production without weeds ($/ha)	Costs without weeds ($/t)	Weed net productivity loss (K) ($/t)
Wheat	2.09	501	240	2.21	388	176	0.24
Oats	1.69	356	211	1.79	243	136	0.31
Barley	2.31	234	101	2.45	121	49	0.24
Canola	1.31	639	488	1.39	526	379	0.21
Lupins	1.44	329	228	1.53	216	141	0.30
Field Peas	1.32	474	360	1.40	361	258	0.28
Chickpeas	1.37	524	383	1.45	411	284	0.18
Sorghum	3.15	232	74	3.34	119	36	0.18
Maize	7.45	586	79	7.90	473	60	0.10
Triticale	1.77	352	199	1.88	239	127	0.32
Sunflowers	1.24	496	401	1.31	383	292	0.24
Soybeans	1.71	405	236	1.82	292	161	0.15
Cotton	2.19	3,275	1,495	2.32	3,177	1,368	0.07
Sugar	88.20	1,271	14	90.85	1,129	12	0.08
Rice	10.29	1,277	124	10.54	1,157	110	0.05
Fruit	12.24	4,037	330	12.36	3,701	299	0.03
Vegetables	16.06	13,105	816	16.22	12,965	799	0.01
Dairy	0.004	2,053	460,181	0.005	2,038	435,005	0.05
Beef/Veal	0.009	16.8	1,812	0.010	16.6	1,704	0.05
Lambs/Mutton	0.016	50.2	3,174	0.017	49	2,930	0.07
Wool	0.010	50.2	5,117	0.010	49	4,723	0.07

Source: This study.

3.3 Results

The results of economic surplus cost analysis are presented in presented in Figure 11. The overall cost is $4,823 million, of which wheat and other broad acre crops comprise $3,166 million. The estimate is higher than that of Sinden et al (2004) where the mean loss in economic surplus was $3,927 million per annum, and the range of loss was $3,442 million to $4,420 million. Of the total, around $1,122m was accounted by winter crops, $396m in summer crops and $2,409 million in livestock industries. Crops have a higher contribution to overall costs in the 2018 cost assessment due to the increase in control costs.

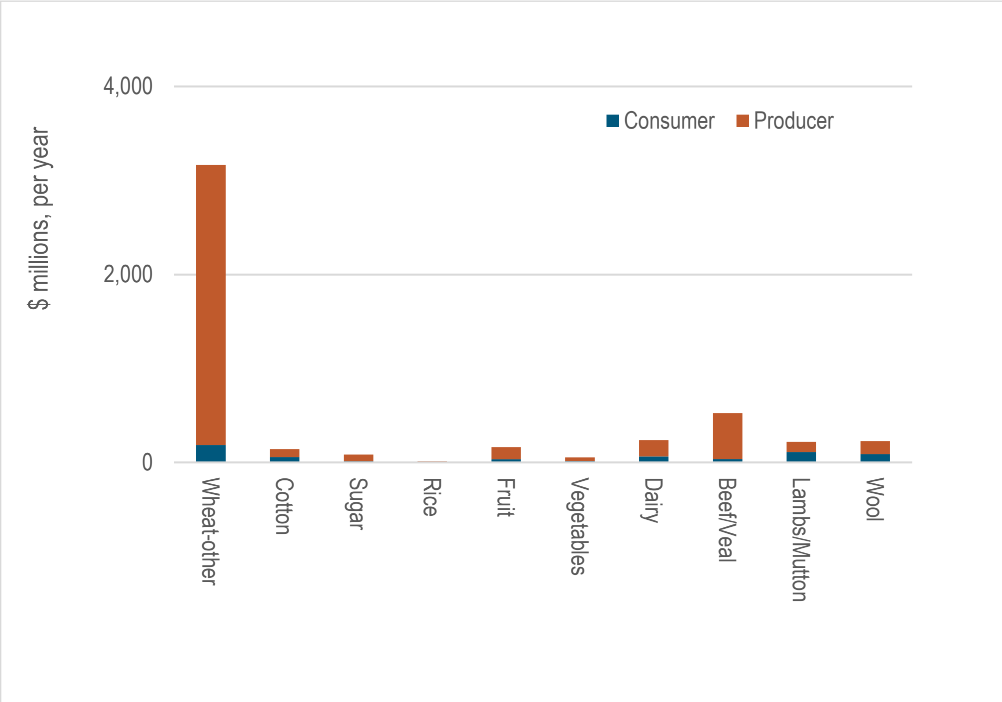

Figure 11: Annual cost of weeds, economic-welfare estimate for 2018

Source: This study

The changes in consumer surplus, producer surplus and total economic surplus are reported in Table 17 for winter crop, summer crop, cotton, rice, sugar, horticulture and livestock industries. It is evident the producers bear the bulk of economic loss, where the impact on consumers due to higher prices is minor.

Table 16: Annual cost of weeds, economic welfare approach, 2018

Industry	Net increase in cost/ton output(K)	Relative Increase in Price(Z)	Change in Total Surplus ($ millions)	Change in Consumer Surplus ($'millions)	Change in Producer Surplus ($'millions)
Wheat	0.24	0.01	1,736	68	1,668
Oats	0.31	0.03	113	9	104
Barley	0.24	0.02	593	49	544
Canola	0.21	0.02	388	32	356
Lupins	0.30	0.03	64	5	59
Field Peas	0.28	0.02	32	3	30
Chickpeas	0.18	0.01	122	10	112
Sorghum	0.18	0.01	86	7	79

Industry	Net increase in cost/ton output(K)	Relative Increase in Price(Z)	Change in Total Surplus ($ millions)	Change in Consumer Surplus ($'millions)	Change in Producer Surplus ($'millions)
Maize	0.10	0.01	14	1	13
Triticale	0.32	0.03	10	1	9
Sunflowers	0.24	0.02	3	0	3
Soybeans	0.15	0.01	4	0	4
Grain (Subtotal)			**3,166**	**187**	**2,979**
Cotton	0.07	0.03	142	58	84
Sugar	0.08	0.01	85	12	73
Rice	0.05	0.01	13	2	11
Fruit	0.03	0.01	161	32	129
Vegetables	0.01	0.00	52	17	34
Dairy	0.05	0.02	236	65	172
Beef/Veal	0.05	0.00	522	35	487
Lambs/Mutton	0.07	0.03	221	110	111
Wool	0.07	0.03	226	88	137
Total			**4,823**	**605**	**4,218**

Source: This study

High and low economic cost scenarios estimates are also calculated. The estimates are presented in Table 18. The high scenario includes higher control costs and greater yield reduction estimates which were outlined in Table 5, and in the loss-expenditure section. The tables also included lower yield and control costs estimates. As the consumer surplus contribution to overall cost is small, this inclusion does not have a large impact on overall cost estimates.

Table 17: Mean, high and low cost of weeds, economic welfare approach, 2018

Industry	Low			Mean			High		
	CON	**PROD**	**Total**	**CON**	**PROD**	**Total**	**CON**	**PROD**	**Total**
Grain	160	2,639	2,799	187	2,979	3,166	217	3,462	3,679
Cotton	63	93	156	58	84	142	125	183	308
Sugar	11	65	76	12	73	85	24	146	169
Rice	2	11	13	2	11	13	2	13	15
Fruit	41	163	204	32	129	161	35	140	175
Vegetables	14	29	43	17	34	52	20	40	60
Dairy	55	146	200	65	172	236	78	207	285
Beef/Veal	29	403	432	35	487	522	42	591	633
Lamb/Mutton	107	108	215	110	111	221	128	130	257
Wool	77	120	197	88	137	226	103	160	263
Total	**558**	**3,777**	**4,336**	**605**	**4,218**	**4,823**	**774**	**5,071**	**5,845**

Source: This study. Abbreviation: CON= change in consumer surplus, PROD= change in producer surplus

The range in economic costs was $4,336 to $5,845 million. The average surplus loss ($4,823.3 million) exceeds the loss-expenditure ($4,813.7 million). A comparison between economic-welfare estimate for 2018 and Sinden et al (2004) is provided in Figure 12. The higher wheat and lower beef and wool costs are evident.

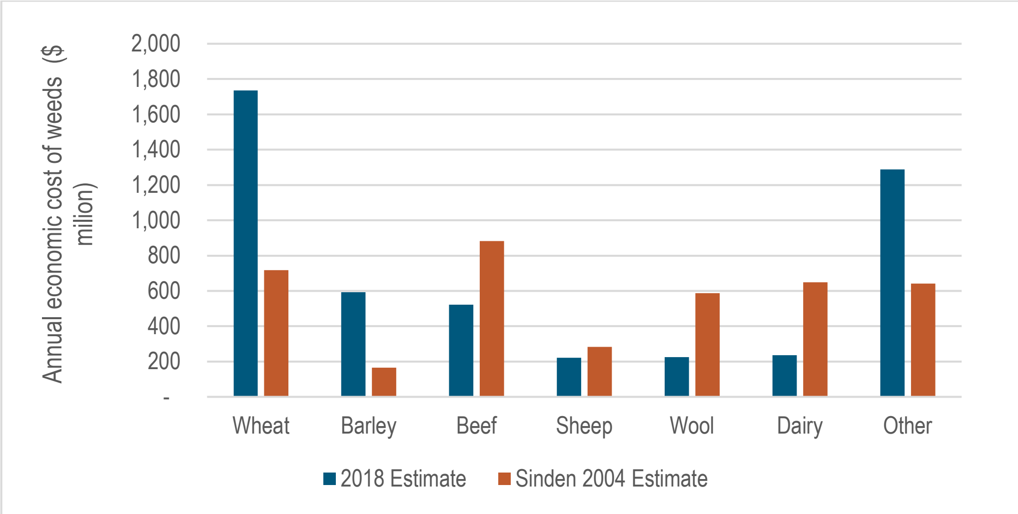

Figure 12: Comparison between economic-welfare estimate for 2018 and Sinden 2004

Source: This study, Sinden et al 2004

3.4 Discussion

The loss-expenditure and economic welfare losses estimated in this 2018 national weed cost update for agricultural industries are similar. The welfare approach has slightly higher cost estimates. Costs for both approaches are about $4.8 billion, which is an increase over the costs estimated in 2004 by Sinden and colleagues.

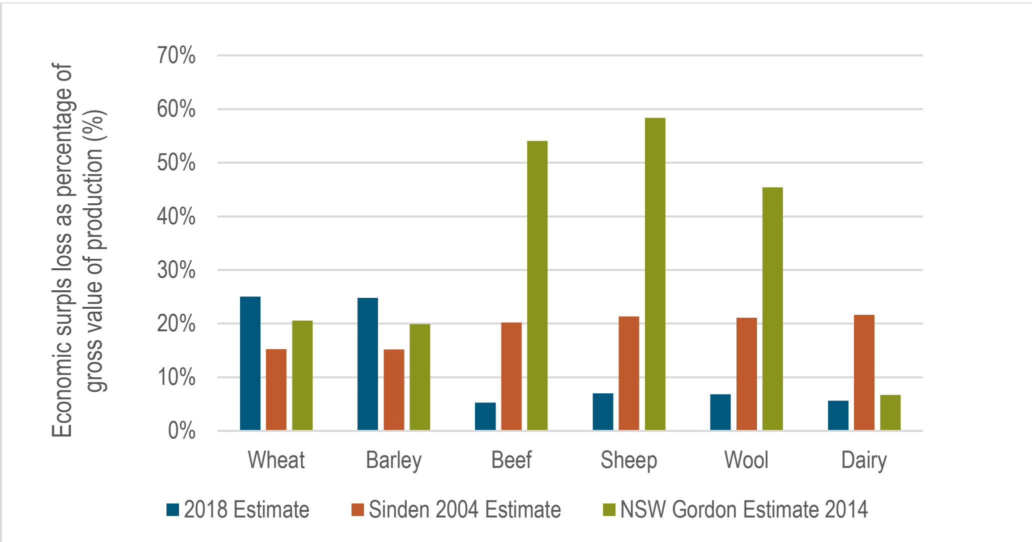

Figure 13: Comparison of economic-surplus cost estimates as a percentage of industry gross values for 2018, Gordon 2014 and Sinden 2004

Source: This study, Sinden et al 2004, Gordon 2014.

Economic surplus weed costs estimates are presented as a percentage of industry gross values in Figure 13. Wheat and other broad acre crop surplus losses are higher at nearly 20% which reflects control and production loss costs of this order. Grain industry surplus losses are at similar proportion of industry values across all included studies. Economic surplus weed costs differ between the three studies for livestock industries. For Sinden et al (2004) they are equivalent to nearly 20% of national livestock industry value and Gordon 2014 more than half of industry production in NSW. In the 2018 update, weeds are assumed to result in a 5% productivity decline.

4 Public weed control expenditure

Government expenditures for national parks, public infrastructure, weed research and for indigenous lands are presented in this section using data from the Sinden et al (2004) study.

4.1 National Parks and natural environments

Sinden et al (2004) collated expenditures by National Parks and Wildlife Services on weed management, and the expenditures of National Heritage Trust (NHT) funds for the year 2001–02. Contact was made with the head office for each National Parks and Wildlife Service throughout Australia. Expenditures included weedicide, labour, contractor costs, and other materials, along with depreciation of equipment, mapping, surveillance and research that were attributable to weed management. Salaries were an additional cost allocated to weed management. Total overall costs were $19.597 million in 2001–02, with direct costs for national parks being $8.282 million. National Heritage Trust funds to control of weeds in natural environments totalled $4.998 million in 2001–02. The overall cost is indexed to 2018 using ABS consumer price indices between 2002 and 2018. 2001-02 costs are inflated by 1.49, to a total of $29.11 million in 2018.

4.2 Public authorities, public expenditures and other public lands

Sinden et al (2004) also collected expenditures outside of national parks for state forests, crown lands, travelling stock routes, land adjacent to roads and railways, land adjacent to water reservoirs, and urban parks. Agencies included departments of agriculture, natural resources or the environment, authorities who maintained road and rail infrastructure, state forests, and reserves such as stock routes. The total expenditure on weed management activities was $80.775 million. When inflated to 2018, this cost increases to $120 million.

Commonwealth authorities that undertake research into weeds management were also included in the Sinden estimate. The Commonwealth Department of Agriculture, Fisheries and Forestry, CSIRO, and Co-operative Research Centres all undertake surveillance, research and other activities concerned with weed management. Sinden et al (2004) estimated these authorities undertook $8.25 million in research. In the absence of data for 2018, the Sinden estimate is indexed by 1.49 to $12.26 million for this year. The combined cost for public authorities is $132.26 in 2018.

4.3 Indigenous lands

Sinden collected weed expenditure data on Indigenous lands in the Northern Territory. They noted weed control is funded from several sources, including government agencies, non-governmental organisations, statutory authorities, and the Indigenous land managers of individual holdings. Data was collected from the Central Land Council (CLC), Indigenous Land Corporation (ILC), Key Centre for Tropical Wildlife, National Native Title Tribunal, Northern Land Council (NLC), NT Department of Business, Industry and Resource Development (DBIRD), and NT Department of Infrastructure, Planning and Environment (DIPE). It was estimated that $15.225 million had been spent on weed control programs on Indigenous lands in the Territory in the past five financial years, an average of $3.045m per annum. This is indexed to $4.52 million in 2018.

4.4 Discussion

Around $300 million in public weed expenditure is estimated in 2018. Like in 2004, this cost is less than 10% of total weed costs. Agricultural control and production costs comprise the majority of costs.

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Appendix 1: Loss-expenditure and welfare estimates

Table 18: Annual loss-expenditure costs, 2018

Industry	Number of farms	Proportion of industry impacted (%)	Area operated per farm (ha)	Area cropped per farm (ha)	Area cropped per industry (ha)	Area operated per industry (ha)	Crop & pasture chemical costs per ha operated	Percentage of crop and pasture chemicals used for weed control (%) b		
	No.	(%)	(ha)	(ha)	(ha)	(ha)	($/ha)	Low	Average	High
Wheat / other	9,420	100%	2,897 [a]	1,605 [a]	15,119,742	27,292,783	43.4 [a]	75%	90%	100%
Cotton	1,009	100%	514 [c]	514 [c]	518,626	518,626	741.0	10%	20%	25%
Sugar	3,626	100%	125 [d]	115 [d]	416,990	453,250	79.0 [e]	90%	100%	100%
Rice	674	100%	123 [f]	123 [f]	82,902	82,902	100.9 [g]	90%	100%	100%
Fruit	8,850	100%	35	35	309,750	309,750	819.0 [i]	22%	29%	36%
Vegetables	3,737	100%	32	32	119,584	119,584	374.0 [j]	8%	13%	30%
Dairy Cattle	6,806	100%	309 [a]	125 [a]	852,061	2,102,930	13.3 [a]	80%	90%	90%
Beef Cattle	19,054	100%	13,592 [a]	40 [a]	758,365	258,987,405	0.2 [a]	80%	90%	90%
Grain-Livestock	10,884	100%	1,930 [a]	579 [a]	6,304,244	21,009,069	18.0 [a]	75%	90%	100%
Sheep-Beef	5,240	100%	4,508 [a]	67 [a]	348,971	23,621,018	1.2 [a]	80%	90%	90%
Sheep	7,917	100%	4,381 [a]	110 [a]	873,993	34,682,625	1.3 [a]	80%	90%	90%
Total	**77,217**				**25,705,228**	**369,179,942**				

Notes:

(a). Average 2013-2017, http://apps.daff.gov.au/agsurf/agsurf.asp, Accessed August 2018.

(b) Derived from Sinden et al (2004). The proportions of total pasture and crop chemical costs dedicated to weed control were specified for each industry as high-low estimates. They included Wheat / other crops (90-100%), Cotton (15-20%), Sugar (90-100%), Rice (90-99%), Fruit (2-20%), Vegetables (2.5-20%), Dairy Cattle (80-90%), Beef Cattle (80-90%), Grain-Livestock (80-95%), Sheep-Beef (80-90%), Sheep (80-90%).

(c) Number of cotton businesses, and area (irrigated and non-irrigated) from ABS 2017, Agricultural Commodities, Australia- 2016-17, for the year 2016/17.

(d) Number of sugar cane businesses, total national area, and area for cane crushing from ABS 2017, Agricultural Commodities, Australia- 2016-17, for the year 2016/17

(e) Chemical cost taken from traditional ratoon gross margin.

(f) Number of rice businesses, and area from ABS 2017, Agricultural Commodities, Australia- 2016-17, for the year 2016/17

(g) Chemical cost taken from NSW Agriculture (2001–2003) Medium Grain Rice Summer Murrumbidgee, gross margin

(h) Number of fruit and vegetable businesses, and area from ABS 2017, Agricultural Commodities, Australia- 2016-17, for the year 2016/17

(i) Gross margin reported for Citrus Production in the MIA, https://www.dpi.nsw.gov.au/agriculture/horticulture/citrus/content/business/business/budget-handbook-and-spreadsheets

(j) Gross margin reported for NSW Agriculture (2001–2003). Fresh winter potato production

Table 18: Loss-expenditure costs (cont)

Industry	Crop and pasture chemical expenditure for weed control ($/ha harvested) for crops and ($/ha operated) livestock enterprises			Industry chemical expenditure for weed control ($ millions)			Non chemical expenditure for weed control ($/ha) k			Industry non-chemical expenditure for weed control ($ millions)			Expenditure for weed control ($ millions)		
	Low	Average	High	Low	Average	High	Low	Average	High	Low	Average	High	Low	Average	High
Wheat / other	58.8	70.5	78.3	888.4	1,066.1	1,184.5	31.7	42.3	52.9	479.7	639.6	799.5	1,368.1	1,705.7	1,984.0
Cotton	74.1	150.0	185.3	38.4	77.8	96.1	11.3	15.0	18.8	5.8	7.8	9.7	44.3	85.6	105.8
Sugar	90.0	100.0	100.0	37.5	41.7	41.7	15.0	20.0	25.0	6.3	8.3	10.4	43.8	50.0	52.1
Rice	90.8	100.9	100.9	7.5	8.4	8.4	45.4	60.5	75.7	3.8	5.0	6.3	11.3	13.4	14.6
Fruit	212.3	283.0	353.8	65.7	87.7	109.6	127.4	169.8	212.3	39.4	52.6	65.7	105.2	140.3	175.3
Vegetables	29.9	47.0	112.2	3.6	5.6	13.4	21.2	28.2	35.3	2.5	3.4	4.2	6.1	9.0	17.6
Dairy Cattle	10.6	12.0	12.0	22.3	25.1	25.1	5.4	7.2	9.0	4.6	6.1	7.6	26.9	31.2	32.8
Beef Cattle	0.1	0.2	0.2	38.1	42.9	42.9	0.1	0.1	0.1	19.3	25.7	32.1	57.4	68.6	75.0
Grain-Livestock	13.5	16.2	18.0	284.3	341.2	379.1	7.3	9.7	12.2	153.5	204.7	255.9	437.9	545.9	635.0
Sheep-Beef	0.9	1.1	1.1	22.1	24.8	24.8	0.5	0.6	0.8	11.2	14.9	18.6	33.2	39.7	43.4
Sheep	1.1	1.2	1.2	37.3	42.0	42.0	0.5	0.7	0.9	18.9	25.2	31.5	56.2	67.2	73.5
Total				**1,445.3**	**1,763.2**	**1,967.5**				**745.0**	**993.4**	**1,241.7**	**2,190.4**	**2,756.5**	**3,209.2**

Notes:
(k). Derived from Sinden et al (2004). The values of non-chemical weed control were include using the ratios outlined by Sinden et al (2004). They included non-chemical costs per $1 of chemical use for Wheat / other crops (0.6), Fruit (0.6), Vegetables (0.6), Dairy Cattle (0.6), Beef Cattle (0.6), Grain-Livestock (0.6), Sheep-Beef (0.6), Sheep (0.6) and Rice (0.6). As in Sinden et al (2004), lower ratios of non-chemical to chemical costs were included for Cotton and Sugar. Cotton was included in this study at (0,1), Sugar (0.2),

Table 18: Loss-expenditure costs (cont)

Industry	Percentage of crop and pasture production lost to weed competition (%)			Industry losses due to weed competition ($ millions)			Control and losses due to weed competition ($ millions)		
	Low	Average	High	Low	Average	High	Low	Average	High
Wheat / other crop [l]	4.5%	6.0%	7.5%	463.1	617.5	771.9	1,831.2	2,323.2	2,755.9
Cotton	4.5%	6.0%	7.5%	82.7	110.2	137.8	126.9	195.8	243.6
Sugar	2.3%	3.0%	3.8%	24.5	32.7	40.8	68.3	82.7	92.9
Rice	1.9%	2.5%	3.1%	4.5	6.0	7.5	15.8	19.4	22.2
Fruit	0.8%	1.0%	1.3%	43.5	58.0	72.5	148.7	198.3	247.8
Vegetables	0.8%	1.0%	1.3%	26.5	35.3	44.1	32.6	44.3	61.7
Dairy Cattle	3.8%	5.0%	6.3%	157.7	210.3	262.9	184.7	241.6	295.7
Beef Cattle [m]	3.8%	5.0%	6.3%	294.8	393.1	491.3	352.2	461.6	566.3
Grain-Livestock [n]	3.8%	5.0%	6.3%	255.1	340.2	425.2	693.0	886.1	1,060.3
Sheep-Beef [o]	3.8%	5.0%	6.3%	88.6	118.1	147.6	121.8	157.8	191.0
Sheep [p]	3.8%	5.0%	6.3%	101.8	135.7	169.7	158.0	202.9	243.1
				1,542.8	**2,057.1**	**2,571.4**	**3,733.2**	**4,813.7**	**5,780.6**

Notes:

(l). Wheat / other crop weed production losses are calculated by attributing beef losses (3%), lamb mutton (15%), wool (13%) and (71%) of wheat and other broad acre crop loss costs. These are the relative receipts of these commodities to the system using average farm data from Agsurf data, averaged 2013-2017

(m). Beef farming weed production losses are calculated by attributing beef losses (76%), lamb mutton (3%), wool (2%) and (1%) of wheat and other broad acre crop loss costs. These proportions are the relative receipts of these commodities to the system using average farm data from Agsurf data, averaged 2013-2017

(n). Grain-Livestock losses are calculated by attributing beef losses (8%), lamb mutton (35%), wool (32%) and (25%) of wheat and other broad acre crop loss costs. These proportions are the relative receipts of these commodities to the system using average farm data from Agsurf data, averaged 2013-2017

(o). Sheep-Beef losses are calculated by attributing beef losses (11%), lamb mutton (17%), wool (17%) and (1%) of wheat and other broad acre crop loss costs. These proportions are the relative receipts of these commodities to the system using average farm data from Agsurf data, averaged 2013-2017

(p). Sheep losses are calculated by attributing beef losses (2%), lamb mutton (30%), wool (36%) and (2%) of wheat and other broad acre crop loss costs. These proportions are the relative receipts of these commodities to the system using average farm data from Agsurf data, averaged 2013-2017

Table 19: Mean annual economic surplus weed costs, 2018

	Average Scenario Elasticity of Supply (e)	Elasticity of Demand (n)	Total Cost of Weeds ($/ha)	Net increase in cost/ton output(K)	Relative Increase in Price(Z)	Net price per Unit ($/tonne)	Quantity of Units (1000 tonnes)	Value of production ($ millions)	Change in Total Surplus ($ millions)	Change in Consumer Surplus ($'millions)	Change in Producer Surplus ($'millions)
Wheat	0.25	6.17	147	0.24	0.01	274	25,320	6,931	1,736	68	1,668
Oats	0.20	2.20	138	0.31	0.03	248	1,428	354	113	9	104
Barley	0.20	2.20	147	0.24	0.02	248	9,651	2,392	593	49	544
Canola	0.20	2.20	154	0.21	0.02	522	3,427	1,791	388	32	356
Lupins	0.20	2.20	139	0.30	0.03	298	689	206	64	5	59
Field Peas	0.20	2.20	142	0.28	0.02	370	308	114	32	3	30
Chickpeas	0.20	2.20	167	0.18	0.01	656	1,046	687	122	10	112
Sorghum	0.20	2.20	166	0.18	0.01	279	1,700	474	86	7	79
Maize	0.20	2.20	251	0.10	0.01	308	428	132	14	1	13
Triticale	0.20	2.20	137	0.32	0.03	226	132	30	10	1	9
Sunflowers	0.20	2.20	148	0.24	0.02	478	24	12	3	0	3
Soybeans	0.20	2.20	180	0.15	0.01	648	40	26	4	0	4
Grain (Subtotal)								**13,147**	**3,166**	**187**	**2,979**
Cotton	1.50	2.20	402	0.07	0.03	2,309	795	1,837	142	58	84
Sugar	0.36	2.20	228	0.08	0.01	32	33,500	1,089	85	12	73
Rice	0.36	2.20	216	0.05	0.01	374	644	241	13	2	11
Fruit	0.20	0.80	523	0.03	0.01	1,531	379	5,982	161	32	129
Vegetables	0.40	0.80	436	0.01	0.00	1,837	192	3,637	52	17	34
Dairy	1.13	3.00	115	0.05	0.02	0.45	9,382	4,207	236	65	172
Beef/Veal	0.10	1.40	2	0.05	0.00	4,185	2,357	9,865	522	35	487
Lambs/Mutton	1.38	1.40	5	0.07	0.03	4,468	706	3,153	221	110	111
Wool	0.90	1.40	5	0.07	0.03	7,689	429	3,297	226	88	137
Total									**4,823**	**605**	**4,218**

Table 19: Low annual economic surplus weed costs, 2018

	Average Scenario Elasticity of Supply (e)	Elasticity of Demand (n)	Total Cost of Weeds ($/ha)	Net increase in cost/ton output(K)	Relative Increase in Price(Z)	Net price per Unit ($/tonne)	Quantity of Units (1000 tonnes)	Value of production ($ millions)	Change in Total Surplus ($ millions)	Change in Consumer Surplus ($'millions)	Change in Producer Surplus ($'millions)
Wheat	0.25	6.17	138	0.23	0.01	274	25,320	6,931	1,653	64	1,588
Oats	0.20	2.20	112	0.25	0.02	248	1,428	354	92	8	85
Barley	0.20	2.20	106	0.18	0.01	248	9,651	2,392	430	36	394
Canola	0.20	2.20	122	0.17	0.01	522	3,427	1,791	311	26	285
Lupins	0.20	2.20	131	0.29	0.02	298	689	206	62	5	56
Field Peas	0.20	2.20	135	0.26	0.02	370	308	114	31	3	28
Chickpeas	0.20	2.20	152	0.16	0.01	656	1,046	687	113	9	104
Sorghum	0.20	2.20	153	0.17	0.01	279	1,700	474	80	7	73
Maize	0.20	2.20	216	0.09	0.01	308	428	132	12	1	11
Triticale	0.20	2.20	121	0.29	0.02	226	132	30	9	1	8
Sunflowers	0.20	2.20	139	0.22	0.02	478	24	12	3	0	2
Soybeans	0.20	2.20	172	0.15	0.01	648	40	26	4	0	4
Grain (Subtotal)								**13,147**	**2,799**	**160**	**2,639**
Cotton	1.50	2.20	434	0.08	0.03	2,309	795	1,837	156	63	93
Sugar	0.36	2.20	202	0.07	0.01	32	33,500	1,089	76	11	65
Rice	0.36	2.20	210	0.05	0.01	374	644	241	13	2	11
Fruit	0.20	0.80	661	0.04	0.01	1,531	379	5,982	204	41	163
Vegetables	0.40	0.80	362	0.01	0.00	1,837	192	3,637	43	14	29
Dairy	1.13	3.00	97	0.05	0.01	0.45	9,382	4,207	200	55	146
Beef/Veal	0.10	1.40	2	0.04	0.00	4,185	2,357	9,865	432	29	403
Lambs/Mutton	1.38	1.40	5	0.07	0.03	4,468	706	3,153	215	107	108
Wool	0.90	1.40	5	0.06	0.02	7,689	429	3,297	197	77	120
Total									**4,336**	**558**	**3,777**

Table 20: High annual economic surplus weed costs, 2018

	Average Scenario Elasticity of Supply (e)	Elasticity of Demand (n)	Total Cost of Weeds ($/ha)	Net increase in cost/ton output(K)	Relative Increase in Price(Z)	Net price per Unit ($/tonne)	Quantity of Units (1000 tonnes)	Value of production ($ millions)	Change in Total Surplus ($ millions)	Change in Consumer Surplus ($'millions)	Change in Producer Surplus ($'millions)
Wheat	0.25	6.17	173	0.28	0.01	274	25,320	6,931	2,017	79	1,939
Oats	0.20	2.20	161	0.36	0.03	248	1,428	354	131	11	120
Barley	0.20	2.20	173	0.28	0.02	248	9,651	2,392	689	57	632
Canola	0.20	2.20	181	0.25	0.02	522	3,427	1,791	451	38	414
Lupins	0.20	2.20	162	0.35	0.03	298	689	206	74	6	68
Field Peas	0.20	2.20	167	0.32	0.03	370	308	114	37	3	34
Chickpeas	0.20	2.20	197	0.20	0.02	656	1,046	687	143	12	131
Sorghum	0.20	2.20	196	0.21	0.02	279	1,700	474	100	8	92
Maize	0.20	2.20	302	0.12	0.01	308	428	132	16	1	15
Triticale	0.20	2.20	160	0.37	0.03	226	132	30	11	1	11
Sunflowers	0.20	2.20	174	0.27	0.02	478	24	12	3	0	3
Soybeans	0.20	2.20	213	0.18	0.01	648	40	26	5	0	4
Grain (Subtotal)								**13,147**	**3,679**	**217**	**3,462**
Cotton	1.50	2.20	852	0.16	0.06	2,309	795	1,837	308	125	183
Sugar	0.36	2.20	452	0.15	0.02	32	33,500	1,089	169	24	146
Rice	0.36	2.20	238	0.06	0.01	374	644	241	15	2	13
Fruit	0.20	0.80	570	0.03	0.01	1,531	379	5,982	175	35	140
Vegetables	0.40	0.80	509	0.02	0.01	1,837	192	3,637	60	20	40
Dairy	1.13	3.00	140	0.07	0.02	0.45	9,382	4,207	285	78	207
Beef/Veal	0.10	1.40	3	0.06	0.00	4,185	2,357	9,865	633	42	591
Lambs/Mutton	1.38	1.40	6	0.08	0.04	4,468	706	3,153	257	128	130
Wool	0.90	1.40	6	0.08	0.03	7,689	429	3,297	263	103	160
Total									**5,845**	**774**	**5,071**

Table 21: Variable cost assumptions

Gross margin	Insecticide and fungicide chemical and application ($/ha)	Expenditure for weed control ($/ha).	Total variable cost ($/ha)	Notes
Long Fallow Wheat (central east NSW), 2012	17.0	High: 130 Base: 113 Low: 62	High:518 Base: 501 Low 450	The gross margin was prepared by NSW DPI in 2012. It noted that weed control, if required, should be implemented either pre-emergent or within 4 to 6 weeks after sowing to limit yield loss. Chemical and application costs were estimated at $62/ha. In the central east of NSW, short fallow had herbicide cost of $60 per hectare while $58 was estimated for dryland NSW. Flood irrigated wheat in the Murray was estimated to have herbicide cost of $49Non chemical costs include 0.03 input of machinery at 0.03 hours per hectare applied 4 times (0.12 hours' total). These costs are less than those calculated by Llewellyn et al (2016) across for all grain broad acre crops. They estimated an average total control cost of $113/ha which included in-season and fallow herbicides, application, weed resistance and integrated weed management practices. Base and high weed cost estimates utilise the $113/ha estimate, while a low scenario assumes weed control cost of $62 using DPI estimates. It is evident that chemical costs per hectare are dominated by herbicides, as insecticide and fungicide chemical and application costs are limited. Losses include an allowance of 3% for crop levies and insurance.
Short Fallow Oats for Grain (central east NSW), 2012	8.9	High: 130 Base: 113 Low: 36	High: 373 Base: 356 Low: 279	Base and high weed control cost estimates utilise the industry-wide $113/ha estimate by Llewellyn et al (2016) across all broad acre grain crops, while a low scenario uses DPI estimates specific to fallow-oats. The gross margin was prepared by NSW DPI in 2012 for short fallow oats (fallow of 5-6 months between crops). A total variable cost of $279 was estimated, with about $16/ha estimated for weed control. Weed costs vary by region and for grain/grazing systems. For example, short fallow [No-till] in the Central Zone - West had herbicide costs of $4.1, whereas in some areas an additional knockdown herbicide application (i.e. glyphosate 540 g/L @ 1.0 L/ha) was included. Irrigated oats in the Murray had herbicide costs of $42. This included fallow broadleaf and grass weed control eg ground spray glyphosate 450 in Dec/Jan and Pre-sowing weed control (Glyphosate) in April/May of nearly $30. It is evident that chemical costs per hectare are dominated by herbicides, as insecticide and fungicide chemical and application costs are limited. Loss estimates include an allowance of 3% for levies and insurance.
Feed Barley (north west NSW), 2012	0.0	High: 130 Base: 113 Low: 73	High: 251 Base: 234 Low: 194	Base and high weed control cost estimates utilise the industry-wide $113/ha estimate by Llewellyn et al (2016) across all broad acre grain crops, while a low scenario uses DPI estimates specific to feed barley. The gross margin was prepared by NSW DPI in 2012 for feed barley in NW NSW, with no till. Black oat control costs were not included in budget. The authors noted Barley is more competitive with weeds than wheat. Barley, although short fallow (No-till) Barley was estimated to have similar herbicide costs of $72/ha in dryland central region. Production in the Dryland central west area had higher herbicide cost of $80, as an additional knockdown herbicide application (i.e. glyphosate 540 g/L @1.0 L/ha) was included in the budget for that region. Flood Irrigated - Border Check / Direct Drill had an herbicide budget of $66 per hectare. It is evident are nil. Loss estimates include an allowance of 3% for levies and insurance.

Table 22: (cont)

Gross margin	Insecticide and fungicide chemical & application ($/ha)	Expenditure for weed control ($/ha)..	Total variable cost ($/ha)	Notes
Long Fallow Canola (Dryland central), 2012	51.2	High: 130 Base: 113 Low: 56	High: 656 Base: 639 Low: 582	Base and high weed control cost estimates utilise the industry-wide $113/ha estimate by Llewellyn et al (2016) across all broad acre grain crops, while a low scenario uses DPI estimates specific to canola. The gross margin was prepared by NSW DPI in 2012 for Long Fallow Canola (Dryland central) after Lucerne. The variable cost with weeds was estimated at $582/ha. Clopyralid was assumed for broadleaf weed control (capeweed, skeleton weeds and saffron thistle). Weed control costs vary by system and region. For example, $68/ha was included for short fallow in same region. This budget included Trifluralin as a pre-emergent for selected grass and broadleaf weeds. Dryland canola in NSW had herbicide costs of $47/ha, and the Irrigated Murray herbicide costs of $24/ha.
Lupins (Dryland no-till NW NSW), 2012	26.4	High: 130 Base: 113 Low: 80	High: 346 Base: 329 Low: 296	Base and high weed control cost estimates utilise the industry-wide $113/ha estimate by Llewellyn et al (2016) across all broad acre grain crops, while a low scenario uses DPI estimates specific to lupins. The gross margin was prepared by NSW DPI in 2012. The with weeds variable cost was $296/ha. The authors noted that weeds must be controlled as lupins are poor competitors Costs of around $80/ha included Simazine pre-emergent herbicide treatment to control capeweed and ryegrass. Costs by region varied to some degree. Broad leaf direct drill in SE zone have herbicide of $79, which was similar to narrow leaf lupins. Loss estimates include an allowance of 3% for levies and insurance. It is evident that chemical costs per hectare are dominated by herbicides, as insecticide and fungicide chemical and application costs are limited.
Field Peas (Short fallow, Central East, No till)	20.6	High: 130 Base: 113 Low: 47	High: 491 Base: 474 Low: 408	Base and high weed control cost estimates utilise the industry-wide $113/ha estimate by Llewellyn et al (2016) across all broad acre grain crops, while a low scenario uses DPI estimates specific to field peas. The gross margin was prepared by NSW DPI in 2012. The with weeds variable cost was $408/ha The authors noted weed control involves grass control with fluazifop, haloxyfop, quizalafop-ethyl or sethoxydim. While Metribuzin may be used for broadleaf weed control. Dryland field peas had an after wheat herbicide cost of $86, with Haloxyfop-R being used for grass weed control. It is evident that chemical costs per hectare are dominated by herbicides, as insecticide and fungicide chemical and application costs are limited.
Chickpeas (Short fallow, no till. Central East NSW)	120.0	High: 130 Base: 113 Low: 76	High: 541 Base: 524 Low: 487	Base and high weed control cost estimates utilise the industry-wide $113/ha estimate by Llewellyn et al (2016) across all broad acre grain crops, while a low scenario uses DPI estimates specific to chick peas. The gross margin was prepared by NSW DPI in 2012. The authors noted Chickpeas are poor weed competitors, with Chloro and a pre-emergent broadleaf herbicide being needed. Optional grass control with fluazifop, haloxyfop, quizalafop, sethoxydim or clethodim herbicides was also noted – noting the crop is sensitive to sulfonylurea herbicide residues. For the central west, an additional knockdown herbicide application (eg. glyphosate 540 g/L @ 1.0 L/ha) was included, while Surface irrigated Murray included herbicide costs of $167/ha.

Table 22: (cont)

Gross margin	Insecticide and fungicide chemical and application ($/ha)	Expenditure for weed control ($/ha).	Total variable cost ($/ha)	Notes
Sorghum (No till, NSW NW), 2013	0.0	High: 130 Base: 113 Low: 118	High: 249 Base: 232 Low: 237	Base and high weed control cost estimates utilise the industry-wide $113/ha estimate by Llewellyn et al (2016) across all broad acre grain crops, while a low scenario uses DPI estimates specific to sorghum. The gross margin was prepared by NSW DPI in 2013. The authors noted no-till sorghum requires a high level of management and greater input of herbicide and fertiliser than "conventional tillage" sorghum. A with weed production cost of $237/ha was estimated, of which $118/ha was for weed control. A similar cost of $120/ha was estimated for NE NSW. This includes a contract group spray rate of $10/ha being assumed. The costs of production without weeds is estimated to be $119/ha. It is evident that chemical costs per hectare are dominated by herbicides, as insecticide and fungicide chemical and application costs are nil.
Maize (No-till NE NSW)	0.0	High: 130 Base: 113 Low: 110	High: 603 Base: 586 Low: 583	Base and high weed control cost estimates utilise the industry-wide $113/ha estimate by Llewellyn et al (2016) across all broad acre grain crops, while a low scenario uses DPI estimates specific to maize. The gross margin was prepared by NSW DPI in 2013. The with weeds variable cost was $583/ha. The herbicide s-metolachlor+atrazine is typically used for grass and broadleaf weed control in irrigated maize. This system has a lower herbicide cost of $89/ha. It is evident that chemical costs per hectare are dominated by herbicides, as insecticide and fungicide chemical and application costs are nil.
Triticale (Short-fallow CE NSW). 2012	0.0	High: 130 Base: 113 Low: 63	High: 369 Base: 352 Low: 302	Base and high weed control cost estimates utilise the industry-wide $113/ha estimate by Llewellyn et al (2016) across all broad acre grain crops, while a low scenario uses DPI estimates specific to Triticale. The gross margin was prepared by NSW DPI in 2012 for short fallow production, which entails 5-6 months between crops. Weed control costs are $53/ha in the Central East and $75/ha in dryland SE NSW. Loss estimates include an allowance of 3% for levies and insurance. It is evident that chemical costs per hectare are dominated by herbicides, as insecticide and fungicide chemical and application costs are nil.
Sunflowers (No-till, NE NSW)	46.0	High: 130 Base: 113 Low: 78	High: 513 Base: 496 Low: 461	Base and high weed control cost estimates utilise the industry-wide $113/ha estimate by Llewellyn et al (2016) across all broad acre grain crops, while a low scenario uses DPI estimates specific to sun flowers. The gross margin was prepared by NSW DPI in 2013 for NE NSW. The variable cost with weeds was estimated at $461/ha. Herbicide costs are estimated to be similar at $91/ha in the NW. Loss estimates include an allowance of 3% for levies and insurance
Soybeans (No-till NE NSW)	79.0	High: 130 Base: 113 Low: 101	High: 423 Base: 405 Low: 393	Base and high weed control cost estimates utilise the industry-wide $113/ha estimate by Llewellyn et al (2016) across all broad acre grain crops, while a low scenario uses DPI estimates specific to soybeans. The gross margin was prepared by NSW DPI in 2013 for NE NSW. The variable cost with weeds was estimated at $393/ha and without weeds $283/ha. Paraquat + diquat is included as a double-knock for herbicide resistance management. Loss estimates include an allowance of 3% for levies and insurance.
Cotton (Furrow Irrigated Cotton, (2018)	581	All: ~160-65	All: 3,275	The gross margin was prepared by the cotton industry's joint extension program, CottonInfo. The variable cost with weeds was estimated at $3,725/ha and without weeds $283/ha. The net loss includes an allowance for picking, cartage and ginning. Chemical costs do not include ABARES reported cotton is grown across 0.5 million hectares in 2018, with an average lint yield of 2.1t/ha and average gross value of $5,832/ha. Averages for the 5-years into 2018 are reported in the calculations.

Table 22: (cont)

Gross margin	Insecticide and fungicide chemical and application ($/ha)	Expenditure for weed control ($/ha).	Total variable cost ($/ha)	Notes
Sugar, Queensland, 2003	0	120	1,271	ABARES reported 0.4 million hectares cropped in 2018, with an average yield of 88t/ha of cane (12.41 t sugar/ha) at an average gross value of around $3 thousand per hectare. An average cost of $1,271 per hectare with weeds is included in the cost analysis. Sugar Research Australia estimated the average value of lost yield due to sub-optimal weed management to be $338/ha, or $70 million in 2008.
Rice (Medium Grain, NSW), 2016-17	0	125	1,277	The gross margin is taken from the NSW DPI 2016-2017, Rice growing guide. The average rice yield in Australia is around 10t/ha. The medium grain gross variable costs for drill sown Reiziq, Langi and Opus rice crop was around $1,277. The authors noted ensuring seedbeds are free of weeds and preventing subsequent weed establishment for approximately 50 days' post sowing is important in attaining the best yield potential of any rice crop. Weed control costs were estimated at $100/ha. Harvest costs around $25/t.
Fruit (Citrus)	688	453	4,037	The value of fruit produced and area under operations were taken from ABARES. Sinden used proxy gross margins for fruit and vegetables given the diverse types of products under this category. For fruit, citrus was used. Weed control costs were estimated to be $283/ha from the overall variable cost of $4,037 per hectare taken from the Sunraysia citrus development budget year 11 to 21. NSW DPI 2018. The non-chemical component was included using the $0.6 delivery per $1 of chemical assumption from Sinden et al (2004).
Vegetable (Potato)	327	75	13,105	Sinden used proxy gross margins for fruit and vegetables given the diverse types of products under this category. For vegetable, potatoes were used. Weed control costs were estimated to be $75/ha from the overall variable cost of $13,105 per hectare taken from NSW DPI 2015, potato fresh winter gross margin analysis. The non-chemical component was included using the $0.6 delivery per $1 of chemical assumption from Sinden et al (2004).
Dairy Cattle	1.2	19	2,053	ABARES estimate that the dairy industry had a gross value of $4.3 billion in 2018, producing 9,250 ML of milk. Based on an area of production of 2 million hectares, this is equivalent to 0.004 ML per hectare. ABARES Agsurf estimated cash costs to be $2,053 per hectare operated over the last 5 years. It's estimated that weed chemical and application costs are around $19/Hecate using ABARES Agsurf data and attribution assumptions from Sinden et al (2004).
Beef Cattle	0.0	0.3	16.8	ABARES Agsurf estimated cash costs to be $17 per hectare operated for beef producers over the last 5 years. It's estimated that weed chemical and application costs are around $0.3/Hecate using ABARES Agsurf data and attribution assumptions from Sinden et al (2004).
Sheep	0.1	1.9	50.2	ABARES Agsurf estimated cash costs to be $50 per hectare operated for sheep producers over the last 5 years. It's estimated that weed chemical and application costs are around $1.9/Hecate using ABARES Agsurf data and attribution assumptions from Sinden et al (2004).

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