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The use of chemical pesticides by the Australian plantation forest industry

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The use of chemical pesticides by the Australian plantation forest industry

Prepared for the

Forest & Wood Products
Research & Development Corporation

by

B.M. Jenkin and B. Tomkins

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Dedication

The origins of this study (in part) start in 1983, when Dr Les T. Carron emphasised to his Australian National University D48 (Forest Policy, Administration and Management) students the need for *all professional foresters* to have an armoury of cocktail party figures at their finger tips to both counter and inform those with whom they come into contact.

Acronyms

1R	First rotation
2R	Second rotation
a.c.	Active constituent
a.i.	Active ingredient
AAAA	Aerial Agricultural Association of Australia
ABARE	Australian Bureau of Agricultural and Resource Economics
ABS	Australian Bureau of Statistics
AFS	Australian Forestry Standard
APVMA	Australian Pesticides and Veterinary Medicines Authority
CDA	Control droplet application
DSE	Dry sheep equivalent
EHS	Environmental health and safety
FSC	Forest Stewardship Council
FWPRDC	Forest and Wood Products Research and Development Corporation
GDP	Gross domestic product
GRWE	Gross roundwood equivalents
MAI	Mean annual increment
ME	Metabolisable energy
MSDS	Material safety data sheet
NFI	National Forest Inventory
NRA	National Registration Authority
OHS	Occupational Health and Safety
PEFC	Programme for the Endorsement of Forest Certification
PGR	Plant growth regulator
PIRI	Pesticide impact rating index
PISC	Primary Industries Standing Committee
SA	Standards Australia
SD	Statistical Division
ULV	Ultra low volumes
VRT	Variable rate technology
WDH	Water dispersible herbicide

Executive summary

It is important to provide an informed contextual framework for any discussion or debate concerning the Australian plantation forestry industry. Recent studies have considered socio-economic and water related issues as they relate to the operations and effects of the industry on rural and regional areas. The use of chemical pesticides by the Australian plantation forestry industry is another issue requiring the same level of analysis and understanding. The Forest and Wood Products Research and Development Corporation (FWPRDC) with industry support, initiated this study to develop such an understanding.

The study utilised published information on a range of issues relating to chemical pesticide use and attributes, made contact with industry experts and conducted a comprehensive and confidential industry survey. The industry survey collected responses from plantation forestry managers covering over 92% of the Australian plantation forestry estate. The information provided gave details of the type, rates of application and scale of use across a range of species and sites. The information was used to help profile the active ingredients (a.i.) and rates used by the industry. It was also the basis of the development of comprehensive chemical pesticide use models for six zones across Australia. The six zones were defined based on combined National Forest Inventory (NFI) zones and the Statistical Divisions (SD) used by the Australian Bureau of Statistics (ABS) to report on farming practices. The NPI zones and ABS SD maps were overlayed to determine the logical combinations of the two sets of spatial data into the six combined zones. The combined zone mapping was then commissioned to be produced by the NPI. The farming data for the ABS SD was purchased and aggregated based on the six combined zones.

The scale of the Australian plantation industry is 1,716,173 net ha of plantations as of December, 2005 as reported by the NFI. The ABS census reports on 440,109,578 ha (capturing data for 99.3% of that area) Of the 168 million hectares of non-rangeland management land across Australia, the plantation forestry estate represents around 1% of that area. The main land uses are meat cattle (42.1%), sheep and lambs (13.3%), cereals for grain (11.9%) and dairy cattle (1.5%). The balance of the land (30.2%) is used for a range of horticulture and other agricultural pursuits.

The regulatory framework for chemical pesticide use in Australia was considered. Information was collected from the Australian Pesticides and Veterinary Medicines Authority (APVMA) on the process of chemical registration and label controlled use. The APVMA is the body responsible for agricultural and veterinary chemicals. The process applied by the APVMA is consistent across all uses and users of chemical pesticides. Registration of an a.i. involves three years of field testing and analysis for a new a.i. and two years of testing to register a new use of an existing a.i.. In the case of the a.i. used by the Australian plantation forestry industry, only one (sulfometuron methyl) was not developed for agricultural production systems. With the exception stated, all other a.i. used by the plantation forestry industry are used by agriculture for food production. Of the 13 most used a.i. (based on spend) five are available for unrestricted purchase from hardware stores and supermarkets. A key driver of the need for the plantation forestry industry to adapt for use a.i. developed for other uses is that the scale of the plantation forestry market is too small to warrant the significant cost of specific a.i. development and registration.

There has been a large volume of scientific and published (peer reviewed) research considering the issue of weed and pest control in plantation forestry. Weeds in a plantation may compete for water, nutrients and space. Pest insects and browsing animals may defoliate or eat the entire planted tree. The two key issues addressed have been the impact on survival of the planted trees and where the trees do survive, the change in growth rates due to competition and physical damage. For example, effective weed control has been shown to improve growth rates by 120% over an untreated control as assessed by volume in a softwood plantation. In the case of 66% insect defoliation in eucalypt seedlings, a loss of growth resulted where the defoliation occurred multiple times in the one season.

The plantation forestry industry has focussed research and development on how to use the a.i. developed for other uses. This has included the adaptation of application technology and the development of new technology. Delivery systems such as dry granule application were introduced utilising proprietary a.i. mixes to be applied over the top of the planted trees. The granules activate once they become moist and begin to release the a.i. contained within. Plantation forestry specific systems have been developed to address issues such as culling non-crop trees within plantations (e.g. silver wattle in a radiata pine plantation).

Plantation forestry varies in scale and intent across Australia, and with that variation in estate size, the realistic options to manage or react to issues will vary. In the case of small estates, it may be possible to conduct manual / non-chemical pesticide forestry (e.g. hand weeding or tree guards to stop browsing animals). Whereas in a large scale industrial plantation (scale of the tasks and the limited window of opportunity), mechanical application of chemical pesticides is required. Further, the production rates (area treated per hour) of aerial application methods allow rapid response to pest insect out-breaks or to apply herbicides during limited fine weather (e.g. in autumn). Once the trees are planted, access restrictions due to the “crop height” further makes aerial application an invaluable tool. A total of 10 million hectares per year is treated by aerial application across Australia, and of that area, less than 0.5% is for the plantation forestry industry.

The usual chemical pesticide regime as applied to forest plantations is to apply herbicides in the first two years and insecticides in response to pest out-breaks. The a.i. used is a function of the target pest, the crop tree species and the climate. A range of regimes is discussed. Weed control usually takes place pre-plant as an initial site clean-up to remove difficult to kill species prior to planting the crop trees. This is usually applied broadcast. After cultivation works, the planting lines may be strip sprayed (e.g. treating 50% of the net planted area) or the site broadcast sprayed. Once planted and depending on weed growth, follow-up weed control may be required in the same planting season or later in the following year. The a.i. used and the rates will be a function of the a.i. and rates of the previous treatment. That is, if a site is well cleaned up initially, there may be reduced need to do other applications.

The plantation forestry approach contrasts with the annual use of chemical pesticides in agriculture (in many crops). Specific analysis is included in the report to compare the chemical pesticide inputs to manage a Tasmanian blue gum plantation, compared to a banana plantation and an onion growing enterprise. In the case of the Tasmanian blue gum plantation, weed control occurs in the first two years and then does not occur again till the crop is harvested and a new crop planted in the eleventh year after the initial plantation development. In the scenario presented, the plantation required insecticide application at age 3 years. Contrast this to a banana plantation with annual repeated applications of herbicides, insecticides and fungicides over the seven years of the crop, or an annual onion enterprise with multiple applications of herbicides, insecticides and fungicides. If an estate is developed of the three crops by planting 100 ha per year for 10 years (up to a total estate of 1,000 ha), the total chemical pesticide input for the three crops would be:

- Tasmanian blue gum plantation: $10,918 /yr (or $10.92 /ha/yr);
- Onions: $933,340 /yr (or $933.34 /ha/yr);
- Banana plantations: $1,979,081 /yr (or ($1,911.08 /ha/yr).

The rate of application of chemical pesticides is legally controlled by the requirements stipulated on the product label. The label rates are the maximum rates allowed. In practice, the plantation forestry industry has developed regimes that may utilise the a.i. up to that maximum rate, but the financial imperative to reduce the cost of inputs means that often the application is at less than that allowed maximum. The results of the industry survey indicated that for all a.i. in use (except simazine), the actual application rate was at less than 50% of the allowed maximum in more than 50% of applications considered. In the case of simazine, more than 50% of the applications considered were at less than 70% the maximum allowed.

The true measure of chemical pesticide use is the rate per hectare combined with the total hectares treated. For atrazine, the maximum allowed rate for plantation forestry is 8 kg a.i./ha. The survey showed a maximum use rate of 5.6 kg a.i./ha. For canola cropping in Western Australia, for example, it may be applied twice per crop at 1.0 kg a.i./ha. For 2005, the industry survey showed that the W.A. plantation industry used 7,444 kg a.i. of atrazine. The W.A. canola industry for 2003 - 04 produced 318,002 ha of crops, to which an estimated 636,000 kg a.i. of atrazine may have been applied or greater than 80 times the amount used by the plantation forestry industry in W.A.

The APVMA maintains and reports on the total chemical pesticide market in Australia. For 2004, the total spend on chemical pesticides was $2.45 billion. This total includes uses such as domestic insecticides ($105.4 million). The information is not presented on a sector basis. In order to estimate the plantation forestry use within that framework, the following was undertaken:

- Analysis of the industry survey: total spend for 2005 $16.2 million after *pro rata* adjustment to 100% of the estate;
- A simple model of plantation forestry spend to estimate the maximum (based on maximum product label rates and /or industry best practice): total spend for 2005 of $20.9 million;
- Detailed models of each of the six zones aggregated into an estimated total spend for 2005 of $16.4 million.

The analysis showed that the total spend by the plantation forestry industry is around 0.7% of the total Australian spend. The results of the analysis further indicates that the Australian plantation forestry industry frequently uses chemical pesticides at less than the label maximums allowable.

In terms of the use of sodium fluoroacetate (1080), 200 kg was used across Australia in 2003 – 04. The industry survey indicated that the plantation forestry sector use was 5.5 kg in 2005 to destroy declared pest animals (e.g. rabbits) and native browsing animals which damage plantations trees. An additional 8.8 kg of 1080 was used to destroy foxes and pigs to comply with legal requirements and to effect good land management.

Water monitoring is a tool used to detect a.i. movement after chemical pesticide applications. The Tasmanian Department of Primary Industries and Water (DPIW) has a comprehensive set of 54 water monitoring sites across Tasmania and water samples are collected to test for 19 a.i.. The sample sites cover all land uses in the catchments tested. Sampling commenced in January 2005 with nil detections. Samples are taken on a quarterly basis and up to seven rounds have been concluded with four detections (see the report for details). A similar initiative in the cotton growing areas of Queensland showed a 100% (13 samples) rate detection of atrazine for 2000 – 01. Time series data for cotton production areas of the Macintyre, Gwydir, Namoi and Macquarie valleys showed a decline in the detection rate for atrazine from 46% in 1991 – 92 (296 samples) down to 19.8% in 2002 – 03 (348 samples). Individual plantation forestry managers conduct water samples associated with operations and report these as part of sustainable forest management reports.

The plantation forestry industry continues to develop alternatives to chemical pesticide use. This is to comply with the requirements of forest certification and to reduce the cost of production. Innovations such as mechanical barriers to insect pests on seedlings have been implemented. Given the potential for new pests, in particular insects, it is imperative that the plantation forestry industry maintains access to a range of a.i. and products able to be applied by a range of techniques. This imperative is reinforced by the need for plantation managers to move into new areas with new species to continue to expand the Australian plantation estate.

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Introduction

An enhanced understanding

The plantation forestry industry has developed a series of key reports to help inform the industry and the wider community. For example, socio-economic studies such as Petheram *et al.* (2000) and more recently Schirmer *et al.* (2005), have contributed greatly to understanding the benefits of plantation forestry in a regional context. Water use by forest plantations and associated issues were reviewed by Keenan *et al.* (2004). The use of chemical pesticides is sometimes a matter of public scrutiny. An understanding of chemical pesticide input statistics for plantation forestry is therefore important to add to the contextual framework for informed discussion. Chemical pesticide use is a function of legal, crop and pest issues. To help in understanding, the ability to compare chemical pesticide input statistics for plantation forestry to other land uses adds to the contextual framework. Application technique (ground or aerial) and coverage (target plant, spot, strip or broadcast) varies with situation (crop and pest) and overall crop management. This study reviewed and assessed the:

- Regulatory controls at Federal, State and Local Government levels;
- The evolution of and change in chemical pesticide use by Australian agriculture and in plantations to provide a historical/contextual framework;
- Use in plantation and agricultural crops industries;
- Potential management regimes.

Chemical inputs defined

The Oxford Dictionary (Pearsall and Trumble, 1996) defines a "*pesticide*" as:

> *"A substance used for destroying insects or other organisms harmful to cultivated plants or to animals."*

It is necessary to further define the term '*pesticide*' used in the context of plantation forestry. A broad definition used in this report is:

> *Any chemical or chemical mixture used for controlling weeds, insects, fungi, nematodes and animals, which adversely affect growth (quantity and quality) and the health of plantations.*

Pesticides are usually subdivided into groups depending on target organisms, or by their action on living organisms. The main subdivisions are:

- Herbicides;
- Insecticides (including miticides, nematicides, molluscicides);
- Fungicides;
- Rodenticides;

- Plant regulators;
- Defoliants;
- Desiccants and anti-transpirants;
- Other types of poisons and repellents;
- Adjuvants (all additives to chemical pesticides mixtures);
- Animal health products.

In some instances pesticides are mixed with adjuvants. The role of an adjuvant is to enhance the action of the pesticide on the target organism.

The pesticide chemical that is active (i.e. affects the outcome) is called the “active ingredient” (a.i.) or active constituent (a.c.) (a.i. will be used in this report). It is usually mixed with other ingredients (e.g. solvents, fillers, surfactants, emulsifiers, dyes, etc) which commonly have no pesticide activity themselves. The purpose of the other ingredients is to act as carriers or to enhance the effectiveness of the a.i. Therefore, most preparations are less than 100% a.i. It is important to understand that many products with the same a.i. may have different concentrations of the a.i. Hence in this report, chemicals will be reported on an a.i. basis unless otherwise specified. For example, a glyphosate product may be purchased at 7.2, 360, or 450 g/L of a.i. of glyphosate salt.

Previous studies in Australia

Flinn and Fagg (1984) reviewed weed control practices in Australian radiata pine (*Pinus radiata*) plantations, and the costs for six State forest agencies and nine companies, representing 95% of the plantation area at that time. The review covered the major weed problems, herbicides then in use, and the techniques of application. Much has changed, however, in the more than 20 years since that review, especially in relation to new herbicides, new application technology, greater emphasis on OH & S and stricter regulation and environmental controls.

Hall (1987) reviewed weed control practices in Australian forestry, with a substantial section of the review centred on plantation forestry. He noted that there was a lack of data on the effects of chemical weed treatment on long-term plantation growth, and that forestry represented only a small market for chemicals, leading to a lack of interest in product development and registration by the chemical companies at that time. Forestry weed research was identified as being very *ad hoc* and applied, and the extrapolation and identification of general principles as difficult.

Lewty (1993) reviewed aspects of plantation weed control in Australia, in particular looking at the practices then current, research activities and future directions. He also identified areas of deficiencies in plantation weed control and a number of emerging areas. Important among these was ‘a developing trend where there is a lack of research capacity (e.g. staff) to fully evaluate new products’. Another development has been the trend away from ‘open’ research leading to the peer reviewed publication of results in the scientific literature, to research conducted on a commercial basis, supported by State forestry organisations and companies, and the chemical companies.

Methods

Analysis basis

The outcomes reported are split into two areas: a comprehensive set of overall plantation forestry chemical pesticide use information and an estimate of the specific use across a series of zones to provide a "local" contextual framework of comparative use. To undertake the analysis, data were required on land use areas and the chemical pesticide inputs required. In order to build up a profile to put plantation forestry use patterns into context, the following approach was taken in the report (based on Jenkin, 2004).

Chemical pesticide use = the area treated * units/ha

General information

A wide range of sources of general information was used in the study and these are identified throughout the report.

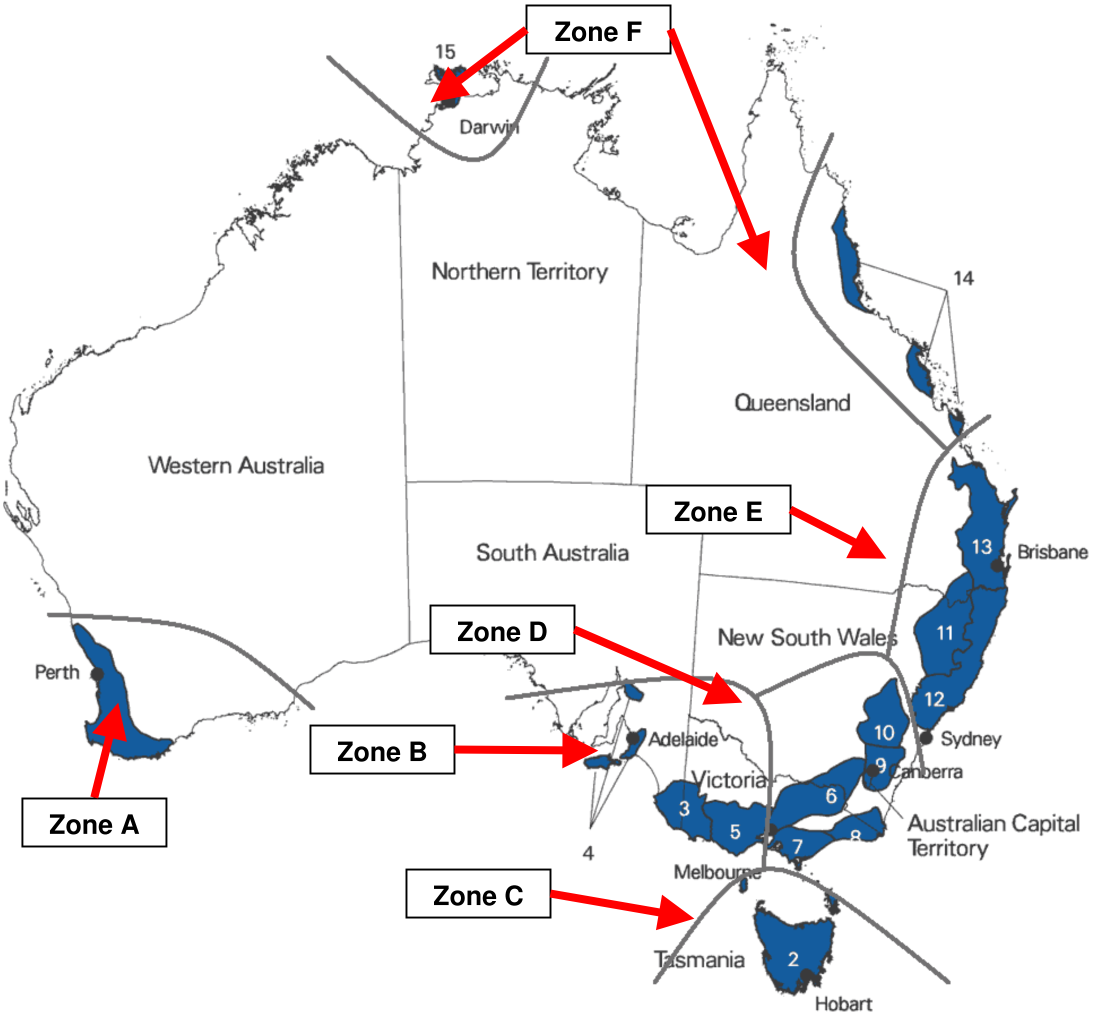
Land use areas

In order to generate regional chemical pesticide use profiles, the study utilised Australian Bureau of Statistics (ABS) and National Forest Inventory (NFI) land divisions to create six zones. Plantation forestry total estate areas and new plantation area statistics were sourced from the NFI report (based on 15 zones: Wood *et al.,* 2001). The NFI regions cross state boundaries. Map 1 shows the NFI zones and Table 1 the region names. Agricultural land use statistics were purchased from the ABS. The statistics were from the 2003 – 04 farm census. Farm census surveys are sent to all registered farms and it is mandatory to complete and return the forms. The data is collected every 2 years. (For full details, visit the ABS web site www.abs.gov.au.) The land use statistics were collected at the Statistical Division (SD) level.

The SD level data spatial arrangement does not correspond with the NFI zones. To address this issue, the NFI zones were combined based on logical boundaries to match combined ABS SDs zones. Map 1 and Table 2 shows the combined zones used in the study. It must be noted that where NFI plantations were shown in an ABS SD, all the SD was included in that zone.

Industry Survey

A commercial in confidence survey was conducted of a wide range of plantation managers to determine the nature of chemical pesticide use. The survey collected data on the active ingredients used, the areas treated and the costs. The survey respondents manage in excess of 92% of the Australian plantation forestry estate. Appendix A contains the survey details and respondents.



Map 1 A summary of the NFI/SD combined zones for market analysis and reporting. (Based on Wood *et al.,* 2001).

Chemical pesticide inputs

Plantation forestry

The industry survey provided detailed information on chemical pesticide use. This was followed up with interviews with industry to identify chemical pesticide management regimes for softwood and hardwood plantations in the different regions. As well, based on industry specific experience, the survey and interview data were combined to generate the plantation management chemical pesticide regimes. The hardwood regimes were split into short rotations (e.g. Tasmanian blue gums: *Eucalyptus globulus*, pulpwood only crops with a 10 year rotation) and long rotation (e.g. shining gum: *E. nitens*, solid wood and veneer crops with a 25 year rotation). The softwood regime is a longer rotation crop to produce sawlogs (e.g. radiata pine 30 years).

Table 1 NFI zone codes as shown in Map 1 and based on Wood *et al.* (2001)

	Name
1	WA
2	Tasmania
3	Green Triangle
4	Lofty Block
5	Central Victoria
6	Murray Valley
7	Central Gippsland
8	East Gippsland/Bombala
9	Southern Tablelands
10	Central Tablelands
11	Northern Tablelands
12	North Coast
13	SE Queensland
14	North Queensland
15	Northern Territory

Crops and horticulture

Generic crop management regimes were sourced covering the main agricultural crops in the different zones. The main source of information was from State Government agencies published gross margin reports (e.g. DoA WA, 2006a; DoA WA, 2006b: canola cropping in Western Australia, the Department of Agricultures web site at www.agric.wa.gov.au). As part of the gross margin analysis, chemical pesticides inputs are defined (in some instances with the specific product listed and in others, as a generic cost). Chemical pesticide inputs collated were herbicides, insecticides, fungicides and animal health products. The gross margins used were matched as closely as possible to the conditions of the six zones in the absence of a crop and zone specific gross margin. It is acknowledged that this was a generic approach, but it allowed the development of broad statistics.

Livestock

The ABS provided data on livestock numbers in the SDs. To convert the livestock numbers to an area basis requires details of stocking rates. Animal stocking rates are driven by the ability to feed (energy requirements) and water the livestock. Energy requirements are expressed as metabolisable energy (ME) measured in megajoules (MJ). A common practice is to express stocking rates based on a standard animal for a set period of time. The benchmark unit is a dry sheep equivalent (DSE) (Malcolm *et al.*, 1996). For example, Malcolm *et al.* (1996) lists a 450 kg dry beef animal as having a DSE rating of 6, or 6 standard sheep animals. Specific carrying capacity data was collected from the range of agricultural references as listed.

Table 2 The combined NFI and ABS spatial data units to give the zones used in this analysis.

Report zones	NFI Zones	ABS Code	State	Statistical Division
A	1	505	WA	Perth
		510	WA	South West
		515	WA	Lower Great Southern
		520	WA	Upper Great Southern
		525	WA	Midlands
		530	WA	South East
B	3,4,5	210	Vic	Barwon
		215	Vic	Western District
		220	Vic	Central Highlands
		225	Vic	Wimmera
		230	Vic	Mallee
		235	Vic	Loddon
		405	SA	Adelaide
		410	SA	Outer Adelaide
		415	SA	Yorke and Lower North
		420	SA	Murray lands
		425	SA	South East
		430	SA	Eyre
		435	SA	Northern
C	2	605	Tas	Greater Hobart
		610	Tas	Southern
		615	Tas	Northern
		620	Tas	Mersey - Lyell
D	6,7,8,9,10	115	NSW	Illawarra
		135	NSW	North Western
		140	NSW	Central West
		145	NSW	South Eastern
		150	NSW	Murrumbidgee
		155	NSW	Murray
		205	Vic	Melbourne
		240	Vic	Goulbourn
		245	Vic	Ovens - Murray
		250	Vic	East Gippsland
		255	Vic	Gippsland
		805	ACT	Canberra
		810	ACT	ACT balance
E	11,12,13	105	NSW	Sydney
		110	NSW	Hunter
		120	NSW	Richmond - Tweed
		125	NSW	Mid North Coast
		130	NSW	Northern
		305	Qld	Brisbane
		310	Qld	Moreton
		315	Qld	Wide Bay - Burnett
		320	Qld	Darling Downs
F	14,15	330	Qld	Fitzroy
		340	Qld	Mackay
		345	Qld	Northern
		350	Qld	Far North
		705	NT	Darwin
		710	NT	NT Balance

Forest plantations overview in the national land use context

Australian land use

The total area of Australia is 7,692,024 km^2 or 769 million ha (Geosciences Australia, 2006). The Australian Bureau of Statistics (ABS) reports on an area of 440,109,578 ha, and has captured land use data for 437,107,239 ha for 2003 - 04 (ABS, 2006). It is estimated based on ABS specific statistics (for non-livestock enterprises) and by applying stocking rates to ABS livestock numbers, and by using the NFI data (Parsons *et al.*, 2006) that 168 million hectares is used for more intensive land management than occurs in the rangeland estate (Figure 1). It shows that plantations make up a small component of the overall Australian land use, with 1,716,173 hectares (1.0%). Appendix B contains details of the specific agricultural enterprises as reported by ABS (2006a) and Parsons *et al.* (2006)

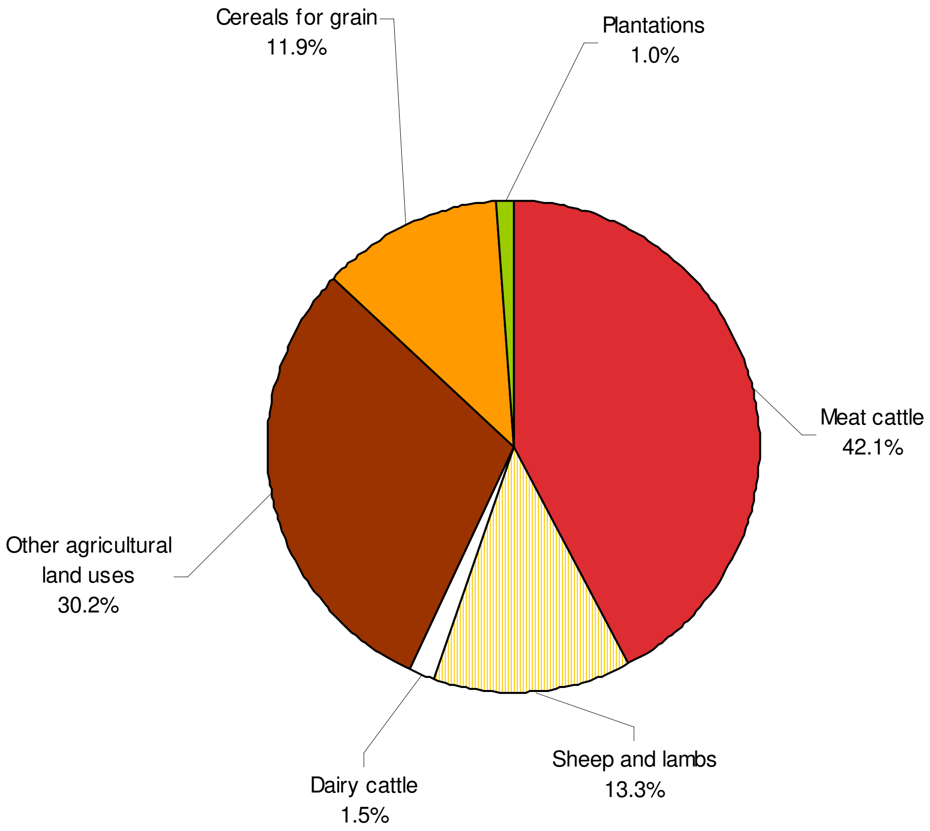


Figure 1 A breakdown of Australia's land use over the 168 million hectares of non-rangeland land use based on ABS (2006a) for 2003 – 04 and Parsons *et al.* (2006) as at December, 2005.

Plantations: a significant contribution

The forest industry sector is a significant contributor to the Australian economy. In 2004 - 05, the rural sector contributed $23.7 billion towards Australia's gross domestic product (GDP) of $863.7 billion (Australian Bureau of Agricultural and Resource Economics: ABARE, 2005a). The gross value of the rural sector production was $39.8 billion in 2004 – 05 (farming: $36.2 billion, forestry roundwood sales: $1.6 billion and fisheries: $2.0 billion) (ABARE, 2006a). The total forestry roundwood sales gross value consisted of: native hardwood: $649 million, plantation hardwood: $150 million, and plantation softwood: $837 million (ABARE, 2006b). For 2004 – 05, the trade in forest products was $4.1 billion imports (ABARE, 2006c) and $2.1 exports (ABARE, 2006d) or a deficit of $2.0 billion. Figure 2 shows a breakdown of Australia's exports split into the farming and forestry sectors (ABARE, 2005b). Farm exports make a significant contribution to the balance of payments. Figure 3 shows direct employment in the farm and forestry sectors and the farm sector is a significant employer (ABARE, 2006e).

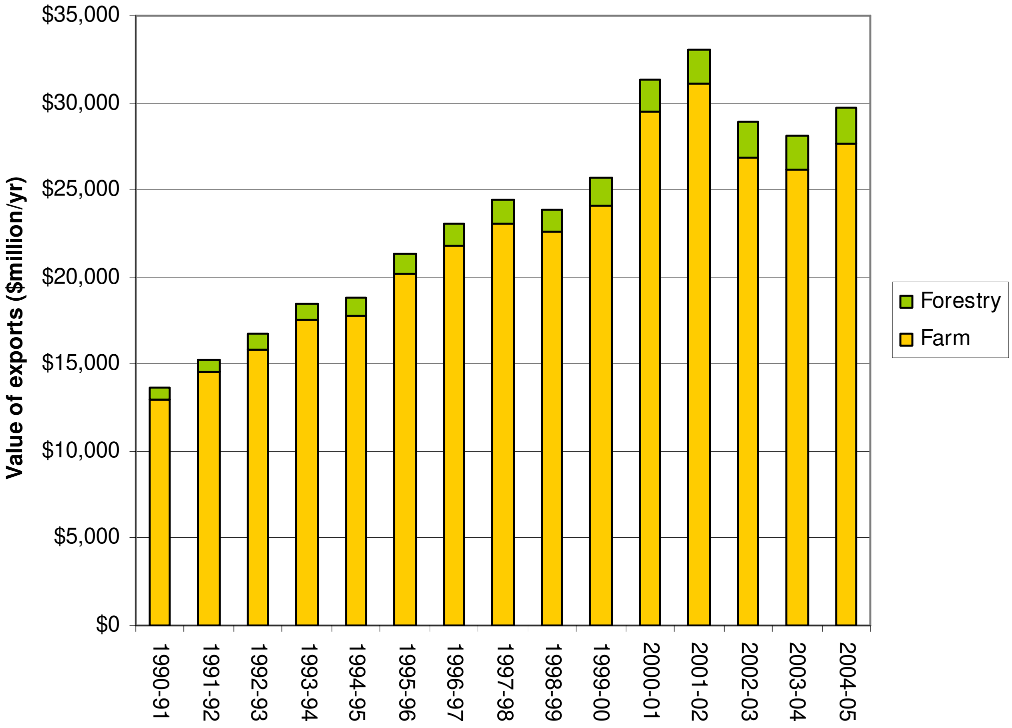


Figure 2 A summary of the value of Australia's exports from the farm and the forestry sectors (based on ABARE, 2005b).

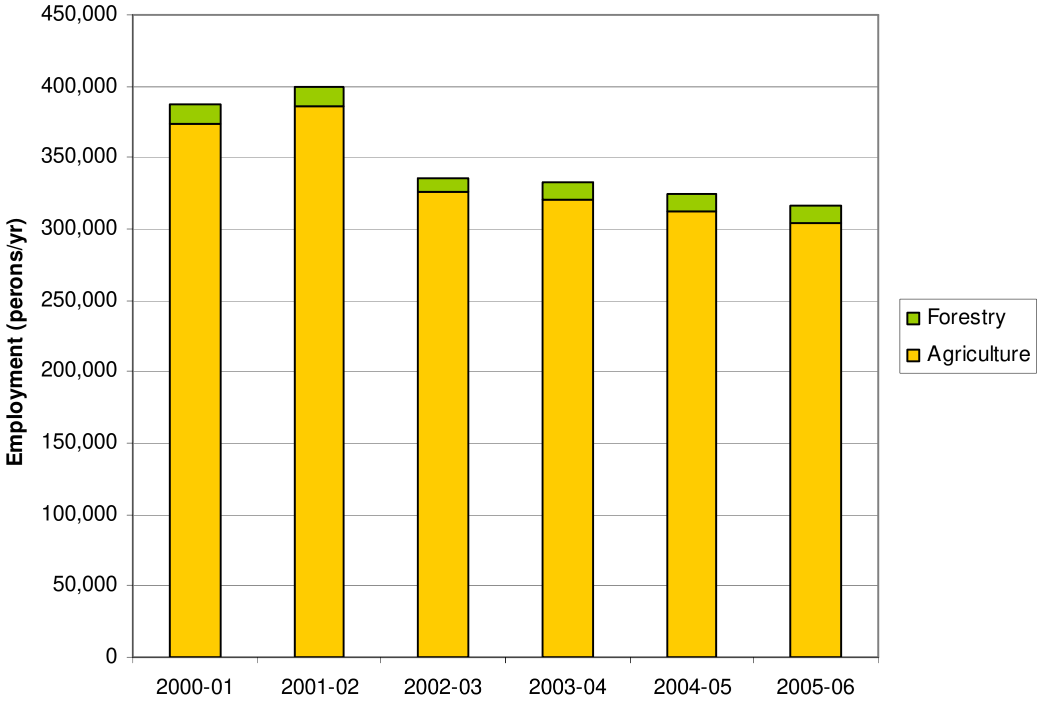


Figure 3 A summary of the employment in the farm and forestry sectors (based on ABARE, 2006e).

Expressed in units of gross roundwood equivalents (GRWE: round measure of true log volume under bark), Australia consumed a total of 22,641,000 m^3 in 2004-05 or 1.11 m^3/capita from all sources (ABARE, 2006f). The total GRWE removal (harvested logs) from all sources was 27,413,000 m^3 for 2004-05: 2,934,000 m^3 from hardwood plantations and 14,446,000 m^3 from softwood plantations (ABARE, 2006g). The total value of the plantation sourced GRWE as delivered to the "mill door" or "wharf gate" was $987.6 million for 2004-05 (ABARE, 2006b). The softwood GRWE production for 2004-05 was divided as 63.6% to saw and veneer logs, 25.2% to paper and paperboard production and 8.7% to wood based panel products (ABARE, 2006g). The hardwood plantation GRWE production for 2004-05 was divided as 90.0% to paper and paperboard production, 9.2% to saw and veneer logs, and 0.8% others (ABARE, 2006g).

Plantation forestry estate

The 2005 plantation estate of 1,729,769 hectares is further segmented into hardwood and softwood species by State (Figure 4) based on the NFI (Parsons *et al.*, 2006). The estate was composed of 989,609 ha of softwoods and 740,160 ha of hardwoods. The softwood estate is more mature than the hardwood estate in that the cycle of harvest and replant continues. Figure 5 shows the new (first rotation 1R: additional areas) of plantation established in 2005 based on Parsons *et al.* (2006). The majority of the 1R plantations were hardwoods. Over 1995 to 2005 the rate of expansion of the plantation estate averaged 61,618 ha/yr (NFI, 2002; NFI, 2003; NFI, 2004; NFI, 2005; Parsons *et al.*, 2006; Wood *et al.*, 2000; Wood *et al.*, 2001). The rate of expansion of the softwood estate has been slower than the rate of expansion of the hardwood estate (see Appendix C for details).

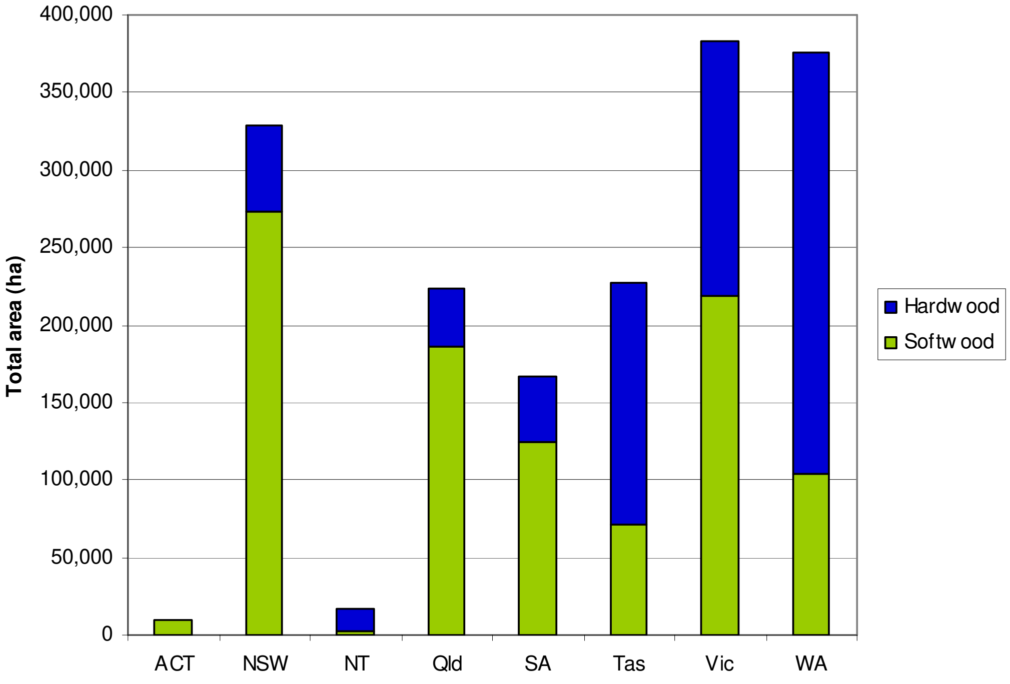


Figure 4 Australia's plantation estate as of December 2005 as reported by Parsons *et al.* (2006).

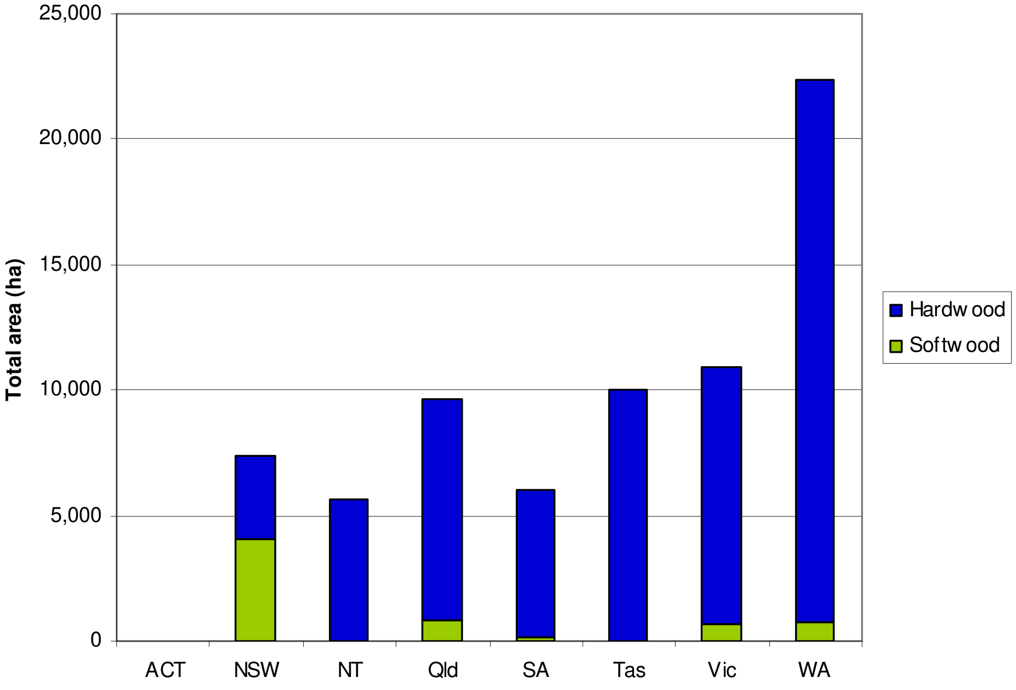


Figure 5 The area of new (1R) plantations planted in 2005 as reported by Parsons *et al.* (2006).

The NFI does not report on the areas harvested and replanted within the current forest plantation estate (e.g. second rotation: 2R or greater: note that throughout the report, 2R is used to indicate areas harvested and re-planted, regardless of whether they are second or subsequent rotations). Based on an assumed 30 year rotation, the softwood estate would be planting around 33,000 ha/yr of post first rotation crops. The hardwood estate harvest is on a smaller but expanding scale as the mid 1990's Tasmanian blue gum crops come on stream. The area of hardwood plantations harvested can be estimated based on the 2004-05 yield of 2,934,000 m^3 GRWE of which 2,640,000 m^3 GRWE was reported to be pulpwood (ABARE, 2006g). Assuming a yield of 200 m^3/ha (based on a short rotation pulpwood crop) and that the current harvest is a clearfall regime, the area harvested is estimated to be 14,670 ha/yr.

Agriculture

As shown in Figure 1, agriculture is a significant Australian land use. Figures 6 and 7 show a more detailed breakdown of the major crops based on ABARE (2006h). The main crops are wheat and barley. Figure 8 shows the national major livestock statistics (based on ABARE, 2006h: statistics on the poultry industry are not reported in this reportt). Sheep are the dominant livestock, with pigs and the dairy herd as the minor component.

Figure 9 shows the value of physical inputs into the Australian farm sector based on ABARE data. It shows that the farm sector spend on chemical inputs (includes animal health products) was $1.7 billion in 2004 - 05, and for 2005 - 06 it is estimated to be $1.7 billion (ABARE, 2006i) (note: based on ABS data, not the Australian Pesticides and Veterinary Medicines Authority: APVMA, data).

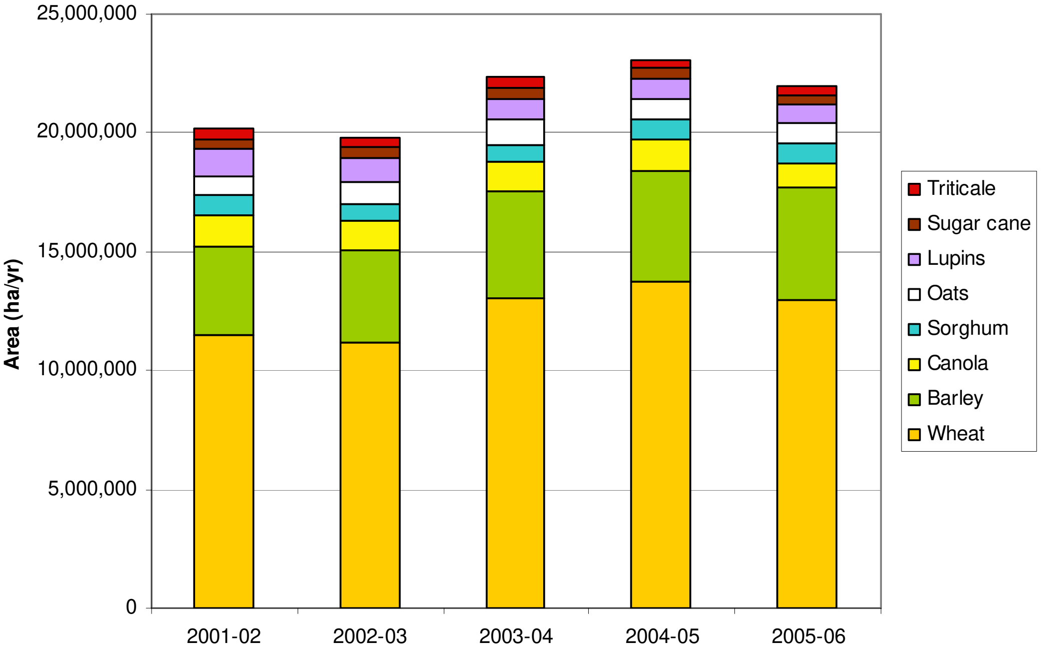


Figure 6 A summary of Australia's agricultural crops based on ABARE (2006h). This chart shows the major crops (area greater than 300,000 ha: 2005 - 06 estimated by ABARE).

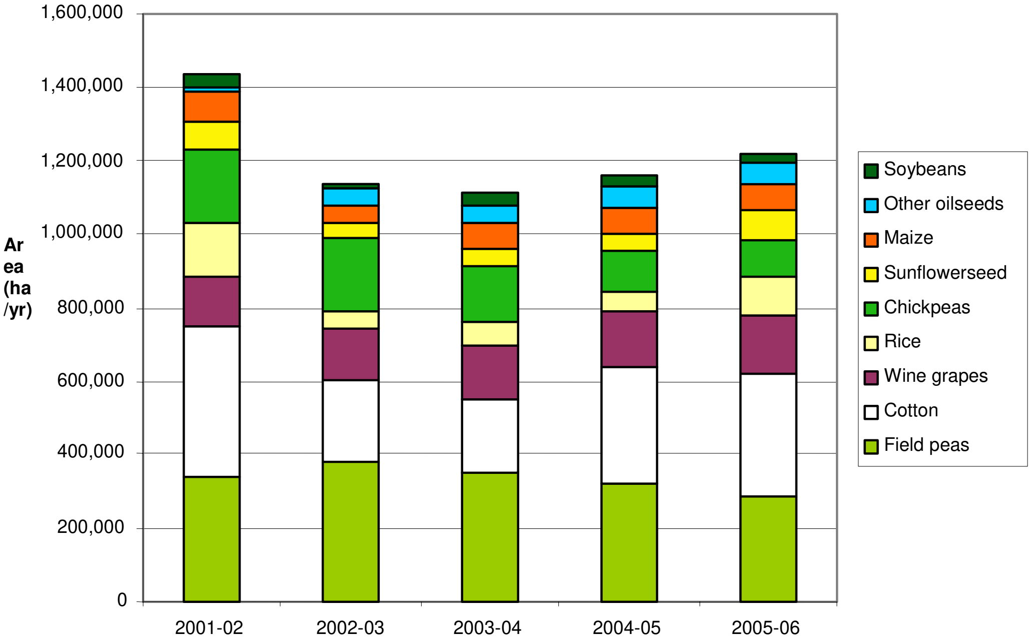


Figure 7 A summary of Australia's agricultural crops based on ABARE (2006h). This chart shows the major crops (areas less than 300,000 ha: 2005 - 06: estimated by ABARE).

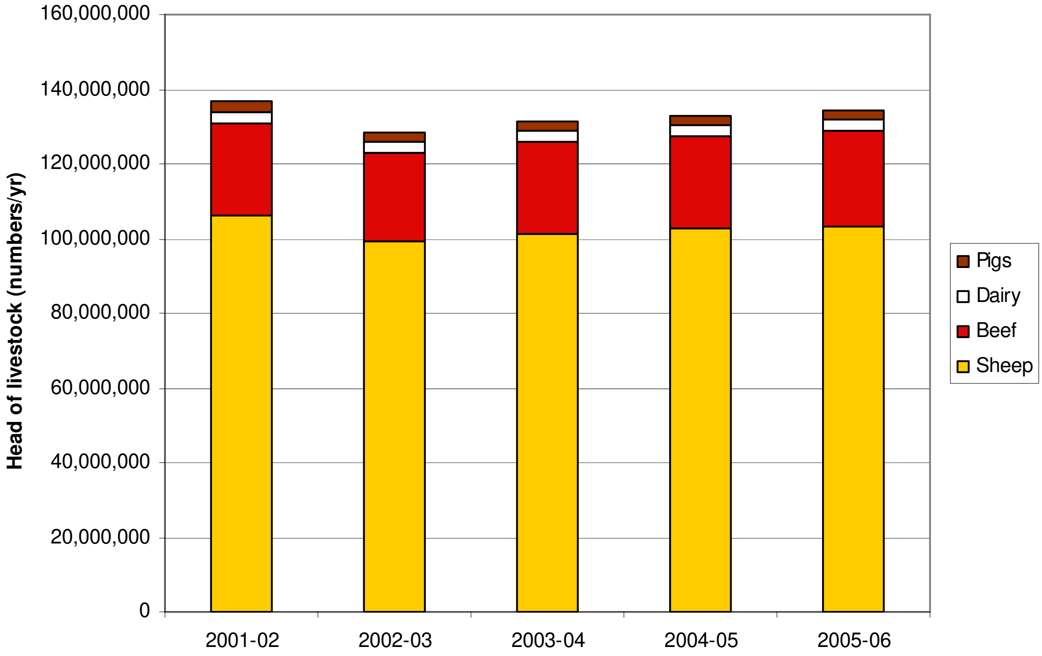


Figure 8 A summary of the Australia's livestock numbers based on ABARE (2006h). (2005 - 06 is as estimated by ABARE.)

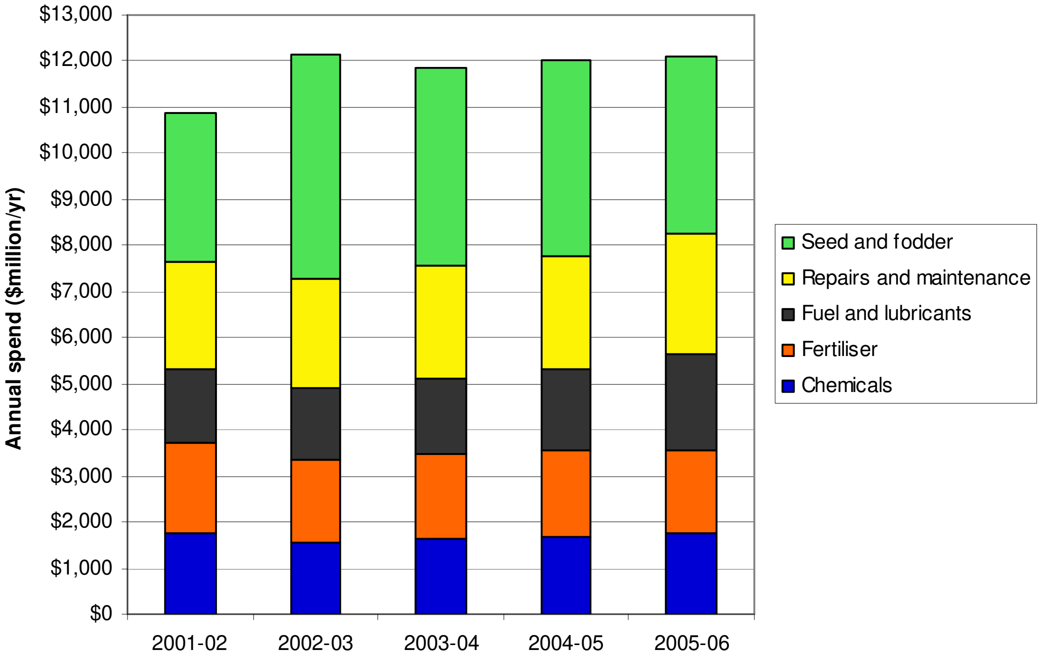


Figure 9 The annual spend on the inputs shown for farming across Australia based on ABARE (2006i). (Note: figures for 2005 - 06 are an ABARE estimate.)

A production imperative

Silviculture

Plantation silviculture involves inputs to achieve tree growth outcomes matching management objectives of the particular plantation. It can be achieved via a number of combinations of inputs, to respond to the needs of a tree species as they relate to a specific site. The options are limited by:

- Legal restrictions (e.g. Occupational Health and Safety: OHS, chemical registration, local planning laws etc);
- Financial constraints;
- Labour availability (quantity and skills);
- Time available for the operation (if reactive to a threat, this can be a significant issue);
- Plantation manager skills and knowledge;
- Past practice (in the absence of an objective assessment of the options);
- Equipment availability.

Figure 10 shows generic inputs to manage a plantation through to rotation.

- Initial site clean-up may remove impediments (e.g. old fences), or treat difficult to kill pest plants with broad-scale application of an appropriate herbicide mixture;
- Cultivation may be used to address specific site issues (e.g. ripping of hardpans or mounding in wet areas);
- Pre-plant herbicide application can be broadcast, in strips over the planting lines or spots to control current vegetation and / or likely future vegetation (e.g. the use of residual herbicides);
- The trees are then planted after any required plant back period;
- Post-plant herbicides may be required to treat areas with competition regrowth;
- At this point the plantation may be fertilised to provide starter nutrients to the trees;
- After canopy closure, the trees may shade out any weed growth, and no further herbicide is required. Depending on tree growth and management requirements, the plantation may be further fertilised. If the plantation is thinned, crown cover will be reduced, with a potential for weed development, which may require treatment;
- In some instances, it may be advantageous to pre-clearfall treat a plantation to control weeds such as bracken or blackberry as the first step to the next rotation;
- Throughout the plantation rotation, there is potential for out-breaks of insects or pathogens. Depending on the expected impact of the insect or pathogen, there may be an imperative to treat the plantation.

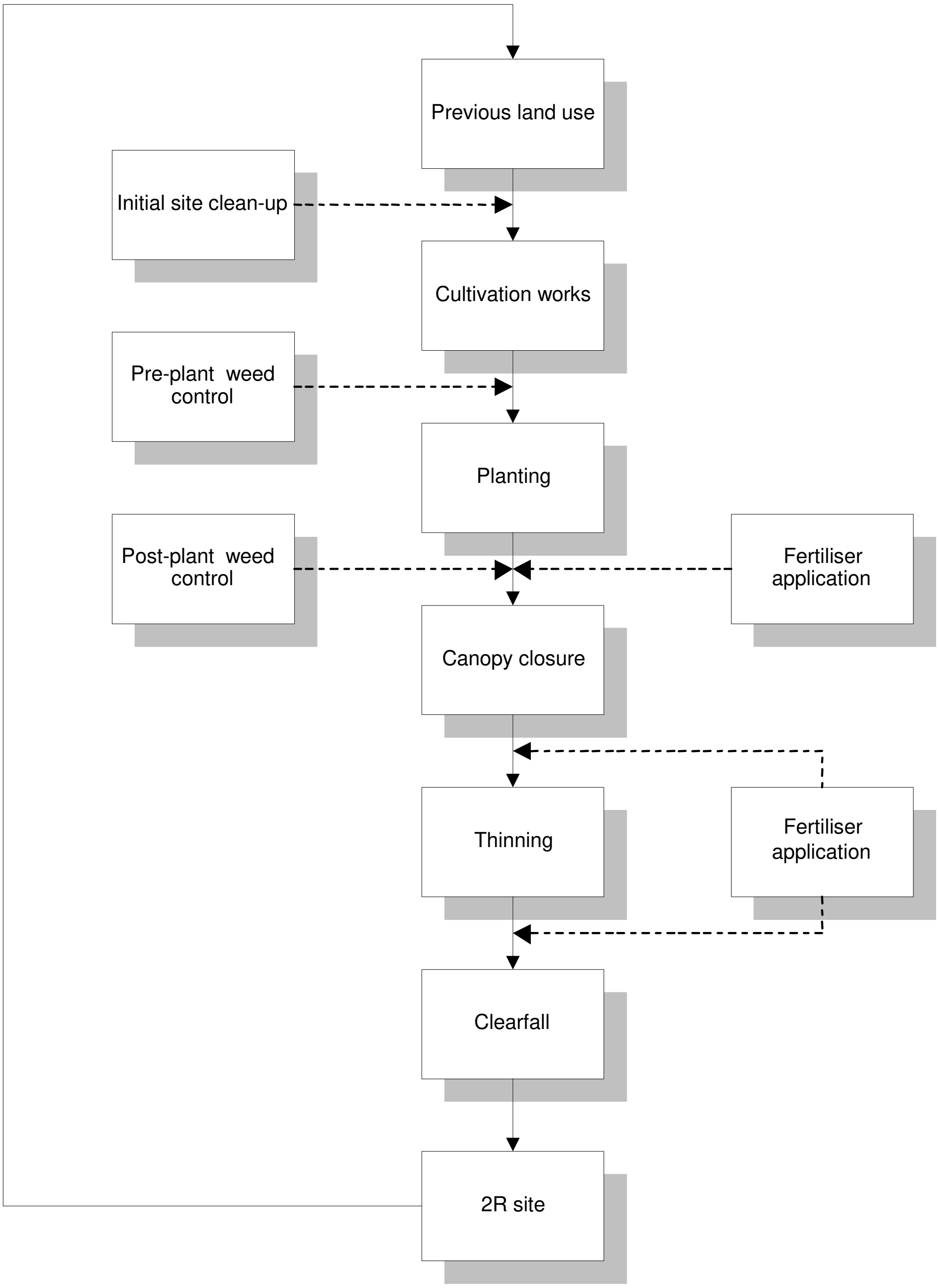


Figure 10 A generic plantation silvicultural regime showing the broad inputs and the sequence of those inputs.

Plantation scale

There are diverse reasons to establish plantations. The scale of such plantings can be small (i.e. a farm woodlot) through to broad-scale industrial plantations (note: in most plantations it is usual to have areas that are not planted due to a range of reasons e.g. roads and easements, and for a property devoid of native vegetation, this can be around 20% of the gross property area). The degree of focus on wood production and the scale can be used to help classify the plantation (Figure 11). In terms of management inputs, the larger the scale of the operation, the less likely that management will be based on manual methods. For example, manual weed competition control in South African plantations was reported to take 4 to 10 person days per hectare depending on weed density and terrain (Schumann, 1990a; Schumann, 1990b). Jenkin (1992) reported that in 1990, one company in Zululand (South Africa) hand-hoed eucalypt plantations up to 5 times in the first year to remove competing vegetation. This would mean between 20 to 50 person days per hectare of manual weeding in the first year. In some horticultural crops manual weeding or chipping is used. For example, DPI NSW (2006a) states that a generic market garden lettuce crop has 60 hrs/ha of chipping/thinning as a weed control (7.5 person days/ha) per crop. It is the small scale of such horticultural crops that allows the use of manual labour as a weed control tool.

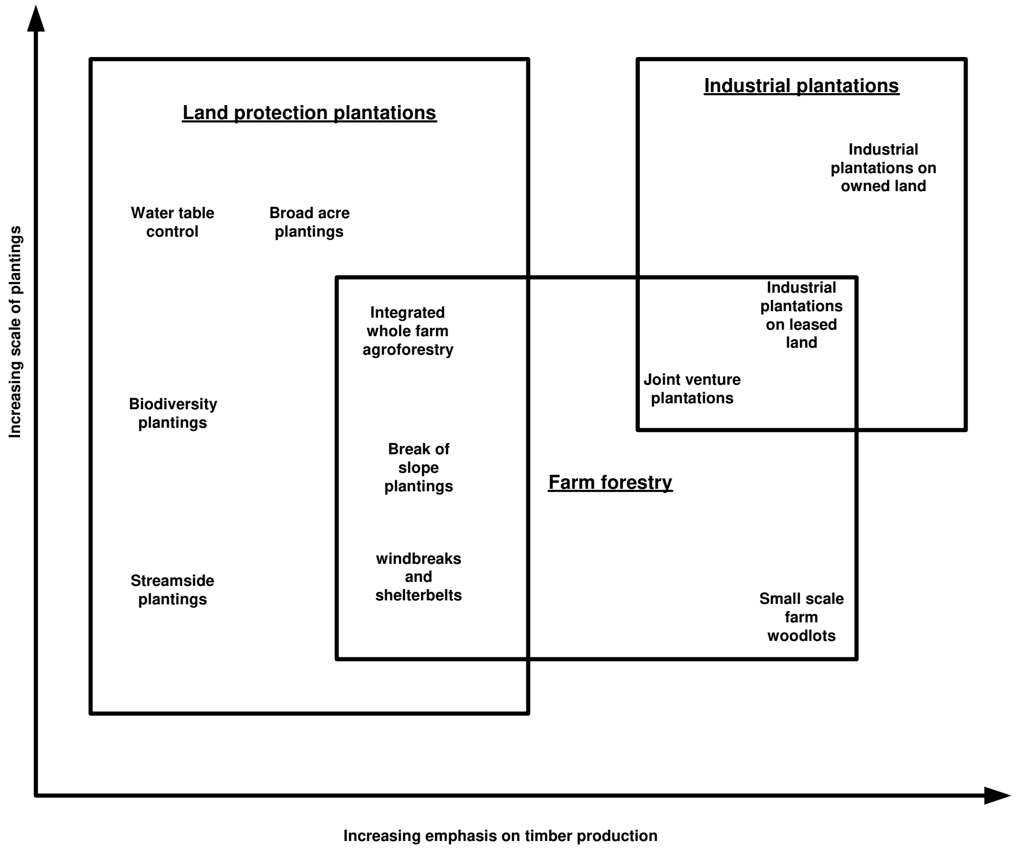


Figure 11 Plantation development can be classified based on scale and emphasis on timber production that underlies the management objectives. The above is based on an analysis completed by Donaldson and Pritchard (2000).

Plantation productivity

Competition control

Forest vegetation management has been defined (Walstad and Gjerstad, 1984) as the practice of efficiently channelling limited site resources into the crop rather than associated non-commercial species. The key limited resources are water, light and nutrients (Richardson, 1993; Florence, 1996). As well, some competing species may physically damage the crop trees e.g. in New Zealand, pampas grass can damage radiata pine (Richardson, 1993). Eucalypts are well documented as having growth buds sensitive to mechanical damage (e.g. Jacobs, 1955), which can be damaged by species such as bracken fern.

The impact of weed competition in reducing plantation productivity is well documented (Squire, 1977; Cellier and Stephens, 1980; Nambiar and Zed, 1980; Balneaves, 1982; Turvey *et al*., 1983; Sands and Nambiar, 1984; Schonau, 1984; West, 1984; Ellis *et al*., 1985; Turvey and Cameron, 1986; Squire *et al*., 1987; Baker *et al*., 1988; Balneaves and Christie, 1988; Ray *et al*., 1989; Smethurst and Nambiar, 1989; Balneaves and McCord, 1990; Messina, 1990; Wilkinson *et al*., 1990; Richardson, 1993; Wilkinson *et al*., 1993). Reduction in productivity can be via reduced growth due to competition, or due to the death of the planted trees and areas remaining un-productive. For example, Wilkinson *et al.* (1993) examined the use of hexazinone for grass and woody weed control in the establishment and long-term growth of radiata pine on a number of replicated sites in Tasmania. Their conclusions:

- On grassy sites, poor survival of radiata pine made weed control essential;
- For woody weed dominated sites, significant tree growth gains (30% volume gain over controls at age 14 years) were obtained with the use of hexazinone. Volume growth gains persisted to at least 14-16 years;
- Thinning to release the final crop could be carried out at least 2 years earlier in treated compared to untreated stands.

Baker *et al.* (1988) examined the use of mixed hexazinone, amitrole plus atrazine and found that there was a close relationship between weed cover and tree volume:

- When weed cover was reduced from 80% to 10%, tree volume increased about 120%, with the highest marginal gains being achieved when weed cover was reduced from 30% to 10%.

Competition from weeds may cause eucalypt seedlings to become spindly: stem diameter and crown volume is affected more than height (Florence, 1996). Following treatment with herbicides, eucalypt seedlings were up to 275% taller after 11 months, with crown diameters nearly five times wider than those of the untreated controls (Schumann, 1989).

Insect damage

Insect damage can reduce plantation productivity through impact on stocking, growth rates, and induce malformation or degrade of log quality at any stage of the plantation growth (Lewis and Ferguson, 1993).

As with the impact of weed competition on tree growth, the impact of insect damage has been assessed for commercially important eucalypt species: (*E. delegatensis* (Alpine ash) (Mazanec, 1966); *E. grandis* (Flooded gum) (Wilkins, 1990; Carne *et al.*, 1974); *E. marginata* (Jarrah) (Abbott *et al.,* 1993); *E. nitens* (Shining gum) (Candy, 1999); *E. regnans* (Mountain ash) (Candy *et al.*, 1992; Cremer, 1972; Cremer, 1973; Elliot *et al.*, 1992); Tasmanian blue gum (Collett and Neumann, 2002)).

In most studies impact was only measured in the immediate period, usually one to two years, after the damage event. There is little published data on the impact of insect damage over the life of a plantation (Jenkin *et al.*, in press). Jenkin *et al.* (in press) noted that:

- Defoliation intensity, frequency and timing as well as tree species, influenced the impact of damage on tree growth and survival;
- In general for commercial species of eucalypts once-off defoliation of less than approximately 50-60% usually has no measurable impact on growth increment;
- For *E. regnans* Candy *et al.* (1992) found that artificial defoliation rates of 33% over summer had no impact on growth, and defoliation rates of 66% only had a significant impact on growth when defoliation was repeated either within the season or in following years;
- Using 1.7 year old, irrigated Tasmanian blue gum*,* Collett and Neumann (2002) found that while repeated 100% total crown defoliation events between December and January suppressed height increment, 100% lower crown defoliation boosted growth throughout the post defoliation period;
- While out-break species like stick insects (Phasmatidae) (Mazanec, 1966) can potentially damage trees of any age, severe defoliation in the first three to four years of a plantation (generally the period prior to canopy closure) is thought to be the most serious threat to plantation profitability (Collett and Neumann, 2002).

There are over 300 species of insects listed as associated with radiata pine (Rawlings, 1960; Ohmart, 1982: in Lewis and Ferguson, 1993), including predators and parasites of harmful species, but as yet, only a dozen or so have become regarded as pests (Lewis and Ferguson, 1993). Neumann and Marks (1976) prepared a synopsis of the insect pests of radiata pine in Australia. The main pest insect of radiata pine is the Sirex wasp. It can be responsible for widespread mortality in radiata pine stands of almost any age.

Pathogens

Diseases are caused by infectious organisms which result in abnormalities of growth or function of the plant (tree) (Lewis and Ferguson, 1993). There is a wide-range of pathogens which can attack plantation grown trees. Keane *et al.*, (2000) present a summary of the pathogens and diseases associated with eucalypts. In the case of radiata pine, all diseases of any significance are fungal. The main radiata pine disease issues are caused by (Dothistroma needle blight: *Dothistroma pini*; Needle casts fungi: *Cyclaneusma minus*; diplodia blight: (*Diplodia pinea*) (Lewis and Ferguson, 1993).

The Regulatory Environment in Australia

Basis of regulation

Australia has an advanced system of regulation for pesticides and fertilisers which has evolved over several decades, although at a community level, there appears to be a poor understanding of the way chemicals are regulated. There are four national chemical assessment and registration schemes. The schemes operate in a complementary manner to ensure there is no duplication or unnecessary regulation (NICNAS, 2006). The schemes are:

- Agricultural and veterinary chemicals (e.g. chemicals which generally destroy/repel pests or plants, or veterinary products used to prevent, diagnose or treat diseases in animals);
- Industrial chemicals (e.g. dyes, solvents, adhesives, plastics and laboratory chemicals);
- Medicines and medicinal products (e.g. therapeutic goods including prescription and non-prescription medicines);
- Food additives, contaminants and natural toxins (e.g. food additives to enhance processing such as colouring or flavouring).

Until the (then) National Registration Authority (NRA) was established under Commonwealth legislation in the mid-1990's, the States and Territories were responsible for all regulation. However, there was an agreement to move to national regulation, with the States and Territories ceding power to the Commonwealth to control regulation of pesticides and veterinary medicines up to the point of retail sale. The States and Territories retain control of the regulation of fertilisers.

The NRA is now known as the Australian Pesticides and Veterinary Medicines Authority (APVMA). The APVMA as the statutory body is responsible for all matters relating to agricultural pesticides and animal health products to point of retail, when State or Territory legislation takes over. AVPMA powers are derived from the following Commonwealth Acts:

- *Agricultural and Veterinary Chemicals Act 1994:* This Act sets out the functions and powers of the APVMA;
- *Agricultural and Veterinary Chemicals Code Act 1994*: The Schedule to this Act incorporates the Agricultural and Veterinary Chemicals Code (the AgVet Code), which deals with the approval and registration of chemical products and their constituents (controlled by the APVMA), as well as the control of chemical products in relation to their supply;
- *Agricultural and Veterinary Chemicals Code Regulations 1995*: This covers various matters outlined in the *Agricultural and Veterinary Chemicals Code Act 1994*.

Registration process

All chemical pesticide products used in agriculture, horticulture, viticulture, non-crop industrial situations (e.g. roads, railways), domestically and in plantation forestry are registered by the APVMA. Three years of research (field trials) are usually required for the registration of a new chemical pesticide. For an existing registered chemical pesticide, usually at least two years are required to evaluate a new use. These trials are governed by a permit system under the APVMA. (See the APVMA web site www.apvma.gov.au.) It often takes more than the minimum three years of research to gain registration for a new chemical in a product. Such chemicals and chemical products are usually already registered for use in other countries. If the APVMA is not satisfied with the submissions, it may reject registration until the concerns are addressed by further trial work.

Registration of a chemical pesticide requires the submission of data for evaluation. Several sections apply, including data relating to OHS and environmental health and safety (EHS), and must include environmental data from testing in Australian conditions. A draft label must be supplied relating to use, as well as a Material Safety Data Sheet (MSDS). The MSDS for chemical products contain product formulation and physical properties, effects, first aid, basic toxicity data (LD_{50}), flammability, storage and transport, and spills and disposal. It is not required to be provided with the label, but must be available if requested from the supplier.

Once approved, the label is a legally enforceable document that specifies information as to what purpose (e.g., crops, target weeds or insect pests) the product may be used for and at what rates. Labels are highly prescriptive documents which include necessary precautionary information. Products may also be used under APVMA permits, which are temporary and are designed to lead to the use being placed on the label.

Implementation of the regulatory environment

State and Territory legislation controls the use of pesticides and fertilisers, under Control of Use Acts and Regulations. These Acts and Regulations vary between States and Territories and legislation is regularly updated. Additionally, there are regulatory requirements that come under other State and Territory Acts. Examples of these Acts include:

- Health or Occupational Health and Safety Acts;
- Environment Protection Acts;
- Poisons or Drugs, Poisons and Controlled Substances Acts;
- Dangerous Goods Acts;
- Transport Acts;
- Environmentally Hazardous Chemicals Acts;
- Lands Protection Acts;
- Weed Management Acts;
- Conservation or Heritage Acts.

Local Government Planning Acts may also impose some requirements in relation to plantation establishment. The States and Territories also have Codes of Practice for forestry or timber production. These have specific clauses relating to, for example, waterways and drainage lines, good neighbour policies etc.

Applications of pesticides to forest plantations are typically carried out by contractors. All States and Territories license such contractors. Their equipment is subject to inspection by relevant authorities that have the power to order repair of faulty machinery. Where licensed contractors are used, this gives the plantation forestry industry an added level of regulation compared to using internal labour. The prescriptions applied are decided by the forestry organization, and must be within the legal limits, and the products applied must be those registered or allowed for the purpose.

Certification

There are two international sustainable forest management certification schemes. Certification under these schemes is voluntary and, in theory, driven by market demand. The largest scheme in terms of the area of forest managed by certified entities is the Programme for the Endorsement of Forest Certification Schemes (PEFC) with 191.5 million hectares (as at 2006). This scheme is an umbrella approach and it recognises national certification schemes. The Australian Forest Certification Scheme (AFCS) which encompasses the Australian Forestry Standard (AFS) is endorsed by the PEFC. A number of large Australian plantation growers are certified against the AFS. Under the AFS, Criterion 1 requires the forest managers to reduce reliance on chemical pesticides, while recognising the need to maintain critical forest management outcomes (Standards Australia, 2003). The other major certification system is the Forest Stewardship Council (FSC). Some 76.5 million hectares of forest are managed by FSC certified entities (as at 2006) including some of the major plantation managers in Australia. The FSC also requires compliance with legislation, including with regard to chemical use. However, the FSC also prohibits the use of certain FSC-designated ‘highly hazardous’ chemical pesticides, although it is possible for forest managers to obtain "derogations' from the FSC for continued use of certain chemicals on the ’highly hazardous’ list under certain circumstances. There is contention about the transparency and objectivity of the process of adding chemical pesticides to this list. A recent submission to the FSC by the Australian certified companies and supported by New Zealand organisations challenges the lack of the usual risk-management objective and the lack of scientific credibility, on the basis of criticisms by Tomkins (2004).

Application rates

Label rates

Application rates refer to the legal maximum at which a chemical pesticide can be applied to the treated area (as noted previously, it is likely that the net planted area of a property is at most, 80% of the gross property area). They are presented on the packaging either as a fixed label or an attached booklet (and in many cases obtainable from the web.) The maximum rates at which chemical pesticides are applied may be altered by the granting of a permit to use the chemical at other rates. The application rates are expressed in units of product per hectare or per volume of carrier (i.e. water). For example, simazine application rates:

- Eucalypt plantations: applied at 1.6 to 6.7 kg/ha of product with 900 g/kg **a.i.** or 1.7 to 6.0 kg a.i./applied ha;
- A product with 900 g/kg a.i. can be applied to canola crops at 1.1 to 2.2 kg/ha of product or 1.0 to 2.0 kg a.i./applied ha;
- A domestic garden formulation to once a year weed paths has simazine at 150 g/kg a.i. and is applied at 100 g/ 20m^2 or 7.5 kg a.i./applied ha.

Table 3 presents a summary of the main plantation forestry chemical pesticides, other labelled uses, and the maximum application rates (see Appendix D an overview of active ingredients). To place the atrazine use rates into context, consider canola cropping in WA may apply 1 kg a.i./ha twice per canola crop (DoA, 2006a; DoA, 2006b). In 2003/04, 318,000 ha of canola were cropped in WA (ABS, 2006) with an estimated atrazine use of around 636,000 kg a.i., compared to the plantation industry (industry survey) result of 7,444 kg a.i. in 2005. Though plantation forestry applied rates are higher, the scale and multiple applications in cropping, means that (e.g. WA) cropping is estimated to use annually greater than 80 times as much atrazine as the plantation forestry industry.

Actual rates

Data on actual regimes applied to agricultural crops is not usually published. The actual application rates in plantation forestry reported for the main active ingredients have been summarized based on the industry survey results (Appendix E). A frequency distribution was generated for the derived application rates (based on the a.i. concentration used). Data for 2003, 2004 and 2005 were included where provided. The frequency distribution is presented on a 10% graduated unit "x" axis of the maximum label rate active ingredient. That is, for glyphosate, the maximum a.i. rate is 3.6 kg/ha, so the graduated units are "0.36". Based on the analysis, with the exception of simazine, the plantation industry uses the a.i. shown at less than 50% the maximum rate in more than 50% of the cases considered. In 50% of the cases of simazine use reported in the industry survey, it was at less than 70% of the maximum rate. Table 3 presents the maximum application rate reported in the industry survey for each of the a.i. shown.

Table 4 Plantation chemical pesticide active ingredients showing the a.i. used, and the other uses of the chemicals. The rates shown are based on the labels of products that contain the a.i. listed.

Active ingredient	Current active ingredient use	Application rate	
		Label (a.i. g/ha)	Industry maximum (a.i. g/ha)
Amitrole	Eucalypt plantations	250 - 1,500	1,600
	Radiata pine (silver wattle control) plantation	1,400 - 2,000	
	Water couch: in drains, channels, margins of streams, lakes & dams	990	
	Pre-planting rye grass & wild oats control in wheat & barley	1,232	
	Pre-harvest preparation for potatoes.	2,750	
	Vineyards and orchards	4,000	
Atrazine	Eucalypts	4,500 - 8,000	5,600
	Radiata pine	4,500 - 8,000	
	Canola	2,000	
	Sorghum, maize, sweetcorn, sugar cane and roadsides	2,970	
Clopyralid	Radiata pine (silver wattle control)	2,550	2,000
	Eucalypts	150 -180	
	Barley, oats, triticale & wheat in combination with MCPA amine	150	
	Pastures and fallow land	600 - 1,200	
Fluroxypyr	Sugar cane for specific weed control	300	500
	Woody weeds in all non-crop areas and rights of way	600	
	Woody weeds in forests	600	
	Softwood plantations	159 - 848	
	Hops, citrus and a range of orchard species	424 - 848	
Glyphosate	Plantation forestry	360 - 2,160	3,200
	Broad acre control of a range of grasses and bracken fern	3,240	
	Pasture manipulation	495 - 2,160	
	Sugar cane - control of ratoons	2,160 - 3,240	
Haloxyfop	Plantation forestry	208 - 416	330
	Couch and rhodes grass control	208 - 416	
	Control of a wide range of grasses in agriculture, horticulture etc.	104 - 416	
	Vineyards, various orchards	208 - 416	
Hexazinone	Radiata pine	1,500 - 3,750	3,800
	Commercial and industrial areas	3,000 - 6,000	
	The combination with diuron is used in sugar cane	1,872	
Metosulam	Plantation forestry	3.6 - 7.0	7
	Wild radish control in lupins	3.6 - 7.0	
Metsulfuron methyl	Plantation forestry on ex-pastures	Up to 9	60
	Established pastures: control of paterson's curse	9	
	Common bracken	36	
	Wheat, barley, triticale and cereal rye: A range of weeds	3 to 4	
	For woody weed on second rotation plantation sites	60	
	Blackberry control on native pastures, rights of way, industrial areas	96	
Simazine	Plantation forestry	1,440 -6,030	6,000
	Pome fruit, apples and pears	3,600	
	Summer rainfall areas, non-crop residual control of grasses / broadleaved weeds	43,200	
Sulfometuron methyl	Proprietary mixture, lower rates otherwise	52.5	60
	Grass / broadleaved weed control for wide range of industrial purposes	150 - 600	
Triclopyr	In sorghum: control of prickly paddy melon	48	2,880
	Fallow cropping land: control of prickly paddy melon	96	
	Broadcast blackberry	2,880	

A history of pesticide use and technological development

Evolution of herbicide use

A snapshot

Figure 12 presents a snapshot of the adaptation and introduction of specific a.i. into plantation forestry from other land management activities (principally agriculture) over the last 40 plus years. Appendix D contains an outline of the main a.i. in use.

The past 50 years have seen significant technological development applied to the application of chemical pesticides in plantation forests. These developments have been very successful in addressing a number of core objectives including:

1. Improved efficacy in control of target pests;
2. Reduced environmental impacts eg on non target organisms, water quality etc;
3. Improved occupational health and safety environment for operators;
4. Reduced costs.

A brief summary of the major technological developments is provided below.

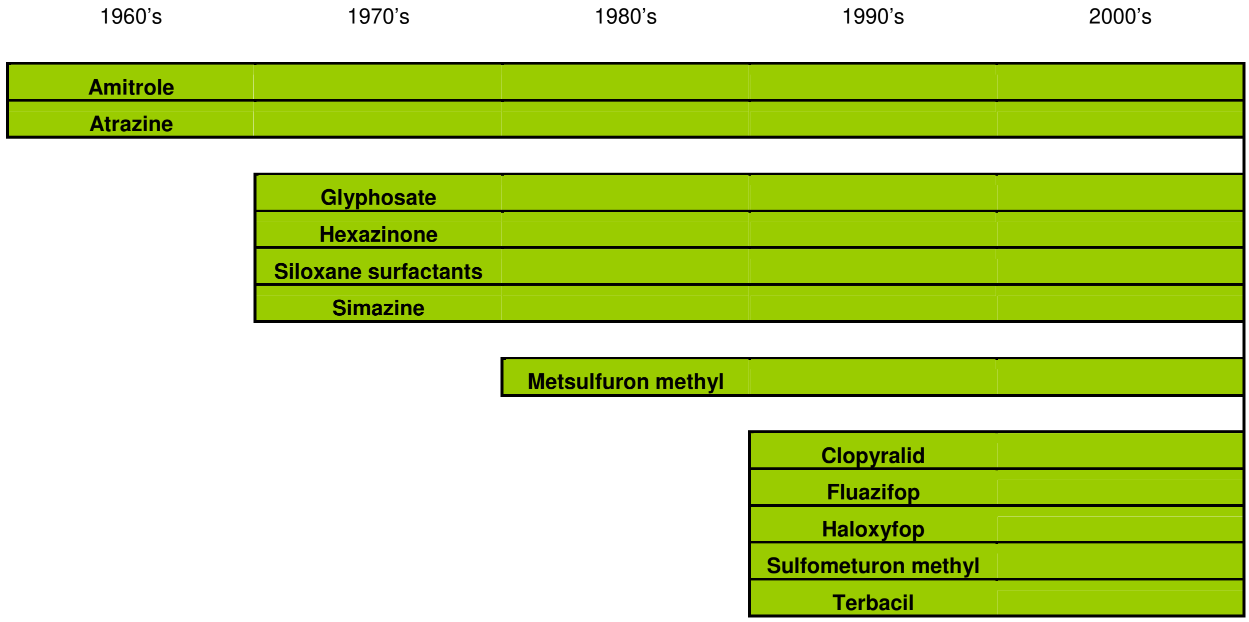


Figure 12 A snapshot of the introduction of the a.i. used in plantation forestry in Australia.

The 1960s

Prior to the 1960's the establishment of radiata pine was essentially a planting operation only. It usually involved the initial clearing and burning of native forest. Herbicides began to be developed in the early

1960's for use in radiata pine plantations. Early research was carried out by Dr David Boomsma for the Woods and Forests Department (South Australia) in the Mt Gambier region. Dr Boomsma developed amitrole/atrazine for the control of grasses (ex-pasture sites) on sandy soils (Boomsma, 2005), which was very effective but did not control the opportunistic invasion of perennial broadleaved weeds such as flatweed or cat's ear (*Hypochoeris radicata*) and sorrel (*Rumex acetosella*). Early use rates of atrazine were far higher than today and resulted in a fertiliser effect because the chemical has high nitrogen content and breaks down to ammonia.

The 1970s

In 1976 Dr Boomsma, working with Mr Kel Stokes of DuPont, began to adapt hexazinone for control of perennial weeds including many woody weed species. This was done in combination with atrazine for residual control of grasses and broadleaves (Boomsma, 2005). The introduction of glyphosate in the late 1970's allowed early site clean-up procedures to be developed. Glyphosate was used to control bracken and sorrel, with the introduction of siloxane surfactants for improved glyphosate performance (Boomsma, 2005). Simazine and atrazine were trialled for use in eucalypt plantations as a residual herbicide, along with a range of chemicals (Cremer *et al.*, 1978).

The 1980s

The mid-80's saw the introduction of the sulfonyl ureas and one, metsulfuron methyl was developed for control of brush weeds such as bracken fern (Dutkowski and Boomsma 1990; Karjalainen and Boomsma, 1989). Improved granular formulations for residual chemicals were developed (Boomsma, 2005) and sulfometuron methyl followed a year or so later.

The 1990s

The 90's saw the rapid expansion of hardwood plantations (mainly Tasmanian blue gum for export woodchips). The use of simazine as the mainstay residual herbicide, and the introduction of grass specific herbicides such as haloxyfop and fluazifop followed. For second season weed control in Tasmanian blue gum, amitrole was further developed as an under spray, in combinations with simazine and sulfometuron methyl. Sulfometuron methyl was also beginning to be used in some pre-planting mixtures. APM Forestry Pty Limited in Gippsland developed a recovery prescription for late first season weed control in eucalypts, that was a mixture of haloxyfop, simazine and clopyralid. Clopyralid had previously been used for aerial treatment of silver wattle (*Acacia dealbata*) in radiata pine, but at very high rates.

In the late 90's a series of screening trials supported collaboratively by forestry organisations and chemicals companies commenced. Several promising companion herbicides have been identified. Macspred Pty Ltd developed two Eucmix products in the late 90's, Eucmix GR®, a dry granule for second season weed control and Eucmix PrePlant WDH® (WDH: water dispersible herbicide). These residual herbicide products contain terbacil, developed from an orchard herbicide, and sulfometuron methyl, which controls grasses and broadleaves such as sorrel.

The 2000's

Post 1990's has seen increasing technological sophistication in application technology, the development of Codes of Practice that bear on chemical use, and increasing scrutiny and regulation.

Whilst this brief background has concentrated on weed control, there has also been development in insecticide technology. Older, more toxic insecticides including certain organophosphates (OP's) are being or have been replaced by newer, less toxic chemicals. This trend follows evolution of agricultural practices.

The biologically based insecticides such as *Bacillus thuringiensis*, spinosad and tebufenozide require very careful timing in their application, but are regarded as being 'softer' in their environmental 'footprint' (Elek, 2006). The first two are of organic origin whereas tebufenozide mimics a naturally occurring organic compound with insecticidal activity. The products are registered for forestry and have greater specificity to target pest insects. They are generally less toxic to benign, non-target or beneficial insects. They also have low environmental toxicity, and are less persistent, breaking down rapidly. Other insecticides are sprayed similarly to agricultural operations, usually at ultra low volumes (ULV) rates of spray mix per hectare e.g. as low as 5 L/ha.

The current system of pesticide classification does not rate toxicity to the environment. Elek (2006) has suggested that the industry needs a system for assessing environmental risk of pesticides, which probably should be operationally based.

Product technology

Plantation forestry has adapted use of a number of agricultural a.i. via product form and application technology to meet the specific needs of plantation managers.

The 1970s

The late 70's saw the introduction of dry granular products. These are applied at prescribed rates per hectare and begin to release the chemical only after activation by an adequate amount of rainfall.

The 1980s

DuPont initiated granule production in Australia in 1986, following wide acceptance of the technology in 1982-83. The development of dry granular herbicides (Velmac G® which contains hexazinone, and Forest Mix G®, a combination of atrazine and hexazinone) for radiata pine establishment followed.

The 1990s

The WDH products were introduced by Macspred in the late 90's - early 2000's. These are a pre-packaged per hectare product in water-soluble plastic bags, which only have to be transferred to the spray tank for mixing, eliminating direct human contact with the concentrated chemical products.

The 2000's

Further development included a Controlled Release (CR) granule, Velmac CR®, which releases chemical more slowly than Velmac G®. A product is to be introduced into the forestry market by Bayer Environmental Science late in 2006 (following 6 years of field trials) which incorporates the insecticide imidacloprid into a fertiliser tablet containing NPK and Mg, which is placed in the planting hole before the tree is planted (Kaapro, 2006). The tablet contains 20% of the insecticide, which is systemic, and provides upwards of one year of protection for the growing tree. Trials in eucalypts have demonstrated a synergistic growth response from the combination (Collett, 2006). Modification of the poti-putki® planting tool to deliver the tablet after soil penetration and before the tree is planted is under development. This eliminates/reduces the requirement for aerial insecticide application during establishment, reduces insect monitoring requirements, targets fertiliser delivery, reduces risk of fertiliser movement in water, and reduces replanting, while giving improved tree growth.

Application technology

The evolution of new product technology was paralleled by the development of new application technology. In the case of granule technology:

- During 1981-82 aerial fixed wing trial applications of granules were conducted, and helicopter application began in 1987 (Boomsma, 2005);
- Manual devices such as the "Weed-A-Metre®" and the "Swissmex®" knapsack applicators were developed to apply a fixed quantity of granules over the top of planted trees in a spot;
- Motorised air blast applicators were developed as back-pack, tractor and helicopter mounted models;
- Bulk transfer equipment for helicopter and fixed wing application have been developed to eliminate manual handling of bags of granules.

A recent Macspred development was that of a 1000 L re-usable shuttle, fitted for direct transfer (pumping) of spray mix, into which is placed the prescribed amount of WDH product at the factory. The shuttles are transported to the site, filled with water and the mix and rinsing liquid are pumped into the spray tank. The latest developments of application technology include:

- Precision in herbicide application;
- Ground based and aerial methods refined;
- Monitoring of water quality.

Current practice - ground application equipment

Granule applicators

Weed-a-metre®

The Weed-a-metre®, developed at the (former) New Zealand Forestry Research Institute, is designed to place an accurate dose of granular herbicide within a 1 to 1.4 m diameter circle, with the diameter of the circle being dependent on the height above ground at which the Weed-a-metre® is operated. It consists of a granule container which releases a given dose over a slotted cone. It is lightweight (about 0.25 kg) and easy to use. Different trigger settings give different doses ranging from 1.5 g to 4.4 g. Use at a height of 0.9 m, set using a training rod, gives a spot diameter of 1 m (based on *Pers. com.* 1 and industry experience).

Swissmex® knapsack applicator

Granules are loaded into a hopper on the knapsack, which has a pump action compressor and a wand with a distribution head. The application is governed by the number of shots fired. The machine is calibrated to provide, on average, 2.5 g using Velmac G® with a single shot, which is equivalent to 15 kg/ha on the spot area that is treated. When using Forest Mix G®, two shots of product per treated spot is equivalent to 30 kg/ha. The spot area approximates to 1.2 m x 1.4 m (based on *Pers. com.* 1 and industry experience).

Macspred Forest Mac granule applicator

The Forest Mac® is a motorised back-pack, air blast granule applicator, powered by a Stihl Power Blower® adapted to apply granular products. Rate of application is adjusted with a metering disc, fine-tuned by altering the idle speed of the motor. The machine is used to apply granules in a strip with an operating swathe of 1.5 m to 2 m (based on *Pers. com.* 1 and industry experience).

Macspred Forest Pack® granule applicator

This applicator is towed by tractor or 4WD. An electronically powered, hydraulically operated variable speed fan blows granules from a metering box into a drop tube which then blows the granules out. The applicator can be adjusted for either single or dual row, or broadcast application as required (based on *Pers. com.* 1 and industry experience).

Liquid mixtures

Vehicle mounted systems

Tractor mounted boom sprays are the conventional method of applying herbicides. The equipment basically consists of a spray tank, pump and boom mounted integrally in a 3-point linkage carrying frame.

The pump is driven off the tractor by a power take-off (PTO) shaft, and there is an in-line filter in the system on the vacuum side of the pump (based on *Pers. com.* 1 and industry experience).

Jets for the boom are plastic, stainless steel or brass, and have a spraying angle of between 60^{o} and 110^{o} (see Appendix F for an overview of jet technology). Application rate and proposed speed of the tractor must be known before the correct size jets can be selected. The speed of the tractor is generally determined by the terrain and normally does not exceed 6 to 8 km/hr for 1R sites and 3 to 4 km/hr for 2R sites. On rough sites, tractor or skidder speeds must be low for safety reasons and to prevent unnecessary wear and tear on the equipment. The jet size is the final factor to be determined in obtaining the desired application rate. Two factors to be considered for selection of jets are wind drift and jet blockages. If both of these factors are to be minimised, the jet size selected will need to be increased. The height of the boom is set to give a double overlap spray pattern. Complete spray units are available from several suppliers, but modifications for plantation forestry use may be required (based on *Pers. com.* 1 and industry experience).

Boomless nozzles (boomjets) are also used to spray in wide swathes (e.g. used to spray bracken under maturing radiata pine that can cover up to five rows at a time) (based on *Pers. com.* 1 and industry experience).

4WD agricultural bike / all terrain vehicle (ATV) or larger machine mounted mini-systems can be trailed behind such machines. Tank size on the agricultural bike is 100 L. Pressure nozzle boom sprayer kits come with fixed 2 and 3 m booms and folding 3, 4, and 6 m booms. Larger booms up to 18 m for towing by utilities and tractors are also available for pressure nozzle or control droplet application (CDA) application (based on *Pers. com.* 1 and industry experience).

Manual spraying equipment

Knapsacks

Hand knapsacks are used for difficult work which cannot be achieved by using a trailed boom spray e.g. for spraying around individual trees in areas not accessible to tractors and for noxious weed control. The semi-pressurised sprayer usually holds 15 L of spray mixture. Pressure is provided in a small pressure dome by semi-continuous pumping while spraying. The main volume of spray is not under pressure, and the knapsack is moulded in a comfortable shape. There are three types of nozzles usually supplied with knapsack sprayers - these are flat fan, solid cone and hollow cone. The flat fan nozzle provides a more even spray distribution and is generally preferred. Hollow cone nozzles are used more for insecticide and fungicide application. To avoid drift, the nozzle is held close to the target and it is important to keep the pressure in the knapsack constant by steady pumping. Soluble dyes are available to indicate where spraying has occurred (based on *Pers. com.* 1 and industry experience).

Spot sprayers

The DuPont Velpar 'Forestry Spot Gun®' is a controlled dose applicator based on the principle of a drench gun, in that it applies a measured volume of chemical pesticide mixtures through a spray wand to the target species. For ease of use the spot gun is attached to a lightweight plastic back-pack. Mixed chemical pesticides are usually sprayed through a solid cone nozzle, but it can be applied as a solid stream with drenching, or a 'soil spear' attachment for injecting chemicals such as hexazinone and clopyralid into the soil at the base of woody weeds. For spraying, the area of application can be varied to some extent by varying the height of application. Rather than adjusting the volume applied, the rate is usually adjusted by dilution. The equipment is used for spot spray application for controlling young short wattle, eucalypt and other woody weeds and grasses, and for weed control in less accessible areas. It is also used for 'slash and squirt' herbicide application to small cut stumps (based on *Pers. com.* 1 and industry experience).

Controlled Droplet Applicators (CDA) for ULV use

CDA equipment or rotary atomisation delivers very small droplets at a high concentration of chemical pesticides. Often the chemical requires little, if any dilution, and mixture application rates can be varied from 0.05 to 30 L/ha. The method is suitable for pre- and post-planting ULV spraying along planting lines. Where soil conditions make use of heavy machinery impossible e.g. on wet sites with duplex soils, CDA has been used instead. Marker dyes allow identification of sprayed areas (based on *Pers. com.* 1 and industry experience).

The Micron Herbi® is a CDA applicator for special situations in forestry use. It has a spinning disc powered by batteries in the battery handle. The motor is governed so that the disc rotates at a constant 1,700 rpm. Flow rates can be varied by the use of different colour-coded nozzles. The applicator produces droplets in the range of 250 to 280 µm, and is suitable for applying chemical pesticides, in a controlled swathe. ATV mounted units may be used for applications of herbicides in situations otherwise inaccessible to larger equipment (based on *Pers. com.* 1 and industry experience).

Wick wipers

Trailed wick wipers

Ropewick applicators may be used when applying chemical pesticides at high rates. There are also ‘brush roller’ types, and carpet and ropewick wipers useful for the application of herbicides such as metsulfuron methyl or glyphosate to bracken fern, where the stomata are on the back of the fronds. Sensors may be used to determine the moisture level of the wick. A low pressure pump cuts in to keep the level relatively constant, thus removing the effect of vehicle speed from consideration (based on *Pers. com.* 1 and industry experience).

Hand-held weed wipers

Hand-held weed wipers are more of a domestic tool, but may be useful where trees are susceptible to herbicide damage by drift. Herbicides (e.g. glyphosate) is usually applied, by wiping unwanted vegetation in two directions with a saturated wick, kept wet by gravity feed from a bottle of herbicide attached to the top of the handle. A concentrated herbicide is usually applied so that it is important to avoid contact of the wick with young trees. Weed wipers are suitable for grasses and broadleaved weeds, but not blackberry which will quickly ruin the wick (based on *Pers. com.* 1 and industry experience).

Stem treatments

Frill treatment and stem injection

This equipment is used to inject herbicide directly into the sapwood to kill unwanted trees (from saplings to large trees) or to apply systemic insecticides. Holes are bored or punched into the sapwood and systemic chemical (herbicide or insecticide) poured or injected into the holes. The correct dosage is achieved by an accurately calibrated applicator. Application can be either basal or at breast height, depending on the equipment being used. Horizontal cuts at intervals of the circumference are made through the bark at an angle to the sapstream of woody weeds, and a controlled dose of liquid herbicides such as glyphosate, triclopyr or picloram is injected. Injection may be through an axe head (based on *Pers. com.* 1 and industry experience).

For example, the Sirax® stem injector developed by Mr Bill Kerruish at CSIRO, is designed for dense young forest stands where many small trees must be treated. The injection hatchet can treat stems as small as 20 mm in diameter. Air pressure drives the chemical storage/pressure cylinder, which injects 1 mL of chemical into the tree under a pressure of 150 to 600 kPa. Alternatively, the Velpar Spot Gun® is commonly used after notching the tree with an axe (based on *Pers. com.* 1 and industry experience).

Cut stump treatments

If a suitable herbicide is applied to newly cut stumps, many woody species can be effectively controlled. The stump should be cut as low as possible and treated within a few minutes of cutting because xylem vessels plug very quickly, thereby preventing absorption. Spraying stumps with a knapsack, drench gun or swabbing liberally with herbicide using a paint brush are effective methods, but sufficient herbicide must be applied to thoroughly wet the sides of the stump as well (based on *Pers. com.* 1 and industry experience).

Basal bark treatments

This is often used to control woody weed regrowth in plantation forestry situations. Application is usually carried out by means of a back-pack with variable stream nozzles at low pressure to reduce deflection of solution. The whole circumference of the trunk of the woody weed is treated low to the ground, and often diesel oil is used as a carrier for triclopyr and picloram herbicides (based on *Pers. com.* 1 and industry experience).

Current practice – aerial application

Industry overview

The first use of aerial application in agriculture in Australia occurred in 1947 (AAAA, 2006a). The area treated annually has grown to over 10 million ha/yr, with around 130 operators Australia wide (Mackay, 2004). The industry peak body is the Aerial Agricultural Association of Australia (AAAA) and members undertake over 90% of all air agricultural operations (Mackay, 2004). The AAAA has a chemical application policy which covers the aerial application of agricultural inputs (AAAA, 2001). Aerial application of chemical pesticides is critical to bananas, cotton, sugar cane, potatoes and is used for pasture top dressing (AAAA, 2006b).

The Industry survey results indicated that around 23,000 ha/yr and 1,500 ha/yr are treated with herbicides and insecticides respectively by plantation forestry managers using aerial application as a tool (the total area of forest plantations reported to be treated with insecticides varied from 25,540 ha in 2003, 32,695 ha in 2004 and 31,112 ha in 2005). There is some use of aerial application of fertiliser. (Note: the industry survey for the aerial component did not cover the same percentage as the main survey.) Even if the actual area treated aerially is 50,000 ha/yr, plantation forestry would represent less than 0.5% of the aerial application occurring across Australia each year.

Aerial application allows effective pesticide application where:

- Ground conditions restrict machine access due to slope, wet conditions and rough surfaces;
- There is a limited window of opportunity due to weather and maximum application speed is required;
- Where there is the need for a rapid response to a pest out-break;
- Where crop heights restricts access.

Fixed wing application

The history of fixed wing application is one of innovation, and much of this has revolved around Field Air based at Ballarat (established in 1963). Around 30 years ago Pawnee aircraft could deliver payloads of about 50 kg at speeds of 120-150kph. Today a variety of Air Tractor aircraft (AT 402, 502, 602 and 802) can deliver payloads of up to 3 tonnes, at speeds of 200 to 250 kph. Applications of fertilisers, chemical pesticides, seed and baits as well as fire-bombing are possible operations (based on information collected from *Pers. com. 2* and industry knowledge).

Trials and applications

Fixed wing application is cheaper and generally faster than helicopters but more often is used where there are large contiguous areas of plantation in relatively flat terrain. Field Air was the operator in trials carried out in association with the SA Woods and Forests Department and Dr David Boomsma in the 1960's. Extensive trial work was also carried out in association with State Forests of NSW. This involved extensive pattern testing for spray deposition and solids application, and the determination of coefficient of variance (CV) spreading patterns. Strict contract specifications were a result of this work and Standard Operating Procedures (SOP's) that are constantly reviewed, became an intrinsic part of operations. Field Air annually completes independent spreader pattern testing to achieve the best possible CV spreading patterns (based on information collected from *Pers. com. 2* and industry knowledge).

Technology development and application

Satellite marking with global positioning systems (GPS) differential correction and geographic information systems (GIS) mapping and data logging compatible with mapping have become routine, so that accurate overlays of swathes are automatically generated. Nozzle development for spraying has seen a change from micronairs, used up until about 10 years ago, to the versatile CP (CP Products Inc. USA) hydraulic nozzles that allow a variable but controlled spectrum of droplets with less fine droplets. These are the most popular aircraft nozzles, which can be changed to alter droplet size and application rate at the nozzle. Change is effected by altering the angular deflection to break up droplets, and by altering the aperture size. One development that has not been widely adopted by forestry is variable rate technology (VRT) application for solids including fertilisers and herbicide granules. This is widely used in agriculture for fertilisers but requires soil monitoring and nutrient testing beforehand. However, there is potential for its use in plantation forestry, including variable rate application of granular herbicide products, and of liquid applications. Bulk loading and handling equipment is also used. For example, Field Air spray loading equipment consists of 8 and 3 tonne spray truck units with specific chemical agitation equipment. Other loading equipment includes a purpose built bulka-bag crane to handle 1 tonne bulka-bags (based on information collected from *Pers. com. 2* and industry knowledge).

Helicopter application

Background need

In 1981, radiata pine plantation failures on the west side of the ACT (Kowen Forest) were related to boron deficiency. The logical questions were - what were the appropriate boron products and how were they to be applied? A forester, Colin Johnston, trialled fixed wing aerial application, without success. Helicopter application was then attempted, but the operator had no forestry experience and again the work was a failure. In Victoria, prior to 1987 there had been some helicopter application of hexazinone to radiata pine in the NE of the State, but there were no standard procedures and only a basic understanding of the method. Because there was off-target damage, the State government placed a moratorium on aerial herbicide application in radiata pine (based on information collected from *Pers. com. 3* and industry knowledge).

Development process

Johnston tried aerial weed control treatments but again, poor equipment led to failures. Consequently, he purchased equipment, built booms with improved nozzles and carried out pattern trials. He took the equipment to the Centre for Pesticide Application and Safety at Gatton College, Toowoomba Qld, where further pattern trials with Dr Nick Woods were conducted in 1983-84 (based on information collected from *Pers. com. 3* and industry knowledge).

For boron application, Johnston rebuilt the buckets and spinners and helicopter boron application problems were overcome, with a set of stringent specifications included. The combined development of this equipment allowed applications of high analysis fertilisers as well as spraying operations. Trials with Monsanto were conducted in 1983-84 and included the first applications of glyphosate and metsulfuron methyl combinations for the control of blackberry and pine wildlings (based on information collected from *Pers. com. 3* and industry knowledge).

In 1984 at a forestry management conference in Canberra (Landsberg and Parsons, 1984) Johnston's equipment was demonstrated at a field day. Subsequently, a proposal was put to the Victorian Department of Conservation, Forests and Lands to aerially treat up to 3,000 wattle infested hectares of radiata pine plantation in the North East and Strzelecki Ranges near Yarram. With stringent specifications, Johnston was contracted as consultant/supervisor and the operation eventually proceeded successfully, after the moratorium on aerial spraying was lifted in 1987 (based on information collected from *Pers. com. 3* and industry knowledge).

Forest Air Helicopters

Johnston bought a helicopter and founded Forest Air Helicopters Pty Ltd (FAH) in 1988 (FAH, 2006). FAH today operates out of Albury. The technological developments in helicopter applications for plantation forestry have been largely brought about by FAH (based on information collected from *Pers. com. 3* and industry knowledge).

Granule technology

In 1989, Mr Ray Fremlin of Conservation and Land Management (CALM) in Western Australia organised a demonstration of helicopter application. A community campaign, objecting to land acquisition by CALM, included opposition to aerial spraying. However, while the community pressure was successful against liquid spraying, DuPont and Johnston were able to successfully launch the herbicide granule technology with the introduction of a specialist spreader from the USA. DuPont supplied the equipment and technical advice to conduct a trial with a 90% active hexazinone granule. This initial trial was the embryo of what is now normal silvicultural practice with granules supplied by Macspred (based on information collected from *Pers. com. 3* and industry knowledge).

Broader application

Fixed wing trials in SA were alluded to earlier, but Mr Mike Bleby (SA Woods and Forests Department) organised trial work in 1990 with FAH. In 1990, CSIRO in Tasmania contracted FAH for fertiliser work in eucalypt native forest in the Huon Valley. Also in 1991, Australian Newsprint Mills, Forestry Commission Tasmania and APPM contracted FAH to successfully overcome previous seeding problems in native forests. Up until 1996, FAH were carrying out spraying, fertilizing and seeding operations in Tasmania with the Forestry Commission Tasmania, ANM and CSIRO. However, the period 1989-94 was also marked by considerable community unrest about aerial spraying in plantations, particularly in WA and Victoria. In 1991, FAH conducted successful strip trials, and pre-plant and granular trials in SA. In Victoria it was becoming a normal silvicultural operation for FAH to aerially apply herbicides in autumn and spring. Similar work commenced at Tumut for State Forests NSW in 1989 and has now expanded to up to 8,000 hectares per annum total with autumn, spring and summer applications (based on information collected from *Pers. com. 3* and industry knowledge).

Technology evolution - application technology

Dothistroma septospora was epidemic in 1991, and treatment with copper oxychloride at high volumes was applied in the Armidale/Tamworth region of northern NSW. FAH asked Micronair in the UK to build hydraulic micronairs, which led to FAH being able to apply 1.6 kg/ha of high analysis copper oxychloride in a mainly oil plus some water spray at 5 L/ha spray volume. 12,000 ha were treated. The ULV technique was based on information from the New Zealand Forest Research Institute (Dr John Ray) but in NZ, the application was at 5 L/ha. FAH are the only operators in Australia whose machines are fitted with hydraulic micronairs. The hydraulic drive units provide a constant cage rpm at the lower airspeeds of helicopter application, unlike the wind-driven units that are designed for fixed wing application. The hydraulic micronairs have allowed low volume (30-50 L/ha) pre- and post-planting herbicide applications. Higher volume rates may be achieved using flat fan nozzles (up to 80 L/ha), and other operators can spray at 100 to 150 L/ha using Accuflow® nozzles. In 1994, FAH conducted successful ULV trials for Monsanto with neat glyphosate at 6 to 9 L/ha. For fertiliser applications, FAH developed their own spinners (centrifugal application) and these allow pattern changes during applications (based on information collected from *Pers. com. 3* and industry knowledge).

Technology evolution - product technology

The mid-90's saw the development of a relationship with Macspred, which since 2001 has involved Mr John Campbell (Macspred) carrying out site assessments and writing prescriptions for aerial applications by FAH, and particularly granular herbicide applications (based on information collected from *Pers. com. 3* and industry knowledge).

Technology evolution - data logging and guidance

By 1989, FAH had installed a Microwave Electronic Guidance System in its machine although this was first used in fixed wing in SA. The system gave very good results in providing an accurate means of treating specified areas. In 1992, FAH installed GPS units in their machines, and had a ground station for differential correction. This increased flexibility and allowed the development of logging and mapping systems. In 1996, MapInfo and Arcview software (GIS) was introduced. Software development has continued and flight (treatment) information is directly logged into the MapInfo package. FAH write their own programs. The most recent development has been the fitting to the front of the helicopters a weather meter probe that automatically records and logs all important weather parameters including wind speed and direction, temperature and relative humidity (based on information collected from *Pers. com. 3* and industry knowledge).

Cost benefit of application methods

Application costs

Published cost information is limited: aerial herbicide application in rice is given as $22/ha (DPI NSW, 2006b); generic helicopter application in Tasmanian agriculture at $34/ha (DPIW, 2006a); and generic insecticide application in Tasmanian plantations at $50/ha (de Little, 2002). Application costs are highly variable and each operation would require an individual costing. Application costs were collected as part of the Industry survey (ground, fixed wing and helicopter). Figure 13 shows the collected herbicide application cost range (highest and lowest), with the exception of application using hoses at $800/ha treated. Insecticide application costs reported in the industry survey ranged from $65 to $75/ha helicopter application and $25/ha for ground based systems. The key drivers of production rates and cost are:

- Distance from the refill point to the target area (flying time);
- The payload of the aircraft (e.g. 300 to 3,000 L/load: Mackay, 2004);
- Application rates (e.g. ULV of 1 to 3 L/ha; Mackay, 2004: to over 100 L/ha);
- Weather conditions and any down time;
- Proximity to property edge and other land uses.

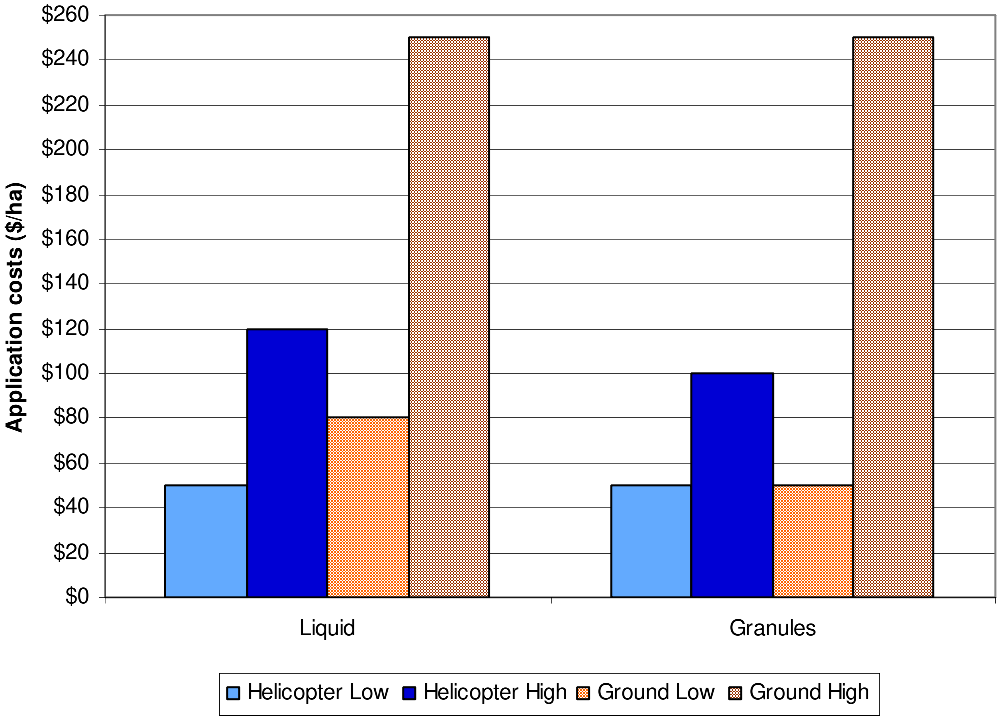


Figure 13 A summary of the maximum and minimum application costs for granular and liquid herbicide application for 2005 based on the industry survey. (Note: there was nil reported use of fixed wing herbicide application by those surveyed.)

As discussed there is a wide range of application methods available for use in plantation forestry. The ultimate decision will be based on management issues. Each method will have a cost and productivity profile specific to the individual operation, and each operation would need to be assessed on that basis. If chemical pesticides cannot be used, and manual weeding is required at establishment, then a production rate of 0.0082 ha/person hr per weeding (taking 122 person hrs/ha) or a cost of around $2,000 /ha. In the absence of the option to use mechanised chemical pesticide application, it can cost up to $800/ha for manual application using long hoses from a 4WD ute (data from the industry survey). Figure 14 shows indicative production rates and the costs of application based on the following assumptions for the aerial options.

- Fixed wing aircraft application was based on a 2,000 L payload, 10 minutes flying to and from the airstrip and loading, 15 minutes application at 50 L/ha and 10 minutes application at 100 L/ha;
- Helicopter application was based on a 300 L payload, 7 minutes (assumes that the helicopter is loaded onsite) loading and application at 50 L/ha and 100 L/ha.

Figure 14 demonstrates the impact of time constraints. For example, if a plantation manager must spray 1,000 ha at 100 L/ha, using any of the methods shown in Figure 14, it would take 17 hours by fixed wing, 39 hours by helicopter, and 400 hours with a 4WD ute or 800 hours by skidder. With a two week window of opportunity (maximum spray time of 14 days by 6 hours/day = 84 hours) it would require one fixed wing or helicopter operation, or at least 5 utes or 10 skidders. (The choice of application depends on the exact nature of the operation.)

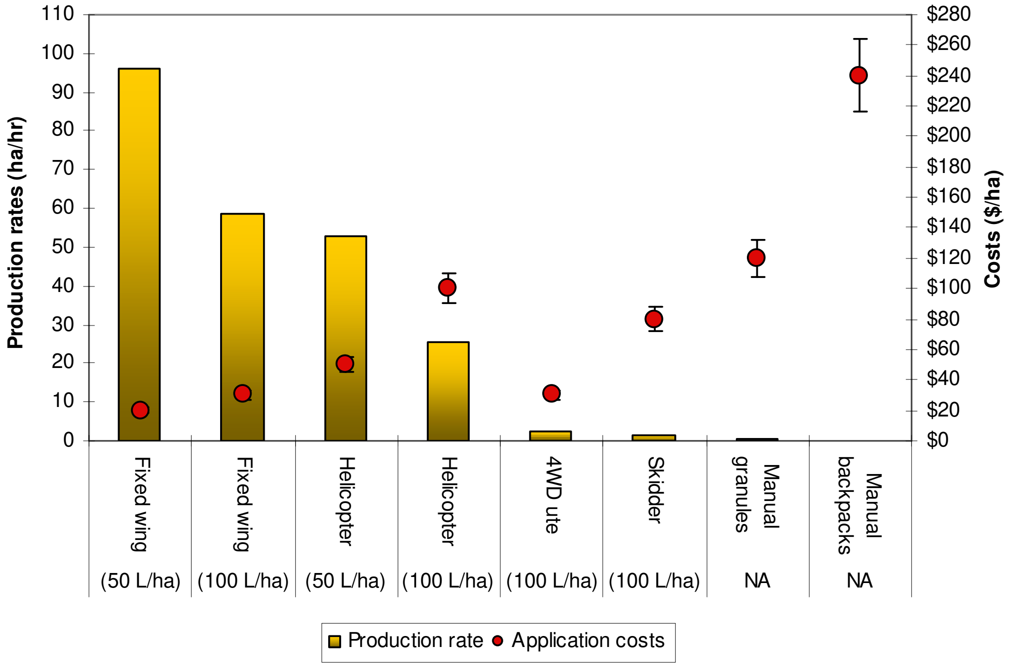


Figure 14 Generic production rates for the application methods shown and the costs of each method (with +/- 10% deviation shown). In general, the slower the process, the higher the cost per hectare treated. The information shown is based on the industry survey; *Pers. com. 5; de Little, 2002, Mackay, 2004; industry experience.*

Plantation returns

Insect out-breaks can cause varying degrees of damage to the crop trees (Jenkin *et al.* in press). To test the importance of helicopter application the following scenario is applied;

- A high productivity plantation site in difficult terrain is expected to yield 300 m^3/ha at age 10 years (mean annual increment: MAI = 30 m^3/ha/yr);
- The site has been established and has grown well with the trees up to well over 1 m tall at age six months.

Figure 15 shows the result of an insect pest out-break in the first summer. In the first instance the attack is a 30% defoliation in early summer. If the out-break is detected and is not expected to continue, it may result in only a minor production loss over the rotation. However, the plantation manager would need to be very confident of the decision to not act, as if the 30% defoliation continues to 80% in early summer or a subsequent defoliation of 80% later that summer, would cause a significant production loss. If at the first detection of the insect pest the damage was light, it could lead to again more complete defoliation later in the summer, again causing a significant production loss. If the plantation manager treats the pest straight away, the increased costs are far out weighed by the potential loss avoided.

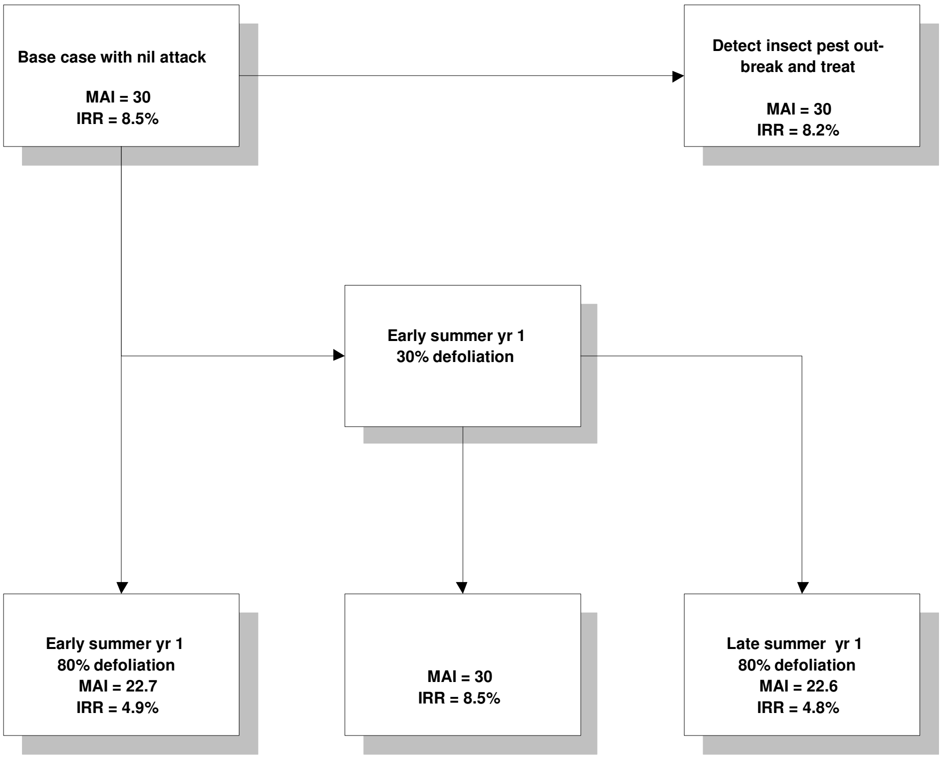


Figure 15 The modelled impact of an insect pest out-break showing possible outcomes to productivity and financial returns.

A key issue is that the use of a helicopter to apply the insecticide gave a rapid treatment. For a 100 ha coupe, given the right weather conditions the treatment would have taken around 2 hours. If the site had poor machine access and manual methods required, it would take around 500 hrs or 83 days for one person (6 hrs/day spraying).

Spray drift

Concerns are often raised about chemical spray drift from ground-based or aerial application. The method of application is often ground-based; however in steep terrain or over large contiguous areas of plantations, aerial application is commonly used.

Pesticides need to be applied under suitable conditions to ensure intended outcomes are achieved. Ground-based spraying does not usually result in any significant drift, because spraying should only be carried out under the most favourable conditions, and in accordance with relevant legislation and codes of practice. In the second season autumn or later after planting of eucalypts, ground-based treatments may be applied to the rows and inter-rows using directed nozzles and/or a dual sprayer, and pose little risk of spray drift, as the trees themselves constitute a significant barrier for chemical spray drift.

Aerial application

Aerial spraying by helicopter usually has a very low probability of drift, given legal constraints on aerial spraying, the low speed of the aircraft and the configuration of the spray equipment. The likelihood of spray drift from aerial applications is further minimised by the preference of plantation forestry companies to use helicopters (as they are more accurate and minimise the likelihood of off-site spray drift). There is a greater probability of spray drift from applications of pesticides by fixed wing aircraft, because speeds are higher. Fixed wing aircraft are usually only used in plantations where there are large contiguous areas of relatively flat terrain, such as in the pine plantation region of the south west of Victoria and south east of South Australia. Development of spray nozzle technology has been shown to reduce spray drift (Richardson *et al.*, 1996).

Regulation

To fully scope regulation, the APVMA released a discussion paper relating to spray drift risk in 2006 that outlined operating principles and registration requirements (APVMA, 2006). Spray drift usually comes under Control of Use Acts. Section 40 of the *Victorian Act*, for example, makes it an offence to cause damage from spray drift by agricultural spraying which:

- Injuriously affects any plants or stock outside the target area;
- Injuriously affects any land outside the target area, so that growing plants or keeping stock on that land could be reasonably expected to result in contamination of the stock or of the agricultural produce.

This regulation applies to all chemical users (company, government, professional) and all types of spray application (aerial, spot spraying, misters, ground driven boom sprays etc). There are licensing requirements for ground-based application, and for the aerial application of agricultural chemicals in all States and Territories.

Application

Specific reports have been prepared (e.g. PISC, 2002) and provide strategies to minimise the risk of spray drift. They include comprehensive detail on operation planning and implementation. For aerial application, the Centre for Pesticide Application and Safety at Gatton College, University of Queensland, Toowoomba conducts week-long advanced training.

It must be emphasised that aerial applications in plantation forestry are small in comparison to other industries. Multiple applications of fungicides are used in the growing of some varieties of potatoes. For example, one variety potato grown around Ballarat and used for crisp production is routinely treated with a rotation of two fungicides up to five times at 10 to 14 day intervals, by helicopter. Similar chemical regimes apply in other Australian states. As noted elsewhere, there are also extensive aerial treatments with chemical pesticides applied annually to crops such as rice, cotton, wheat and grain crops and canola.

Analysing chemical usage

Area treated

There are three basic spray treatment spatial arrangements and the land units are expressed on the actual area treated or the area planted. The three basic arrangements are:

1. 100% coverage or broadcast spraying of all the area under the trees (planted = treated area);
2. Strip spraying on a line either on the mounds or in the inter-row. A 2 m wide strip treated with rows 4 m apart would spray 0.5 ha / ha planted giving 50% treatment;
3. Spot spraying around the planted tree. A 2 m diameter circular spot would spray 3.1 m^2/spot. At 1,000 stems/ha, this would spray 0.3 ha / ha planted or 30% treatment.

Chemical attributes

The chemical pesticides used in plantation forestry and agriculture in Australia have a wide range of **a.i.** and concentrations. However, the number of individual chemicals used in plantation forestry is far more limited than in agriculture. A fundamental basis of any analysis is the units to be used. Table 4 shows a range of chemical pesticides with details of the a.i., the a.i. concentrations and generic costs (note: the costs are based on local supplier prices in Victoria, in 2006). (A complete list of product names for each a.i. can be sourced on the APVMA web site.) Of more importance are the rates at which the products are used. Rates are expressed on a per hectare treated basis. Label application minimum and maximum rates were recorded for the a.i. shown in Table 4 and these were plotted against the product price per unit sold (volume or weight) to test whether chemical pesticide spending is a reasonable index of pesticide use. (See Appendix G.) In the pesticides analysed, in general, as the price per unit increases, the application rate (a.i./ha) decreases. The main exception is hexazinone, which is a major softwood plantation forestry chemical pesticide.

Table 4 A break down of product costs per unit, concentration and cost per a.i.. Cost data is based on a Victorian supplier for 2006.

Broad group	a.i.	a.i.	a.i.		Product	
	(name)	(units)	(quantity)	(units)	($/unit)	($/kg a.i.)
Fungicides	Benomyl	kg/L	0.500	L	$73.60	$147.20
	Copper oxychloride	kg/L	0.500	L	$13.30	$26.60
	Mancozeb	kg/kg	0.800	kg	$7.50	$9.38
	Mancozeb/metalaxyl	kg/kg	0.640	kg	$20.50	$32.03
Herbicides	2,4 - D amine	kg/L	0.625	L	$7.75	$12.40
	Amitrole	kg/L	0.250	L	$8.34	$33.36
	Atrazine	kg/kg	0.900	kg	$7.20	$8.00
	Clopyralid	kg/kg	0.750	kg	$133.00	$177.33
	Clopyralid	kg/L	0.300	L	$53.20	$177.33
	Diquat	kg/L	0.200	L	$21.75	$108.75
	Fluroxypyr	kg/L	0.200	L	$21.10	$105.50
	Glyphosate	kg/L	0.450	L	$3.90	$8.67
	Haloxyfop	kg/L	0.520	L	$160.00	$307.69
	Hexazinone	kg/kg	0.750	kg	$89.00	$118.67
	Linuron	kg/kg	0.500	kg	$42.50	$85.00
	Metsulfuron methyl	kg/kg	0.600	kg	$90.00	$150.00
	Oxyfluorfen	kg/L	0.240	L	$29.50	$122.92
	Paraquat	kg/L	0.200	L	$10.25	$51.25
	Pendimathalin	kg/L	0.455	L	$7.20	$15.82
	Simazine	kg/kg	0.900	kg	$7.20	$8.00
	s-metolachlor	kg/L	0.960	L	$23.00	$23.96
	Sulfometuron methyl	kg/kg	0.750	kg	$235.00	$313.33
Insecticides	Alpha-cypermethrin	kg/kg	0.100	kg	$11.40	$114.00
	Carbaryl	kg/kg	0.500	kg	$10.62	$21.24
	Chlorpyrifos	kg/kg	0.500	kg	$9.00	$18.00
	Dimethoate	kg/L	0.400	L	$6.98	$17.45
	Fipronil	kg/L	0.200	L	$318.27	$1,591.35
	Imidacloprid	kg/L	0.200	L	$240.00	$1,200.00
	Maldison	kg/L	0.500	L	$7.70	$15.40

General herbicide prescriptions

Investment in herbicides in a plantation crop is a function of site, crop and management objectives. A plantation manager must develop site specific regimes to match the site's needs and the management objectives. The following present typical plantation competition control regimes for hardwood and softwood plantations in Australia (following the inputs shown in Figure 10) as an example of the range of options currently implemented. The information is split between temperate and sub-tropical/tropical Australia. Information presented is based on industry experience, *Pers. com.* 6 and *Pers. com.* 7. Appendix H contains details of the typical regimes and flow charts of the regimes for Tasmanian blue gum and radiata pine. Appendix D presents a summary of the specific a.i. used in plantation forestry. As a convention, application rates of 100 g a.i./ha or less are expressed as XX g a.i./ha, and greater than 100 g **a**.i./ha are expressed as XX kg a.i./ha.

Temperate eucalypts

Initial site clean-up

This is usually either an application of glyphosate or a tank mixture of glyphosate, metsulfuron methyl and an organosilicone surfactant. On first rotation pasture sites in southern Australia, a typical broad acre prescription could be 0.72 to 1.44 kg a.i./ha of glyphosate, 6 to 9 g a.i./ha metsulfuron methyl, plus an organosilicone surfactant at 0.2% v/v. Sometimes oxyfluorfen is added at 18 g a.i./ha as a swathe marker.

Pre-plant weed control

There are two main prescriptions in southern Australia, both usually applied to the rows (or mounds). Glyphosate and metsulfuron methyl can be omitted if the mounds are weed free. If weed is present, usually glyphosate use at 0.72 to 1.08 kg a.i./ha is sufficient. Metsulfuron methyl is usually applied at 6 to 9 g a.i./ha, and sulfometuron methyl if used either instead of metsulfuron methyl or in addition, at no more than about 22 g a.i./ha. If the site is thistle prone, or has a major capeweed problem, clopyralid is added at 0.15 to 0.60 kg a.i./ha. However, the high rates of clopyralid are usually to control some weeds better controlled by low rates of other herbicides.

The second prescription is a propriety WDH product which contains terbacil and sulfometuron methyl. It is a pre-packaged 1 kg/ha product in a water soluble bag which contains 880 g terbacil and 40 g sulfometuron methyl. It is also usually only applied to the mounds. It may also be mixed with glyphosate and clopyralid at the rates indicated in the previous prescription description. It is not as well favoured on sandy soils because chemical, particularly sulfometuron methyl, is too easily lost through leaching.

Post-plant weed control

On ex-pasture sites, these are usually recovery treatments arising from the breakdown of the pre-planting treatment. Typically, a combination of haloxyfop with clopyralid is used, often with simazine. The haloxyfop rate depends on the grass density and development and is usually in the range of 0.10 to 0.42 kg a.i./ha. The clopyralid rate is usually in the range of 90 g a.i./ha to 0.18 kg a.i./ha, and simazine if added is usually at rates of 1.50 to 2.5 kg a.i./ha. Sometimes the presence of wild radish or wild turnip requires the addition of metosulam at rates of 5 to 7 g a.i./ha.

Maintenance

Maintenance works are reactive to the development of pest weeds post the establishment year. Treatments to Tasmanian blue gum include a directed spray application to the mounds, a granular treatment (also to the mounds), and a separate treatment to the inter-rows. For spray applications, dual sprayers are commonly used, with a mound treatment by directed spray comprising a mixture of amitrole or glyphosate, simazine and sulfometuron methyl. Amitrole is usually at 0.25 to 0.50 kg a.i./ha or glyphosate at 0.36 to 0.72 kg a.i./ha. Both result in a certain amount of bottom leaf scorch with a transient effect. Simazine is usually applied at a total rate to mounds and inter-rows of 2.50 to 4.00 kg a.i./ha. Sulfometuron methyl, usually applied only to the mounds, is at rates of around 20 to 40 g a.i./ha.

A proprietary granular treatment is a dry granule at 30 kg/ha of product, delivering 1.32 kg a.i./ha of terbacil and 60 g a.i./ha of sulfometuron methyl. The granules require up to 50 mm of rainfall for activation, and this slows chemical release. The granules can also be applied aerially by helicopter on a row basis, or by ground-based methods, including spot treatments to individual trees.

Sub-tropical/Tropical Hardwoods

Initial site clean-up

This is usually either an application of glyphosate or a tank mixture of glyphosate, metsulfuron methyl and an organosilicone surfactant, or fluroxypyr. Farm forestry treatments for eucalypt establishment in Queensland can include (for woody weed problems), fluroxypyr at 0.40 kg a.i./ha applied with glyphosate once pre-planting and pre-site preparation. Alternatively, triclopyr at 90 g/100L plus picloram at 30 g/100L may be applied once, pre-planting and pre-site preparation. For woody weed control on eucalypt sites, metsulfuron methyl at 24 to 36 g a.i./ha is applied, or glyphosate at 1.44 kg a.i./ha with 0.20 kg a.i./ha fluroxypyr for mullein (tobacco weed) control.

Pre-plant weed control

For eucalypt establishment in northern New South Wales, after ripping and mounding and a second cultivation of the mounds, glyphosate at 1.44 kg a.i./ha, simazine at 2.50 kg a.i./ha and s-metolachlor at 1.44 kg a.i./ha is a standard prescription (under APVMA permit). Farm forestry treatments for eucalypt establishment in Queensland can include one or two strip (row) treatments with glyphosate at a rate of 1.80 kg a.i./ha (applied to half the area with a 2 m inter-row spacing), plus (for the immediate pre-planting treatment) 4.80 to 6.00 kg a.i./ha of simazine.

Post-plant weed control

Vegetation is usually retained on the inter-row. However, a second post-planting application may be made in either the first or second seasons by shielded spray. Haloxyfop plus clopyralid is applied outside the shield onto the mounds, and inside the shield glyphosate at up to 1.44 kg a.i./ha plus fluroxypyr at

0.96 kg a.i./ha is applied to the outside of the mounds and part of the inter-row. Slashing may be used instead of the inside application.

In northern New South Wales, post-planting treatments to eucalypts are similar to the late first season treatment to hardwood plantations. Haloxyfop at 0.130 kg a.i./ha plus clopryalid at 0.30 kg a.i./ha with or without simazine at 2.50 kg a.i./ha is a standard prescription. The addition of simazine depends on the amount of bare ground and the time of treatment. In Queensland, glyphosate/fluroxypyr mix (2.70 kg a.i./ha glyphosate plus 0.40 kg a.i./ha fluroxypyr) is used as a directed spray. For some site-specific problems such as brassica or thistles, a permit for diflufenican has been requested based on trial demonstration of efficacy.

Maintenance

Farm forestry post-planting treatments to eucalypts in Queensland can include up to three or four directed row applications of glyphosate at 1.80 kg a.i./ha plus simazine at 4.80 to 6.00 kg a.i./ha in the first year and a further one to two applications in the second year. In a small percentage of cases, fluazifop-p-butyl can replace glyphosate in one to two first year treatments at a rate of 0.37 kg a.i./ha. Oils and surfactants are commonly used, such as canola oil with glyphosate and alcohol alkoxylates (with fluazifop), both at about 20 mL/10 L of spray mix. Fluroxypyr may be applied once to control woody weeds when the plantation is more than 3 years old; alternatively, triclopyr at 90 g/100L plus picloram at 30 g/100L may be applied once in northern Queensland eucalypts.

Temperate softwoods

Initial site clean-up

On 1R pasture sites in southern Australia, a typical broad acre prescription could be 0.72 to 1.44 kg a.i./ha of glyphosate, 6 to 9 g a.i./ha metsulfuron methyl, plus an organosilicone surfactant at 0.2% v/v. Sometimes oxyfluorfen is added at 18 g a.i./ha as a swathe marker. On 2R radiata pine sites, woody weeds including native species are usually a major consideration, as well as pine regeneration. Glyphosate rates are usually as high as permitted, e.g. 2.16 kg a.i./ha, together with metsulfuron methyl at 60 to 96 g a.i./ha plus organosilicone surfactant at 0.2% v/v. Fluorinate and carfentrazone are being developed in combinations with glyphosate and metsulfuron to control pine wildlings.

Pre-plant weed control

More often herbicide treatments are applied post-planting in radiata pine depending on initial site clean-up. However, hexazinone is the main pre-planting herbicide, applied at rates of 1.50 to 3.80 kg a.i./ha depending on site factors. The low rates are used on ex-pasture sites and the highest rate on woody weed sites, about 1 month before planting. The products used are either dry granules or a Dry Flowable (DF) spray mix.

Post-plant weed control

Post-plant weed control is more usual than pre-plant. The chemicals used as spray or granular treatments include hexazinone, atrazine, amitrole and clopyralid. Treatments with hexazinone or hexazinone/atrazine combinations are usually about one to two months after planting. If used alone, the hexazinone rate varies from about 1.50 to 3.80 kg a.i./ha, depending on the site and weed characteristics. If used in combination with atrazine, the rates are usually 1.50 to 2.00 kg a.i./ha, with the major granular product and WDH formulations being 1.50 kg a.i./ha plus 4.50 kg a.i./ha of atrazine. Forests NSW have experimented with a rate of 0.75 kg a.i./ha in combination with atrazine.

There have been extensive plantings of maritime pine (*Pinus pinaster*) on nutritionally poor sands in Western Australia in recent years. There is little or no weed control at establishment. Instead the rows are scalped and the trees planted. At about age one year, in cold conditions in mid-winter, the trees may be over sprayed, usually with 0.36 kg a.i./ha glyphosate, but sometimes with chlorsulfuron (related to sulfometuron and metsulfuron) at low rates of about 12 to 24 g a.i./ha

Maintenance

Clopyralid is usually applied later in the early stages of plantation development to control emergent or suckering silver wattle. Use rates for clopyralid vary from 0.15 to 2.55 kg a.i./ha, depending on the growth stage of the wattle, and whether clopyralid is being applied as a pre-emergence treatment. The high rates are only applied for silver wattle control at 6 to 7 years and close to canopy closure. Amitrole is used in South Australia and has been used in New South Wales, in combination with atrazine as an aerial second season treatment. The amitrole rate is usually in the range 0.37 to 0.50 kg a.i./ha with atrazine at 4.50 kg a.i./ha.

Tropical and sub-tropical softwoods

Initial site clean-up

In northern New South Wales, pre-planting clean-up treatments for exotic pine species (including hybrids) include skidder or aerial application of glyphosate at 2.16 kg a.i./ha plus metsulfuron methyl at 60 g a.i./ha. For hoop pine (*Araucaria cunninghamii*), pre-site preparation treatment is glyphosate at 2.16 kg a.i./ha plus metsulfuron methyl at 60 g a.i./ha, in order to control wildlings as well as other weeds. In Queensland, pre-planting treatment for the establishment of exotic tropical pines is usually an aerial application of glyphosate at 2.70 kg a.i./ha plus fluroxypyr at 0.40 kg a.i./ha. For woody weeds, triclopyr or triclopyr/picloram applications are used, and for wildling pine, 2,4-D isopropylamine is preferred, because results have shown that glufosinate-ammonium is not effective all year round.

Pre-plant weed control

In northern New South Wales pre-planting treatments for exotic pine species can be either glyphosate at 1.44 kg a.i./ha plus sulfometuron methyl at 75 g a.i./ha aerially, or if to bare soil, only the sulfometuron methyl component. For hoop pine, pre-planting treatment is with glyphosate at 1.44 kg a.i./ha plus simazine at 5.00 kg a.i./ha plus fluroxypyr at 1.44 kg a.i./ha.

Post plant weed control

In northern New South Wales, post-planting treatment to the exotic pines includes haloxyfop at 0.13 kg a.i./ha plus clopyralid at to 0.30 kg a.i./ha. Post-planting treatments in Queensland are usually either simazine at 4.50 kg a.i./ha over the trees, or combined with 1.35 kg a.i./ha of glyphosate by directed spray.

Maintenance

Further applications of the post-planting treatment may be required within the first two years.

Pesticide use over a crop life

Basis of analysis

Any discussion of chemical pesticide use needs to be based on an understanding of the application regime over the life of a crop. (Appendix H contains details of typical plantation forestry regimes based on a combination of information from the industry survey, operational and research experience.) In order to compare with agricultural crops, "standard crop regimes" were explored. Gross margin analysis is a method of comparing agricultural crops: between crops or between years for a single crop. The analysis presents the variable inputs costs, which often gives very detailed information on the chemical pesticide regime applied. Gross margins for a wide range of crops, in different regions, are prepared by State Government agricultural departments and published on the web (with periodic updates). It is recognised that gross margin analysis is a generic approach, but was considered as appropriate for the broad scale comparisons as follows.

A single crop

Crops vary in their chemical pesticide inputs each year and the inputs over the life of a crop. Plantation forestry differs from many other agricultural crops. In general plantation forestry has the majority of chemical pesticide inputs in the first two years, with other inputs over the balance of the crop life on a reactive basis (i.e. to treat a pest out-break). Table 5 presents a generic regime to grow a first rotation (1R ex-pasture site) Tasmanian blue gum crop. The regime assumes a high degree of weed control. It also includes a reactive insecticide treatment to control an out-break of autumn gum moth (*Mnesampela privata*) at age 3 years. Based on the industry survey, the most commonly used insecticide is alpha-cypermethrin, and it was assumed to be used at the registered maximum rate of 300 mL/ha for this pest. Figure 16 presents the inputs to age 10 years when the crop is clearfallen and re-planted in the same year (the 2R crop). (If a coppice crop is used, then herbicide inputs would be minimal.)

Table 6 and Figure 17 shows the chemical pesticide inputs for an onion crop growing in Tasmania (DPIW, 2006b) where all the inputs are in the one year for a single crop. Table 7 and Figure 18 show the chemical pesticide inputs required to grow a banana crop on the Atherton Tablelands in far north Queensland (DPI Qld, 1999). The banana enterprise has a one year plant crop followed by six years of "ratoon" crops (regrown from the plant crop) to give a total crop life cycle of 7 years. It is difficult to make a meaningful comparison between the three crop regimes due to differences in the quantity and actual a.i. used, and the timing and degree of repetition of application. This can be addressed by considering the management of an estate of each crop.

Table 5 A generic regime used in a 1R Tasmanian blue gum plantation.

Operation	Year	Active ingredient	Rate		$/ha planted	Comments
Pre-planting clean-up	1	Glyphosate	720.0	g a.i./ha	$12.26	Broadcast 100% of area
		Metsulfuron methyl	6.0	g a.i./ha		
		Adjuvant	0.2	L/ha		
Pre-planting residual plus knockdown	1	Glyphosate	720.0	g a.i./ha	$25.05	Strip application (50% coverage) to 100% of the area
		Simazine	4.0	kg a.i./ha		
		Sulfometuron methyl	22.5	g a.i./ha		
		Adjuvant	0.2	L/ha		
Post-planting recovery	1	Haloxyfop	130.0	g a.i./ha	$80.84	Recovery operation strip (50% coverage) to 100% of area
		Simazine	4.0	kg a.i./ha		
		Clopyralid	180.0	g a.i./ha		
Post-planting	2	Amitrole	500.0	g a.i./ha	$28.96	Strip application (50% coverage) to 100% of the area
		Simazine	4.0	kg a.i./ha		
		Sulfometuron methyl	22.5	g a.i./ha		
Reactive insect control	3	Alpha-cypermethrin	30.0	g a.i./ha	$5.00	Autumn gum moth attack in year 3, treating 100% of the planting.

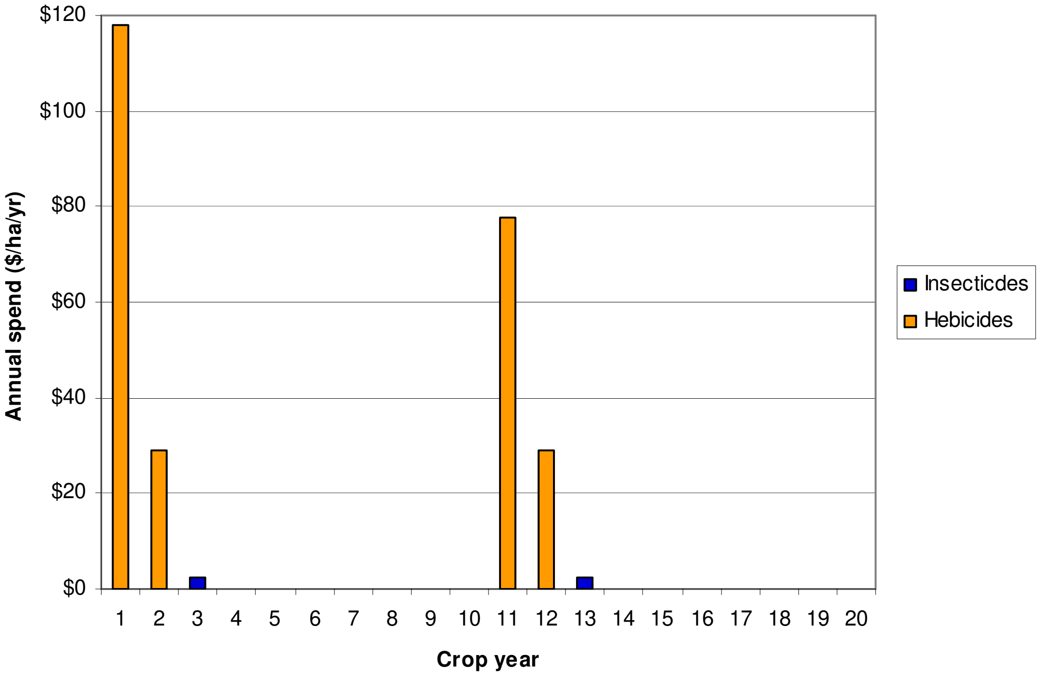


Figure 16 The pesticide inputs to a single 1R crop of Tasmanian blue gums on an ex-pasture site and then to develop a planted 2R crop on the same site. (Costs are as per Table 5.) The first crop is harvested and re-established in year 11.

Table 6 The chemical pesticide inputs to grow a single crop of onions in Tasmania (taken from DPIW, 2006b).

	a.i. (name)	a.i. (units)	a.i. (quantity)	Product (units)	Units/spray (units/ha)	Applications (No./ha/crop)	Total units (Units/ha)	a.i. (a.i./ha)	Total ($/ha/crop)
Herbicides	Propachlor	kg/L	0.48	L	9.00	1	9.00	4.32	
	Diquat	kg/L	0.20	L	1.50	1	1.50	0.30	
	Paraquat	kg/L	0.20	L	1.50	1	1.50	0.30	
	Ethofumesate	kg/L	0.50	L	0.80	1	0.80	0.40	
	Paraquat	kg/L	0.20	L	2.00	1	2.00	0.40	
	Methabenzthiazuron	kg/kg	0.70	kg	0.30	3	0.90	0.63	
	Ioxynil	kg/L	0.25	L	0.50	3	1.50	0.38	
	Total					11			$400.75
Insecticides	Dimethoate	kg/L	0.40	L	0.80	2	1.60	0.64	
	Alpha-cypermethrin	kg/kg	0.10	kg	0.25	1	0.25	0.03	
	Total					3			$37.49
Fungicides	Mancozeb	kg/L	0.80	L	2.20	5	11.00	8.80	
	Mancozeb/metalaxyl	kg/L	0.64	L	2.50	2	5.00	3.20	
	Benomyl	kg/kg	0.50	kg	1.00	2	2.00	1.00	
	Copper oxychloride	kg/kg	0.50	kg	1.00	3	3.00	1.50	
	Total				12	12			$495.10

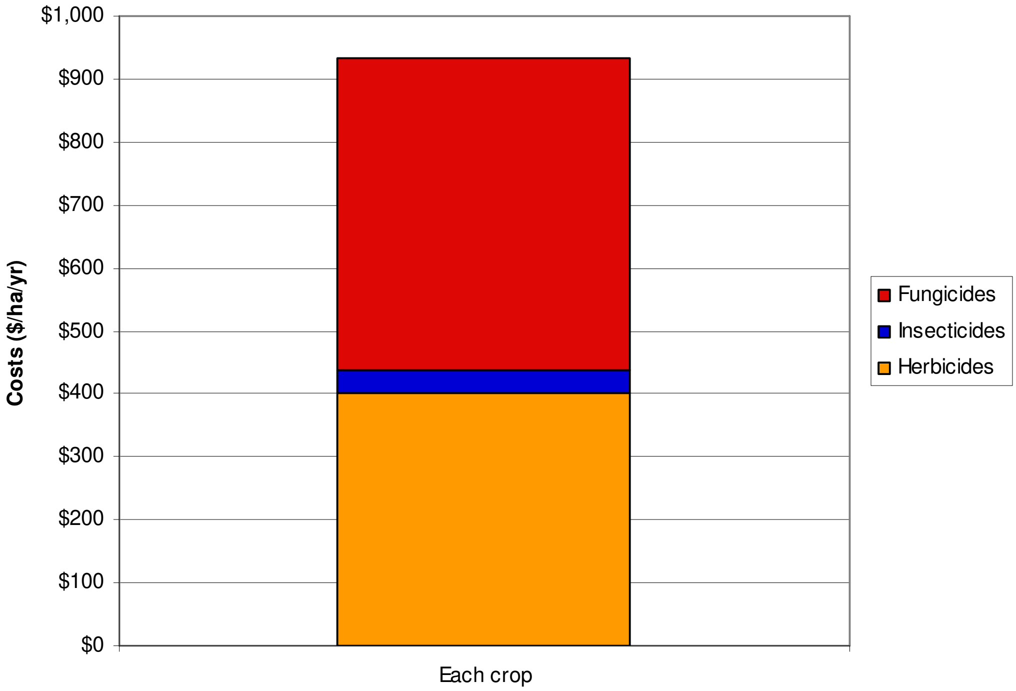


Figure 17 The pesticide inputs to grow a single crop of onions in Tasmanian (based on DPIW, 2006b).

Table 7 A standard regime to manage a banana plantation in northern Queensland based on DPI Qld (1999), with the costs based on the references listed and industry data.

		a.i. (name)	a.i. (units)	a.i. (quantity)	Product (units)	Units/spray (units/ha)	Applications (Number/ha/yr)	Total units (Units/ha/yr)	a.i. (a.i./ha/yr)	Total ($/ha/yr)
Plant crop	Herbicides	Glufosinate-ammonium	kg/L	0.200	L	4	4	16.0	3.20	
		Oryzalin	kg/L	0.500	L	4	1	4.0	2.00	
		Totals					5			$467.94
	Fungicides	Oil	L		L	5	6	30.0		
		Totals								$88.68
	Insecticides	Fenbutatin oxide	kg/L	0.550	L	0.37	1	0.4	0.20	
		Mancozeb	kg/kg	0.125	kg	2.5	6	15.0	1.88	
		Chlorpyrifos	kg/L	0.500	L	0.14	1	0.1	0.07	
		Chlorpyrifos	kg/kg	0.010	kg	8.5	1	8.5	0.09	
		Totals								$168.70
Ratoon crop	Herbicides	Glufosinate-ammonium	kg/L	0.200	L	4	2	8.0	1.60	
		Totals								$159.61
	Fungicides	Propiconazole	kg/L	0.250	L	0.4	2	0.8	0.20	
		Oil	L		L	5	12	60.0		
		Mancozeb	kg/kg	0.125	kg	2.5	10	25.0	3.13	
		Totals								$442.66
	Insecticides	Fenbutatin oxide	kg/L	0.550	L	0.37	2	0.7	0.41	
		Clofentezine	kg/L	0.500	L	0.25	1	0.3	0.13	
		Chlorpyrifos	kg/L	0.500	L	0.14	1	0.1	0.07	
		Chlorpyrifos	kg/kg	0.010	kg	8.5	1	8.5	0.09	
		Cadusafos	kg/L	0.100	L	36	2	72.0	7.20	
		Cadusafos	kg/L	0.100	L	54	1	54.0	5.40	
		Chlorpyrifos	kg/L	0.500	L	1.5	1	1.5	0.75	
		Prothiofos	kg/L	0.500	L	1	1	1.0	0.50	
		Totals								$1,440.56

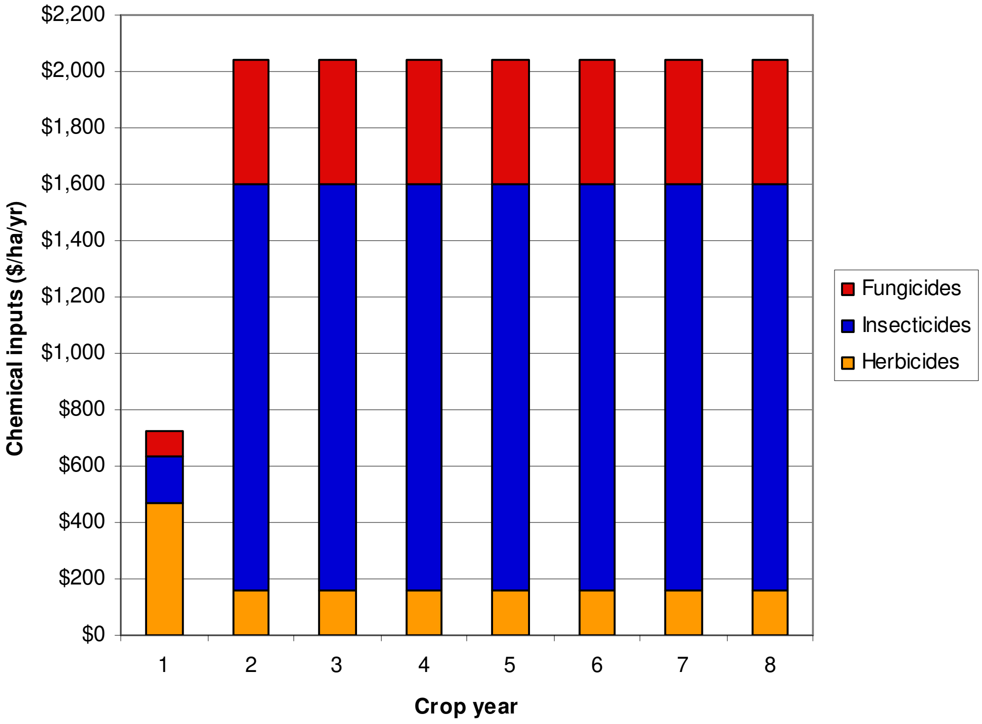


Figure 18 The chemical pesticide inputs to grow a plant crop and six years of ratoons of bananas in far north Queensland (based Table 7).

Estate development

Given the irregular nature of chemical pesticide inputs to a plantation (in the case shown it was a eucalypt plantation, but similar patterns occur in a softwood plantation), it is important to examine the pattern of pesticide inputs to an estate. In a "normal forest", there are a number of similar areas of trees, planted over successive years, so that the area harvested is re-planted that same year to give a uniform woodflow. Assume that 100 ha of eucalypt plantations are established each year for 10 successive years. In the first year there are 100 ha of plantations in a single stand. After the next year, there is one stand of 100 ha age one year and one stand of 100 ha of newly planted trees (a total estate of 200 ha). By year ten, there is a total estate of 1,000 ha of trees composed of 10 stands of 100 ha each. Taking the regime shown in Figure 16, the herbicide inputs for the establishment year (year 1) cost $118.15 /ha ($11,815 for the stand). In year 2, another $28.96 /ha ($2,896 for the stand) of herbicides are required for the first 100 ha planted, as well as herbicide inputs cost of $118.15 /ha ($11,815 for the stand) for the next 100 ha planted. The totals estate costs for year two are $11,815 plus $2,896 = $14,711, but spread over 200 ha to give an estate cost of $73.55 /ha. The total costs are spread over a bigger area, effectively diluting the herbicide spend. The cycle continues. Figure 19 shows the development of the estate up to a total of 1,000 ha, after which it remains stable as the areas harvested are replanted. All the pesticides used on the estate each year are totalled (i.e. successive applications of the regime shown in Table 4 and Figure 16) and then divided by the estate area gives an average input per hectare of the estate (Figure 19). With each successive planting year and the estate expansion, the average pesticide spend is diluted down to

$10.92 /ha/yr. Contrastingly, if the same is applied to an onion and banana crop building up to an estate of 1,000 ha, due to the annual pesticide inputs (see Tables 6 and 7 and Figures 20 and 21), the inputs to the estate increases each year, up to a spend of $933.34 /ha/yr for the onions and $1,911.08 /ha/yr for the banana crop.

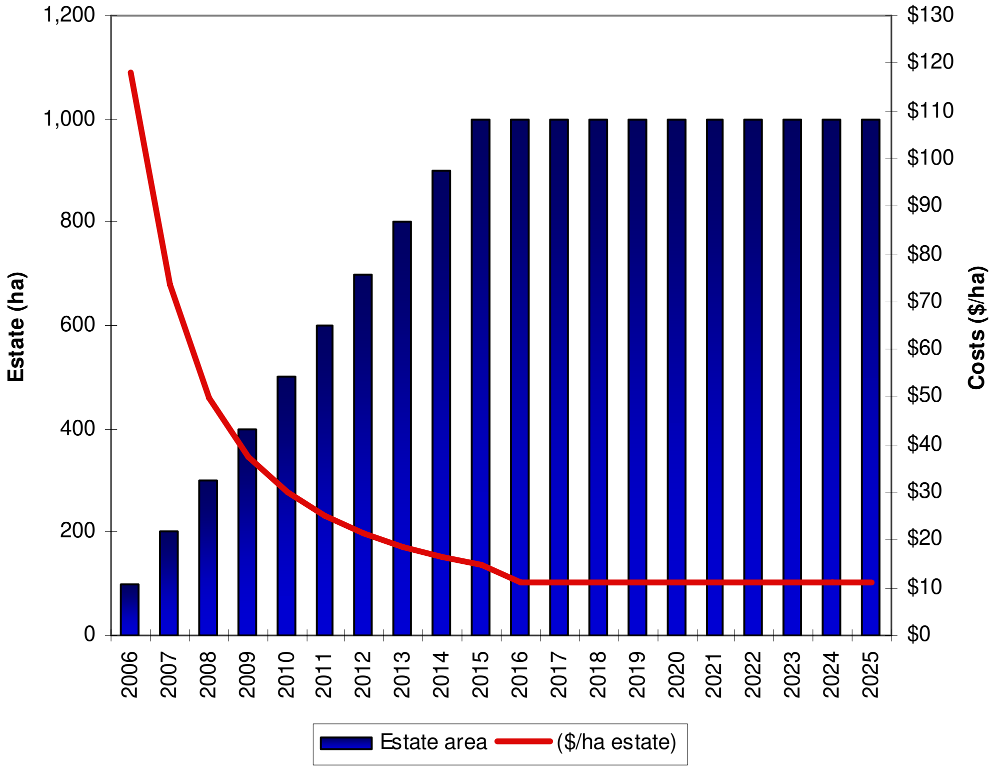


Figure 19 The development of a eucalypt plantation estate by increasing the area planted each year by 100 ha up to a total estate of 1,000 ha. The estate average chemical pesticide spend is shown.

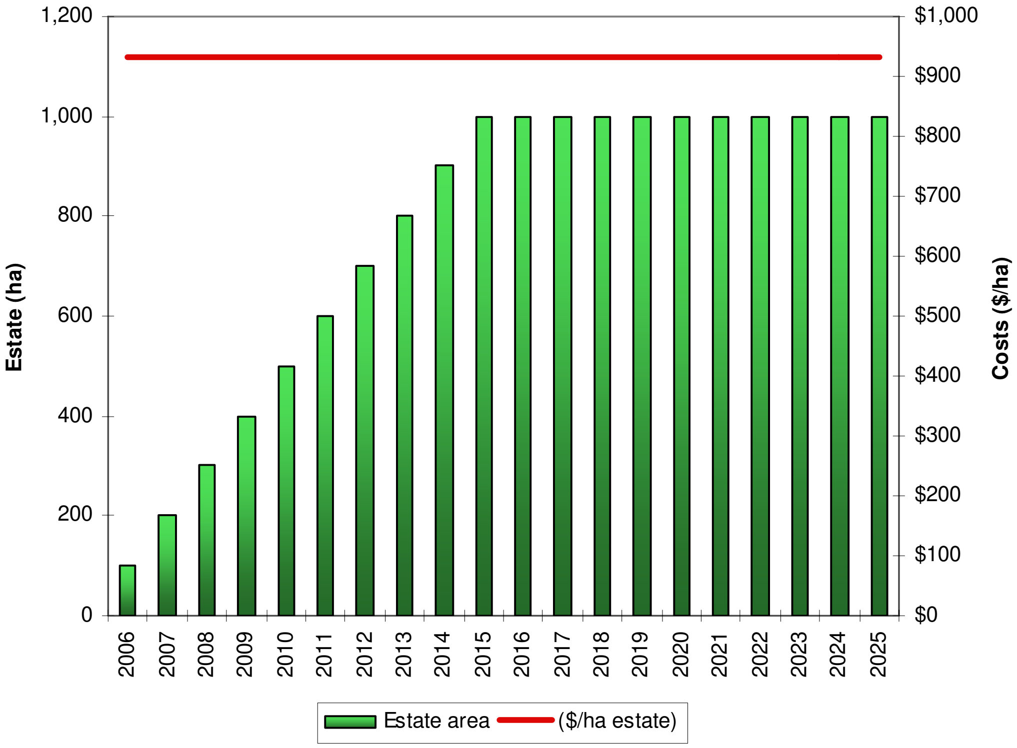


Figure 20 The development of an onion production enterprise by increasing the area planted each year by 100 ha up to a total enterprise of 1,000 ha. The enterprise average pesticide spend is shown assuming one crop per year is grown.

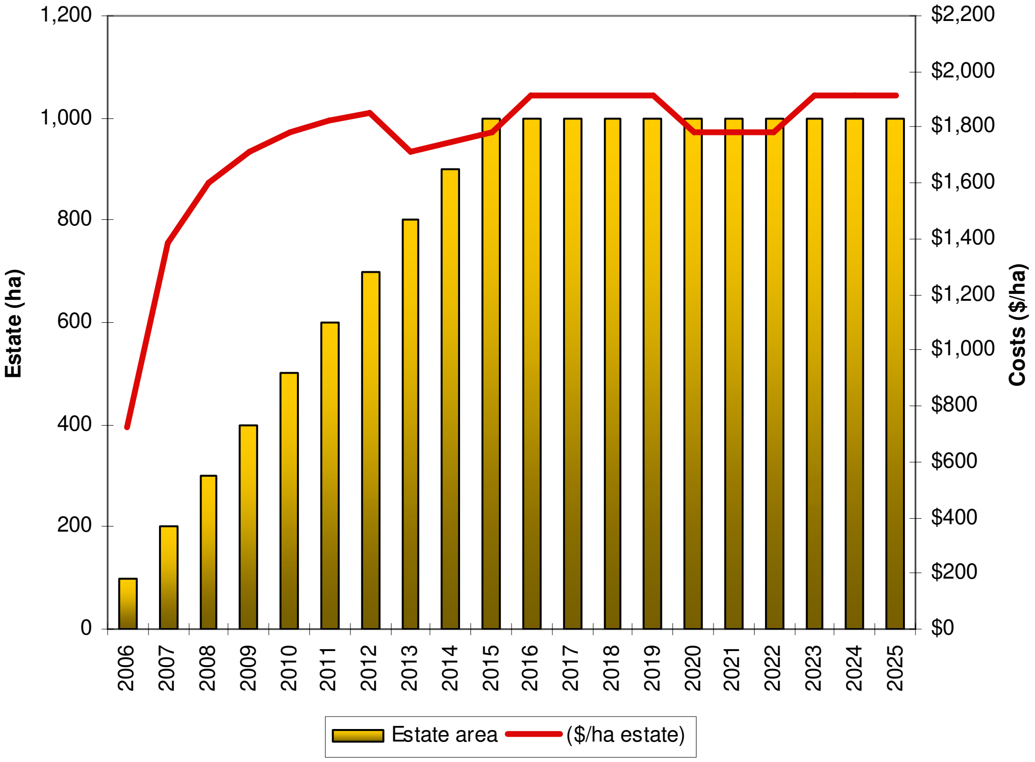


Figure 21 The development of a banana plantation by increasing the area planted each year by 100 ha up to a total estate of 1,000 ha. The plantation average pesticide spend is shown.

Total estate pesticide inputs

It is useful to consider total estate gross chemical pesticide inputs (estate average $/ha * the estate ha). Figure 22 shows the total estate pesticide inputs to manage the Tasmanian blue gum plantation, the onion crops and the banana plantation. It shows the development of the estate up to the total of 1,000 ha for each of the crops discussed previously.

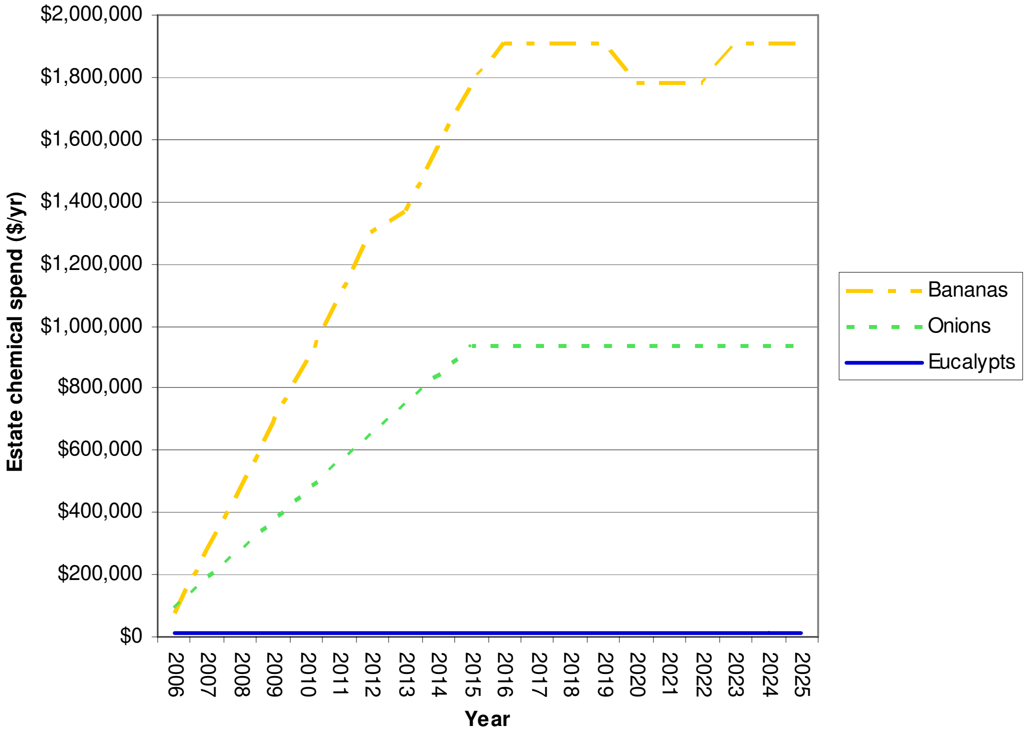


Figure 22 The total annual spend on chemical pesticide inputs for the three crops shown ramping up as the estate expands up to a total estate area of 1,000 ha.

Australian chemical pesticide use

Introduction

Any discussion of the plantation forestry pesticide use must be in the context of the overall Australian market. It is important to consider the total Australian chemical pesticide spend, as it gives an indication of the wide use of a range of chemical pesticides and the degree of penetration of use down to the households level. Specific pesticide use data is published by the APVMA and ABARE. ABARE data are part based on APVMA and ABS data and other analysis (see ABARE, 2005c for details). Specific plantation forestry industry chemical pesticide use data are not collated or reported.

Total market

Based on APVMA data (APVMA, 2005a), Australia's total spend on chemical pesticides for 2004 was $2.45 billion (see Table 8 for a breakdown). The APVMA data are collected from industry supplied sales data. To protect commercial confidentiality, the data are aggregated into the classes shown. Table 8 is aggregated into the ABARE reported categories (to show the composition of the ABARE) and the additional categories reported by the APVMA. It is acknowledged that the ABARE aggregation of "insecticides" included products that are not strictly insecticides (i.e. nematicides; molluscicides; miticides). ABARE lists Australian sales and prices of chemicals, by product type under "Farm Inputs" in Australian Commodity Statistics (ABARE, 2005c) for 2004 with a total spend of $2.15 billion (Figure 23). It shows a steady growth in the use of chemical pesticides since 1990. The total market data include plantation forestry use and will be further discussed in a later section.

Vertebrate poisons include sodium fluoroacetate (1080) and pindone. The use of 1080 is currently under review by the APVMA and they have published an environmental assessment (APVMA, 2005b). The report states that the total Australian 1080 use is around 200 kg/yr and that the main use of 1080 is to control rabbits and the second highest use is to control wild dogs. Foxes, feral pigs, feral cats and rodents are also controlled using 1080 and in some cases marsupials (APVMA, 2005b).

Table 8 A full breakdown of the Australian 2004 pesticide market based on APVMA (2005a), with the ABARE (2005c) assumed market split and the balance of the market.

Broad classifications	**APVMA classifications**			
Herbicides[1]	Herbicides	$996,719,444	$996,719,444	
Fungicides/PGR[1]	Plant regulators	$7,231,128		
	Fungicides	$149,644,993		
	Growth promoters/regulators	$13,230,397	$170,106,518	
Insecticides[1]	Nematicides	$3,283,494		
	Molluscicides	$7,680,661		
	Miticides	$15,799,369		
	Mixed function pesticides	$59,278,105		
	Insecticides	$288,152,121	$374,193,750	
Animal health[1]		$607,747,775	$607,747,775	$2,148,767,487
Additives	Surfactants	$5,242,950		
	Wetting agents	$16,343,295		
	Adjuvants	$23,214,853	$44,801,098	
Domestic / recreation	Pool products / algicides	$53,753,503		
	Household insecticides	$105,446,874	$159,200,377	
Industrial	Wood preservatives	$2,232,445		
	Disinfectants	$3,843,100		
	Dairy cleaners	$10,093,733		
	Antifouling boat	$10,834,361		
	Seed treatment	$50,085,447	$77,089,086	
Others	Repellents dogs/birds etc	$939,212		
	Hormones	$79,610		
	Miscellaneous	$5,018,382	$6,037,204	
Vertebrate poisons[2]	Vertebrate poisons	$15,325,621	$15,325,621	$302,453,386
Totals				$2,451,220,873

1 Note: the allocation of nematicides, molluscicides and miticides to “insecticides” is not strictly correct, but has been done so to match the ABARE applied classifications;

2 Vertebrate poisons includes sodium fluroacetate (1080) and pindone.

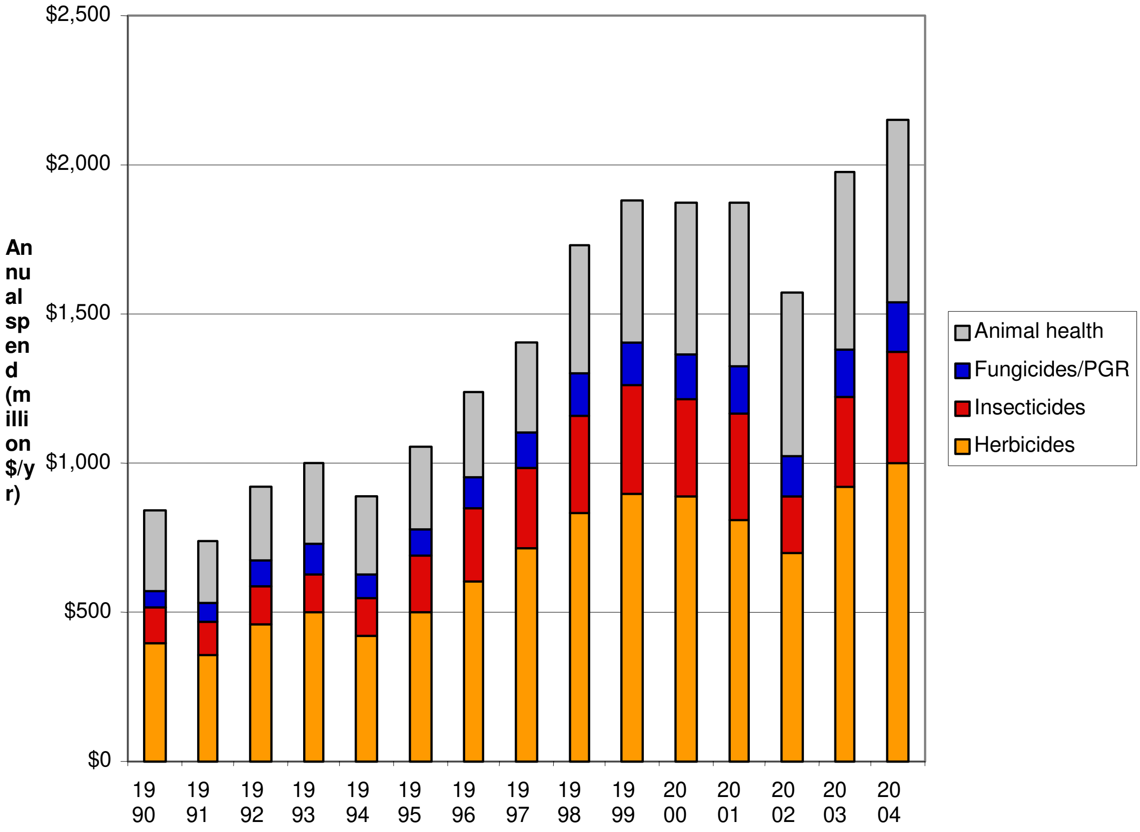


Figure 23 The Australian chemical pesticide total spend based on ABARE (2005c). (Note: PGR = plant growth regulators.) The data shown excludes some APVMA classes.

Household and industrial use

APVMA (2005a) (Table 8) splits out household insecticide use ($105,446,874 for 2004), but bulks all other household chemical pesticides into the other categories (i.e. domestic garden herbicides). Appendix I is a snapshot of the range of chemical pesticides used by households based on spot surveys of major hardware shops and supermarkets. All the products are available off the shelf and include directions for use. No training is required for the use of these products. Some of the constituent chemicals are used in plantation forestry, for example, the herbicides amitrole/ammonium thiocyanate, simazine, glyphosate, and triclopyr (with picloram for basal bark treatments of woody weeds in radiata pine). Insecticide examples include, carbaryl (as a bait for wingless grasshopper) and dimethoate (under permit in South Australia). For further information on household chemical use, see Selinger (1999). Industrial (non-plantation forestry) herbicide use is reported to be reducing as infrastructure managers opt for knockdown only herbicide regimes (*Pers. com.* 4.)

Plantation forestry

Given the lack of plantation data on chemical pesticide use by the Australian plantation industry, estimates have been prepared based on three approaches:

1. A simple model approach based on broad generic regimes;
2. Data from the industry survey;
3. A detailed modelling approach based on 1 and 2.

A simple model

A simple model approach is important to cross check a more sophisticated approach by estimating the maximum theoretical chemical pesticide use. Appendix H presents a summary of softwood and hardwood standard herbicide regimes cost per hectare to cover the establishment and first year maintenance herbicide inputs. Insecticide inputs were based on the costs shown in Table 5 and assuming a 5% hardwood and nil softwood estate treatment rate. (Note: the rates assumed are based on the industry survey results and specific follow-up with the main plantation managers. In the event of a new pest insect or the out-break of an existing pest insect, the areas sprayed could be larger.) These were applied to the NFI data for the 2005 estate (see Table 9), to give an **estimated total maximum spend of $20.9 million** for 2005 or $12.08 /ha/yr for the Australia's plantation estate (softwoods = $9.84 /ha/yr; hardwoods = $15.08 /ha/yr: note, this rate is higher than shown in Figure 19, as the hardwood estate is still expanding).

Table 9 An estimate of the maximum 2005 Australian plantation forestry industry spend on chemical pesticides. Note: the estimates assumes similar planting in 2004 to cover establishment and first year maintenance costs.

			Area[1]	Costs	
			(ha)	($/ha)	($/yr)
Herbicides	Hardwood[2]	1R	65,551	$143.31	$9,459,665
		Estate	14,670	$103.61	$1,519,959
		Total	80,101		$10,979,624
	Softwood[3]	1R	6,477	$160.76	$1,041,243
		Estate	32,771	$265.40	$8,697,512
		Total	39,477		$9,738,754
	All plantations	Total	100,290		$20,718,378
		Treated[4]	Area	Costs[5]	
		(% estate)	(ha)	($/ha)	
Insecticides	Hardwood	5.0%	37,008	$5.00	$185,040
	Softwood	0.0%	0	$5.00	$0
		Total	37,008		$185,040
Total					$20,903,418

1 Based on Figures 4 and 5 and estimated **estate** areas.

2 Hardwood plantation costs based on Appendix H: 1R = 100% use of options A, B, D, and E; Estate = 100% use of options G, H, K and 50% of option J.

3 Softwood plantation costs based on Appendix H: 1R = 100% use of options A and C; Estate = 100% use of options G, 50% option H, 40% option I and 10% option L.

4 Based on the industry survey and follow-up industry information.

5 Based on Table 5 to cover softwood and hardwood.

The industry survey

The outcome of the industry survey was an estimate of the total spend on chemical pesticides for 2005 of $14.9 million by the forestry plantation industry for the survey participants. The industry survey captured data covering 92% of the Australian plantation forestry estate. Therefore, to estimate the total estate spend, the industry survey result has been increased on a *pro rata* basis to give an estimate of the full estate spend of $16.2 million (Table 10). The survey results for 2005 indicated that the plantation forestry industry spent zero dollars on fungicides and nematicides for use in the field (excluding nursery use). The industry survey provided details of the chemical pesticides used. Figures 24 and 25 show the market percentage for the a.i. used based on the value of the spend on each. Comparing the result of the simple analysis (shown in Table 9) and the industry survey result, this would indicate that the actual regimes applied in practice by forest plantation managers are less costly than those in the simple model estimate. This would indicate the use of chemical pesticides at lower rates than the maximums allowed per the label (this is supported by the results of the industry survey as shown in Appendix E).

Table 10 A summary of the plantation industry survey results showing chemical pesticide use in 2005. The industry survey captured 92% of the Australian plantation forestry estate, hence the results have been adjusted on a *pro rata* basis to cover 100% of the estate.

		($/yr)
Industry survey result for 92% of the estate	Herbicides	$14,006,475
	Adjuvants	$704,037
	Insecticides	$152,638
	Total	$14,863,150
Pro rata up to 100% of the estate	Herbicides	$15,224,429
	Adjuvants	$765,258
	Insecticides	$165,911
	Total	$16,155,598

1080 is used in a variety of products at a range of a.i. rates (e.g. 140 to 670 mg/kg of carrots for rabbit control or 2.7 to 4.4 mg/bait for fox control: APVMA, 2005b), it is reported on a kilograms of a.i. basis. The industry survey results showed two separate 1080 uses. The first was to control feral carnivores such as foxes, pigs and wild dogs. Such animals (mostly) do not impact on tree growth and control is undertaken for legal compliance and as part of good neighbour policy. The environmental benefits include reduction of predator pressures on native animals within the plantation estate (e.g. in retained native vegetation). For 2005, 8.8 kg of 1080 was used in meat based baits by plantation forestry managers. The second use of 1080 is to control herbivores (feral and native) as a means of reducing browse pressure at establishment, or to control feral animals such as rabbits. For 2005, 5.5 kg of 1080 was used in herbivore targeted baits by plantation forestry managers.

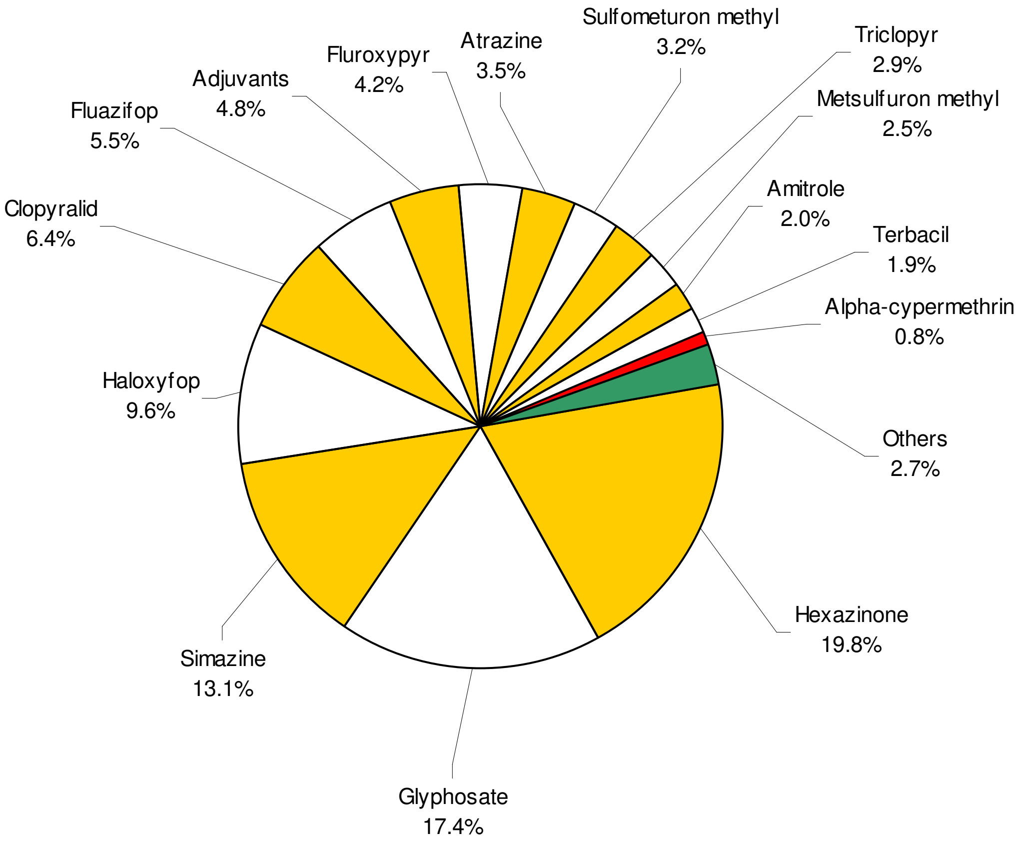


Figure 24 A breakdown of the industry survey results to show the a.i. used by the Australian plantation forestry sector. Herbicides are shown in “yellow” and “white”, and insecticides are shown in “red”.

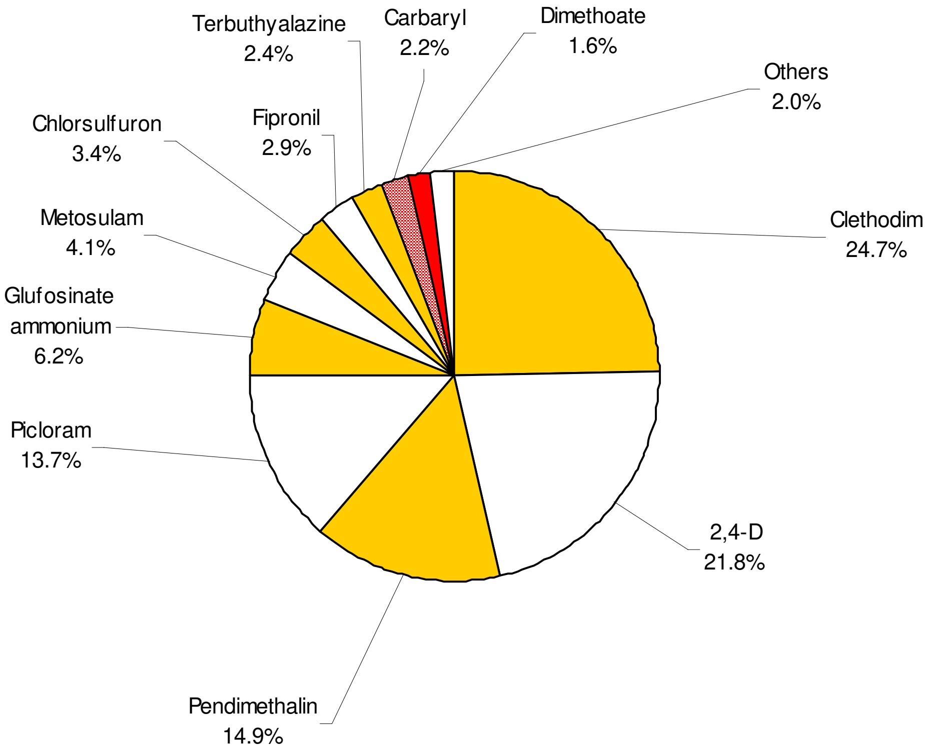


Figure 25 A break down of the minor / other a.i. in use and shown in Figure 24 as “others”. Herbicides are shown in “yellow” and “white”, and insecticides are shown in “red”.

Market data revised

There is a need to reconcile total Australian chemical pesticide spend to demonstrate the context of the plantation industry use. This is important to add a check to any detailed estimate. The APVMA (APVMA, 2005a) gives a total chemical pesticide market of $2.45 billion for 2004 (as stated, APVMA data is sourced from chemical pesticide suppliers). This is the best estimate of the total market. The following points are:

- ABARE lists farm chemical inputs for 2003 – 04 as $1.649 billion (see Figure 4: ABARE, 2006i:). The data are referenced back to ABS (Australian National Accounts, National Income and Expenditure Cat. No. 5204.0 and 5206.0);
- As stated, ABARE lists Australian sales and prices of chemicals, by product type under "Farm Inputs" (ABARE, 2005c: Figure 23). For 2004 a total spend of $2.15 billion;
- Even though it is reported under "Farm Inputs", it reflects the total market for herbicides, non-domestic insecticides and fungicides. Household insecticides are excluded;
- ABARE (2005c) states that the source is the APVMA;

In conclusion, there is some confusion as to the total farm spend on chemical pesticides. In order to get a better indication of the herbicide market, it is necessary to estimate non-agricultural and non-plantation forestry use:

- 2004 total herbicides sales = $996,719,444 (APVMA, 2005a);
- Assume domestic use @ $70,000,000 (7,638,200 households, which includes flats: ABS, 2006b; using around $10 /yr of domestic herbicides i.e. a 1 litre of premix glyphosate);
- Assume industrial use (e.g. around factories and railways) at $15,000,000 /yr (*Pers. com.* 4);
- Assume turf management (golf courses, sports grounds etc) at $6,500,000 /yr (*Pers. com.* 8).

Therefore, the combined agricultural and plantation forestry spend on herbicides is likely to be around $905 million per year (compared to total sales of $996 million per year).

A detailed model of chemical pesticide use

Individual zones

Detailed models of the six zones (see Map 1) were prepared and Appendix J contains the aggregated stand-alone result of the analysis to give a total for Australia for the area covered by the zones. The results are presented on a total spend and dollars per hectare per year basis for the ABS identified crops. The following is an aggregation of the six zones data to give an Australia wide summary.

Total spend

This study has estimated that the Australian plantation forestry spend on chemical pesticides was approximately $16.4 million in 2004 - 05. This equates to approximately 0.7% of the total $2.45 billion APVMA reported, market spend (see Table 8). Figure 26 shows the relative spend of plantation forestry and the balance of the market. This estimate matches the industry survey results of the total spend. The balance of the market relating to agriculture has been accounted for in the specific Zone models (see the Zone details in the appendices).

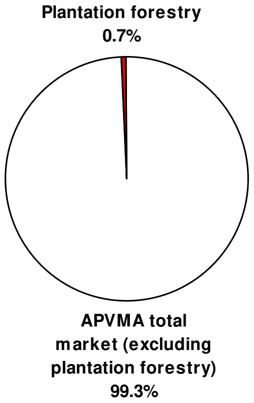


Figure 26 A summary of proportion of the overall chemical pesticide market attributable to plantation forestry.

Comparison to the APVMA/ABARE data

Figure 27 shows a break down of the agricultural and plantation forestry chemical pesticides use in Australia estimated by this study compared to the APVMA/ABARE data. The following comments are made:

- The gap shown in the herbicide spend relates to the domestic, turf and industrial markets as discussed previously;
- The insecticide and fungicide spend is close to the stated totals;
- The difference in the animal health spend is explained by this study accounting for 89.9% of the sheep and 72.4% of the cattle in Australia (as reported by the ABS, 2006a) by the study zones used.

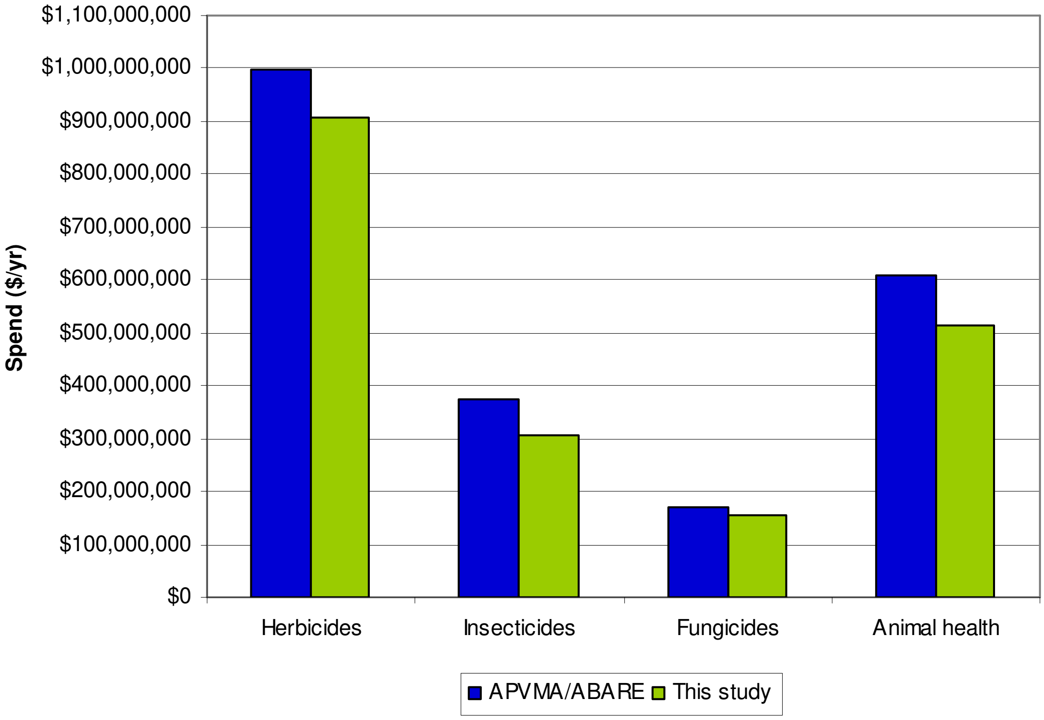


Figure 27 A comparison of the 2004 APVMA/ABARE stated (see Table 8 and Figure 23) chemical pesticide market and this study's estimate.

Plantations in detail

A key finding of the analysis is that the majority of the plantation industry spend on chemical pesticides is for herbicides (Figure 28). The majority of the spend is in the mature softwood plantation estate, while the hardwood estate spend occurs mostly in short rotation pulpwood crops. In the analysis, it was assumed that 5% of the hardwood estate and 0% of the softwood estate is treated each year for insect pests (based on the industry survey and the follow-up with industry). This may mean a slightly higher rate than is actually occurring, but it shows that the spend on such insecticides is low. There is nil to little annual spend on fungicides. That spend will generally be in reaction to pest out-breaks and could be higher from year to year.

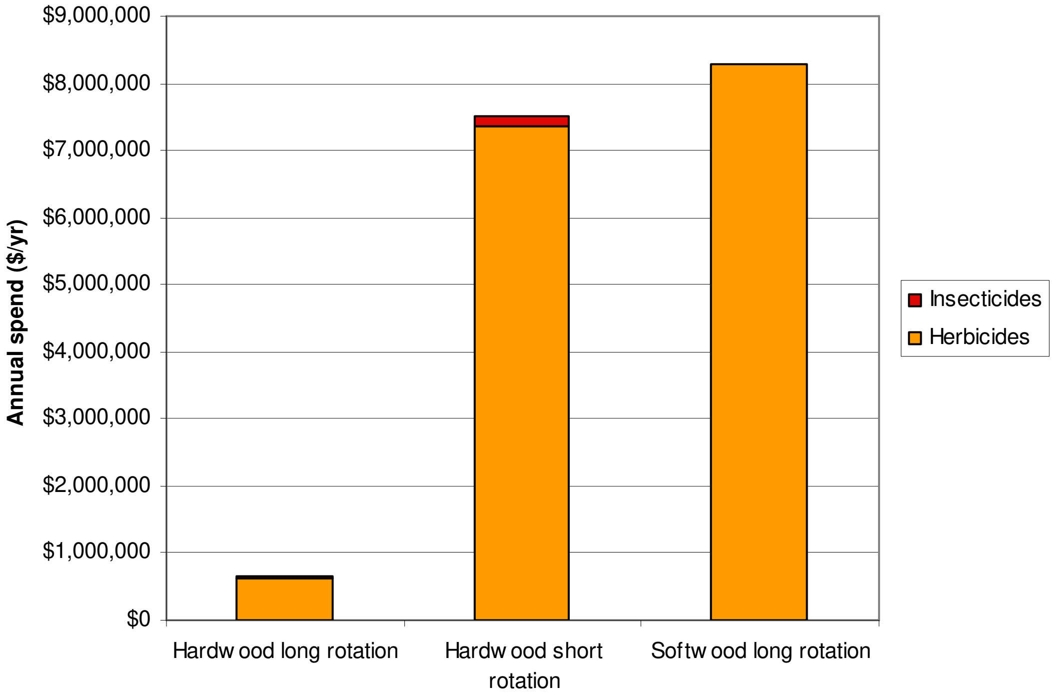


Figure 28 A break down of the estimated plantation forestry spend on chemical pesticides for short rotation hardwood (pulpwood crops), long rotation hardwoods (sawlog crops) and long rotation softwoods (sawlog crop).

Zone summaries

Detailed results of the six zones are shown in the zone summaries.

Risk management

Water monitoring

The main developments in environmental monitoring have centred around water quality. Claims are often made that plantation forestry use of agricultural chemical pesticides has resulted in significant and frequent contamination of streams and water supplies. Whilst it is undeniable that there have been some episodes, it is also true that many claims have been wildly exaggerated, and that the levels detected have been very low and often close to the limits of detection.

Tasmanian state wide assessment

In response to community concerns over the use of chemical pesticides, the then Department of Primary Industries, Water and Environment (Note: now the Department of Primary Industries and Water or DPIW) set up a system of stream monitoring in 2005. The program includes the most commonly used agricultural and forestry chemical pesticides, and others with high toxicity or potential mobility. The baseline monitoring program commenced in January 2005 at 28 sites. The scale of the monitoring was expanded to 54 sites by July, 2005. The sites include a wide range of catchments across the north and east of the state, covering agricultural and plantation forestry land use (DPIW, 2006c). DPIW uses the following definitions in the presentation of the monitoring results:

> *Limits of detection: The lowest level of a pesticide that can be reliably detected and reported using the particular analytical method and instrumentation.*
>
> *Guideline Value: The level published in the Australian Drinking Water Guidelines at which steps should be taken to determine the source and to stop further contamination. In terms of drinking water, exceeding the guideline value indicates that undesirable contamination has occurred and advice from the relevant health authority should be sought. It does not necessarily indicate a hazard to public health.*
>
> *Health Value: The level published in the Australian Drinking Water Guidelines for use by health authorities in managing the health risks associated with inadvertent exposure, such as a spill or misuse of a pesticide. The values are set at about 10% of the acceptable daily intake (ADI) for an adult of 70 kg consuming 2 litres of water per day. The values are very conservative and include a range of safety factors.*

At the time preparation of this report, six rounds of monitoring had been conducted, over up to 54 sites testing for up to 19 chemical pesticides (note: a micrograms of pesticide per litre of water (µg/L) is 1 millionth of a gram or 10^{-6} grams per litre):

- Baseline monitoring (January, 2005 over 28 sites) with no detections of chemical pesticides;

- April, 2005 over 28 sites, one detection on the Montague River at Stuarts Road of 0.07 µg/L of simazine (limit of detection 0.05 µg/L; guideline value 0.5 µg/L; health values 20 µg/L);
- July, 2005 over 28 sites, one detection on the Rubicon River at the tidal limit of 0.14 µg/L of atrazine (limit of detection 0.05 µg/L; guideline value 0.1 µg/L; health values 40 µg/L);
- October, 2005 over 54 sites, one detection on the South Esk (upstream of Macquarie River at Perth) of 2.2 µg/L of simazine (limit of detection 0.05 µg/L; guideline value 0.5 µg/L; health values 20 µg/L);
- October, 2005 over 54 sites, one detection on the South Esk (upstream of Macquarie River at Perth) of 0.1 µg/L of terbacil (limit of detection 0.1 µg/L; guideline value 10.0 µg/L; health values 30 µg/L);
- Januaray, 2006, there were no detections at the 54 sites.

In the flood monitoring program, where a number of samples are taken when stream levels are rising (events), four streams have been intensively monitored. In 40 events, and 430 samples, there has been one detection event (23rd June to 27th June, 2005) of terbacil peaking at *0.32 µg/L (limit of detection 0.1 µg/L; guideline value 10.0 µg/L; health values 30 µg/L). These results are publicly reported, quarterly on the DPIW website, by media statement, and notices to Health, Water Authorities and Local Councils (Mollison, 2006). Such exercises are inevitably very expensive, and time consuming.

Individual monitoring

As part of quality assurance and to meet other management objectives, individual plantation managers may conduct water quality monitoring. For example, Hancock Victorian Plantations Pty Ltd conducts water sampling pre-application, immediate post-application and after the first rainfall events, for specific herbicide operations (*Pers. com.* 9). In another example, Forestry Tasmania conducts water sampling at the time of the operation (pre- and post-application) and after the first significant rainfall event for each chemical pesticide application operation (Forestry Tasmania, 2005). Gunns Limited conducts water monitoring where chemical residues have the potential to move off-site. As with Forestry Tasmania, water samples are taken prior to and immediately after spraying, and then after the first significant rainfall event. Of the 761 samples taken and tested in 2004 - 05, none of the tested results exceeded Australian Drinking Water Health Guidelines (Gunns, 2006a).

Other crops

Pest management in cotton crops is a critical issue and the industry publishes a pest management guide each year (Farrell and Johnson, 2005) and the industry uses a range of chemical pesticides (e.g. DPI NSW, 2006c). A broad water monitoring program (The Central and North West Regions Water Quality Program: CNWRWQP) for up to 34 agricultural chemical pesticides is applied to the Macintyre, Gwydir, Namoi and Macquarie valleys (Mawhinney, 2004). Figure 29 shows the number of samples per year and Figure 30 the percentage of samples showing detection of the chemical pesticides shown.

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* In the original version of this report placed on the web site on 23/10/06 this figure was inadvertently given as 33 µg/L. This correction was made on 3/11/06.

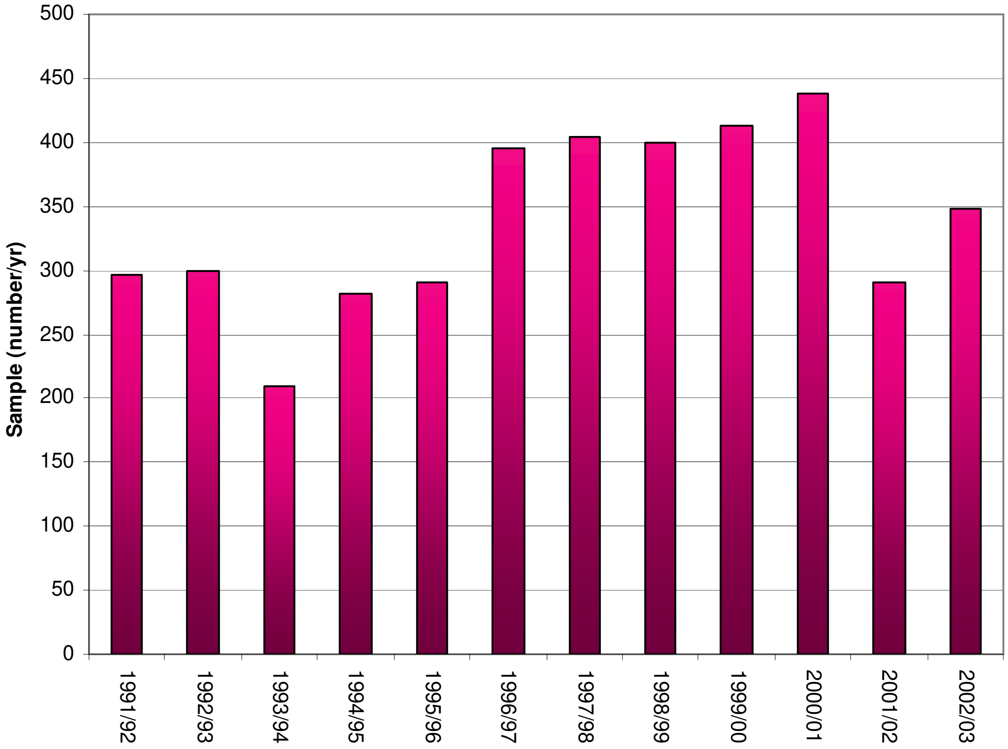

Figure 29 The number of water samples tested for chemical pesticides in the Macintyre, Gwydir, Namoi and Macquarie valleys (Mawhinney, 2004).

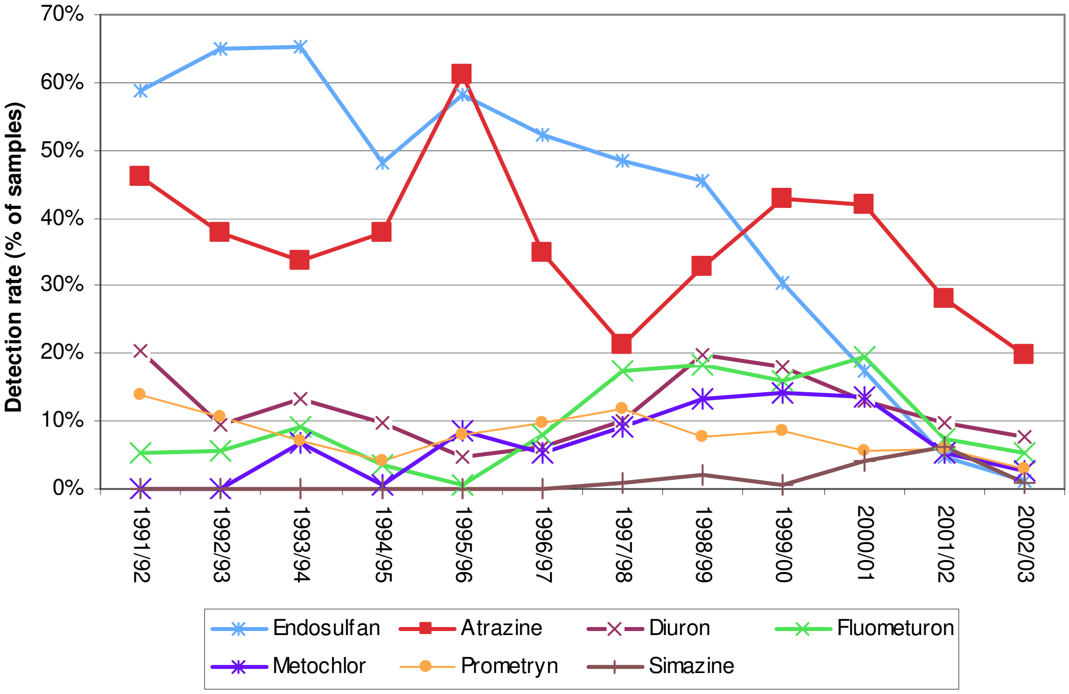

Figure 30 The detection rates for the chemical pesticides shown in the water samples shown in Figure 29 (Mawhinney, 2004).

Waters (2004) reported on water quality in Queensland catchments and the cotton industry. Water monitoring was undertaken in the Loudoun and Chinchilla Weirs over eight seasons for 52 chemical pesticides. For 2000 – 01 (13 samples), the percentage of sample with detections were: 0% for endosulfans; 38.5% for simazine; 46.1% for prometryn; 92% for metolachlor; 100% for atrazine. Waters (2004) concluded that storms and sediment are the main two factors affecting movement of chemical pesticides off-site. In the region considered, mean sediment concentration leaving the cotton tail drains ranges from 3 to 9 g/L in storm and irrigation run-off. Mawhinney (2004) added spray drift and vapour transport as mechanisms of chemical pesticide transport into the river systems and that such mechanisms contribute low level but almost continuous inputs.

Chemical remediation

One practice that probably does not receive sufficient attention by some plantation growers is that of cross-draining. This simple procedure diverts drainage from table drains back into plantation or buffer areas at appropriate points. A recent development from Orica has been the use of an enzymatic clean-up with a point source treatment e.g. a drain (Richardson, 2006a). A product is already available for the insecticide diazinon (not used in forestry), and another triazine herbicide enzyme is expected to be commercialised within 18 months. These enzymes accelerate the breakdown of the pesticide to metabolites within a matter of minutes. The triazine enzyme will work in both soil and water (Richardson, 2006a). The challenge will be for forestry to adopt this technology where the risk is considered to be high, or where there is an accidental spill, for example.

Risk assessment

Spray drift

The current major approaches to spray drift management are common to agriculture and forestry. They include:

- Control of droplet size;
- Wind speed limits for use;
- Spray release height;
- Protective buffer zones;
- Equipment type and arrangement.

There are a number of predictive models for assessing the potential for spray drift. These include the AgDRIFT Model for all uses up to 800 metres, and AGDISP (Loschke, 2006). Ensis has developed Spraysafe Manager, an aerial application Decision Support System which also uses AGDISP and Arcview (Richardson, 2006b).

The Pesticide Impact Rating Index

The Pesticide Impact Rating Index (PIRI) program was developed by CSIRO for agriculture, and now has some global exposure (Kookana and Correll, 2006). It can be used to identify safe windows for chemical pesticide spray operations, designing chemical pesticide-monitoring programs and in identifying chemical pesticides that need to be targeted for better management. PIRI combines information about toxicity to aquatic organisms with information about the potential for chemical pesticides to move off-site and pollute adjacent waterways (Kookana and Correll, 2005). It has an in-built database for about 300 chemical pesticides, but can be used with other data. It has built-in toxicity data on (Kookana and Correll, 2006):

- Fish (rainbow trout);
- Waterflea (daphnia);
- Algae (limited information);
- USEPA Health Advisory Levels;
- User defined (e.g. water quality guidelines).

The Risk factors included in PIRI are:

- Chemical pesticide amount and method of application;
- Timing of application (soil dryness state/index);
- Pesticide properties (half-life, sorption);
- Site conditions (hydrology, slope, soil loss);
- Soil properties (organic matter, texture);
- Pathway of movement (runoff, drift);
- Weather conditions (rainfall, temperature);
- Climate (temperate vs tropical);
- Toxicological considerations (fish, flea, algae, mammals, humans).

Corroboration studies have been conducted in cotton crops, in the Murray Irrigation Area, and in the SA/Victorian Riverland, with a correct assessment in 80% of cases. Forestry Tasmania has begun using PIRI (Elek, 2006) and other forestry organizations (e.g. SA Forestry Corporation) are evaluating it. Some development may be required to adapt PIRI fully for plantation use (Mcguire, 2006). A further program that may have applicability is SAFEGAGE, developed for use in Queensland for sugar cane. It has some similar features to PIRI but some useful differences (Mcguire, 2006). Predictive tools such as these will undoubtedly become part of the standard management tools in the future.

Alternatives to chemical use

A continuing need

When large-scale industrial plantation development is the aim, there does not appear to be any technology that will eliminate the need for the use of chemical pesticides for pest control in the foreseeable future. This may be qualified for small-scale woodlots where it may be practicable to use manual methods, in the same way that a home gardener controls weeds and possibly other pests such as snails. For plantation weed control, various mulching methods and weed mats have been tried, but costs are excessive when translated to a large scale. Another example is heat sterilisation of soil for weed control using gas burners or steam, which has a very high energy use, as well as burning fuel which produces greenhouse gases. Mechanical methods of weed control can damage trees and cost of machinery operation in extensive plantations is prohibitive.

Ongoing development

There is currently a program to develop a biological control for the pine aphid (Hopkins, 2006). However, there are so many weed and insect pests that biological control can be expected to control a few at most, and development times and quarantine to prevent escape of organisms that may have potential deleterious consequences must be considered. The unintended escape of the rabbit Calicivirus is a salutary lesson, although the consequences in that case appear to have been beneficial, at least in the short term. One current program in New Zealand is investigating the use of the leaf eating weevils (*Cleopus japonicus*) to control buddleja (*Buddleja davidii*): an ornamental tree that has become a woody weed and it is the biggest pest plant in New Zealand plantations (Ensis, 2006).

Tree breeding to give faster early growth may in time reduce the need for second season weed control in eucalypts. Genetic manipulation to enable commercial tree species to express chemicals that defend against insect or fungal attack, or to prevent weed emergence, may lie in the future. However, the emphasis in genetically modified (GM) crops at this time is to provide protection for the use of specific herbicides.

Biomimetic chemicals are another possibility, for example, the insecticide tebufenazide. However, it is foolish to imagine that all such chemicals will necessarily be benign and non-toxic to non-target species or will not have other undesirable consequences (Elek 2006). There is a herbicide developed from a root exudate of an Australian native plant which one of the authors is evaluating for possible use in plantation establishment, and there are examples of apparent allelopathic effects from other species.

Australian plantation industry experience

The best complementary methods for weed control are already generally practised. These include chopper rolling (mulching) of 2R slash in pine plantations (e.g. Dumbrell, 2006), spray topping with low rates of herbicide to prevent annual weed seed set on pasture sites during the spring the year before planting, whole site ploughing or mounding late spring-early summer, cover cropping during the summer, and inter-row grazing when the trees are beyond damage from grazing animals. One practice adopted in WA is to scalp away the grass mat to create a furrow for softwood establishment, but there can be an increased risk of phytotoxicity (Dumbrell, 2006).

Site preparation techniques have also been developed over the decades that aim to manipulate weed populations. Examples include pre-site preparation broadcast treatments, sometimes on ex-pasture in the spring the year before planting to prevent annual weed seed set, and mounding which buries some of the seed bank too deeply for germination, and also increases the nutrient available to the growing trees. In radiata pine, slash retention after harvesting the previous crop is now a routine procedure. The harvesting residues are chopper rolled to provide mulch, which suppresses weeds and retain moisture as well as nutrients.

There have been a few successes with biological controls. For example the Sirex wood wasp control program uses predatory nematode inoculation in trap trees deliberately stressed by sub-lethal injections of herbicide, which attract adult wasps.

A mechanical barrier to African black beetle (*Heteronychus arator*) has been developed for use with eucalypt seedlings. The beetle feeds on the seedling stems and can cause significant losses. A plastic mesh is placed over the seedling at planting to form a mechanical barrier to beetle attack (Bulinski and Alexander, 2002).

Future trends

Potential future pests

Potential pests are legion, particularly where insects are concerned, but many troublesome weeds are also introduced species. The Asian gypsy moth (*Lymantria dispar)* is an insect which has the potential to devastate multiple tree species should it ever become established. The environs of Auckland in New Zealand were sprayed in recent years after species of tussock moths, which could threaten New Zealand's forests and plantations, were discovered. Guava rust (*Puccinia psidii*) attacks the shoots of juvenile trees, coppice and seedlings and can kill up to 90% of young eucalypts in plantations (Tommerup, 2002). There are many potential threats to the health of radiata pine plantations; so far, significant damage has only been caused periodically or before control measures were introduced by Sirex wood wasp, the Monterey pine aphid (*Essigella californica*) and a needle cast fungus (*Dothistroma septospora*). Minor problems were also experienced with a bark beetle, (*Ips grandicollis*), which mainly affects edge trees. Buddleja could take hold in Australian plantations.

Likely changes to the context of chemical use

The experience in pine plantation establishment indicates that different problems will be experienced as rotations are completed and sites replanted. On ex-pasture sites, other non-pasture weeds such as blackberry are introduced by birds and become significant problems. This will require changes in pre-planting site clean-up procedures and herbicide prescriptions. This is already the situation for post-first rotation pine sites.

Emerging chemical technologies

Some of these have already been mentioned, for example the development of water dispersible herbicide packaging (WDH), the bulk shuttle, the slow release granular technology, and the fertiliser/insecticide Initiator tablet. Other technologies may prevent any off-site movement of chemicals, for example, the emerging use of enzymes to break down pesticides in run-off water (Richardson, 2006a).

Plantation industry willingness to adopt new chemicals and alternatives

Plantation forest managers have the combined drivers of cost reductions, legal and social obligations which focus attention on the need to develop and adopt improvements in all operations. Where an organisation has made a commitment to a formal certification process such as the Australian Forestry Standard, there is added impetus towards development of alternatives provided such introductions are cost-effective and provide the same or better efficacy. In order to expand the area under management, plantation forestry managers are considering new species in old areas, and new species in new areas as the available land in such areas becomes too expensive. Such a trend provides an impetus to a clear focus by the plantation forestry managers to identify and adopt new practices.

Conclusions

The following are the key conclusions resulting from this study.

- Plantation forestry is a minor component of Australian chemical pesticide use, its estimated \$16.4–20.9 million expenditure in 2003-04, accounting for 0.7 per cent of the \$2.4 billion national total;

- Australian plantation forestry chemical pesticide spending is estimated to be 99.0 per cent on herbicides (including adjuvants) and 1.0 per cent on insecticides;

- The chemical pesticides used by plantation forestry in Australia have been developed for other uses and have been adapted to the needs of the plantation industry;

- All chemical pesticides used by the Australian plantation forest industry are also used in food production systems by Australian agriculture with the exception of sulfometuron methyl, which is approved for other industrial uses in Australia;

- Of the 13 major herbicides used (based on expenditure) by the Australian plantation industry, five are also available for purchase ‘off the shelf’ in hardware stores and/or supermarkets;

- The adaptation and use of chemical pesticides by the Australian plantation industry is regulated under the same framework as all other chemical pesticide users. Because of the general use of licensed application contractors, plantation forestry has an additional regulatory overlay for the use of chemical pesticides compared to the greater use of unregulated operators in other industries;

- There are fundamental differences in the way chemical pesticides are used by the Australian plantation industry compared to agriculture. Use in plantations is usually confined to the first two years of a plantation crop cycle (for example a 10-year crop cycle for pulpwood or a 30-year crop cycle for softwood sawlogs). For the rest of the life of the plantation chemical pesticide application is very limited and generally only occurs in reaction to pest or disease out-breaks. Agricultural crops tend to have a higher frequency of use, and in some cases, have multiple applications in each year or for each crop;

- The area over which chemical pesticides may be applied within a plantation can vary from 100 per cent to about 30 per cent of the planted area, depending on the management objective;

- Industry survey results indicate most chemical pesticides are used at less than 50 per cent of the maximum label rate;

- The Australian plantation forest industry has developed and adapted a range of application technologies to meet industry needs;

- Aerial application of chemical pesticides by the plantation forest industry accounts for a maximum of 0.5 per cent of the total 10 million hectares of land aerially treated with a range of chemical products each year across Australia; and

- Environmental monitoring is generally conducted on a risk management basis by individual plantation managers. Where conducted on a systematic basis, water monitoring on a whole-of-catchment basis in Tasmania has shown few detections of chemical pesticides from any source.

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Appendix A Industry Survey

Confidential industry survey covering note

The project

Development of comparative chemical pesticide input statistics for various land management industries is important to provide a contextual framework for informed discussion. Chemical pesticide use will be a function of legal, crop and pest issues. Application technique (ground or aerial) and coverage (target plant, spot, strip or broadcast) varies with situation (crop and pest) and overall crop management. This project aims to review and/or consider:

- The evolution of and change in chemical pesticide use by Australian agriculture and in plantations to provide a historical/contextual framework;
- A confidential chemical pesticide use survey of the major plantation organizations;
- Regulatory controls at Federal, State and Local Government levels;
- Plantation and agricultural crops industry codes of practice;
- Chemical free alternatives in the context of the situation where used;
- Potential future chemical use trends;
- Potential management regimes;
- Some chemicals may be de-registered and others will be developed;
- Emerging “new generation options” such as biological agents.

It is proposed to develop broad chemical pesticide use profiles based on the National Forest Inventory (NFI) zones. Comparisons to “neighbouring” land chemical pesticide use will be included. In some instances, crops and plantation species are similar and zones will be combined. Major agricultural zones not covered will be addressed for the main crops grown. A comprehensive report will be prepared for FWPRDC review and publication.

The project was undertaken by Braden Jenkin (*Sylva Systems Pty Ltd*) and Dr Barry Tomkins (*GreenTree Forestry Services*).

A confidential survey

The following notes accompany the attached Excel® spreadsheet-based chemical pesticide and fertiliser use survey of your organisation. The information collected will be done so in strict “commercial in confidence”. Data is to be aggregated by NFI zones (see Figure A.1). Within each NFI zone, the data will be further aggregated to give tonnes of active ingredient (a.i.) and total value of the chemical pesticides used split into:

- Herbicides;
- Insecticides;

- Fungicides;
- Adjuvants;
- Nematicides;
- Baits and poisons.

Figure A.1 National Forest Inventory (NFI) zones (taken from National Forest Inventory (2004) *Plantations of Australia Information CD*, Bureau of Rural Sciences, Canberra.).

Survey headings

Company / organisation

Please fill in the name of your organisation.

Region

Please fill in the number of the NFI region as shown in the map in Figure A.1. If your operations are outside NFI regions, please list the area. Note: please complete a separate survey file for each NFI zone in which your organisation operates.

Active Ingredient

Individual product (by trade name) use is not requested in most cases. Data are to be aggregated based on active ingredient (a.i.). Please fill data lines for each a.i. shown. Where an a.i. used is not listed, please fill in the spaces provided ("other – please name"). Certain propriety products (named) contain a.i. mixtures. Please fill in the quantity of the named product, and the a.i. quantities will be determined later.

Year

If available, please provide data on chemical use for the calendar years 2003, 2004 and 2005.

A.I./unit product

Please indicate the product concentration as per the container labels in grams per unit (please specify the units e.g. litres or kilograms).

For example, glyphosate 360, 450, or 540 g/L product.

A.I. used or Product used

Please provide the gross quantity of chemical used either by a.i. (a.i. kg/yr) or units of product (product units/year). If you do not wish to calculate total a.i. used, please give product quantity/year.

Area treated

Please indicate the total area (ha) per year treated by the chemicals indicated. Whilst the a.i. use and area treated will allow a mean a.i. per hectare application rate to be calculated, use rates vary depending on locality, and will not indicate individual regimes.

Indicative cost

Please provide indicative cost of the chemical type (i.e. herbicides, fungicides etc) purchased for the years shown ($000's/yr). An aggregate cost for all chemicals is essential for an accurate assessment of total chemical pesticides used in Australian plantations.

Acknowledgement

Your assistance with this survey will be acknowledged in the report.

Industry survey participants

The industry survey was sent out to the main Australian plantation forestry organisations. Each organisation was contacted by telephone in the first instance to identify the most appropriate contact person and to discuss the study. An electronic survey spreadsheet was sent by email to the identified person. Table A.1 presents a list of the organisations that provided a response to the survey.

Table A.1 A summary of the industry survey respondents. Note: the aggregated area statement was used where the plantation managers did not have area statements in the public domain. The percentage shown is against the total plantation forestry estate as of December 2005.

EnvironmentACT	(Public)	9,500	Parsons *et al.* (2006)
Forest Products Commission (WA)	(Public)	106,172	Parsons *et al.* (2006)
Forestry Plantations Queensland	(Public)	193,407	Parsons *et al.* (2006)
Forestry Tasmania	(Public)	85,100	Parsons *et al.* (2006)
Forests NSW	(Public)	250,113	Parsons *et al.* (2006)
SA Forestry Corporation	(Public)	87,000	Parsons *et al.* (2006)
Public estate total		731,292	42.3%
AKD Softwoods	(Private)	4,000	AKD (2006)
Albany Plantation Company of Australia Pty Limited	(Private)	23,000	APFL (2006)
Auspine Limited	(Private)	35,181	Auspine (2005)
Forest Enterprises Australia Limited	(Private)	32,000	FEA (2006)
Great Southern Plantations Limited	(Private)	110,000	GSP (2006)
Gunns Limited	(Private)	110,000	Gunns (2006)
Hancocks Victorian Plantations Pty Limited and Grand Ridge Plantations	(Private)	169,000	HVP (2006)
ITC Limited	(Private)	140,000	ITC (2006)
Timbercorp Limited	(Private)	80,000	Timbercorp (2006)
WA Plantation Resources Pty Limited	(Private)	33,000	WAPRES (2006)
Willmott Forests Limited	(Private)	30,000	Willmott (2006)
Private estate (with published areas)		766,181	44.3%
Green Triangle Forest Products; Insignis Forestry Services; Midway Pty Ltd; Norske Skog; South East Fibre Exports; Plantations International Limited; Tumba Pine Pty Limited; Woollybutt Pty Limited.	(Private)	95,000	5.5%
		1,592,473	92.1%

Total plantation forestry estate of identified hardwood and softwood as at December, 2005 (Parsons *et al.*, 2006)	1,730,195

Other information and survey responses were collected from a range of the Regional Private Forestry Committees and other farm forestry groups.

Data management and analysis

The industry survey participant's data sets were received as filled in survey spreadsheets, available internal presentation/format or by telephone discussions. All data were converted into a data set. The completed industry survey spreadsheets were converted into lines of data. Where data were incomplete, they were either followed up with the responding organisation or deduced based on the data provided and chemical product information. If a respondent provided information in internal company format, the data were converted into the study database format. Incomplete data were amended based on telephone follow-up or determined based on product information. In the cases where data were provided verbally, they were entered into the database. The datasets were then available for analysis based on the information shown.

Appendix B Land use data

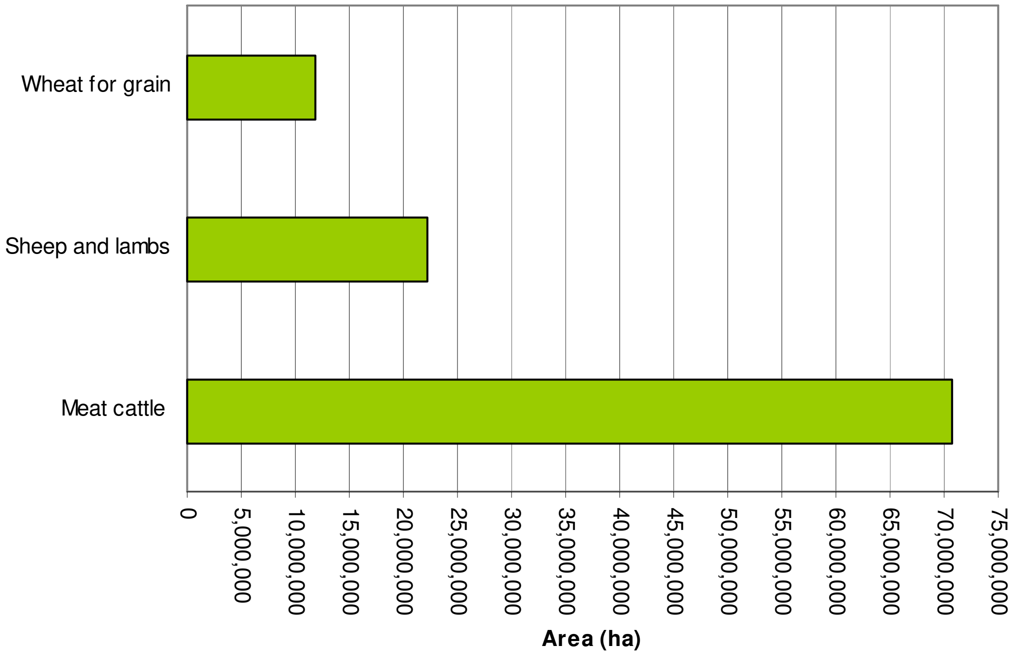


Figure B.1 ABS (2006a) land use data for Australia for the six zones included in this study.

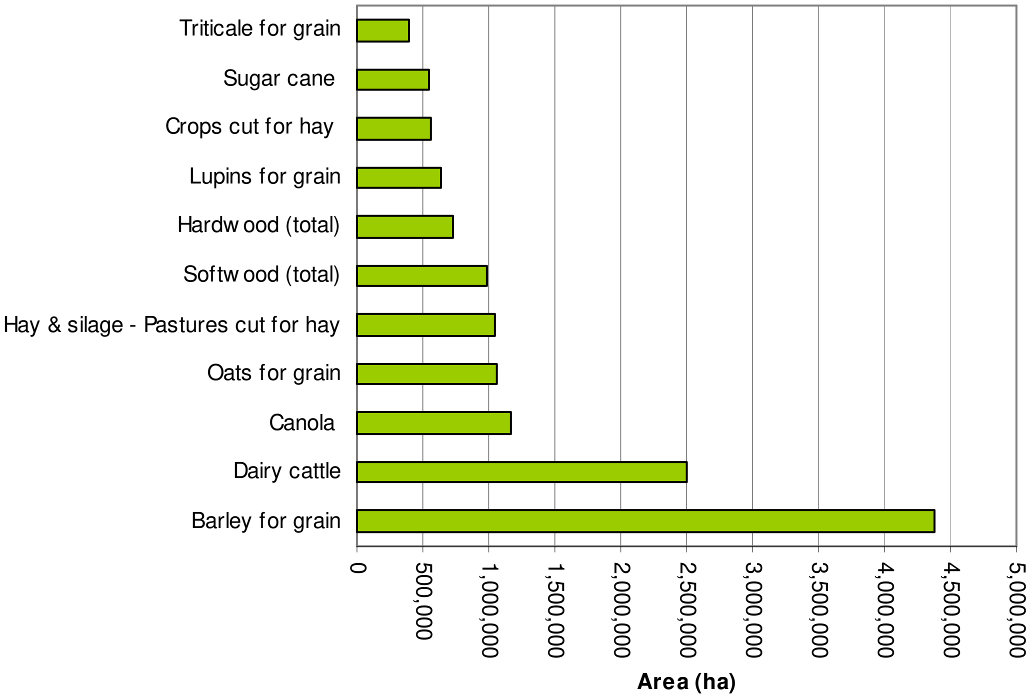


Figure B.2 ABS (2006a) and Parsons *et al.* (2006) land use data for Australia for the six zones included in this study.

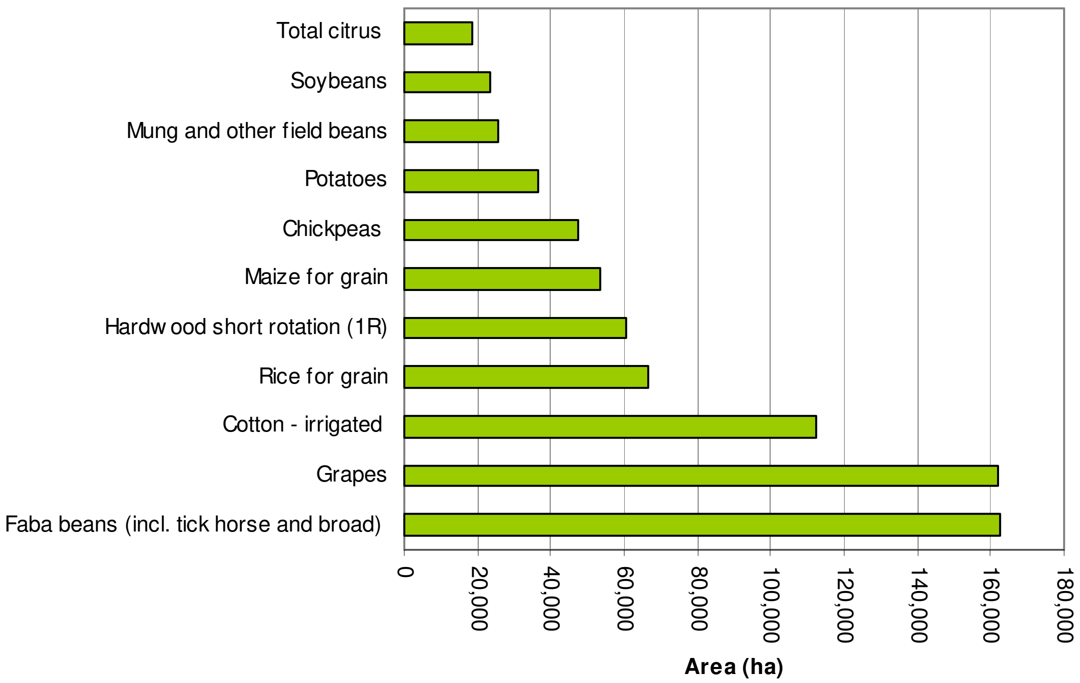


Figure B.3 ABS (2006a), Parsons *et al.* (2006) and Davey and Maynard (2003) land use data for Australia for the six zones included in this study.

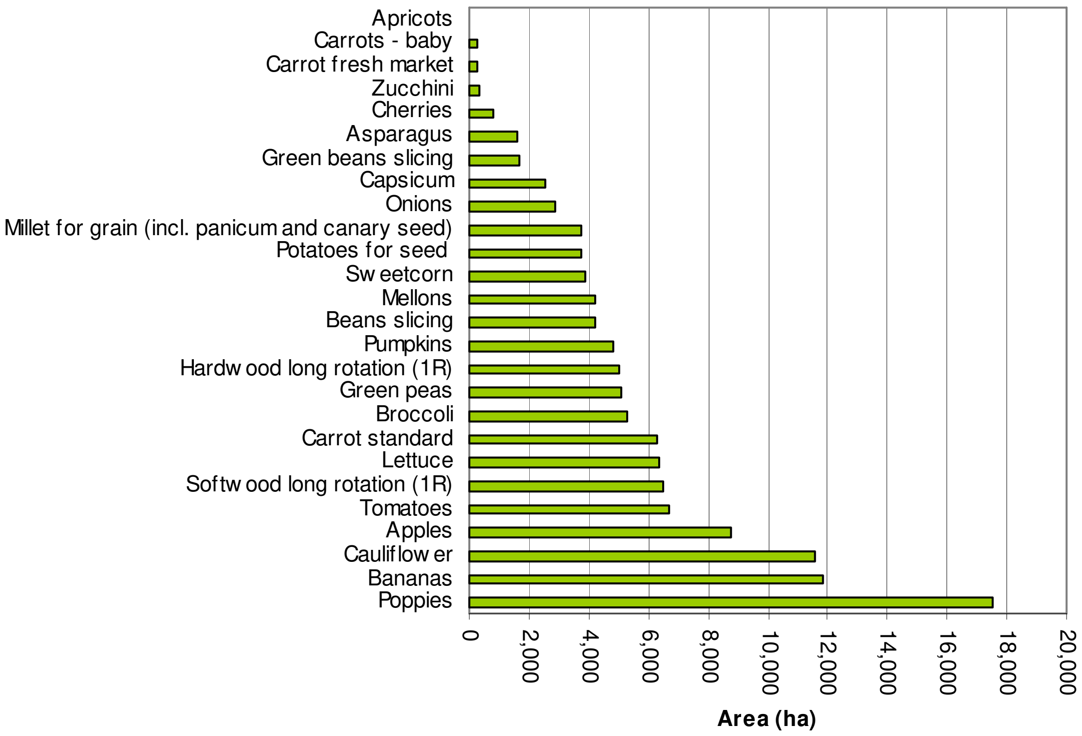


Figure B.4 ABS (2006a) and Parsons *et al.* (2006) land use data for Australia for the six zones included in this study.

Appendix C Australia's plantation expansion

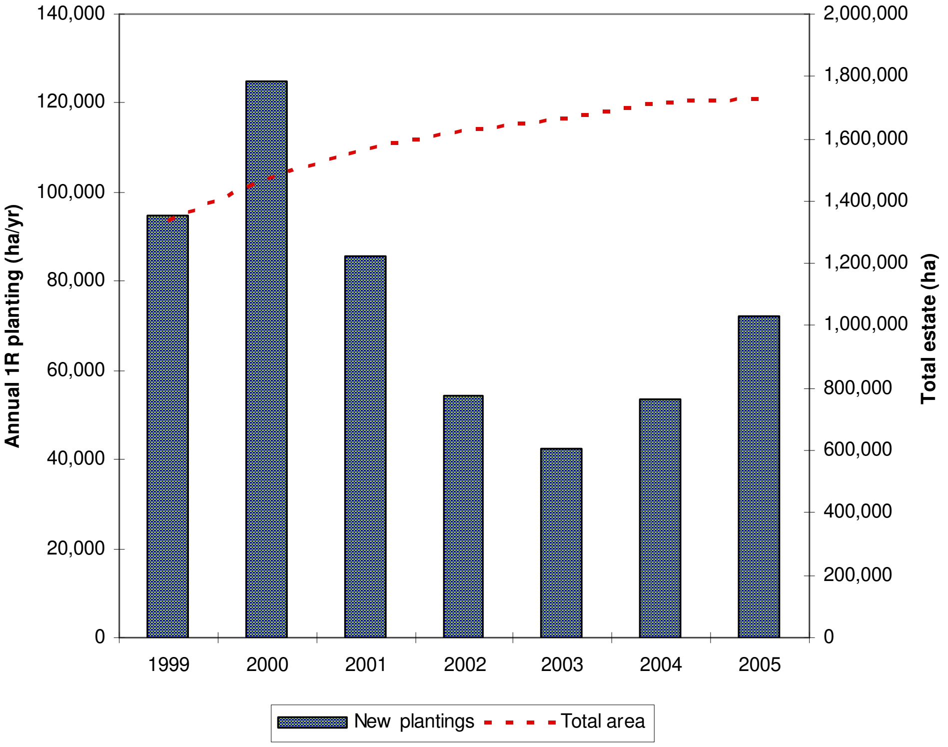


Figure C.1 A summary of the Australian plantation estate expansion (NFI, 2000; NFI, 2002; NFI, 2003; NFI, 2004; NFI, 2005; Parsons, *et al.*, 2006; Wood *et al.*, 2001).

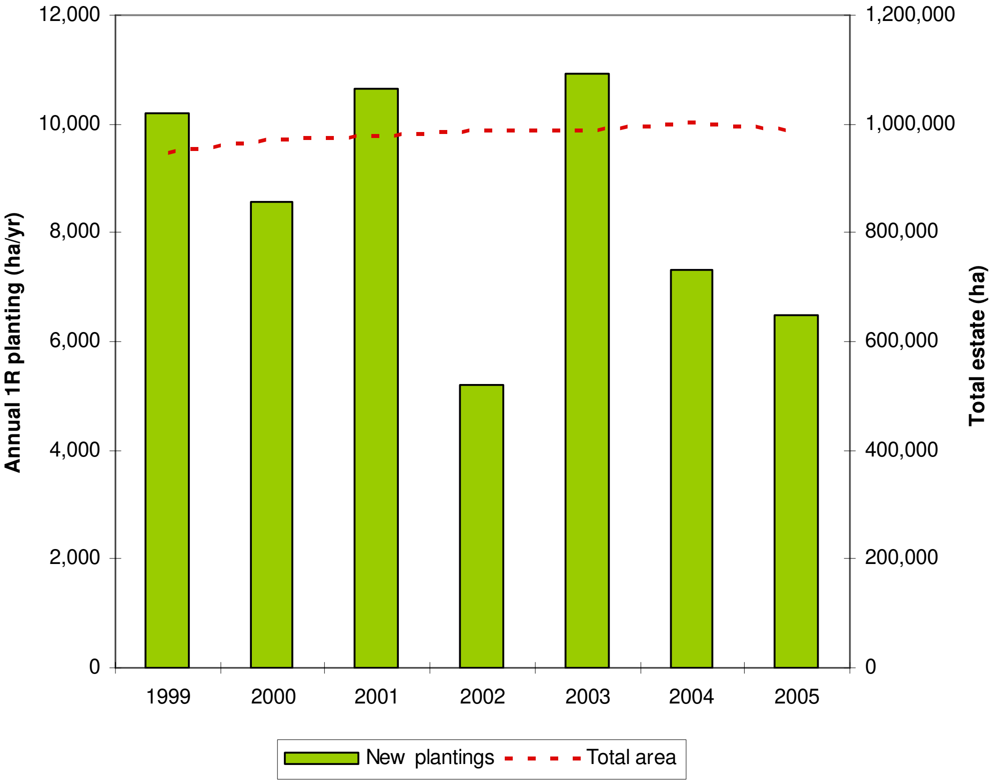


Figure C.2 A summary of the Australian softwood plantation estate expansion (NFI, 2000; NFI, 2002; NFI, 2003; NFI, 2004; NFI, 2005; Parsons, *et al.*, 2006; Wood *et al.*, 2001).

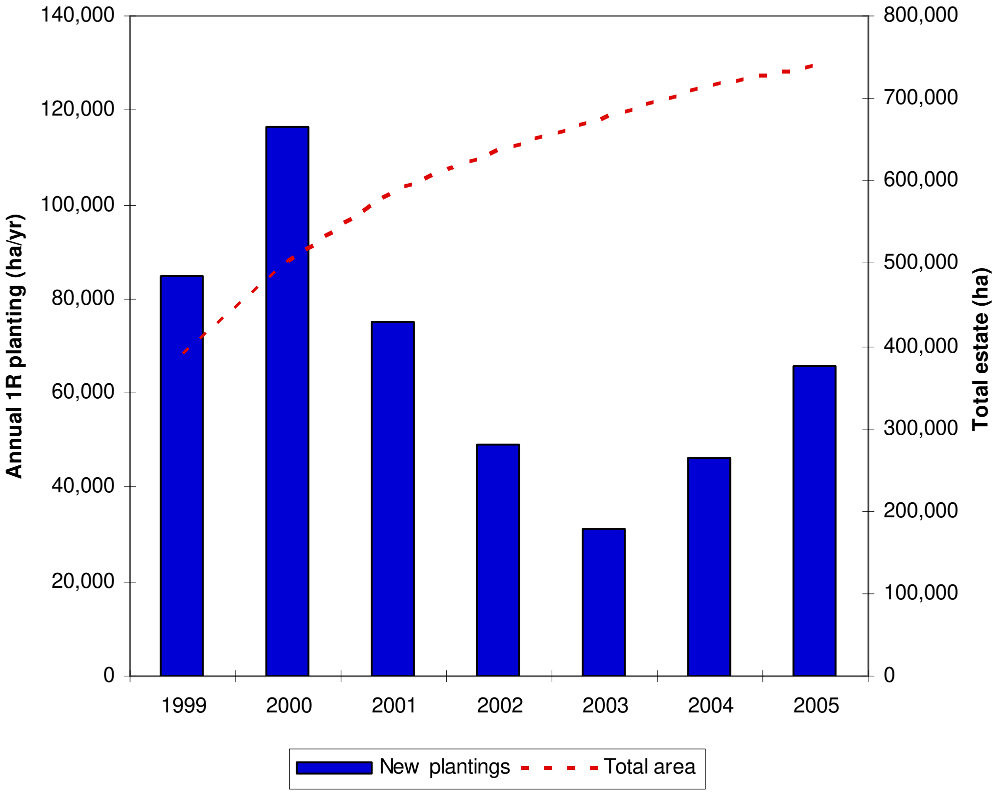


Figure C.3 A summary of the Australian hardwood plantation estate expansion (NFI, 2000; NFI, 2002; NFI, 2003; NFI, 2004; NFI, 2005; Parsons, *et al.*, 2006; Wood *et al.*, 2001).

Appendix D Chemical pesticide profiles

Herbicides

2,4-D isopropyl amine salt

2,4-D is a foliar active systemic auxin type herbicide, causing initial distortion and twisting of leaves and stems. Products are usually 0.225 g a.i./L. It is used in Queensland for tropical pine wildling control.

Amitrole

Amitrole is a broad spectrum rather slow acting systemic foliar herbicide, with only very slight soil residual activity. The products contain 250 g a.i./L plus 220 g a.i./L ammonium thiocyanate. It has a forestry registration for radiata pine but the use rates are considerably out-of-date. It is used in the second season in both radiata pine and eucalypt. In radiata pine, it has been applied aerially in South Australia at 250 to 500 g a.i./ha in combination with atrazine at 4.5 kg a.i./ha. In second season Tasmanian blue gum, it is applied at 250 to 500 g a.i./ha in combination with simazine and/or sulfometuron methyl as a row treatment by directed spray.

Atrazine

Atrazine is a triazine herbicide. For plantation forestry use, the formulations are 600 g a.i./L and 900 g a.i./kg. There are many products. Registered use rates for plantations of pine and eucalypts are up to 8 kg a.i./ha, but there is a 4.5 kg a.i./ha limit for sandy soils or soils described as highly erodible. It is used in combination with hexazinone in certain propriety forestry herbicide products, which are a 150 g a.i./kg dry granule (G), or a 625 g a.i./kg Water Dispersible Herbicide (WDH) pre-packaged in water-soluble plastic bags on a per hectare basis. Atrazine is a soil residual systemic herbicide that controls grasses and some broadleaved weeds. It has a weak foliar effect if sprayed onto weed. It is predominantly used in establishing pine plantations, although it also registered for use in eucalypts. It is not particularly soil fast and can be rapidly lost from sandy soils through leaching. Triazines should not be applied to waterlogged soils.

Carfentrazone-ethyl

Carfentrazone-ethyl is contact herbicide being developed for pine wildling control,. The product is a 240 g a.i./L emulsifiable concentrate (EC). It will be used in combination with glyphosate and metsulfuron methyl similarly to glufosinate-ammonium later on. Carfentrazone responds to light, which suggests why it is more effective in the increasing daylight hours in spring. Use rates for radiata pine wildling control will be from 24 to 36 g a.i./ha.

Clethodim

Clethodim is one of a group of grass specific foliar active systemic ‘dim’ herbicides. The product is a 240 g a.i./L **EC**. There is a general forestry registration at 120 g a.i./ha. Clethodim is not widely used - mainly in eucalypts on ex-pasture. There is potential for increased use, particularly at half-rate in combination with a ‘fop’ grass herbicide also at half-rate. This is often more effective than either at full rate. For example, in southern central NSW, a typical post-planting prescription applied to rows includes clethodim at 60 g a.i./ha with haloxyfop at 104 g a.i./ha (with simazine and clopyralid).

Clopyralid

Clopyralid is both a foliar active and soil residual systemic herbicide. Products include 240 g a.i./L and 750 g a.i./kg formulations. There is a specific forestry product (750 g a.i./kg) which is supplied as a WDH formulation in a water soluble plastic bag. Clopyralid is used differently in pine and eucalypts. In radiata pine it is applied at rates of 1.8 kg a.i. to 2.55 kg a.i./ha to control silver wattle (*Acacia dealbata*). In ex-pasture situations for Tasmanian blue gum establishment it is used at much lower rates (150 g a.i. to 200 g a.i./ha) both pre- and post-planting to control a range of broadleaved pasture weeds. It is particularly effective for the control of capeweed (*Arctotheca calendula*) and many thistles, both as a foliar knockdown and soil residual herbicide. In Queensland it is used for vine control at 150 g a.i./ha, for most wattles at 375 g a.i./ha and for *Acacia mangium* in the north at 900 g a.i./ha.

Dicamba

Dicamba is a pre- and post-emergence, selective translocated herbicide, foliar absorbed and with soil residual activity. Products are 200 g a.i./L, and are used infrequently for stem injection of trap trees for survey and control of *Sirex* wood wasp in un-thinned radiata pine plantations of intermediate age.

Diflufenican

Diflufenican has been undergoing development for potential forestry use for some years. The product is a 500 g a.i./L suspension concentrate (SC). Its use rate in agriculture is 100 g a.i./ha to control small Brassica weeds such as wild radish (*Raphanus raphanistrum*) and wild turnip (*Rapistrum rugosum*), but it is also effective on thistles in Queensland, where a permit has been applied for this site-specific use. It can only be used pre-planting (unless possibly by directed spray) because it is a phytotoxic bleaching chemical if applied to foliage.

Fluazifop-p-butyl

Fluazifop-p-butyl is registered for use in three tropical pine species in Queensland and is undergoing re-registration for general forestry use. It is one of the ‘fop’ group of systemic foliar active grass specific herbicides. The product is a 128 g a.i./L EC. The use rate ranges from 159 to 845 g a.i./ha. It is sometimes used ‘off-label’ in Tasmanian blue gum plantations in Victoria to control summer active grasses (where such use is allowed under certain conditions).

Fluroxypyr methylheptyl ester

Fluroxypyr is a foliar active systemic herbicide used primarily in Queensland under permit for pre-planting site preparation for tropical pine species and eucalypts both aerially and ground-based, and also as a directed spray post-planting, usually in combination with glyphosate (in certain conditions). Full plantation forestry registration is anticipated in the near future. The products are 200 g a.i./L EC’s. The use rate is typically 200 to 600 g a.i./ha.

Glufosinate-ammonium

Glufosinate-ammonium is not yet registered for forestry, but is being developed for pine wildling control on 2R or later rotation sites. The product is a 200 g a.i./L formulation, and the chemical is a contact herbicide with only slight systemic activity; it passes into the needles and 'cooks' the foliage through the release of ammonia. Use rates for pine wildling control will be from 600 to 1000 g a.i./ha, usually in combination with glyphosate and metsulfuron methyl to control other weeds. It is effective on sub-tropical pine species as well as radiata pine, but 2,4-D is preferred in Queensland because glufosinate does not have all-year round efficacy. On radiata pine it appears to be more effective in summer and autumn but extreme drought conditions appear to limit its effectiveness.. Its effectiveness is enhanced by a specific surfactant that will be designated on the forestry label.

Glyphosate

There are many glyphosate products registered for various uses in Australia. For plantation forestry use, the main ones are formulations with 360 g a.i./L, 450 g a.i./L, 510 g a.i./ha, 540 g a.i./L and 850 g a.i./kg. Glyphosate products are salts and are formulated with a number of cations. In Australia, these cations include ammonium, isopropyl-ammonium, sodium, and potassium. Use rates for glyphosate range generally from as low as 360 g a.i./ha to 2.16 kg a.i./ha, and sometimes higher. Glyphosate is a broad-spectrum foliar knockdown systemic herbicide, which controls many grasses and broadleaved weeds, and many woody weeds at higher rates. Although it is very soil-fast, it does not have soil residual activity. There are a few common pasture weeds not well controlled at lower rates by glyphosate. These include sorrel and docks (*Rumex* spp.) and some clovers (*Trifolium* spp.). For pre-site preparation clean-up procedures in Southern Australia, glyphosate is often applied in mixture with metsulfuron methyl and an organosilicone surfactant. In Northern Australia, fluroxypyr may replace metsulfuron methyl.

Haloxyfop

Haloxyfop R-methyl ester is another of the grass specific foliar active systemic 'fop' herbicides. Products are 520 g a.i./L EC's. There is a general forestry registration. Haloxyfop is used mainly in Tasmanian blue gum establishment, late in the first season to control a wide range of annual and perennial grasses, in combination with clopyralid and/or simazine. It also controls one broadleaved weed – storksbillls (*Erodium* spp.). Use rates vary from 104 g a.i./ha to 416 g a.i./ha depending on grass species and grass weed density. It is also used in northern Queensland for grass control, usually at rates of 216 to 260 g a.i./ha.

Hexazinone

Hexazinone belongs to the same group of herbicides as atrazine, but is a triazinone. Formulations for radiata pine plantations are a 750 g a.i./kg Dry Flowable (DF) product for spray application, and dry soil applied granular products at 200 g a.i./kg or 167 g a.i./kg. In combination with atrazine in granular products, the formulations are 67 g a.i./kg, 50 g a.i./kg and 25 g a.i./kg. In a WDH combination with atrazine, the concentration is 208 g a.i./kg. Hexazinone is a broad-spectrum systemic herbicide with both foliar and soil knockdown and soil residual properties, but it is primarily used for its residual effect. Use rates range from 0.75 kg a.i./ha to 3.8 kg a.i./ha. The lower rates are predominantly on ex-pasture sites or sites low in woody weed, and the higher rates for sites with some or considerable woody weed. It is quite mobile, but is a mainstay for the establishment particularly of radiata pine.

Metosulam

Metosulam is used mainly in ex-pasture situations. There is a specific forestry product that is a 714 g a.i./kg Dry Flowable (DF). Metosulam is a foliar active systemic herbicide with some soil residual activity. It is specifically used to control wild radish, wild turnip and other *Brassica* spp. at rates of 5 to 7 g a.i./ha.

Metsulfuron methyl

Metsulfuron methyl is a sulfonyl urea herbicide. There are several products, mostly 600 g a.i./kg formulations. A specific forestry product is a 200 g a.i./kg formulation. Use rates can be as low as a few g a.i./ha in pasture site preparation to as high as 96 g a.i./ha to control hard-to-kill woody weeds. Metsulfuron methyl is used primarily as a foliar knockdown systemic herbicide, but it has some soil residual activity. Plant-back periods, that is, the time from application to when trees are planted, depend on climatic and soil edaphic factors, but are usually about 1 to 2 days per g of 600 g a.i./ha product applied. Pasture use rates are low because metsulfuron methyl provides very effective control of sorrel, docks and clovers at low rates. High rates are used to control hard-to-kill woody weeds such as blackberry and some native species. Two products combine glyphosate and metsulfuron methyl. These differ in their composition but both are supplied in water-soluble satchels, pre-measured for application to a given area. One contains glyphosate at 835 g a.i./kg and metsulfuron methyl at 10 g a.i./kg, and the other contains 760 g a.i./kg and 63 g a.i./kg respectively. For foliar effectiveness, metsulfuron methyl application requires the addition of an organosilicone surfactant, usually at a rate of 0.2% of the spray volume (200 mL of surfactant per 100 L of spray mix).

Oxyfluorfen

Oxyfluorfen is a soil surface active, systemic pre-emergence or immediate post-emergence soil residual herbicide. Many products are 240 g a.i./L EC's, but the forestry product will be a 480 g a.i./L Soluble Concentrate (SC). It is not widely used, but recent developments suggest that it is effective in controlling blackberry nightshade (*Solanum nigrum*) emergence when applied over Tasmanian blue gum late in the first season. It is also used at very low (sub-lethal, 18 g a.i./ha) rates in combination with glyphosate applications because it rapidly browns out grasses and broadleaves, and is a very effective indicator of swathe. Oxyfluorfen is in the process of being registered for use in pine and eucalypt establishment, in combination with other herbicides at a use rate of 0.72 to 0.96 kg a.i./ha. However, it is phytotoxic to Tasmanian blue gum if applied at or about planting on sandy soils (particularly those low in organic matter), when it can leach into the root zone. On other soils it is extremely soil fast and does not leach. It is not phytotoxic to radiata pine at the above rate.

Pendimethalin

Pendimethalin is a soil residual root contact herbicide with no systemic activity or knockdown effect. Product formulations are 330 g a.i./L EC and a 445 g a.i./L aqueous concentrate. It is registered for use in eucalypts at 2.97 kg a.i. to 3.96 kg a.i./ha. It is effective only when applied to bare soil for the control of some weeds and the suppression of many weeds. It is particularly effective for the control of wireweed (*Polygonum aviculare*) at rates of 1.32 to 1.98 kg a.i./ha and also for rye grasses (*Lolium* spp.). It is not widely used in eucalypt plantations, but has found use in irrigated plantations of spotted gum (*Corymbia maculata*) and flooded gum (*E. grandis*) in the Murray River irrigation areas, and for the establishment of oil mallee plantations and farm forestry plantations in southern central NSW. It is also being used for Wireweed control in some Tasmanian blue gum plantations in the Green Triangle region of south west Victoria and south east South Australia.

Picloram

Picloram is a selective systemic post-emergence herbicide with foliar and soil activity. Products used are usually in combination with triclopyr (see next), and include picloram at 50 g a.i./L. It produces an auxin-type response – twisting and curling of leaves and stems in most broadleaved plants, but has no activity on grasses. It is soluble and mobile with often extended soil residual activity. It is primarily used for basal bark treatment of wattles and eucalypts in radiata pine (in combination with triclopyr), and in Queensland in pre-planting site preparation in combination with triclopyr to control woody weeds.

s-Metolachlor

s-Metolachlor is used pre-planting under permit in combination with glyphosate and simazine in the establishment of eucalypts on the north coast of NSW. It has both foliar and some residual activity. The product is a 960 g a.i./L formulation. The use rate is usually 1440 g a.i./ha.

Simazine

Simazine is used in Queensland for post-planting weed control in tropical pines and eucalypts at 4.5 kg a.i./ha over the trees alone, or by directed spray in combination with glyphosate at 1.45 kg a.i./ha. Simazine is also a triazine herbicide. For plantation eucalypt establishment, the formulation is 900 g a.i./kg. There are many products. The registered use rate range for eucalypt plantations is 1.44 kg a.i./ha to 6 kg a.i./ha. It is commonly used at between 2 and 5 kg a.i./ha. Simazine is a soil residual systemic herbicide that controls grasses and some broadleaved weeds. It is predominantly used in establishing eucalypt plantations although it also registered for use in pines. It is more soil fast than atrazine.

Sulfometuron methyl

Sulfometuron methyl is a sulfonyl urea herbicide. There are several products, mostly 750 g a.i./kg formulations. There is a specific dry granular forestry product which is a 2 g a.i./kg formulation, and a WDH product in combination with terbacil which contains 40 g/kg. Use rates can be as low as a few g a.i./ha to as high as 60 g a.i./ha in ex-pasture sites. It is not used in agriculture; rather it is an industrial weed control chemical and is used at much higher rates (150-600 g a.i./ha) for railway lines, roadsides, and around factories for example. Sulfometuron methyl has both foliar and soil residual systemic activity, but is used only for its soil residual effect. It is used in both first and second season in eucalypts but has limited use, primarily in South Australia, in second and third season radiata pine. It is very mobile and care has to be taken with its use. It controls a widen range of pasture weeds, including grasses, sorrel and docks.

Terbacil

Terbacil is a component of two propriety products used for establishment of Tasmanian blue gum, shining gum (*E. nitens*) and mountain ash (*E. regnans*). In both, the other component is sulfometuron methyl. One product is a WDH formulation with 880 g a.i./kg of terbacil, used pre-planting, and the other is a dry granule with 44 g a.i./kg used in the second season after planting. These products are registered only for Tasmanian blue gum, shining gum and mountain ash. Developed for plantation eucalypts from an orchard herbicide, terbacil is a soil residual systemic herbicide that in combination with sulfometuron methyl controls a wide range of pasture grasses and broadleaved weeds in the establishment of plantations of the above three eucalypt spp.

Terbuthylazine

Terbuthylazine is a triazine herbicide. There will shortly be a specific forestry product that is an 850 g a.i./kg WDH in a water-soluble plastic bag. Terbuthylazine is the mainstay triazine herbicide in plantation forestry in New Zealand. Its properties are similar in some respects to atrazine and simazine, but it has more foliar knockdown effect on existing weed. Use rates are similar to atrazine and simazine

Triclopyr

Triclopyr is also a selective systemic post-emergence herbicide with foliar activity but little soil activity. Products used are usually in combination with picloram, and include triclopyr at 100 g a.i. and 150 g a.i./L. It also produces an auxin-type response. Its main use is as for picloram, but both these herbicides are also used for the control of woody weeds such as blackberry and gorse, and can be used for stem injection. In Queensland it is used alone in pre-planting site preparation or in combination with picloram to control woody weeds.

Insecticides

Alpha-cypermethrin

The cypermethrins are synthetic pyrethroid (SP) insecticides. Alpha-cypermethrin products contain two cypermethrin isomers, and the main products used in plantations are 100 g a.i./L formulations. These are usually used in 0.5 to 1% spray mixes. There are also ULV (Ultra Low Volume) formulations at 16 and 40 g a.i./L., which are applied undiluted. Application is usually aerial. Alpha-cypermethrin is a contact and stomach poison with some anti-feeding action, effective against a wide range of chewing and sucking insects, particularly of the orders Lepidoptera, Coleoptera and Hemiptera in eucalypt plantations.

Carbaryl

Carbaryl is a carbamate insecticide. Products are often 500 g a.i./L SC's (soluble concentrates), and are used in 0.2% or higher aqueous preparations e.g. 20 mL of 500 g a.i./L product per 5 L of spray mix. It is also applied in baits for control of wingless grasshopper. Carbaryl is a contact and stomach poison with slight systemic activity. It is effective in eucalypt plantations against chewing insects (wingless grasshoppers, locusts, leaf rollers, leaf feeding moths, beetle larvae), sucking insects (aphids, leaf hoppers and thrips), leaf miners (leaf blister sawfly), and soil borne larvae including cut worms and scarabs.

Dimethoate

Dimethoate is a organophosphate (OP) insecticide. Products are often 400 g a.i./L EC's. Aqueous preparations are usually at 0.03% (75 mL of 400 g a.i./L product in 100 L). Dimethoate has contact and stomach action, inhibiting the nervous system. It has residual activity, and has been used in eucalypt plantations; it is under permit in South Australia. It is effective against a wide range of foliage feeding insects and mites (*Acarina*), especially leaf miners, psyllids, sawfly, scale, aphids, leaf hoppers, thrips and mealy bugs.

Fipronil

Fipronil is a 200 g a.i./L product with low water solubility. It is a contact, respiratory and stomach poison, with moderate systemic activity. It is used aerially at 50 mL/ha of product in spray mix. It is effective against wingless grasshopper. Plantations only need to be sprayed around the perimeter in a band, or striped. After contact, grasshoppers stop eating and die within 2 days. It has a residual effect for up to a month, and can be used in plantations generally.

Imidacloprid

Imidacloprid is a systemic insecticide, which targets only the insects which feed on the trees and so is less harmful to non-target insects than some other insecticides. Trial work has been conducted for the control of a range of insect pests in eucalypt plantations in southern and sub-tropical Australia (Carnegie *et al.*, 2005). Its systemic absorption into trees is also being developed in combination with fertiliser in tablet form, applied at planting, and as a soil drench after planting. The tablet product is currently undergoing registration for use in eucalypt plantations.

Methidathion

Methidathion is a organophosphate (OP) insecticide, but is rarely used because it has the highest Poison Schedule (S7). The products are 400 g a.i./ha EC's. Methidathion is prescribed on label for forestry situations under 'Ornamentals, Trees, Shrubs, Annuals' for the control of scale insects, caterpillars, sawflies, leaf miners, plant bugs, aphids, thrips, lerps and coccids. The use rate is usually 50 g a.i./100 L of spray volume.

Spinosad

Spinosad is a bio-insecticide, consisting of spinosyn A and D. It is short lived on plant surfaces. For plantations, it is only registered for chrysomelids which are rarely controlled in sub-tropical Australia. There is only a small window of opportunity to spray, requiring monitoring and knowledge of this window. It has potential for control of chrysomelid leaf beetles in southern Australia (Carnegie *et al.*, 2005), and has undergone extensive trial work in Tasmania (Elek *et al.*, 2003)

Tebufenozide

Tebufenozide is a biomimetic insecticide, that is, it mimics the actions of naturally occurring insecticides. Tebufenozide lethally accelerates the moulting process in insects. It controls Lepidopteran larvae at rates of about 34 g a.i./ha to 340 g a.i./ha. It has low to moderate soil persistence.

Bacillus thuringiensis var. *tenebrionis* & subsp. *kurstaki*

These are biotic insecticides. They are not routinely used in Australian plantations due, in part, to their specific environmental/climatic conditions necessary for effective control (Carnegie *et al.*, in press, see above). The var. *tenebrionis* has been trialled in eucalypt plantations in Tasmania (Elek, 1998; Elek and Beveridge, 1999). A product containing the subsp. *kurstaki* is registered for use against Lepidopteran larvae in forestry.

Adjuvants

This is a term used to describe any addition to a spray mix designed to improve the efficacy of a pesticide. It includes surfactants and spray oils which lower the surface tension and allow the spray mix to spread out on leaf surfaces, anti-antagonists which prevent antagonism between pesticides, buffering agents to adjust pH’s, dyes and marking agents.

Alcohol alkoxylate – surfactants

There are a number of similar products, usually at about 1000g/L of the alcohol alkoxylate. Use rates are usually 0.1 to 0.2% of spray volume.

Dodecyl benzene sulphonate

The product is an ionic surfactant used to improve the spreading and wetting of picloram and triclopyr herbicides.

Dyes and marking agents

Marker dyes are usually a solution of Rhodamine B in diethylene glycol, and are used with herbicides for spot applications and as a colouring agent in broad acre swathe marking. Foam markers are a foam liquid concentrate used also for swathe marking. As noted above, a low rate of the herbicide oxyfluorfen can also be used, particularly with glyphosate applications.

Organosilicones

Again there are a number of similar products, which are usually about 1000 g a.i./L of a polyalkyleneoxide modified polydimethyl siloxane. Organosilicone surfactants have also been shown to improve uptake of glyphosate through the leaf stomata (Balneaves *et al.,* 1993), and are usually used with metsulfuron methyl products and often with glyphosate. Use rates are usually 0.1 to 0.2% of spray volume, but may be up to 0.5%.

Phospholipids

The product is a mixture of 345 g/L phospholipids and 355 g/L propanoic acid. It is used at rates of 0.1% of spray volume for pH reduction (of hard water) and at 0.25 to 0.5% as a penetrant.

Synthetic latex

Synthetic latex is used as a sticker, extender and deposition agent for use with contact mode of action pesticides. The product is a 450 g a.i./L synthetic latex. It protects against chemical loss from rainfall, sunlight and wind.

Spray oils

Products are sometimes oils only, but there are products that include wetting agents also. Petroleum oils are usually about 700 to 900 g/L liquid hydrocarbons. They are used as anti-evaporant wetting agents and carriers for herbicide applications. They can improve targeting, spreading, wetting, and penetrative action of herbicides, insecticides and fungicides. Vegetable oils have similar properties to the petroleum oils, and are usually canola oils.

Fungicides

Copper oxychloride

This inorganic fungicide is applied aerially at 1.66 kg Cu/ha in copper oxychloride to control the pine fungal infection *Dothistroma septospora*. It is used to treat plantations up to 15 years of age, and can be re-sprayed after 250 mm of rainfall if required. It is also used to treat *Diplodia pinea* (a needle cast fungal infection) in pine plantations.

Phosphonate

This inorganic fungicide could be used to treat *Phytopthora cinnamomi* in plantations. (It is used in native forest areas in Western Australia to treat this pathogen). The products are usually 200 g/L or 400 g/L solutions of phosphoric acid plus 200 to 400 g/L potassium hydroxide.

Appendix E Plantation forestry application rates

The following charts are a summary of the application rate data from analysis of the confidential industry survey. The charts show use rate frequency data with increments of 10% of the maximum a.i. label rate for plantation application. The maximum label rate is indicated on the charts as the last use rate class, and any use at above that rate is greater than the maximum allowed. For example, in Figure E.1 for amitrole, the maximum allowed application rate is 2.0 kg a.i./ha, and so the frequency distribution classes are in units of 0.2 kg a.i./ha. Any use greater than 2.0 kg a.i./ha (> 2.0) is in excess of the label maximum rate. The data shown is not weighted for area, as it represents the industry survey rates reported for 2003 to 2005.

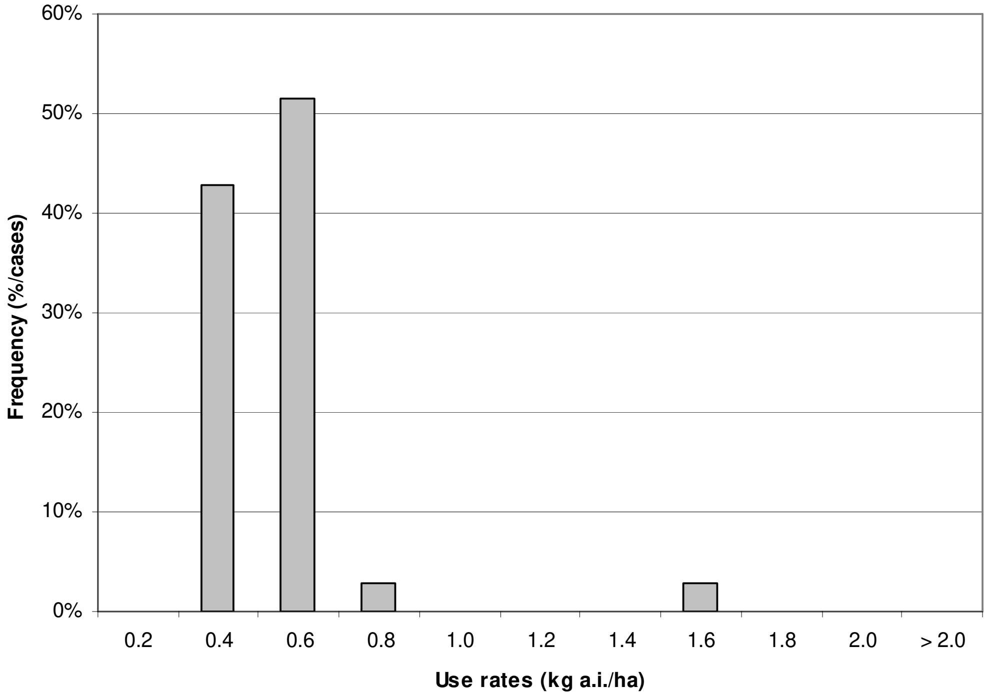


Figure E.1 Analysis of the data provided by the confidential industry survey of plantation managers' chemical pesticide use for amitrole. Most use is at less than 50% of the maximum rate.

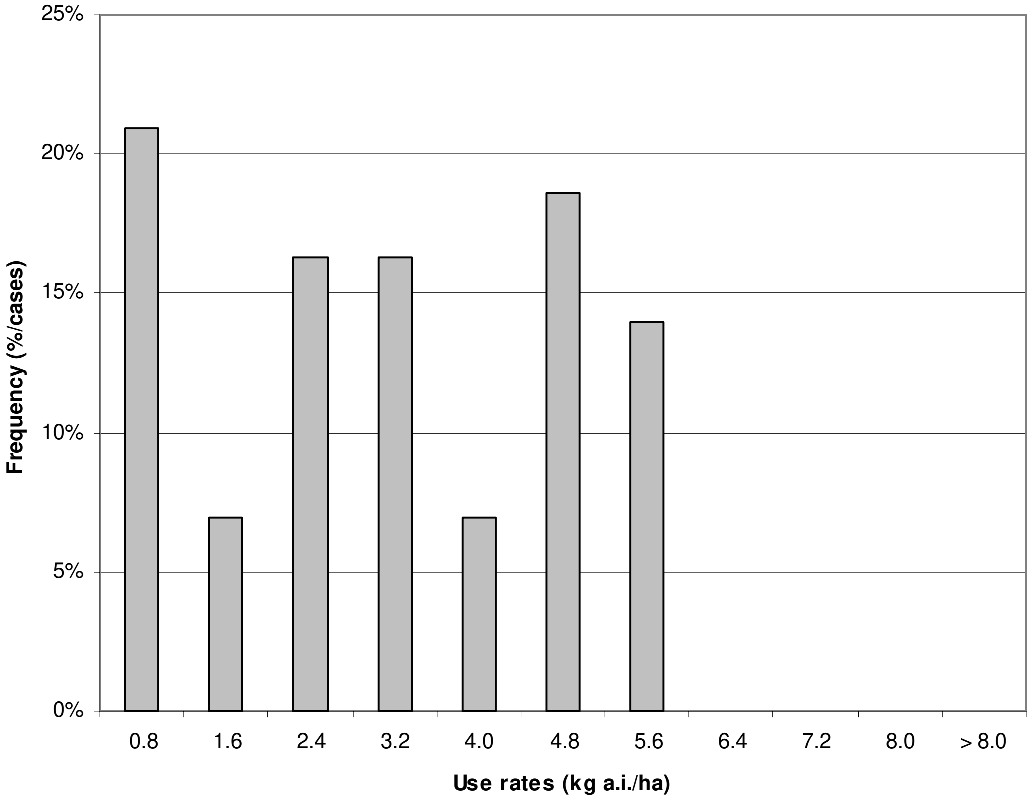


Figure E.2 Analysis of the data provided by the confidential industry survey of plantation managers' chemical pesticide use for atrazine. Most use is less than 50% of the maximum label rate.

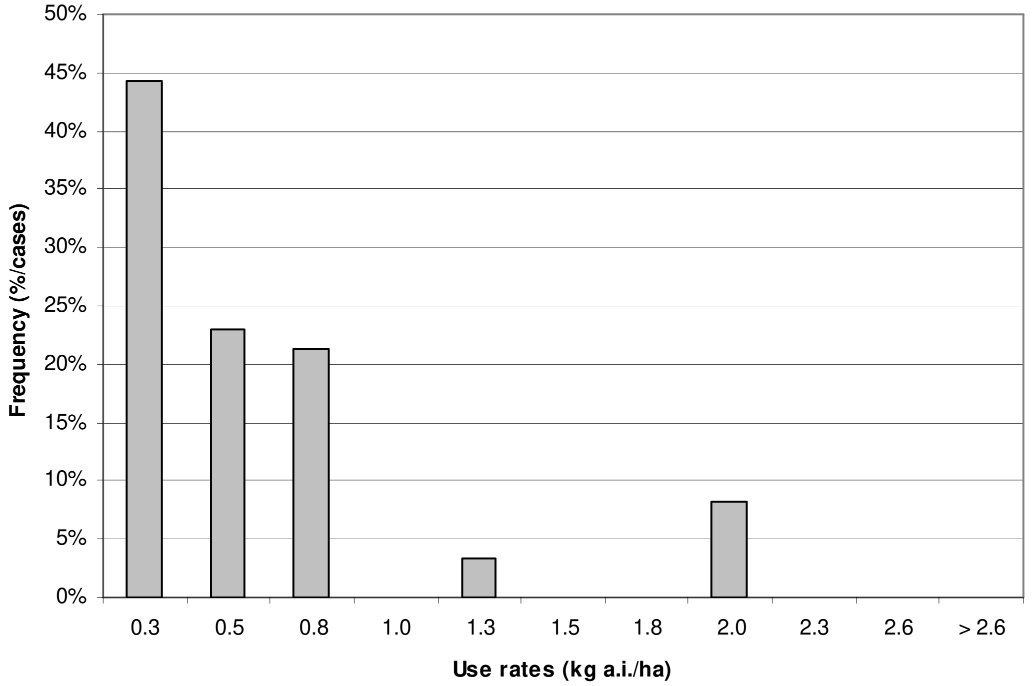


Figure E.3 Analysis of the data provided by the confidential Industry survey of plantation managers' chemical pesticide use for clopyralid. Most use is less than 50% of the maximum label rate.

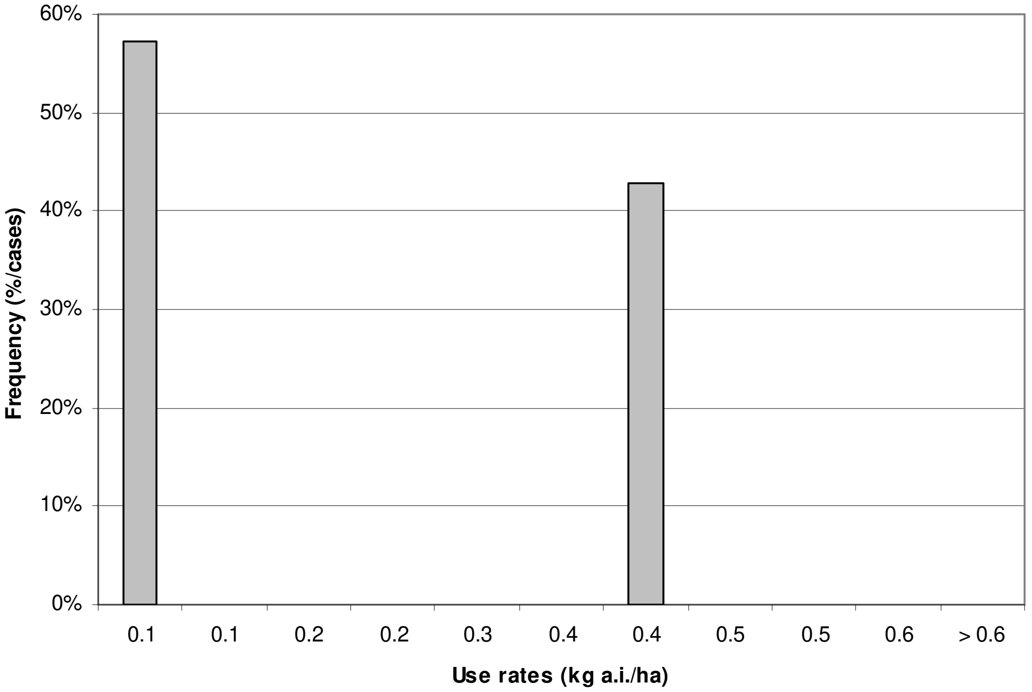


Figure E.4 Analysis of the data provided by the confidential industry survey of plantation managers' chemical pesticide use for fluroxypyr. Most use is at low rates.

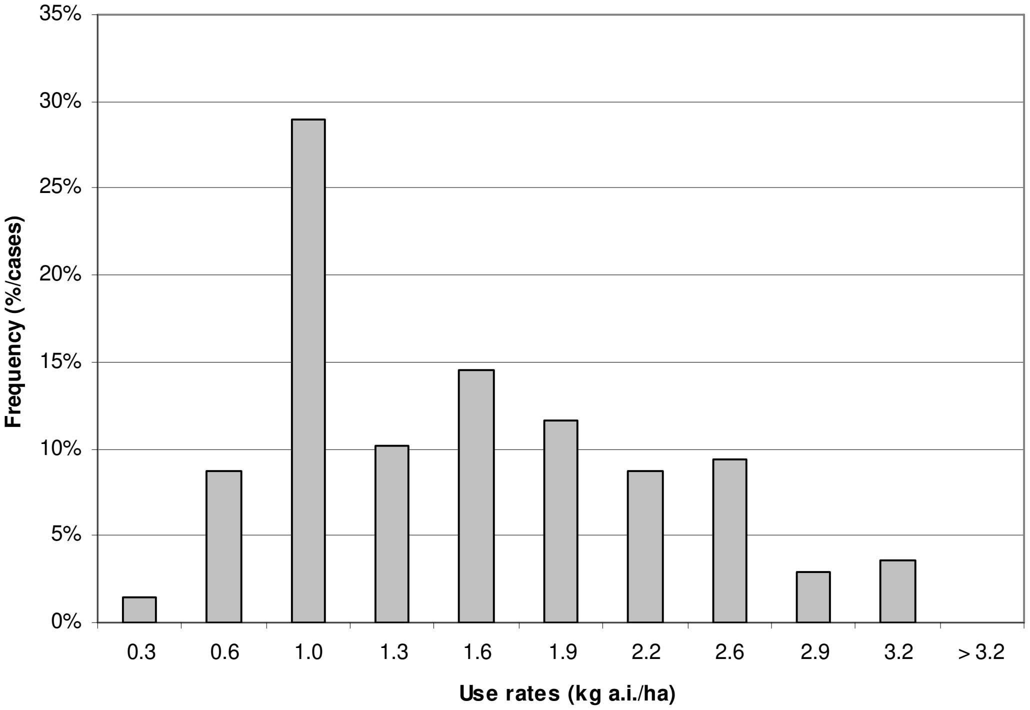


Figure E.5 Analysis of the data provided by the confidential Industry survey of plantation managers' chemical pesticide use for glyphosate. Most use is at below the maximum label rate.

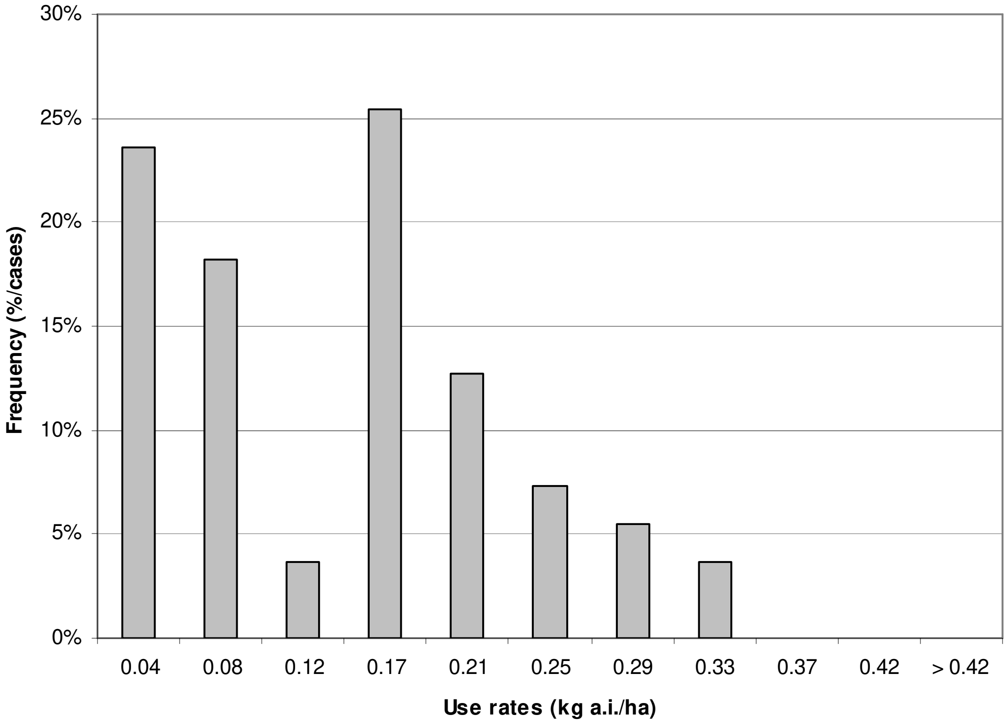


Figure E.6 Analysis of the data provided by the confidential industry survey of plantation managers' chemical pesticide use for haloxyfop. Most use is at below 50% of the maximum label rate.

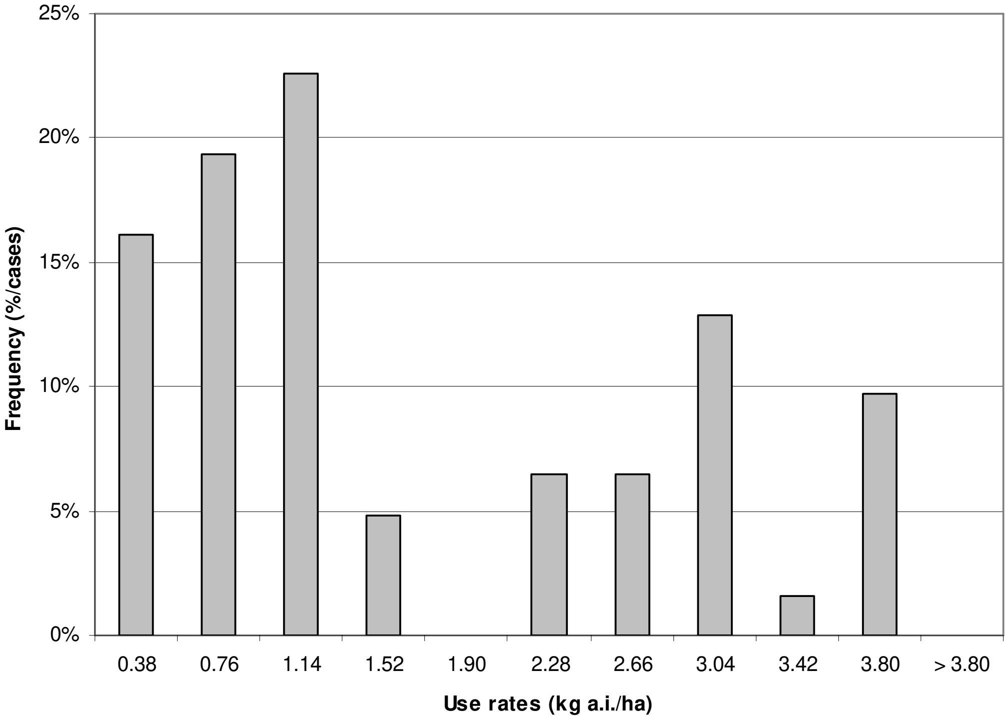


Figure E.7 Analysis of the data provided by the confidential industry survey of plantation managers' chemical pesticide use for hexazinone. Most use is at less than the maximum label rate.

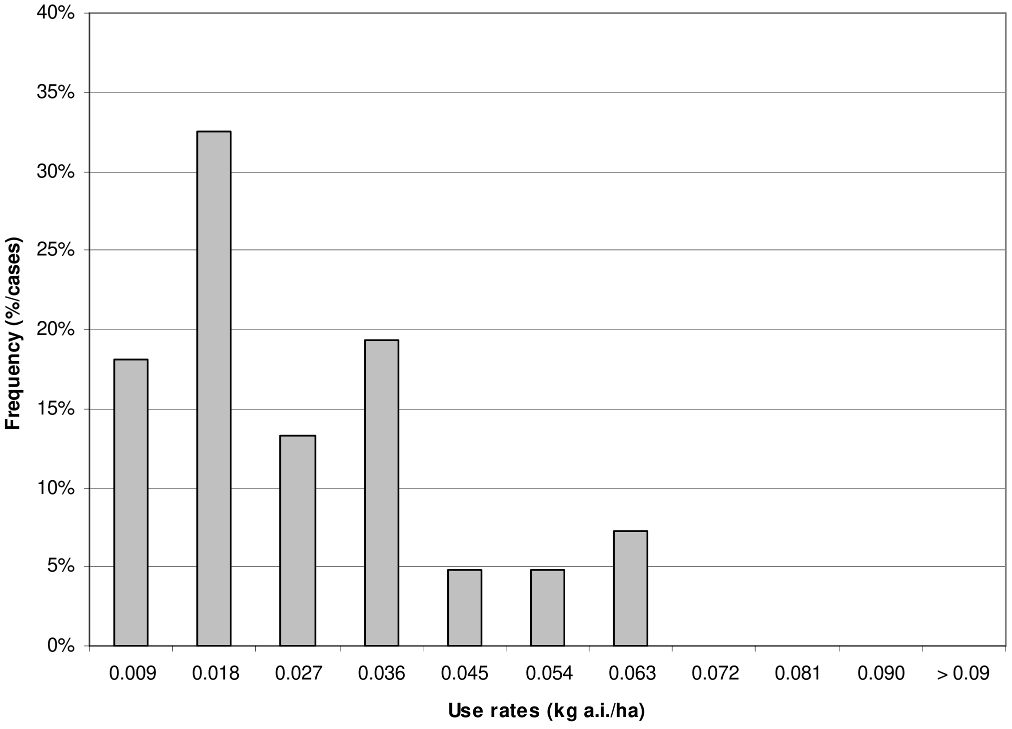


Figure E.8 Analysis of the data provided by the confidential industry survey of plantation managers‘ chemical pesticide use for metsulfuron methyl. Most use is below 50% of the label maximum rate.

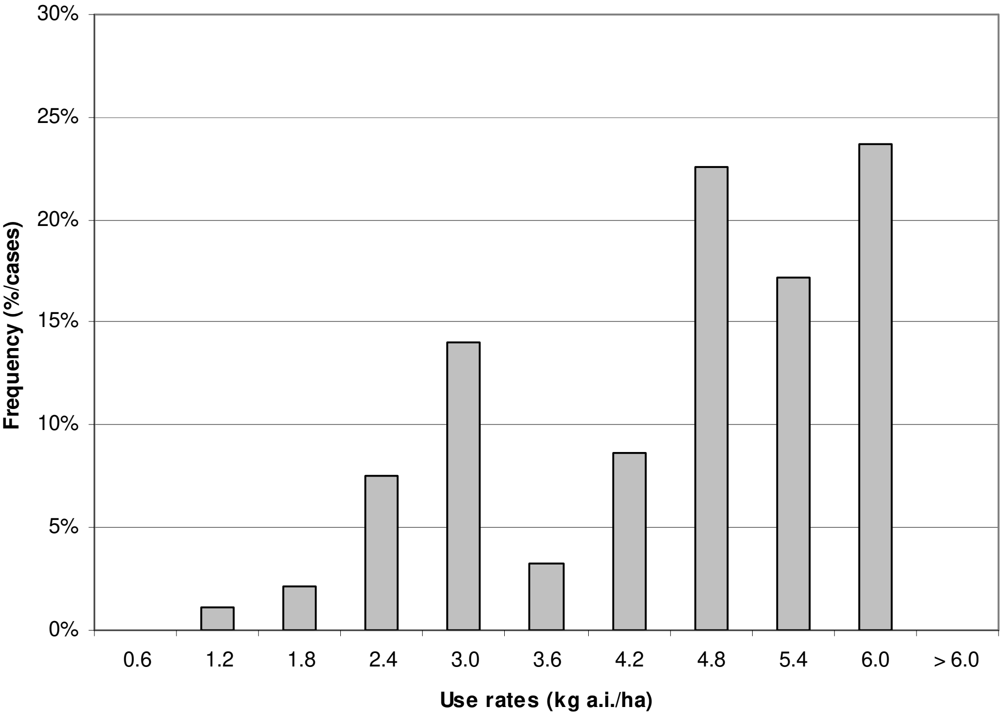


Figure E.9 Analysis of the data provided by the confidential industry survey of plantation managers’ chemical pesticide use for simazine. Most use is at less than the label maximum rate.

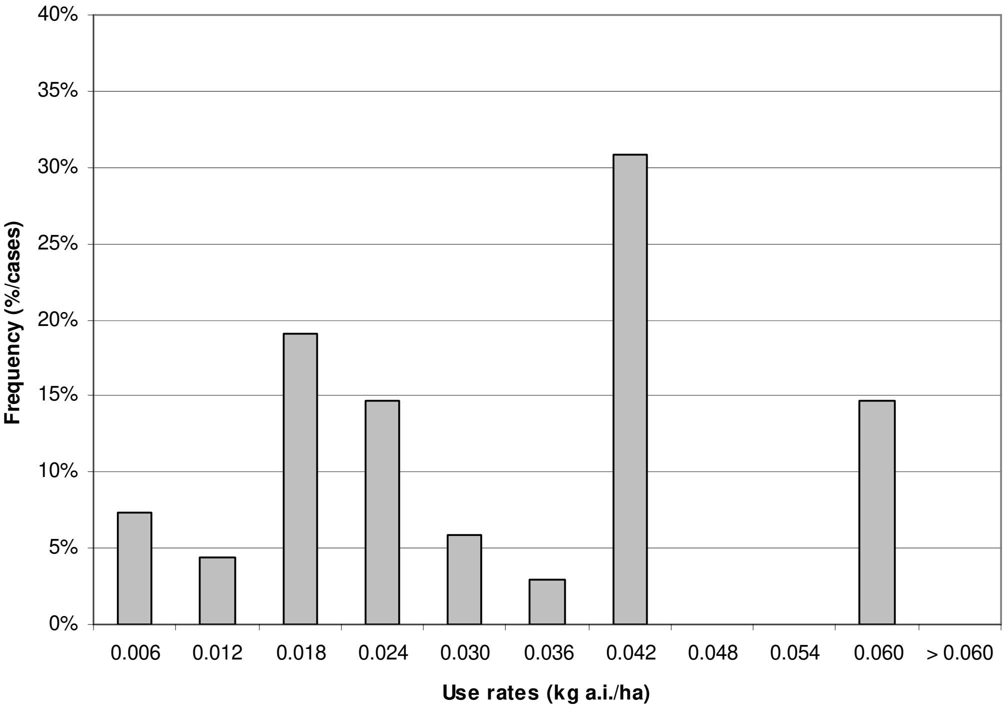


Figure E.10 Analysis of the data provided by the confidential industry survey of plantation managers' chemical pesticide use for sulfometuron methyl. Most use is at less than 50% of the label maximum rate.

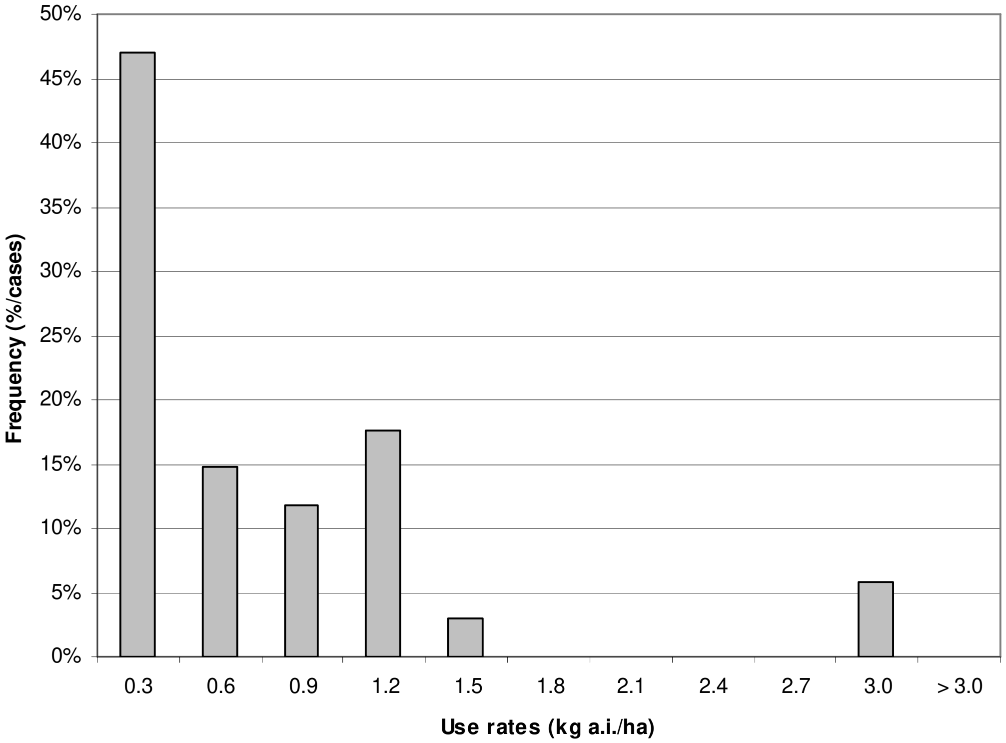


Figure E.11 Analysis of the data provided by the confidential industry survey of plantation managers' chemical pesticide use for triclopyr. Most use is at below 50% of the maximum label rate.

Appendix F Spray technology – nozzles

The following case study has been adapted from information provided by Peter Alexander, (*Pers. com.* 10 TeeJet Australasia Pty Ltd) an expert in nozzle technology.

Pre 1940

As early as 1900, horse drawn sprayers were used to apply a range of chemical pesticides in Australian agriculture. These used either manually or ground driven pumps to supply the mixture to full cone nozzles, either mounted on a crude boom, or attached to a hand wand. In the 30's and 40's, the pumps were motorised and horses were replaced by tractors.

1940's-1970's

Spraying Systems Co (USA) is credited in developing the first flat fan nozzle in 1947 in response to the introduction of the herbicide 2,4-D. This was the TeeJet TP brass flat-fan nozzle, still available (and widely used in some markets) today. The TP gained widespread acceptance globally in the 1950 and 60's, especially as the popularity of the phenoxy acetic acid herbicides (2,4-D and MCPA) increased worldwide. However, issues of spray drift, pesticide resistance, accuracy, standards and usability were not considered in those early days, so for nearly 30 years, (apart from the introduction of alternative materials to brass such as stainless steel and sintered aluminium), the standard flat fan was the nozzle of choice.

1970's – 1980's

Public concern in relation to chemical pesticide use dramatically increased in the late 60's and early 70's. DDT, dioxins, food residues, Agent-Orange, cancer clusters, etc became household concerns. Until the mid 70's most nozzle design focused on spray distribution and pattern quality. Spray drift was recognised as a significant issue and became a focus of anti-chemical pesticide lobbies. In response, the early 80's saw a shift to larger drop producing nozzles and minimising small drift-prone droplets. The first of these was the Low Pressure (LP) flat fan nozzle. Subtle internal geometry changes to the TP inlet orifice enabled lower operating pressures and larger droplets without reduction of spray angle or distribution quality.

In 1986 the Extended Range (XR) nozzle was introduced. The XR TeeJet quickly became popular globally because of its ability to operate over an extended range of pressures which provided droplet size flexibility. It could be used to apply pre-emergent fertiliser or herbicides at low pressures minimising drift. It could also be used at higher pressures for post emergent applications where canopy coverage and penetration is required. The XR TeeJet remains today the industry standard, and is often cited in studies as the baseline by which spray nozzles and spray campaigns are measured and compared. In addition to the XR, flat fan nozzles that used a pre-orifice were developed around this time. The pre-orifice performs the primary flow metering function whilst the larger exit orifice provides secondary metering and pattern formation. The droplet size (VMD) is typically 20-40% coarser than the equivalent XR nozzle. Examples include the TeeJet DG (Drift Guard). In the 80's, techniques were developed to manufacture flat fan tips in harder wearing materials such as ceramic and injection moulded plastics. At the same time, Spraying Systems Co developed the VisiFlo® colour-coding system for flow rate identification of spray tips. It is now the ISO standard used by every nozzle manufacturer.

1990's - 2000's

As herbicide chemistry became more selective, glyphosate resistant genetically modified crops (GM) crops became widespread and society became more litigious, resulting in spray drift became the most significant factor facing the industry worldwide. International standards to define spray quality (or drop size distribution) were developed in the 1990's. Though continually being refined, these standards provide a framework for end-users to compare and select nozzles based on chemical label requirements. Other standards to define drift reduction capabilities and spray distribution/uniformity were also introduced. In terms of nozzle developments, advancements in plastic moulding allowed for new non-conventional geometry and moulded pre-orifices. The first of these was the TT (Turbo TeeJet) released in the mid 90's, a flat fan/anvil hybrid with a very wide pressure range, less fines, and excellent distribution and blockage resistance. The TT remains the most popular "low-drift" flat fan nozzle used in Australia today.

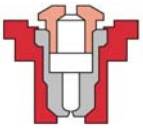
2000 and beyond

Spray drift continued to be the driving force behind nozzle development, though the widely accepted view that coarse droplets result in poor coverage (and therefore poor efficacy) generated a lot of interest in air induction nozzles. First developed in the 60's as a foaming nozzle (for spraying detergents), air induction nozzles have gained widespread acceptance in mainstream agriculture. Designed to draw air into the liquid stream (through a venturi), these flat fan nozzles can (depending on the chemical/surfactant load) produce larger air-included/filled droplets that shatter on impact. In effect, drift reduction benefits of applying large droplets, without significant sacrifices in coverage. The next generation AI nozzles are more compact, produce larger drops, and operate at lower pressures. An example is the TTI (Turbo TeeJet Induction) that produce very coarse droplets and unlike other designs, the percentages of fine droplets do not increase with pressure.

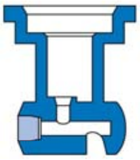
Table F.1 The evolution of the T-jet spray nozzle for chemical pesticide application.

1940's-1970's The standard fan TeeJet.

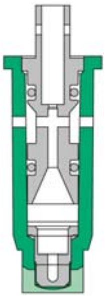
In 1986 the XR (or Extended Range) nozzle was introduced.



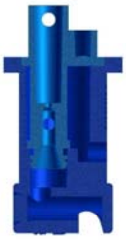
An evolution of the XR nozzle was the addition of a pre-orifice in the nozzle design.



During 1990 to 2000, Turbo TeeJet was introduced to help address spray drift.



A foaming nozzle first developed in the 1960's aims to reduce spray drift.



The latest evolution is nozzles designed to produce large droplets such as the Tubo TeeJet Induction nozzle.

Appendix G Cost as a proxy to usage

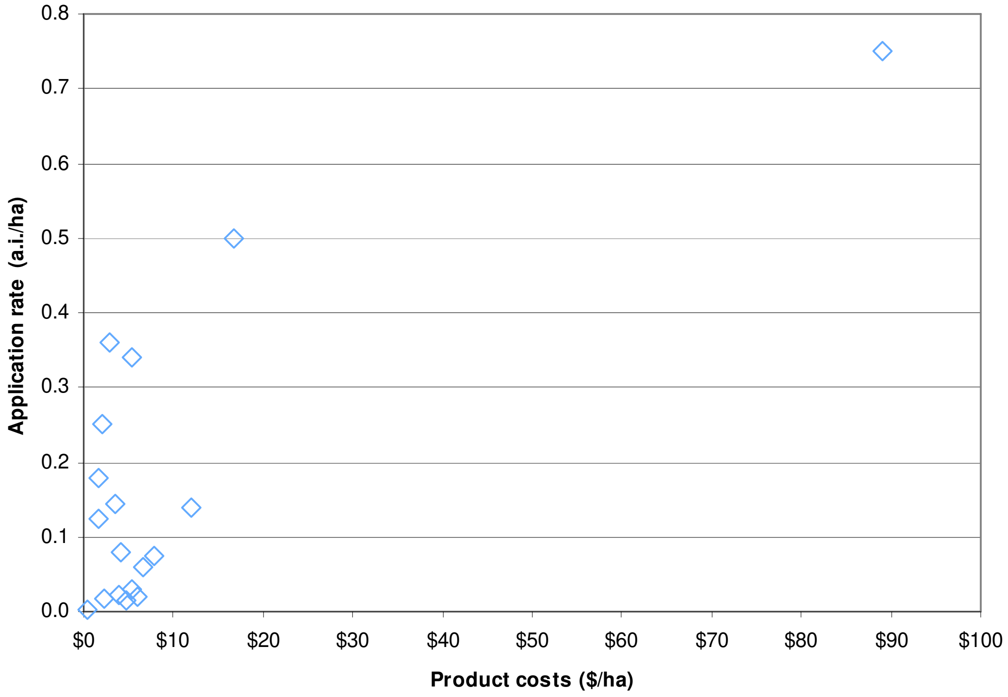


Figure G.1 An analysis of the relationship between herbicide product costs and the lowest label rate of a.i. applied / ha. In general, the greater the product cost, the less applied a.i. /ha. The outlier is hexazinone, which has a longer duration of effect than the other chemicals shown.

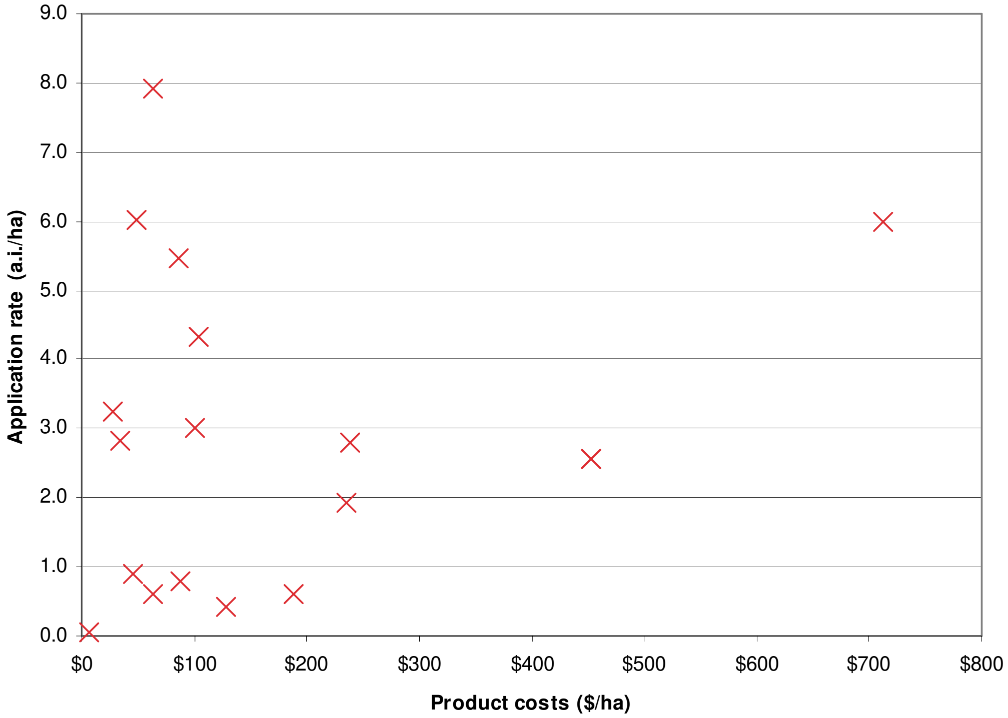


Figure G.2 An analysis of the relationship between herbicide product costs and the highest label rate of a.i. applied / ha. In general, the greater the product cost, the less applied a.i. /ha. The outlier is hexazinone, which has a longer duration of effect than the other chemicals shown.

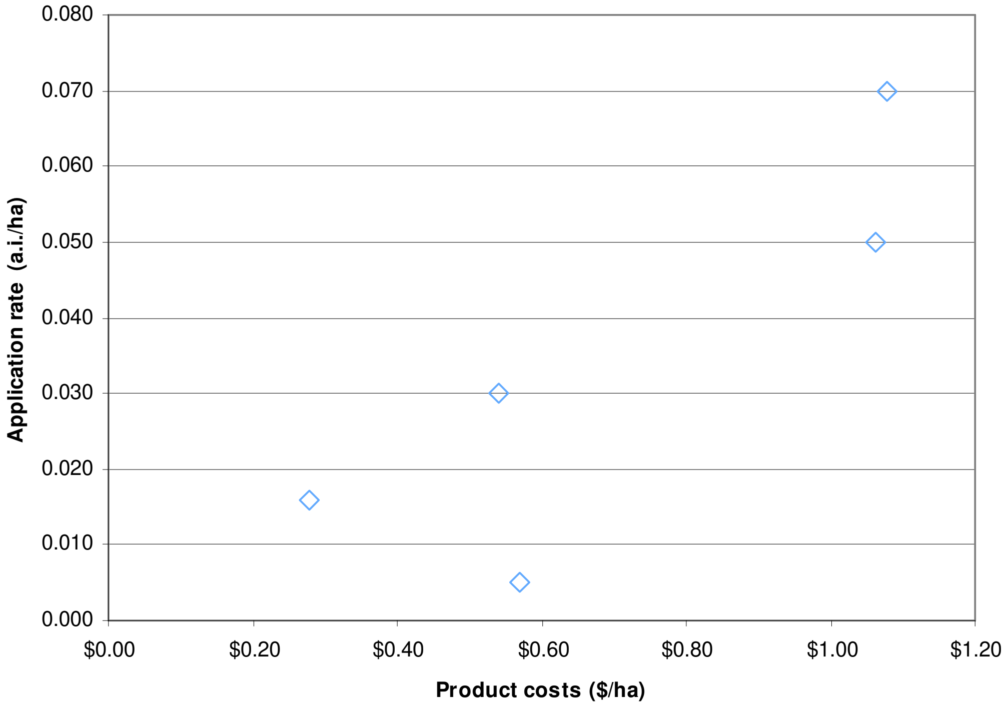


Figure G.3 An analysis of the relationship between fungicide product costs and the lowest label rate of a.i. applied / ha. In general, the product cost has little impact on the applied a.i. /ha.

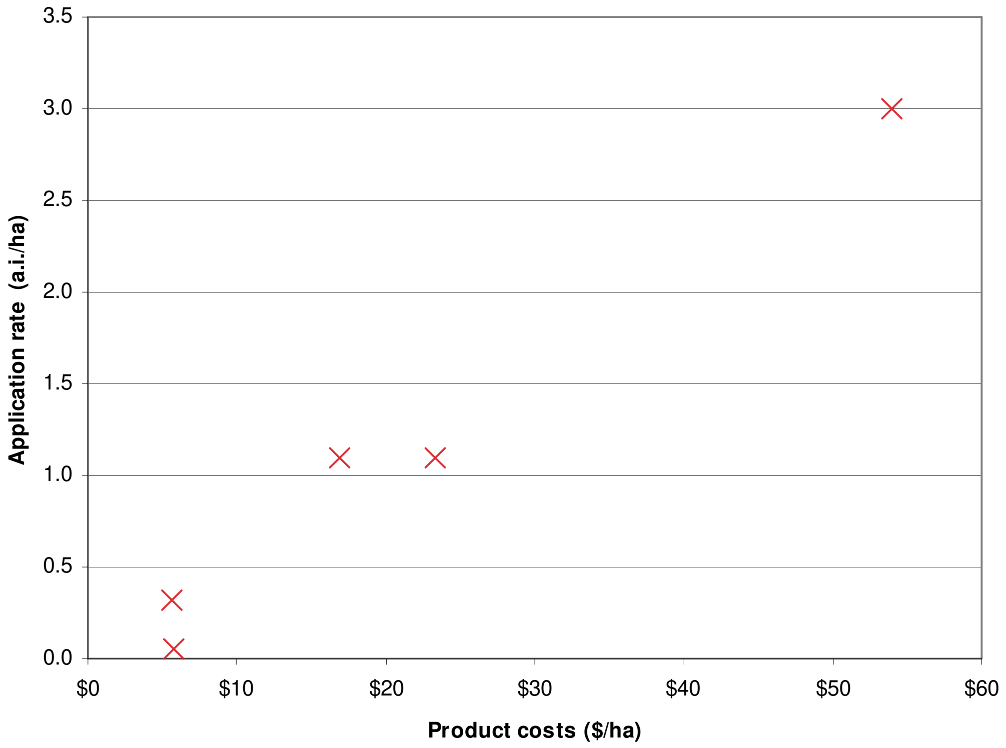


Figure G.4 An analysis of the relationship between fungicide product costs and the highest label rate of a.i. applied / ha. In general, as product cost per hectare increases, so does the applied a.i. /ha.

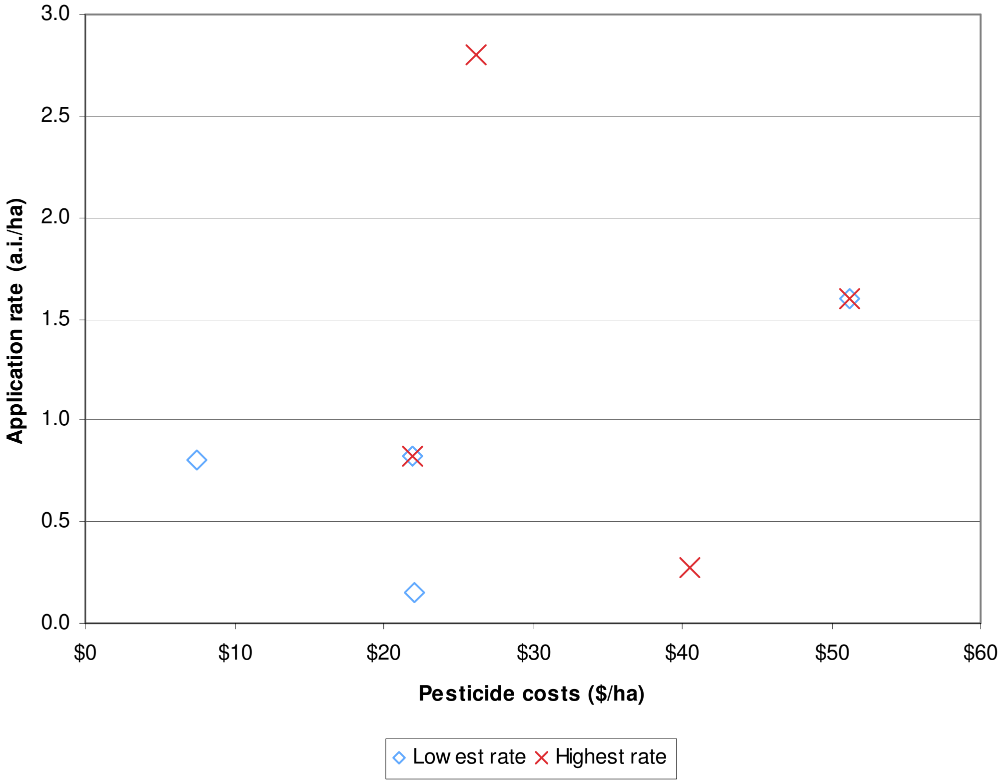


Figure G.5 An analysis of the relationship between insecticide product costs and the lowest and highest label rate of a.i. applied / ha.

Appendix H Standard regimes

Radiata pine

Table H.1 A summary of generic regimes applied to 1R radiata pine plantations. The regimes shown are the maximum likely chemical pesticides to be used.

Previous land use	Code	Operation	Year	Active ingredient	Rate		Coverage	Planted ($/ha)
Grass (1R site)	A	Pre-planting clean-up	0	Glyphosate Metsulfuron methyl Pulse	720.0 6.0 0.2	g a.i./ha g a.i./ha L/ha	Broadcast	$12.26
	B	Post-planting residual	1	Hexazinone	3.0	kg a.i./ha	Strip	$178.00
	C	Post-planting residual	1	Hexazinone Atrazine	1.5 4.5	kg a.i./ha kg a.i./ha	Strip	$148.50
	D	Post-planting residual	2	Hexazinone	1.5	kg a.i./ha	Strip	$178.00
	E	Post-planting residual	2	Hexazinone Atrazine	1.5 4.5	kg a.i./ha kg a.i./ha	Strip	$148.50
	F	Post-planting residual	2	Hexazinone	3.0	kg a.i./ha	Spot	$32.04

Table H.2 A summary of generic regimes applied to 2R radiata pine plantations. The regimes shown are the maximum likely chemical pesticides to be used.

Previous land use	Code	Operation	Year	Active ingredient	Rate		Coverage	Planted ($/ha)
Pine plantation (2R site)	G	Pre-planting clean-up	0	Glyphosate	1,800.0	g a.i./ha	Broadcast	$12.70
				Metsulfuron methyl	36.0	g a.i./ha		
				Pulse	0.2	L/ha		
	H	Post-planting residual	1	Hexazinone	3.0	kg a.i./ha	Broadcast	$356.00
	I	Post-planting residual	1	Hexazinone	3.0	kg a.i./ha	Strip	$178.00
	J	Post-planting residual	2	Hexazinone	3.0	kg a.i./ha	Broadcast	$356.00
	K	Post-planting residual	2	Hexazinone	3.0	kg a.i./ha	Strip	$178.00
	L	Post-planting residual	2	Hexazinone	3.0	kg a.i./ha	Spot	$33.46

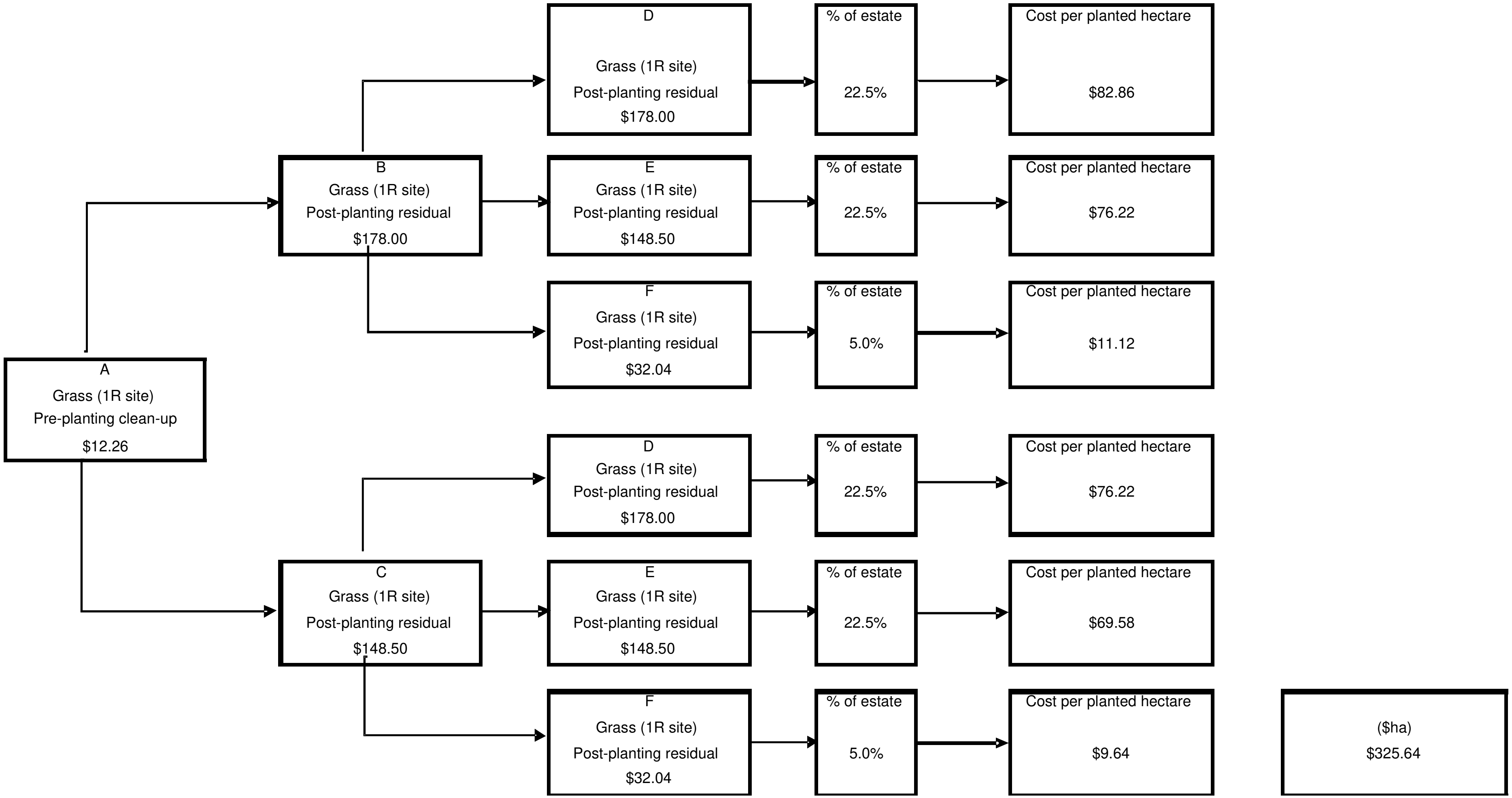


Figure H.1 The costs of the various combinations which make up a herbicide regime for 1R radiata pine. (Note: costs are as per Table H.1)

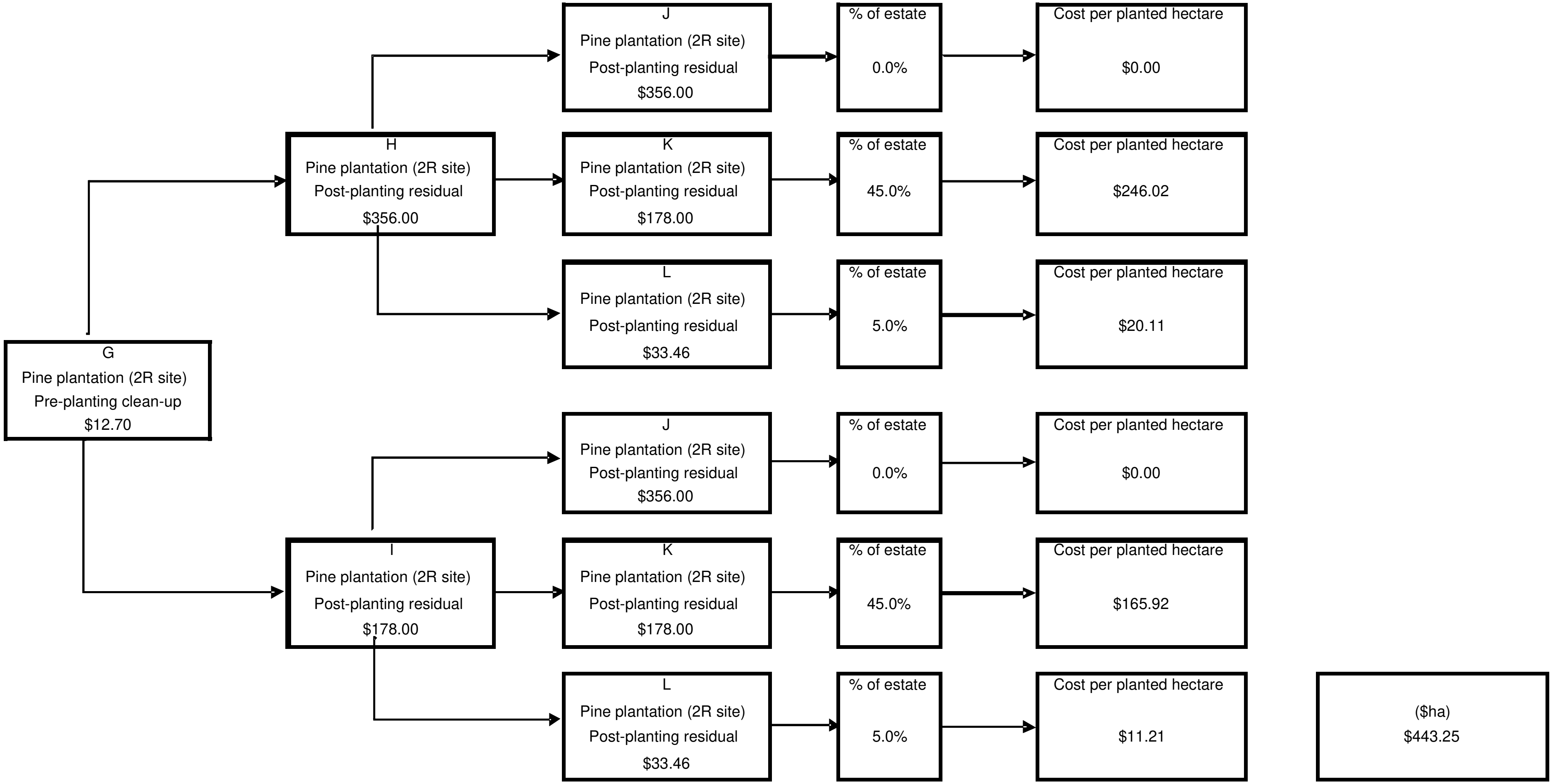


Figure H.2 The costs of the various combinations which make up a herbicide regime for 2R radiata pine. (Note: costs are as per Table H.2)

Tasmanian blue gums

Table H.3 A summary of generic herbicide regimes for 1R Tasmanian blue gum plantations. The regimes shown are the maximum likely chemical pesticides to be used.

Previous land use	Code	Operation	Year	Active ingredient	Rate	-	$/ha planted	Coverage
Pasture (1R site)	A	Pre-planting clean-up	1	Glyphosate	720.0	g a.i./ha	$12.26	Broadcast 100% of area
				Metsulfuron methyl	6.0	g a.i./ha		
				Adjuvants	0.2	L/ha		
	B	Pre-planting residual plus knockdown	1	Glyphosate	720.0	g a.i./ha	$22.25	Strip application (50% coverage)
				Simazine	4.0	kg a.i./ha		
				Sulfometuron methyl	22.5	g a.i./ha		
	C	Pre-planting residual plus knockdown	1	Glyphosate	720.0	g a.i./ha	$21.97	Strip application (50% coverage)
				Simazine	4.0	kg a.i./ha		
				Metsulfuron methyl	6.0	g a.i./ha		
				Adjuvant	0.2	L/ha		
	D	Post-planting recovery	1	Haloxyfop	130.0	g a.i./ha	$80.84	Recovery operation strip (50% coverage)
				Simazine	4.0	kg a.i./ha		
				Clopyralid	180.0	g a.i./ha		
	E	Post-planting	2	Amitrole	500.0	g a.i./ha	$28.96	Strip application with 50% coverage.
				Simazine	4.0	kg a.i./ha		
				Sulfometuron methyl	22.5	g a.i./ha		
	F	Post-planting	2	Amitrole	500.0	g a.i./ha	$13.12	Strip application with 50% coverage.
				Sulfometuron methyl	22.5	g a.i./ha		

Table H.4 A summary of generic herbicide regimes for 2R Tasmanian blue gum plantations. The regimes shown are the maximum likely chemical pesticides to be used.

Previous land use	Code	Operation	Year	Active ingredient	Rate		$/ha planted	Coverage
Ex eucalypt plantation (2R)	G	Pre-planting clean-up	1	Glyphosate	720.0	g a.i./ha	$12.26	Broadcast 100% of area to kill coppice
				Metsulfuron methyl	6.0	g a.i./ha		
				Adjuvant	0.2	L/ha		
	H	Pre-planting residual plus knockdown	1	Glyphosate	720.0	g a.i./ha	$21.97	Strip application
				Simazine	4.0	kg a.i./ha		
				Metsulfuron methyl	6.0	g a.i./ha		
				Adjuvant	0.2	L/ha		
	I	Pre-planting residual plus knockdown	1	Glyphosate	720.0	g a.i./ha	$22.25	Strip application (50% coverage)
				Simazine	4.0	kg a.i./ha		
				Sulfometuron methyl	22.5	g a.i./ha		
	J	Post-planting recovery	1	Haloxyfop	130.0	g a.i./ha	$80.84	Recovery operation strip (50% coverage)
				Simazine	4.0	kg a.i./ha		
				Clopyralid	180.0	g a.i./ha		
	K	Post-planting	2	Amitrole	500.0	g a.i./ha	$28.96	Strip application with 50% coverage.
				Simazine	4.0	kg a.i./ha		
				Sulfometuron methyl	22.5	g a.i./ha		
	L	Post-planting	2	Amitrole	500.0	g a.i./ha	$13.12	Strip application with 50% coverage.
				Sulfometuron methyl	22.5	g a.i./ha		

Table H.4 cont. A summary of generic herbicide regimes for 2R Tasmanian blue gum plantations. The regimes shown are the maximum likely chemical pesticides to be used.

Ex eucalypt plantation (2R coppice)	M	Spot clean-up	1	Glyphosate	720.0	g a.i./ha	$1.23	Spot treat 10% of area to kill weeds
				Metsulfuron methyl	6.0	g a.i./ha		
				Adjuvant	0.2	L/ha		

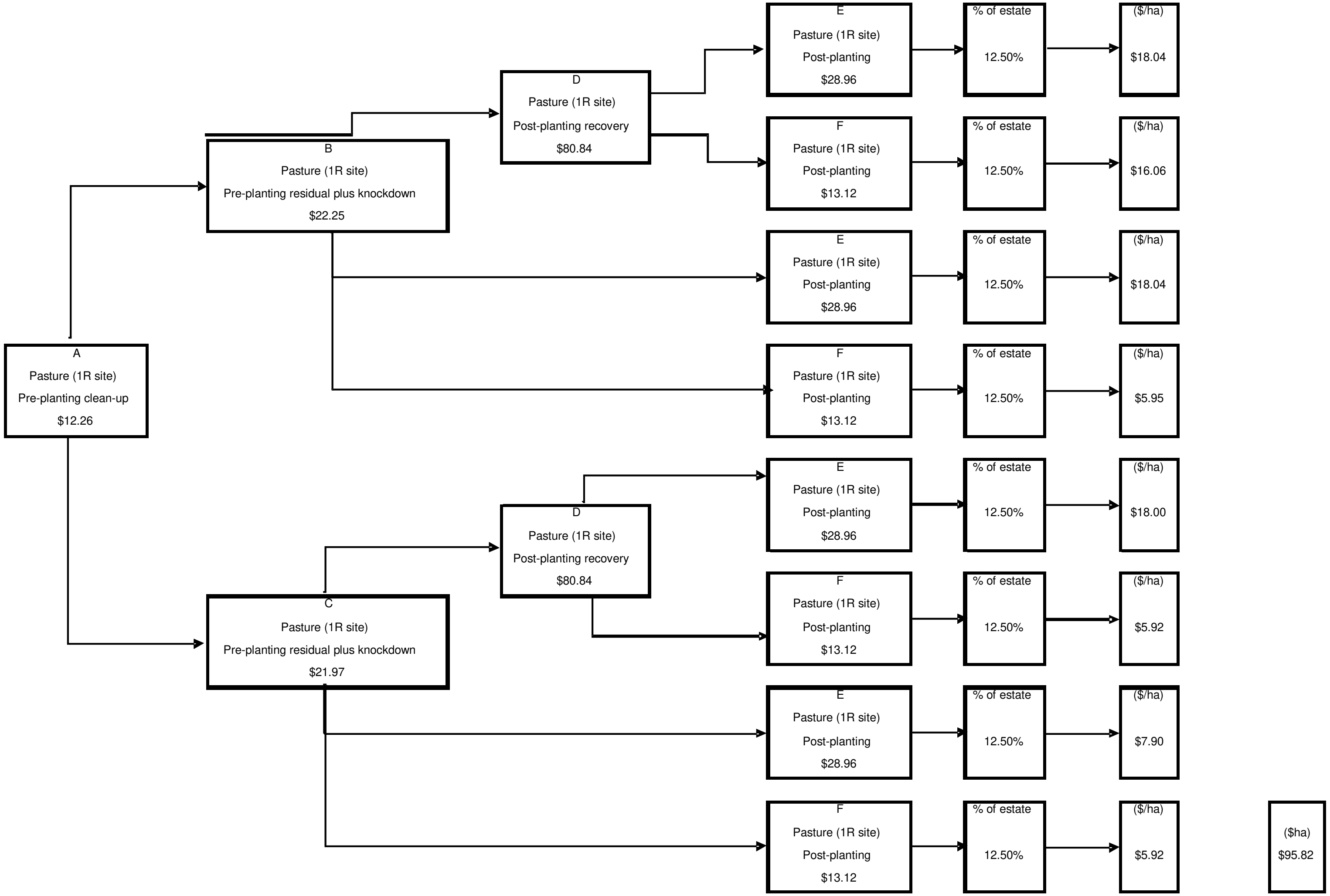


Figure H.3 A summary of the various herbicide regime options for a generic Tasmanian blue gum crop on a 1R site.

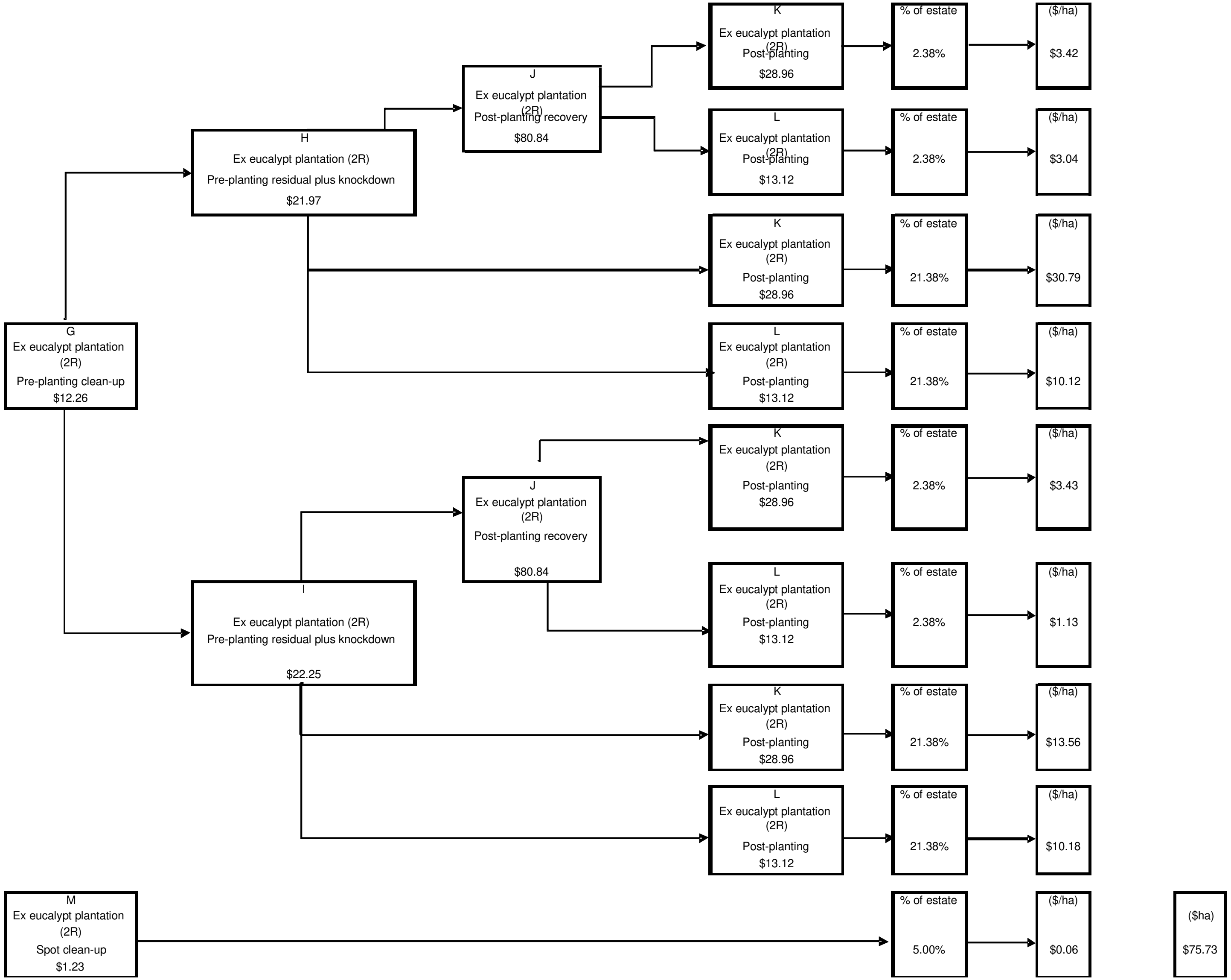


Figure H.4 A summary of the various herbicide regime options for a generic Tasmanian blue gum crop on a 2R site.

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Appendix I Household chemical pesticides

Table I.1 A summary of the chemical pesticides available for household use and available *off the shelf* for sale at large retail hardware stores and supermarkets.

Pesticide	Active ingredient(s)	Units	Units	Comments
Fungicides	Benomyl	g/kg	500	Garden fungicide
Fungicides	Bitertanol	g/L	0.75	Rose & ornamental spray
Fungicides	Copper oxychloride	g/kg		Bordeaux mixture
Fungicides	Copper oxychloride + elemental sulphur	g/kg	40 + 400	Tomato dust
Fungicides	Copper oxychloride + elemental sulphur + carbaryl	g/kg	120 + 200	Tomato spray
Fungicides	Furalaxyl	g/kg	250	Systemic fungicide, *Pythium, Phytophthora* for ornamental plants
Fungicides	Mancozeb	g/kg	40	Rose dust with sulphur and rotenone insecticide
Fungicides	Myclobutanil	g/L	0.05	Rose fungicide - combined with tau-fluvalinate insecticide
Fungicides	Myclobutanil	g/L	4.4	Rose fungicide - combined with tau-fluvalinate insecticide
Fungicides	Phosphorus acid (mono-di potassium phosphate)	g/L	200	Systemic fungicide, for downy mildew, Phytophthora etc
Fungicides	Triadimefon	g/kg	50	Powdery mildew, black spot, butt rots etc - wide range
Fungicides	Triforine	g/L	19	Rose treatment
Fungicides	Triforine	g/L		Powdery mildews, rusts, black spot, lawn fungal diseases etc

Pesticide	Active ingredient(s)	Units	Units	Comments
Herbicides	Amitrole + ammonium thiocyanate	g/L	200 + 220	
Herbicides	Amitrole + ammonium thiocyanate	g/L	250 + 220	Oxalis control
Herbicides	Amitrole + ammonium thiocyanate + simazine	g/L	20.5 + 36.9 + 18	Once a year path weeder
Herbicides	Amitrole + ammonium thiocyanate + simazine	g/L	50.0 + 208.0 + 150.0	Once a year path weeder
Herbicides	Amitrole + ammonium thiocyanate + simazine	g/L	9 + 5 + 4.4	Once a year path weeder
Herbicides	Glyphosate (various salts)	g/L	7.2	Broad spectrum foliar knockdown
Herbicides	Glyphosate (various salts)	g/L	360	Broad spectrum foliar knockdown
Herbicides	Glyphosate (various salts)	g/L	490	Broad spectrum foliar knockdown
Herbicides	Glyphosate (various salts)	g/L	540	Broad spectrum foliar knockdown
Herbicides	MCPA + bromoxynil	g/L	200 + 200	
Herbicides	MCPA + dicamba	g/L	15 + 2.3	Lawn weeder-feeders, mixed with fertiliser
Herbicides	MCPA + dicamba	g/L	23 + 3.5	Lawn weeder-feeders, mixed with fertiliser
Herbicides	MCPA + dicamba	g/L	340 + 80	Broadleaf weed control
Herbicides	MCPA + dicamba + bertazone	g/L	112 + 19 + 192	Multi weeding of lawns
Herbicides	Mecoprop + dicamba	g/L	240 + 40	Lawn weed killer
Herbicides	Propyzamide	g/kg	100	Grass control
Herbicides	Triclopyr	g/L	60	Tree and blackberry killer

Table I.1 (cont) A summary of the chemical pesticides available for household use and available *off the shelf* for sale at large retail hardware stores and supermarkets.

Pesticide	Active ingredient(s)	Units	Units	Comments
Insecticides	*Bacillus thuringiensis*			Moth killer
Insecticides	Bifenthrin	g/L	0.03	Broad range of insects
Insecticides	Bifenthrin	g/L	0.5	Broad range of insects
Insecticides	Bioallethrin + bioresmethrin	g/kg	2.09 + 0.39	Insect fly spray
Insecticides	Bioallethrin + bioresmethrin	g/kg	3.7 + 0.7	Household and public health insect control, insect coils, wide range etc
Insecticides	Carbaryl	g/kg	25	Tomato dust
Insecticides	Carbaryl	g/kg	80	Tomato spray with fungicides
Insecticides	Carbaryl	g/kg	800	
Insecticides	Chlorpyrifos	g/kg	10	Lawn beetle, grubs, ant and roach dust
Insecticides	Chlorpyrifos	g/kg	40	Lawn beetle killer
Insecticides	Chlorpyrifos	g/kg	30-50	Ant control
Insecticides	Cyfluthrin	g/kg	0.2	Lawn grub and garden insects
Insecticides	Cyfluthrin	g/L	12.5	Lawn grub and garden insects
Insecticides	Deltamethrin	g/L	0.3	
Insecticides	Dimethoate	g/L	100	
Insecticides	Fenthion	g/L	100	Insect pests in fruit, vegetables - wide range
Insecticides	Imadacloprid	g/kg	15	Lawn damaging and leaf chewing insect
Insecticides	Malathion	g/L	100	Anti-scale, also includes petroleum oil
Insecticides	Malathion	g/L	500	CRC Malathion
Insecticides	Metaldehyde	g/kg	15	Snail pellets
Insecticides	Methiocarb	g/kg	20	Snail and slug bait
Insecticides	Omethoate	g/kg	2	Aphids, caterpillars, scale insects etc
Insecticides	Permethrin	g/L	3.0	Ant and roach spray & dusts
Insecticides	Permethrin	g/kg	10	Ant and roach spray & dusts
Insecticides	Permethrin	g/L	100	
Insecticides	Permethrin + tetramethrin	g/kg	2.7 + 1.38	Odourless Surface Spray
Insecticides	Petroleum oil	g/kg	150	Summer Oil
Insecticides	Pyrethrin	g/L	1.0 + 10.0	Insecticidal pet shampoo
Insecticides	Pyrethrin + petroleum oil	g/L	1.2 + 0.3 + 20	Leaf scale treatment
Insecticides	Pyrethrins	g/L	0.3 + 1.2	Wide range of insects
Insecticides	Tetramethrin + phenothrin	g/kg	10 + 3.5 + 0.18	Fly and insect killer
Insecticides	Propoxur	g/kg	10	Household insecticide dust
Insecticides	Rotenone	g/kg	5	Rose dust, insecticide and acaricide

Table I.1 (cont) A summary of the chemical pesticides available for household use and available *off the shelf* for sale at large retail hardware stores and supermarkets.

Pesticide	Active ingredient(s)	Units	Units	Comments
Insecticides	Rotenone	g/kg	7.5	Rose dust, insecticide and acaricide
Insecticides	Spinosad	g/L	10	Leaf chewing insects
Insecticides	Tau-fluvalinate	g/L	0.1	Wide range of insects
Insecticides	Tau-fluvalinate	g/L	7.5	Wide range of insects
Insecticides	Tau-fluvalinate	g/L	10	Wide range of insects
Insecticides	Tetramethrin + s-bioallethrin + bioresmethrin	g/kg	3.82 + 1.1 + 0.75	Knockdown insect spray
Insecticides	Trichlofon	g/L	500	Lawn grub killer
Rodenticide	Brodifacoun	g/kg	0.05	Rodent killer

Appendix J Australian chemical pesticide estimates

The Figures in this Appendix show the estimated Australian chemical pesticide use by the crops shown in the six zones as per Map 1. In the case of the plantation crops, they are presented on softwood and hardwood split into:

- Inputs for the 1R crops areas;
- Inputs for the existing estate (harvested and replanted) and the 1R areas as a **total** estimate.

The **total** for each plantation type that is the best comparison of the relative chemical pesticide inputs compared to the other crops shown.

The information is structured as follows:

- Figures J.1 to J.4 show the estimated chemical pesticide use for each of the land uses shown;
- Figures J.5 to J.7 show the per hectare chemical pesticide use for each of the land uses shown.

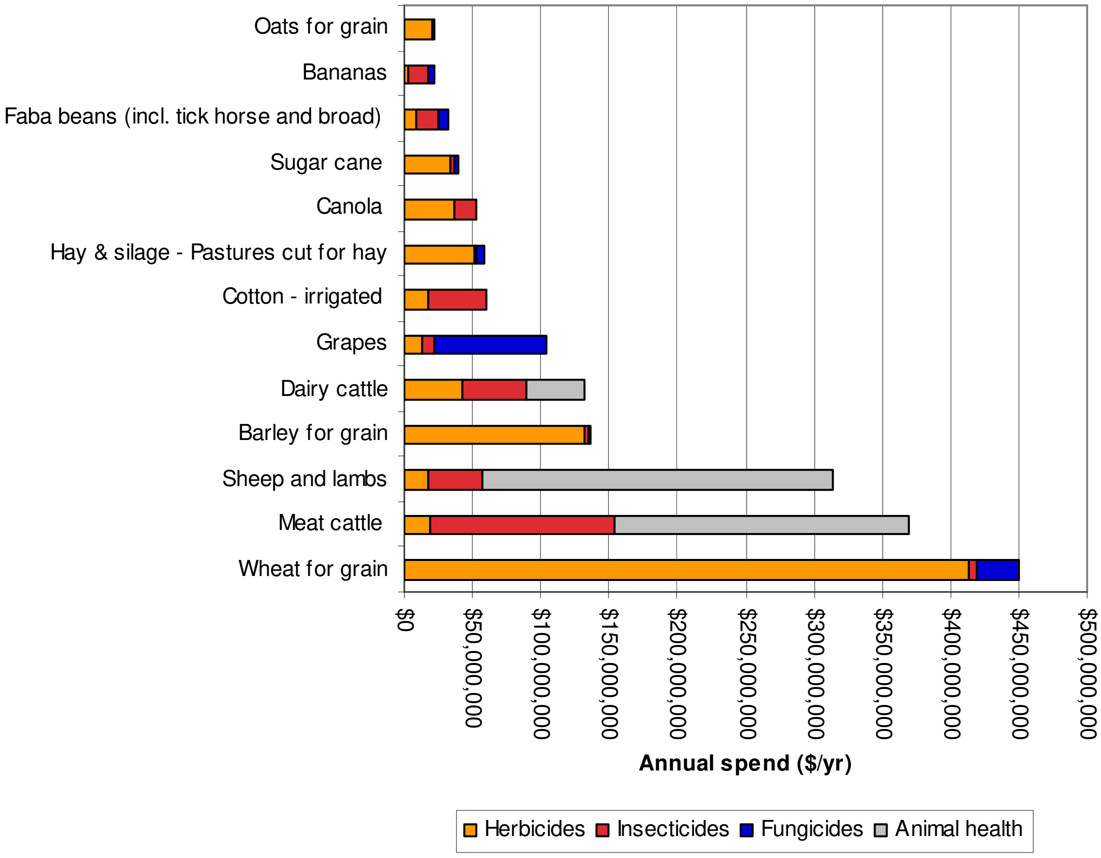


Figure J.1 The estimated spend on chemical pesticides for the six zones modelled.

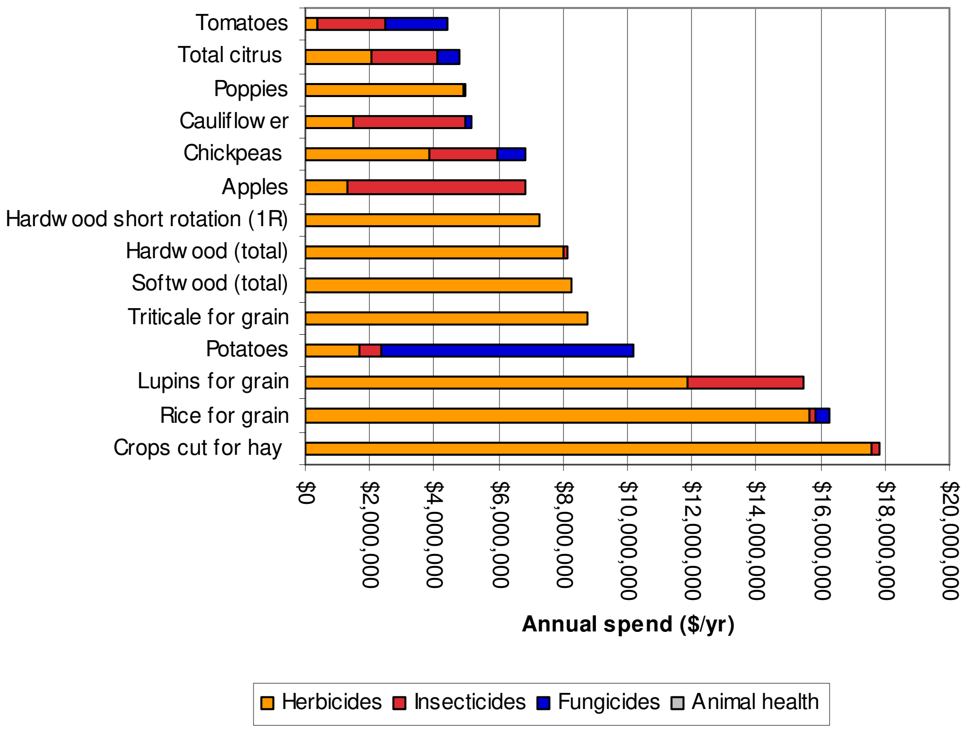


Figure J.2 The estimated spend on chemical pesticides for the six zones modelled.

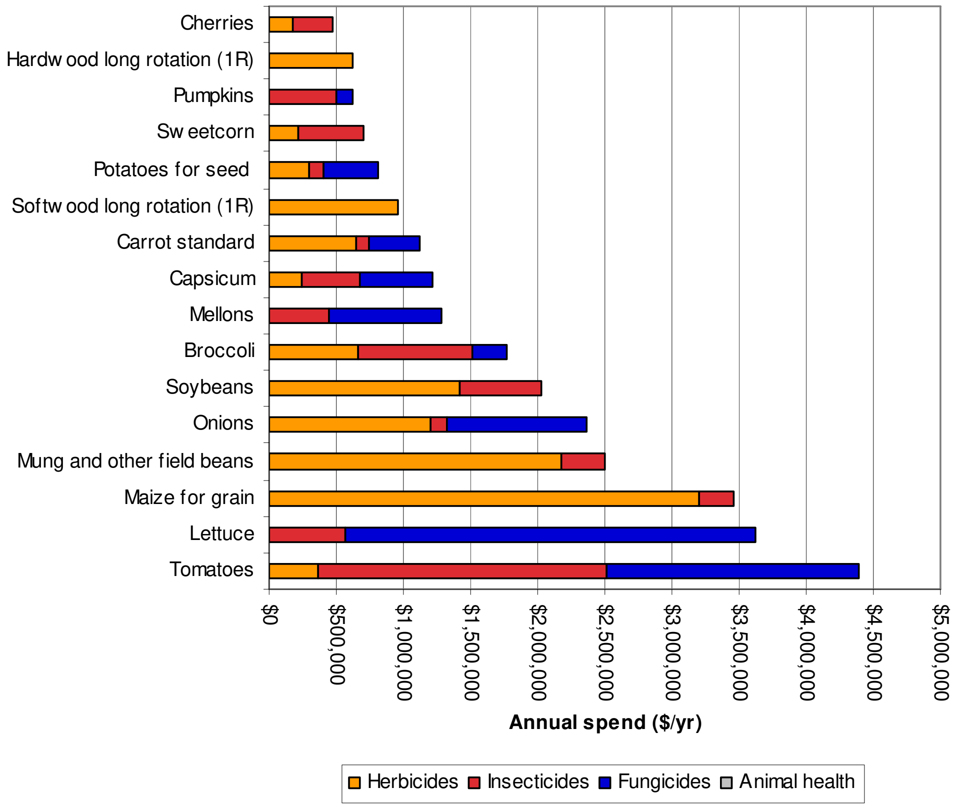


Figure J.3 The estimated spend on chemical pesticides for the six zones modelled.

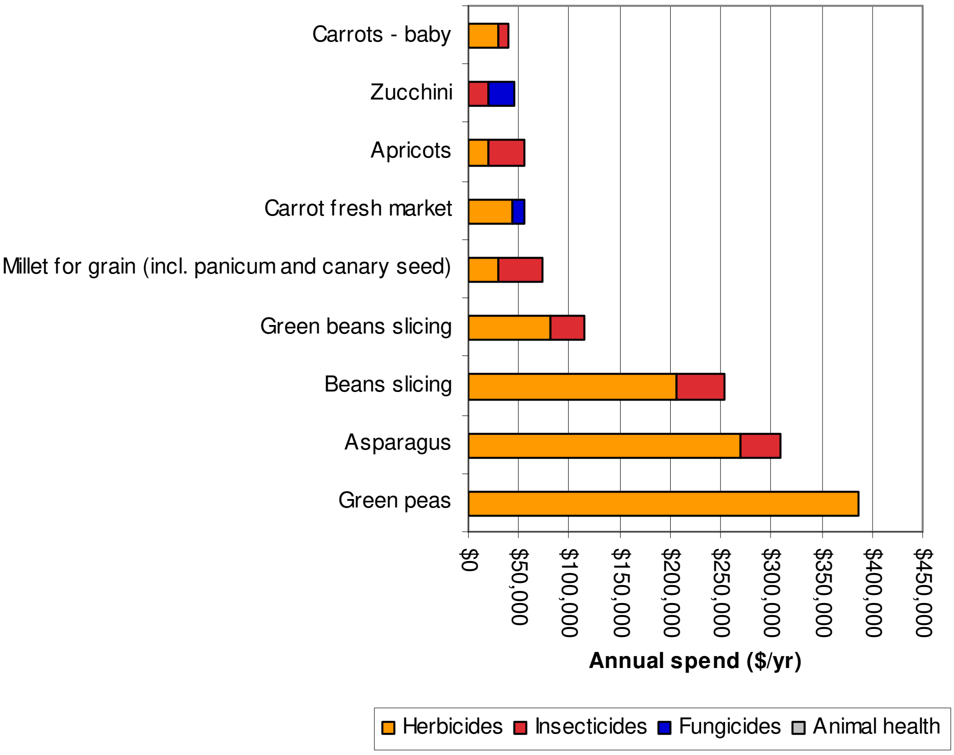


Figure J.4 The estimated spend on chemical pesticides for the six zones modelled.

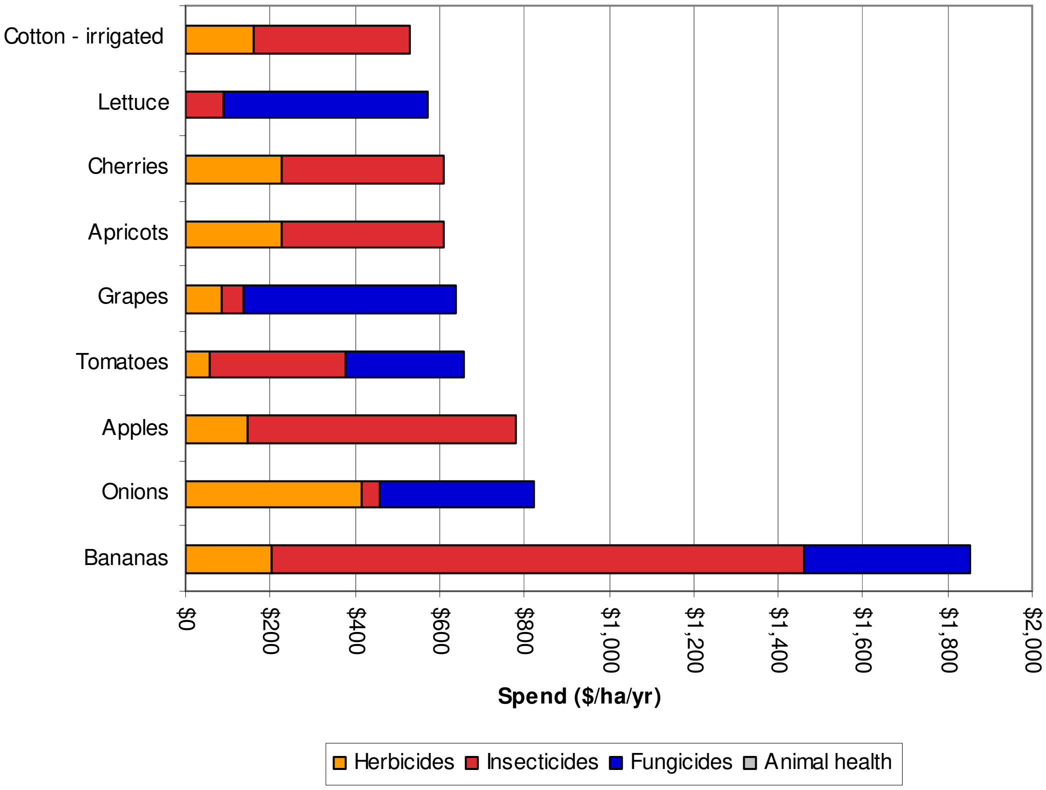


Figure J.5 The estimated spend on chemical pesticides for the six zones modelled.

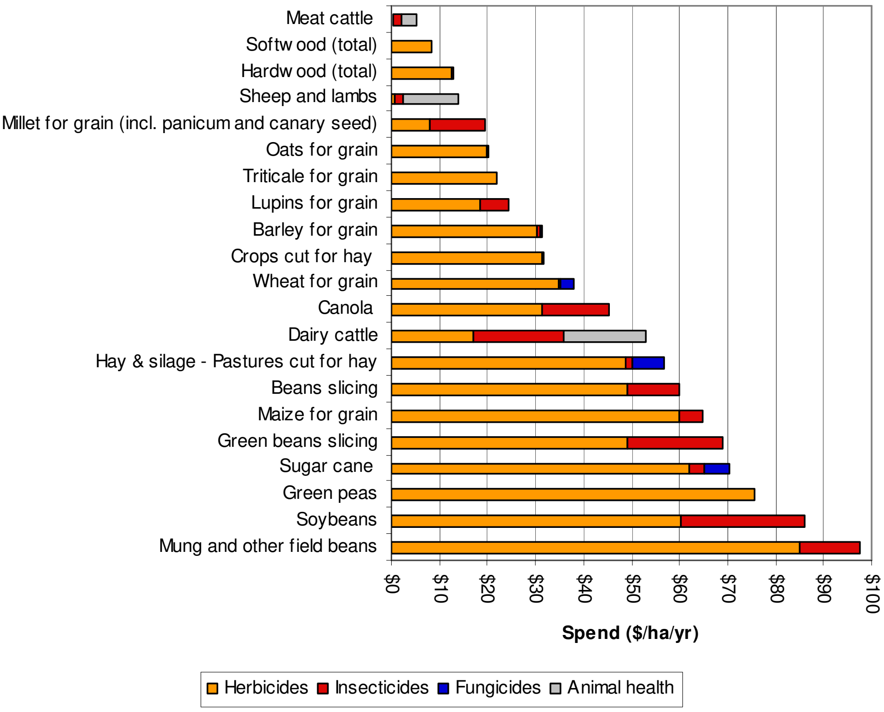


Figure J.6 The estimated spend on chemical pesticides for the six zones modelled.

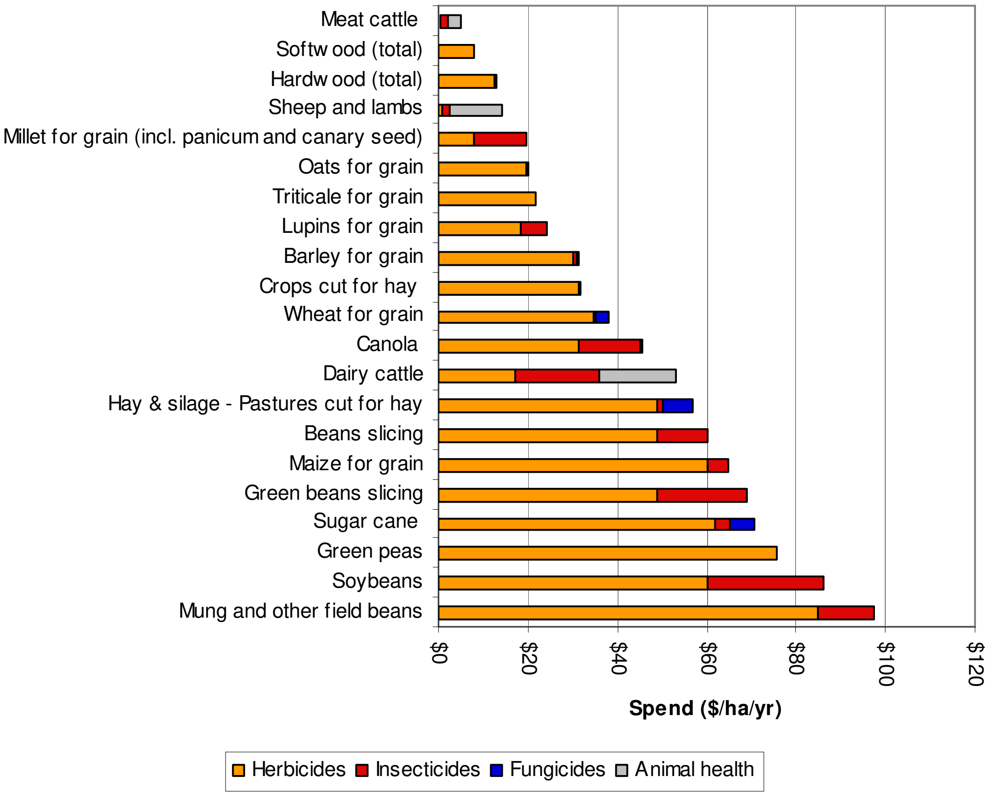
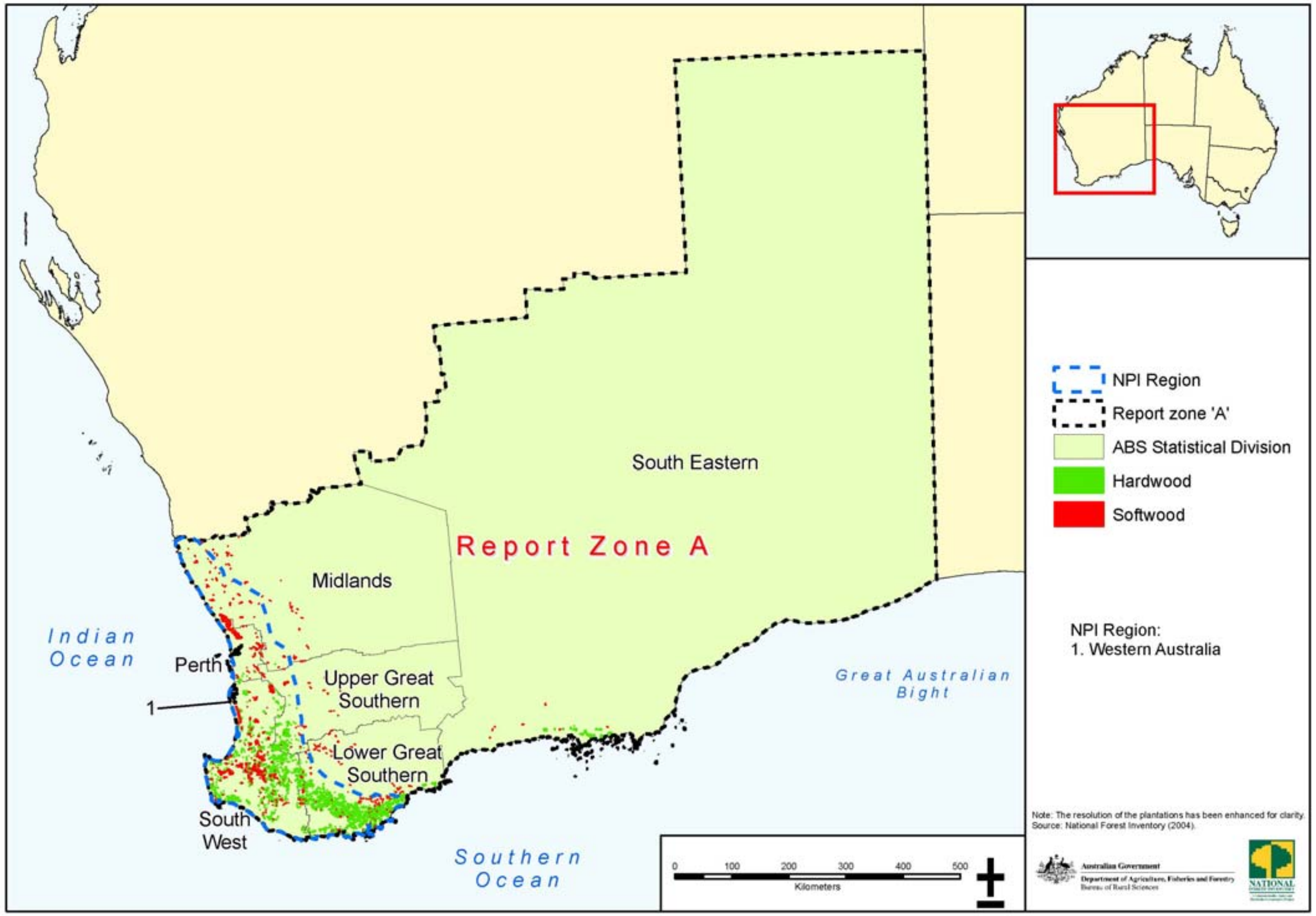


Figure J.7 The estimated spend on chemical pesticides for the six zones modelled.

Zone A details

- Map A shows the areas covered by Zone A and defines the NFI zones and the ABS SD's;
- Figures A.1 to A.3 show the area of each land use in the zones based on the NFI (Parsons *et al.*, 2006) and ABS data (ABS, 2006);
- Figures A.4 to A.6 show the estimated total chemical pesticide use for each of the land uses shown;
- Figures A.7 to A.8 show the per hectare chemical pesticide use for each of the land uses shown.



Map A An outline of the area covered by Zone A. The map shows the NFI zones and the ABS SD's (prepared by NFI, 2006)

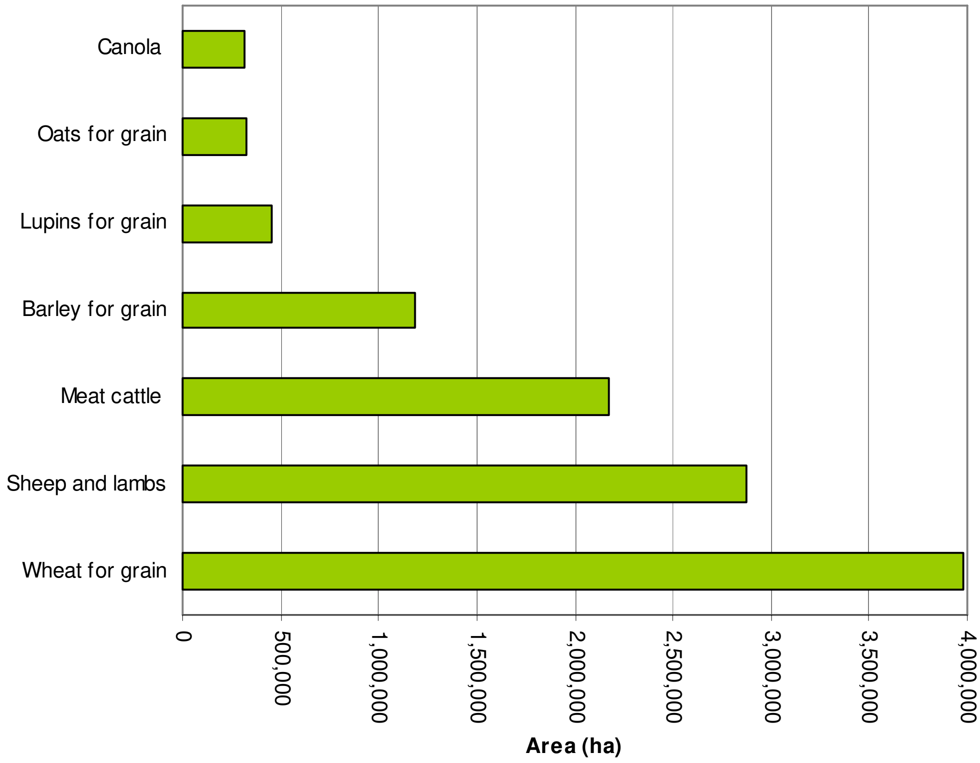


Figure A.1 A breakdown of the zone land use based on ABS (2006a) and Parsons *et al.* (2006).

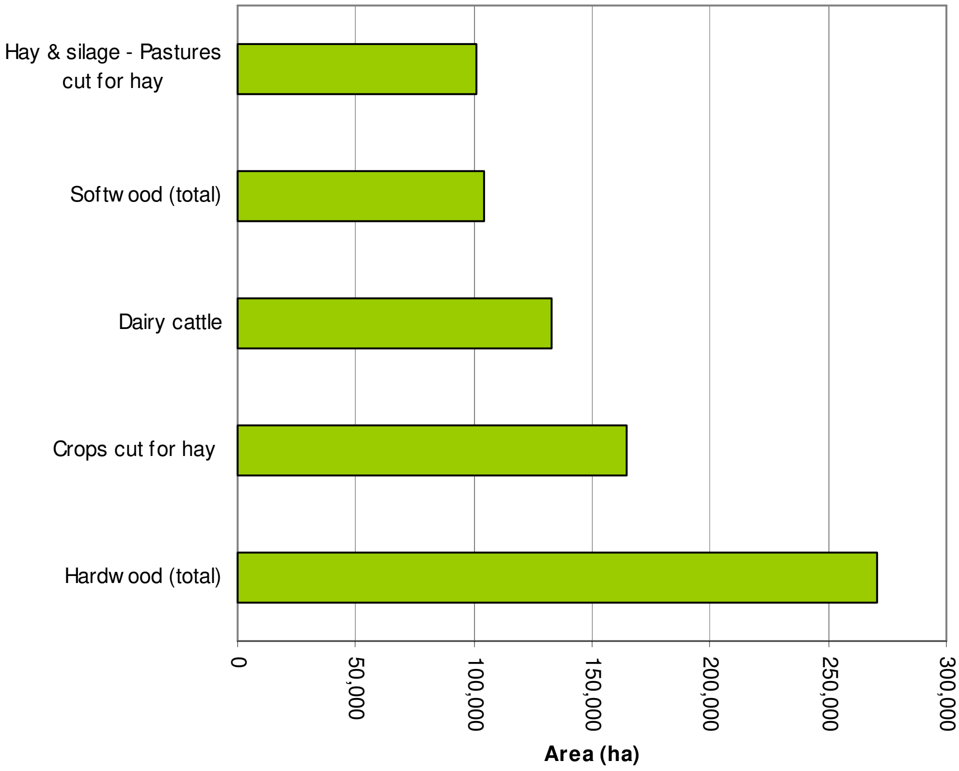


Figure A.2 A breakdown of the zone land use based on ABS (2006a) and Parsons *et al.* (2006).

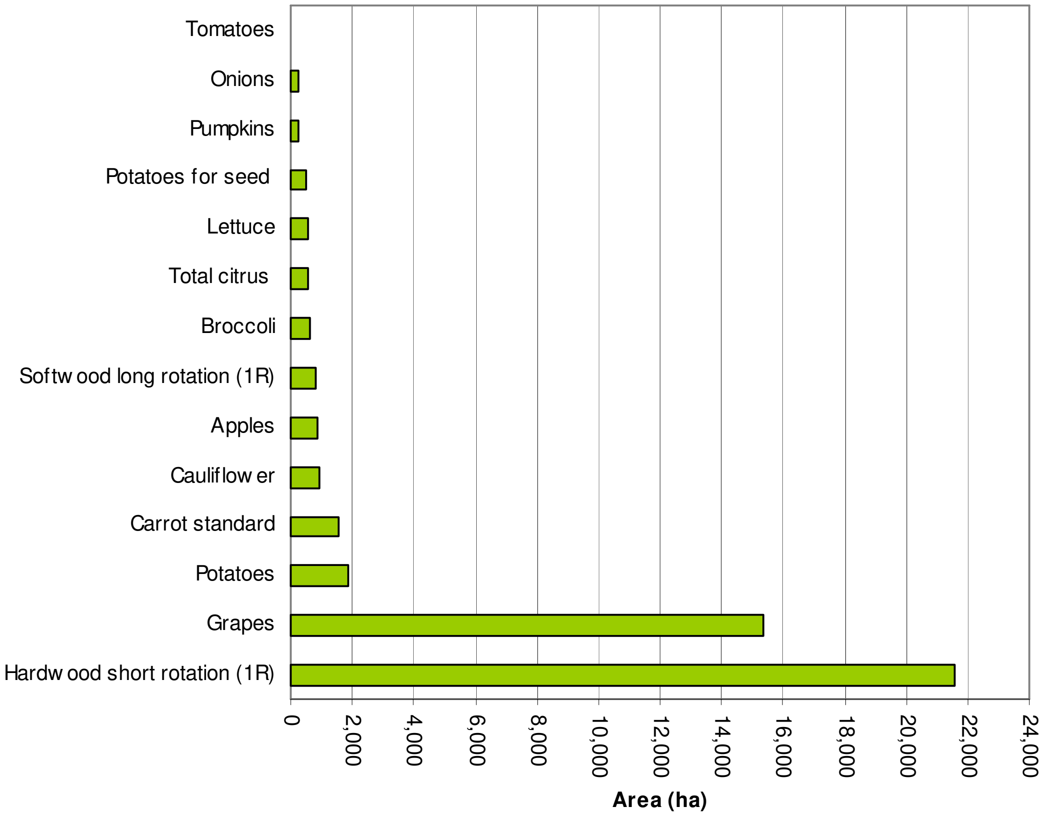


Figure A.3 A breakdown of the zone land use based on ABS (2006a) and Parsons *et al.* (2006).

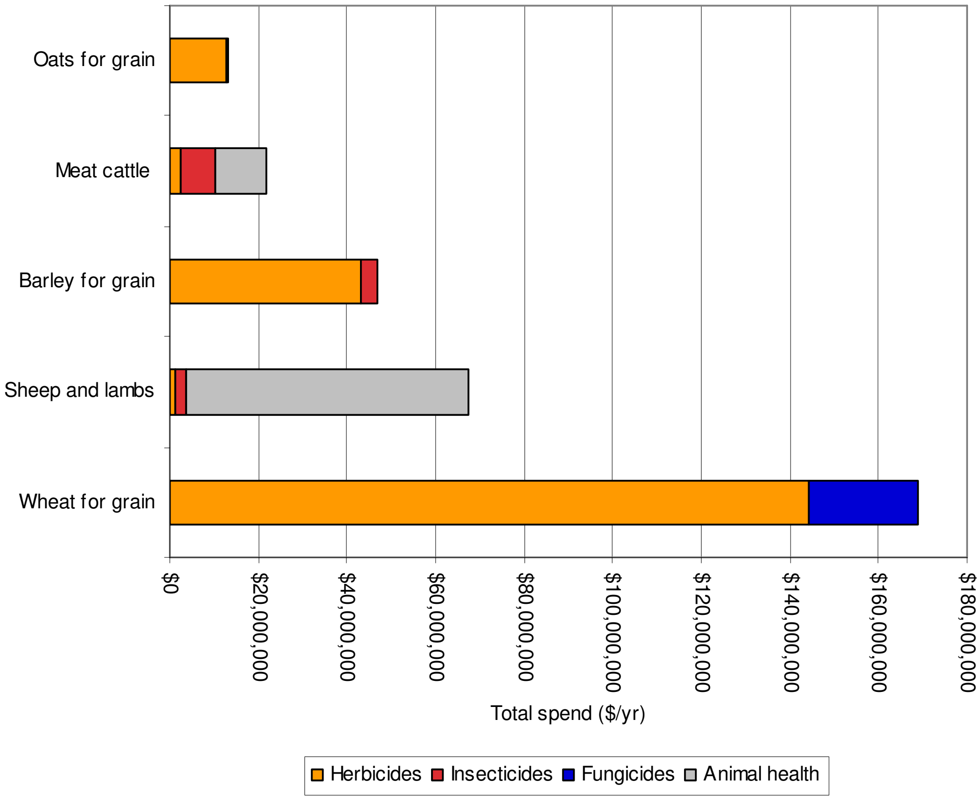


Figure A.4 The modelled results of the total chemical pesticide inputs to grow the crops shown in the zone.

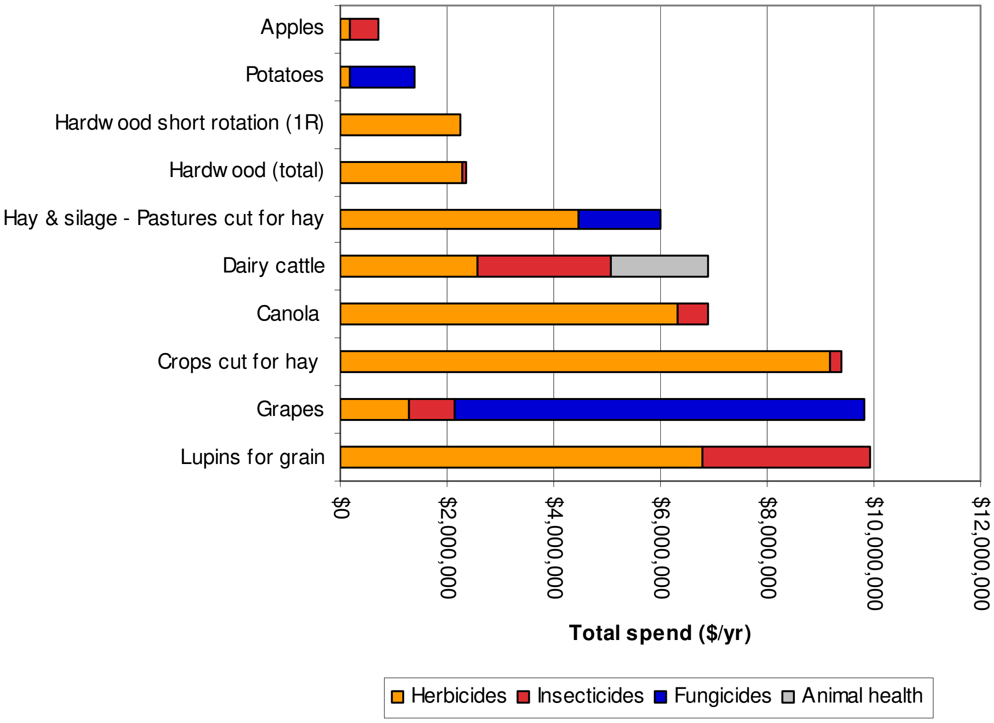


Figure A.5 The modelled results of the total chemical pesticide inputs to grow the crops shown in the zone.

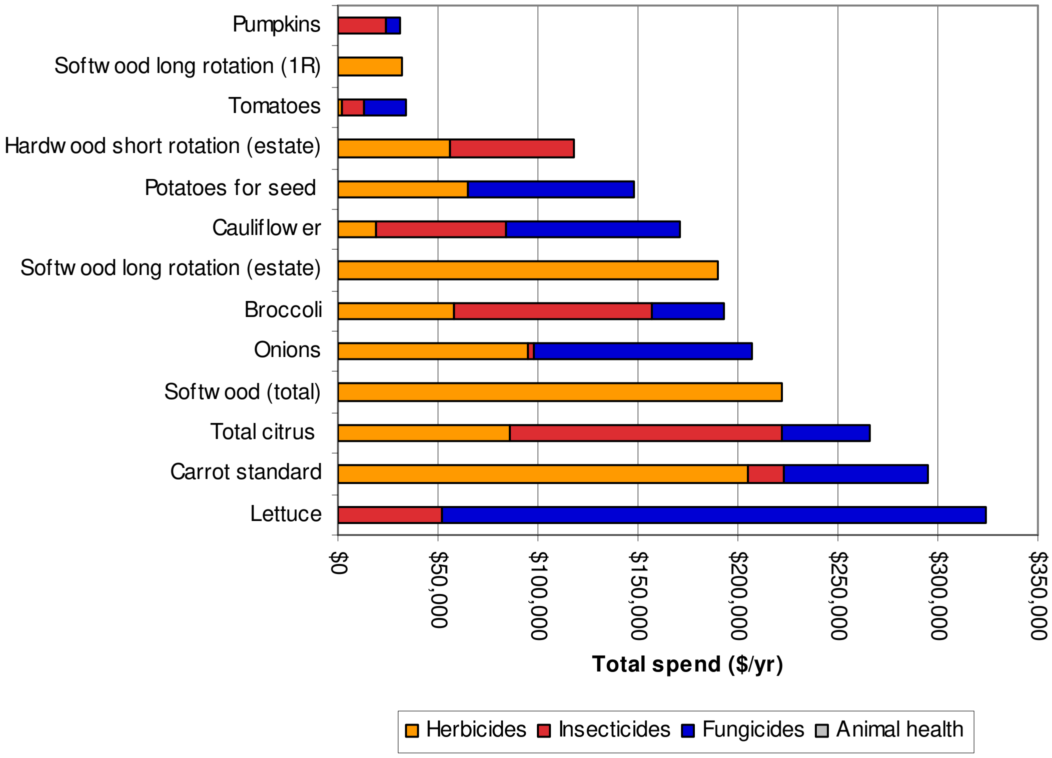


Figure A.6 The modelled results of the total chemical pesticide inputs to grow the crops shown in the zone.

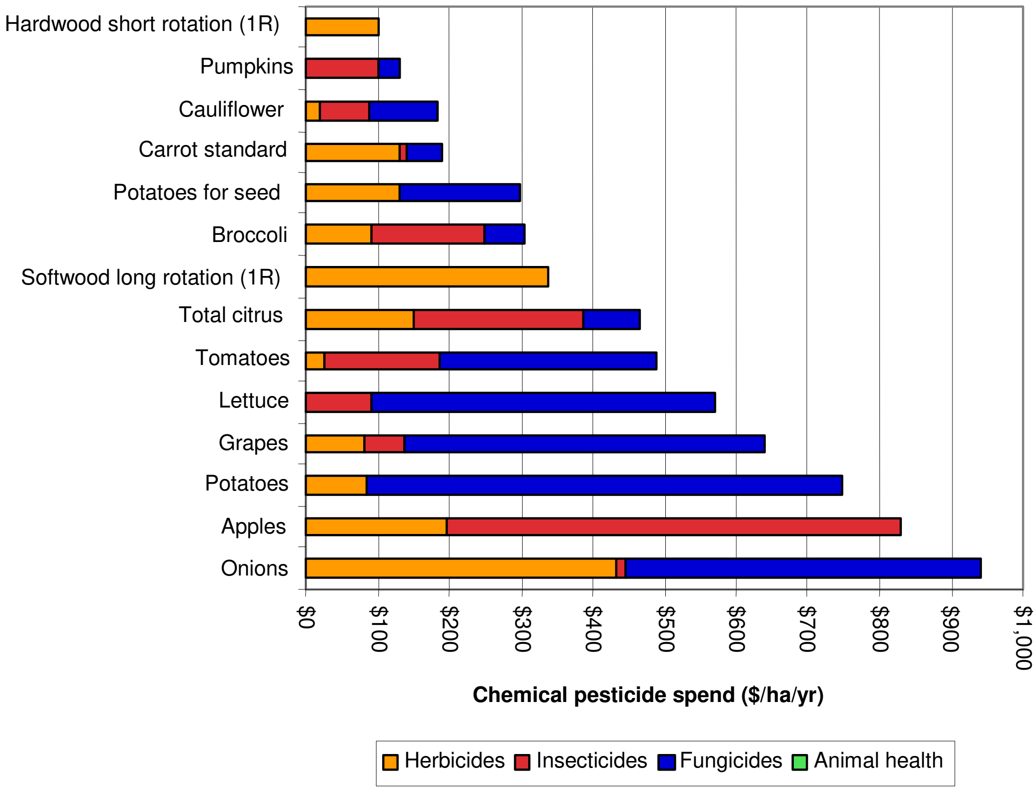


Figure A.7 The modelled results of the per hectare chemical pesticide inputs to grow the crops shown in the zone.

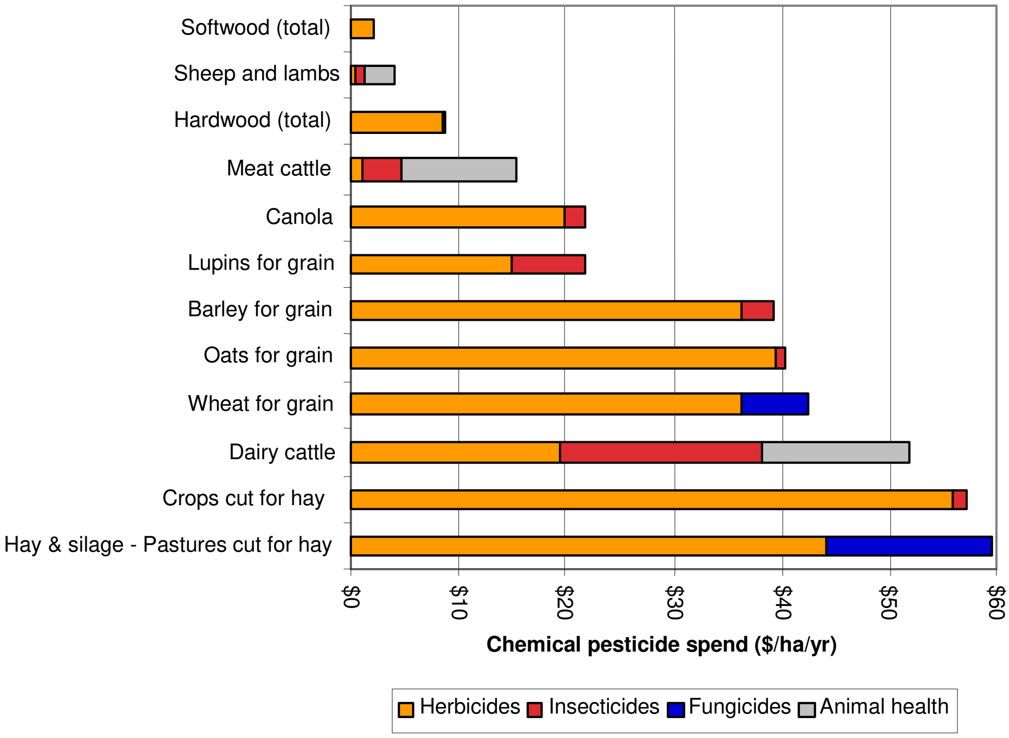
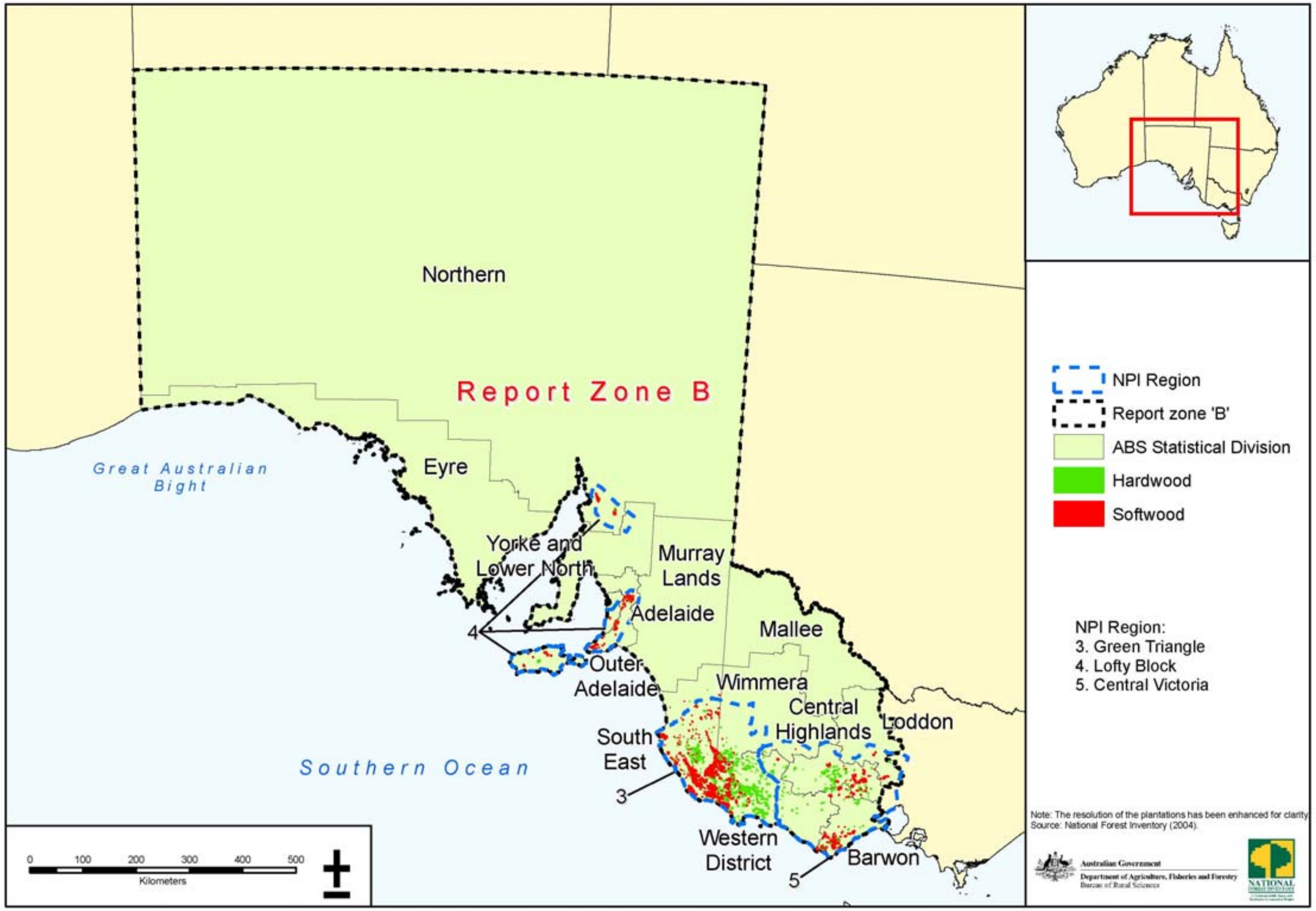


Figure A.8 The modelled results of the per hectare chemical pesticide inputs to grow the crops shown in the zone.

Zone B details

- Map B shows the areas covered by Zone B and defines the NFI zones and the ABS SD's;
- Figures B.1 to BA.3 show the area of each land use in the zones based on the NFI (Parsons *et al.*, 2006) and ABS data (ABS, 2006);
- Figures B.4 to B.6 show the estimated total chemical pesticide use for each of the land uses shown;
- Figures B.7 to B.8 show the per hectare chemical pesticide use for each of the land uses shown.



Note: The resolution of the plantations has been enhanced for clarity
Source: National Forest Inventory (2004).

Map B An outline of the area covered by Zone B. The map shows the NFI zones and the ABS SD’s (prepared by NFI, 2006)

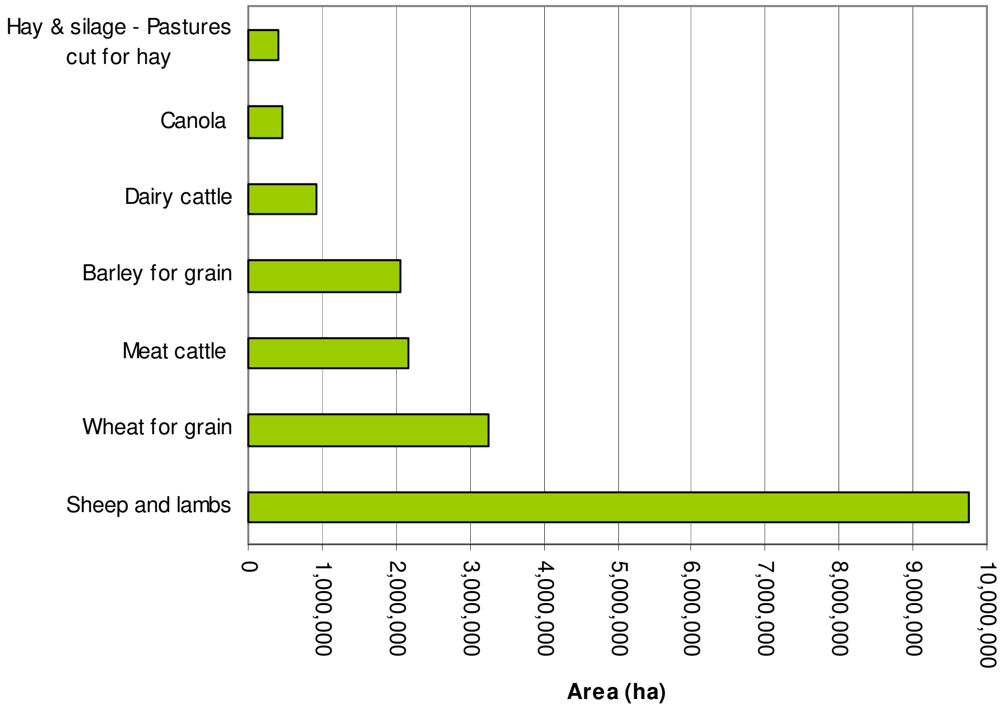


Figure B.1 A breakdown of the zone land use based on ABS (2006a) and Parsons *et al.* (2006).

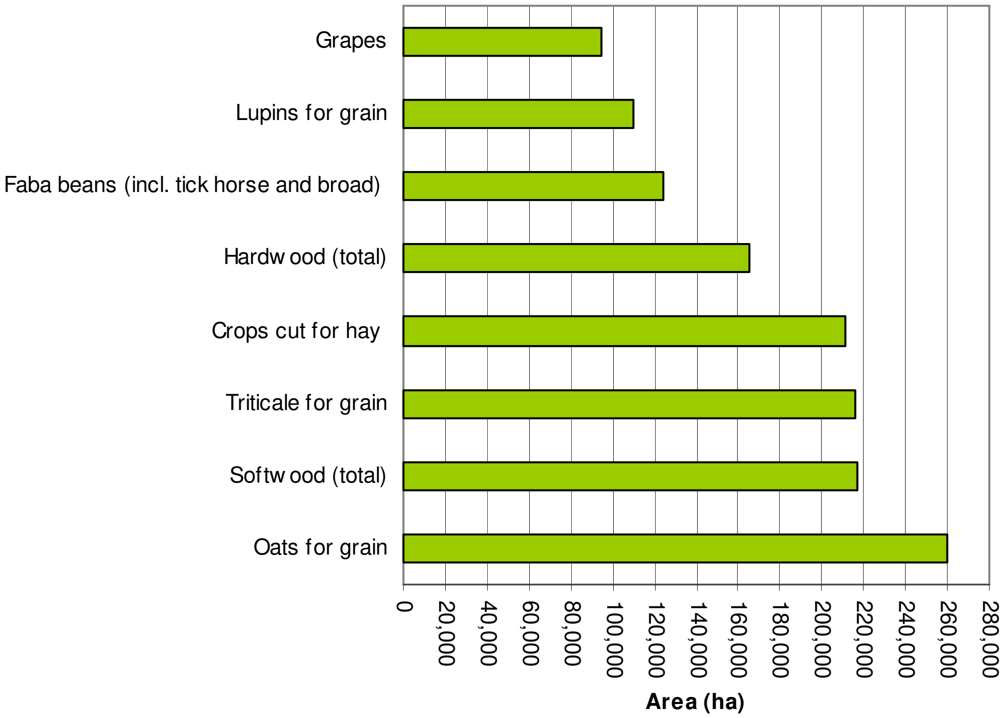


Figure B.2 A breakdown of the zone land use based on ABS (2006a) and Parsons *et al.* (2006).

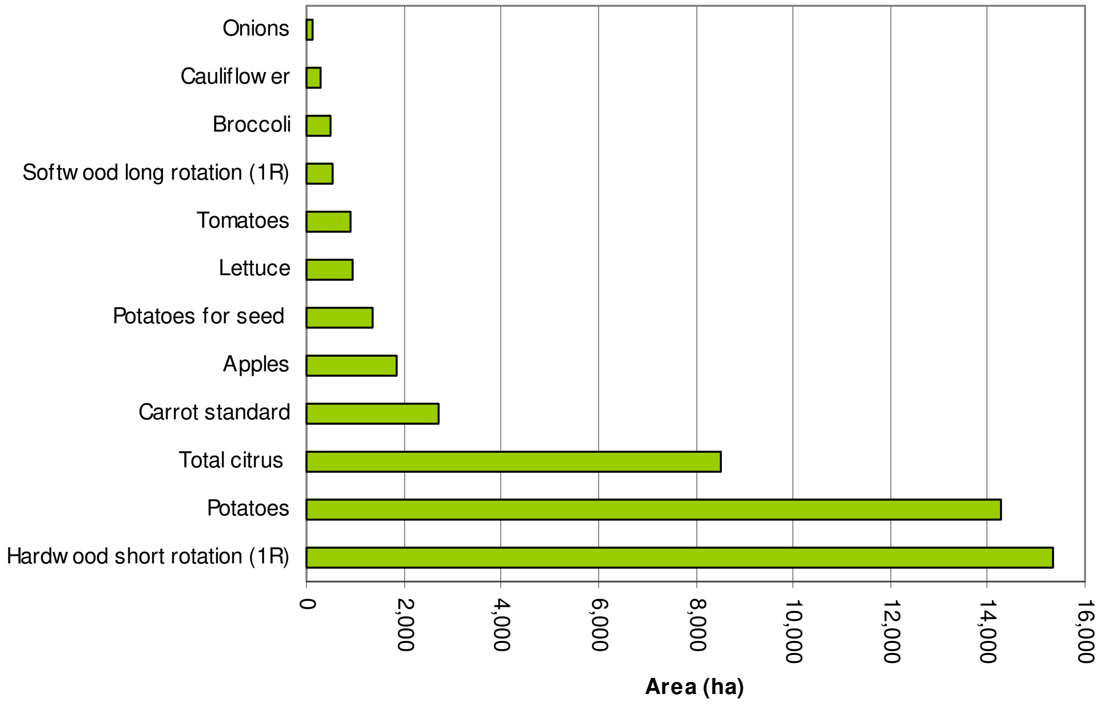


Figure B.3 A breakdown of the zone land use based on ABS (2006a) and Parsons *et al.* (2006).

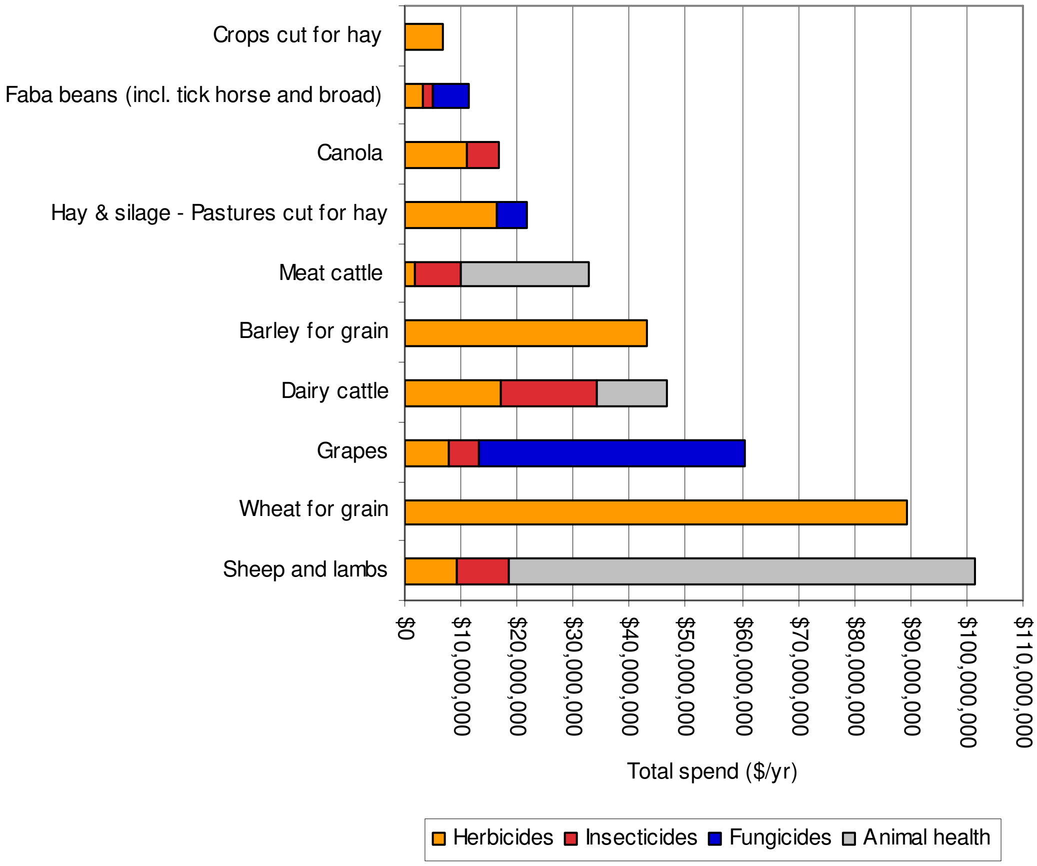


Figure B.4 The modelled results of the total chemical pesticide inputs to grow the crops shown in the zone.

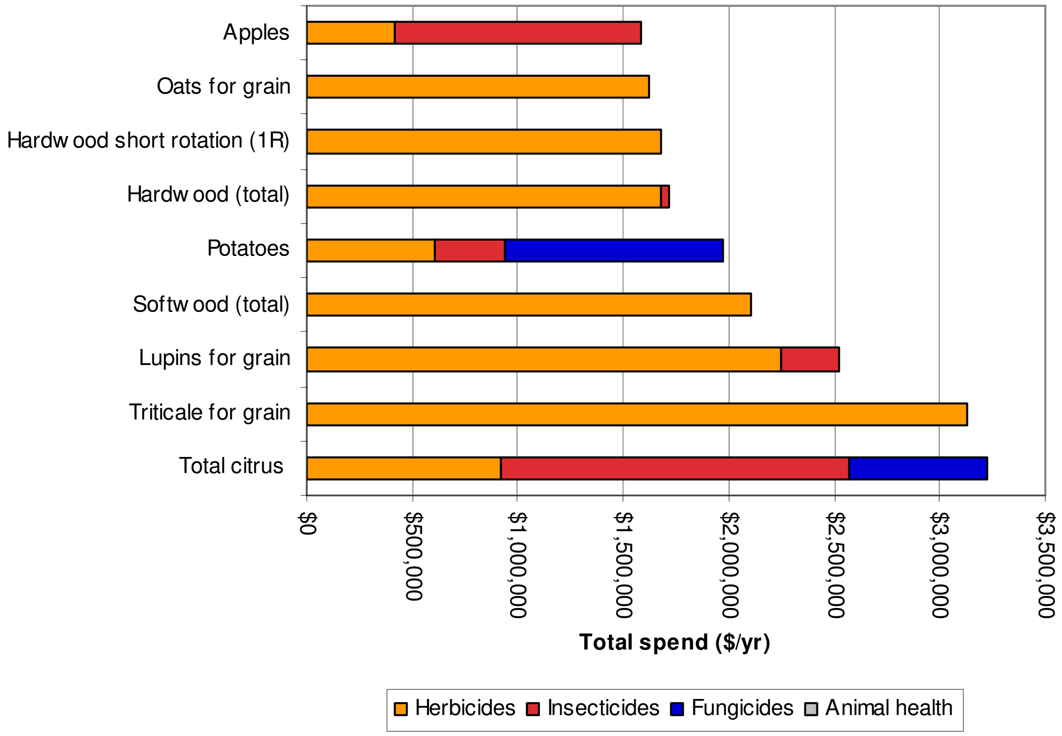


Figure B.5 The modelled results of the total chemical pesticide inputs to grow the crops shown in the zone.

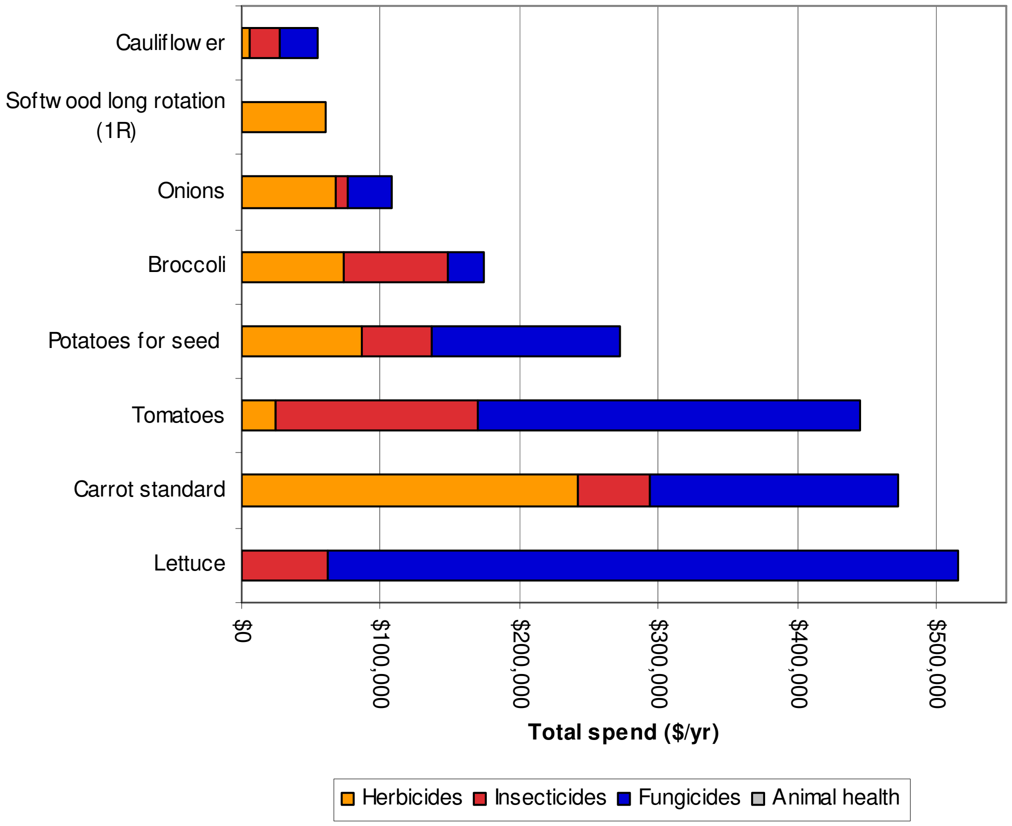


Figure B.6 The modelled results of the total chemical pesticide inputs to grow the crops shown in the zone.

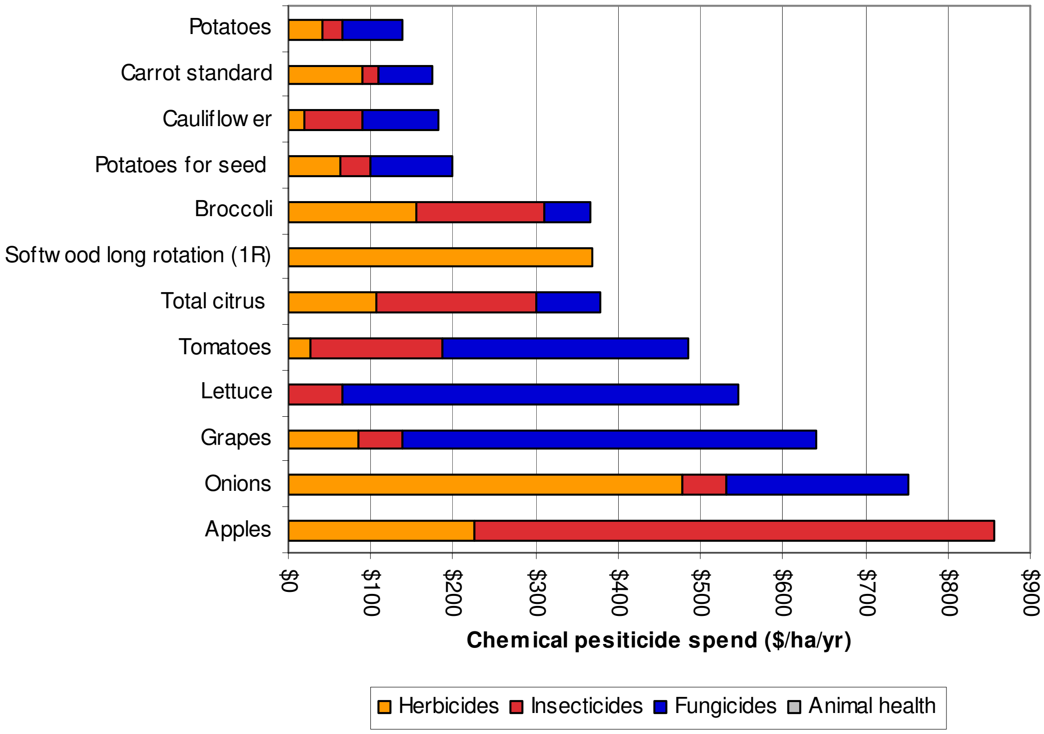


Figure B.7 The modelled results of the per hectare chemical pesticide inputs to grow the crops shown in the zone.

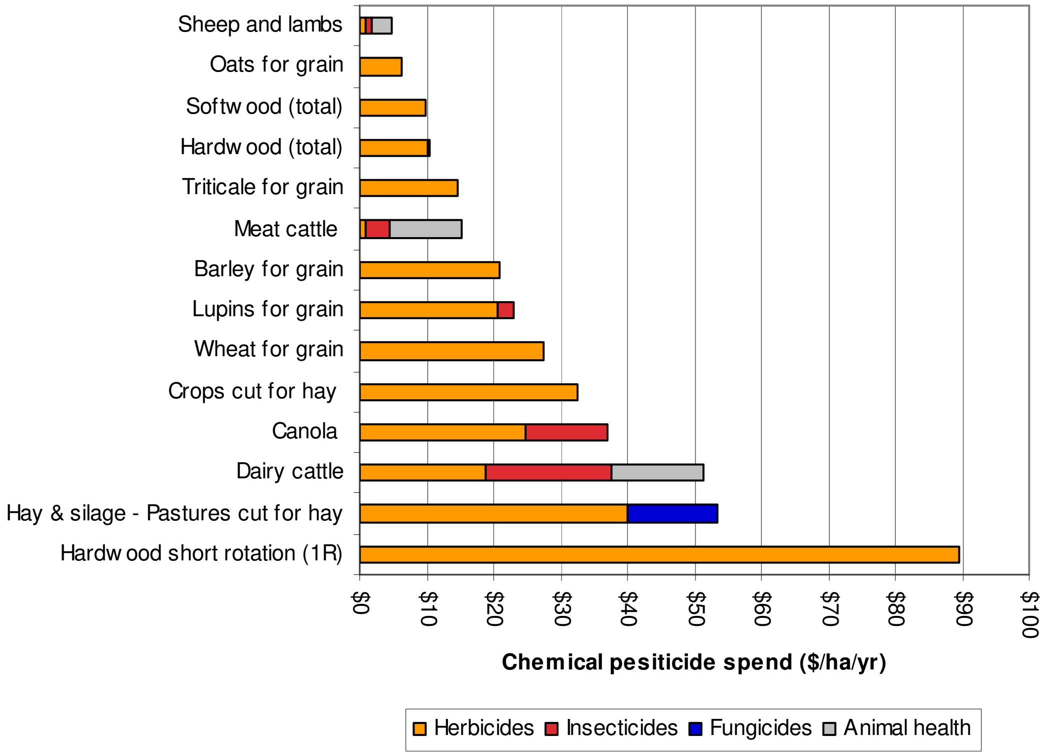
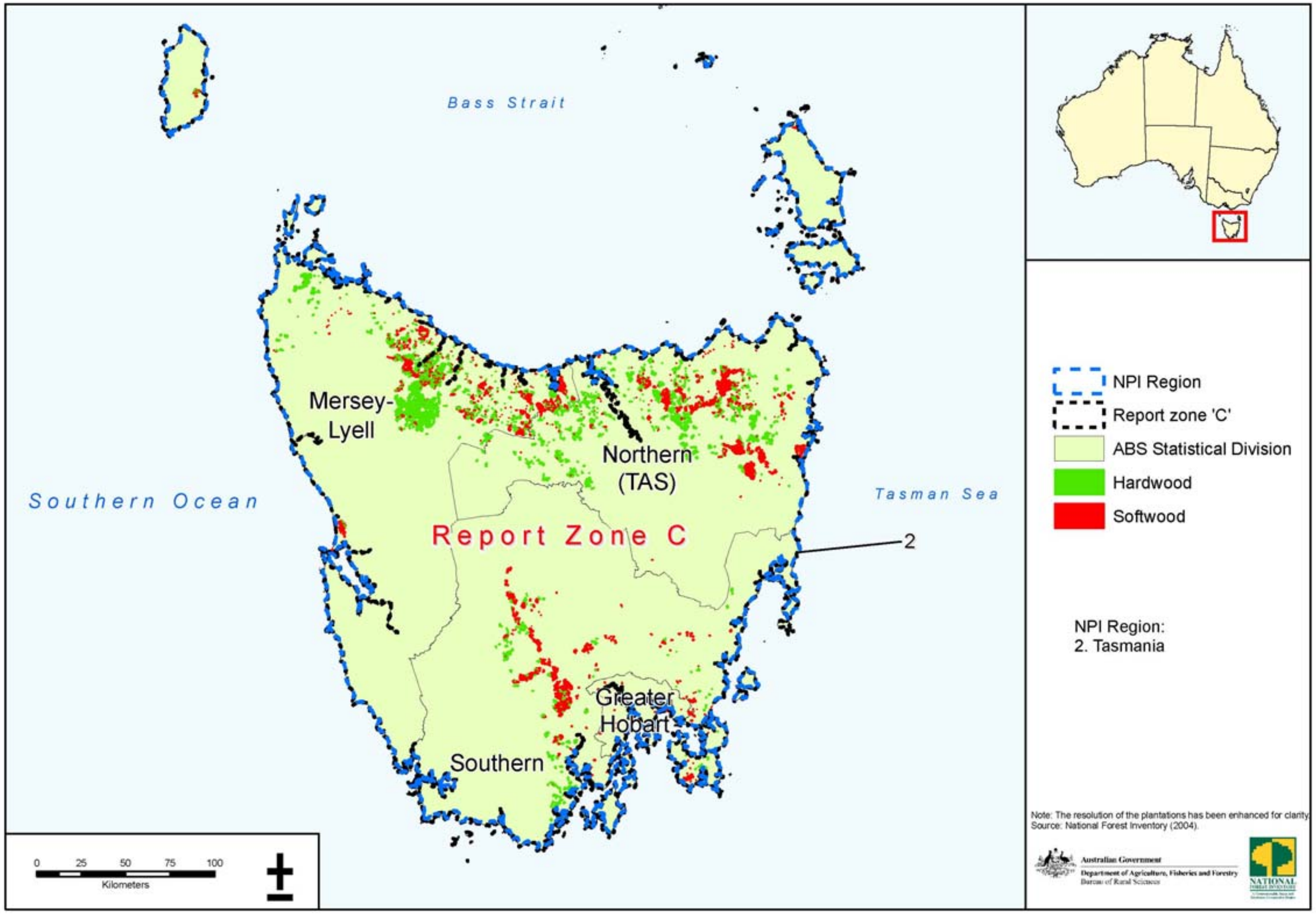


Figure B.8 The modelled results of the per hectare chemical pesticide inputs to grow the crops shown in the zone.

Zone C details

- Map C shows the areas covered by Zone C and defines the NFI zones and the ABS SD's;
- Figures C.1 to C.2 show the area of each land use in the zones based on the NFI (Parsons *et al.*, 2006) and ABS data (ABS, 2006);
- Figures C.3 to C.5 show the estimated total chemical pesticide use for each of the land uses shown;
- Figures C.6 to C.7 show the per hectare chemical pesticide use for each of the land uses shown.



Note: The resolution of the plantations has been enhanced for clarity.
Source: National Forest Inventory (2004).

Map C An outline of the area covered by Zone C. The map shows the NFI zones and the ABS SD's (prepared by NFI, 2006)

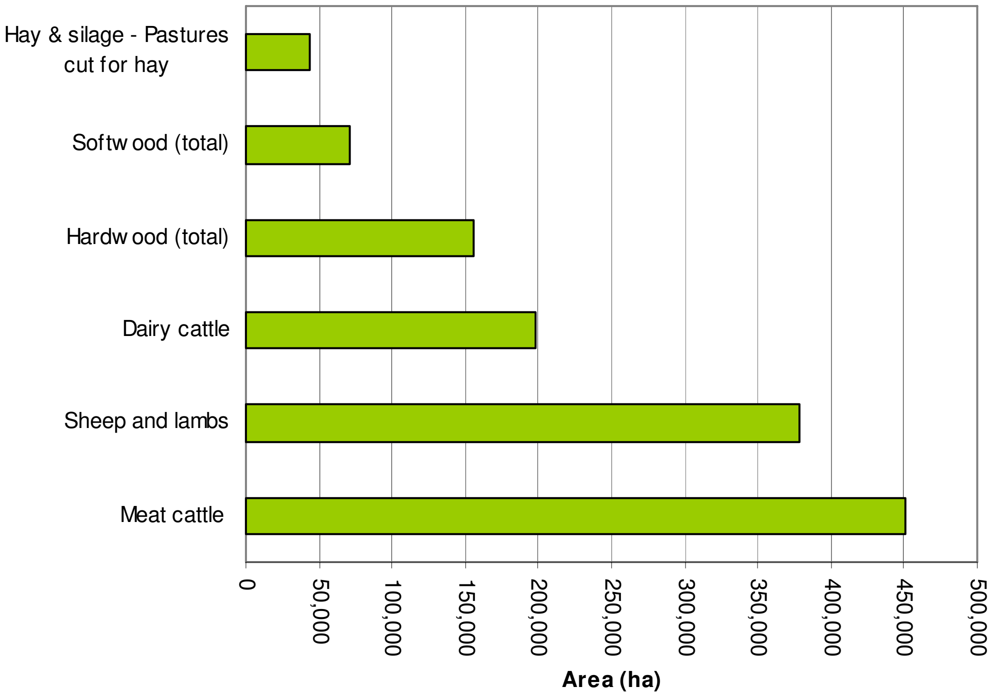


Figure C.1 A breakdown of the zone land use based on ABS (2006a) and Parsons *et al.* (2006).

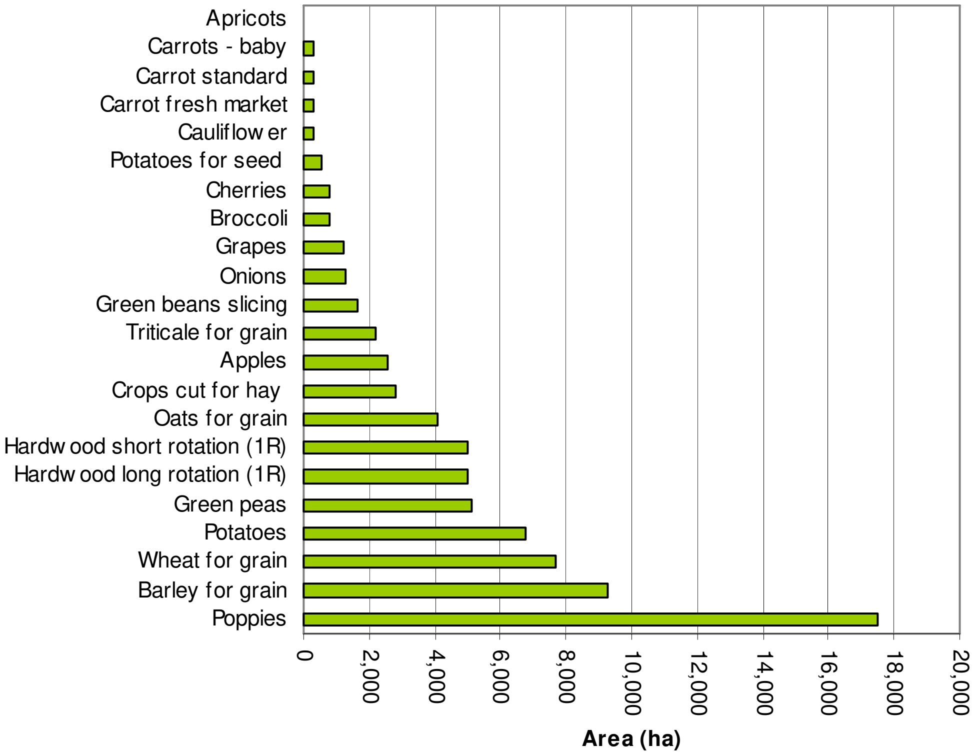


Figure C.2 A breakdown of the zone land use based on ABS (2006a) and Parsons *et al.* (2006).

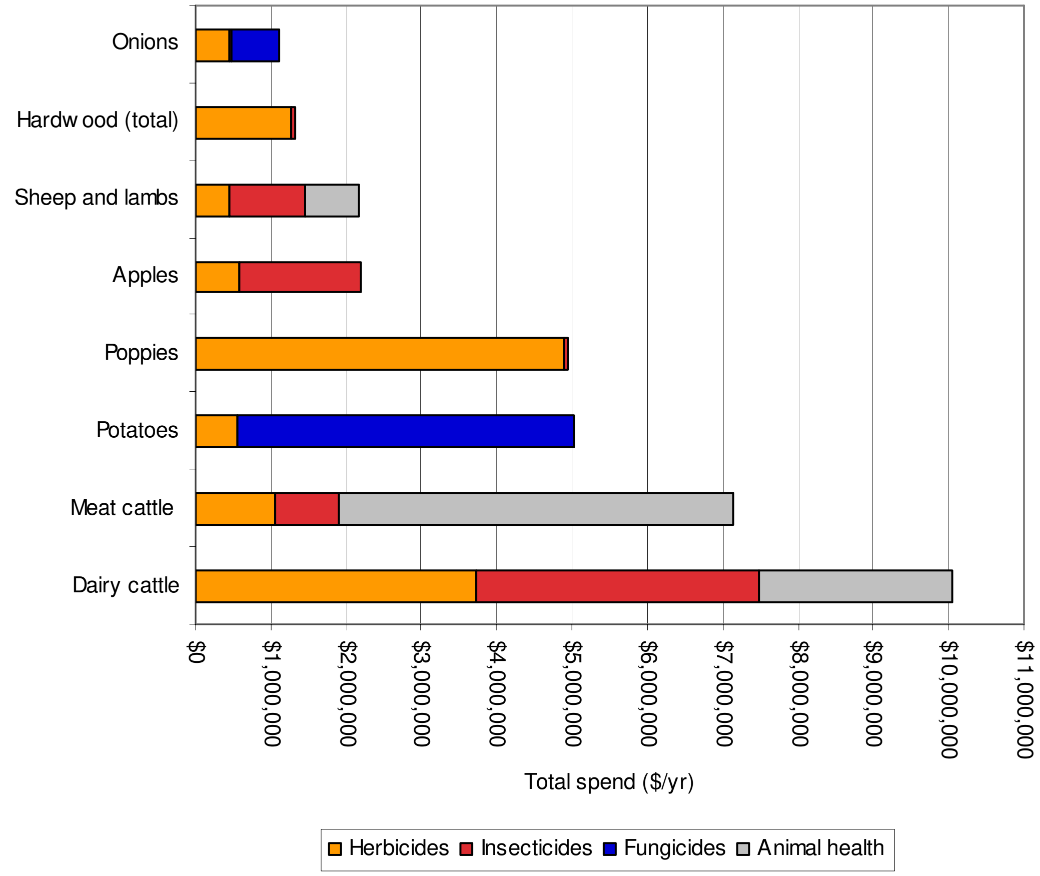


Figure C.3 The modelled results of the total chemical pesticide inputs to grow the crops shown in the zone.

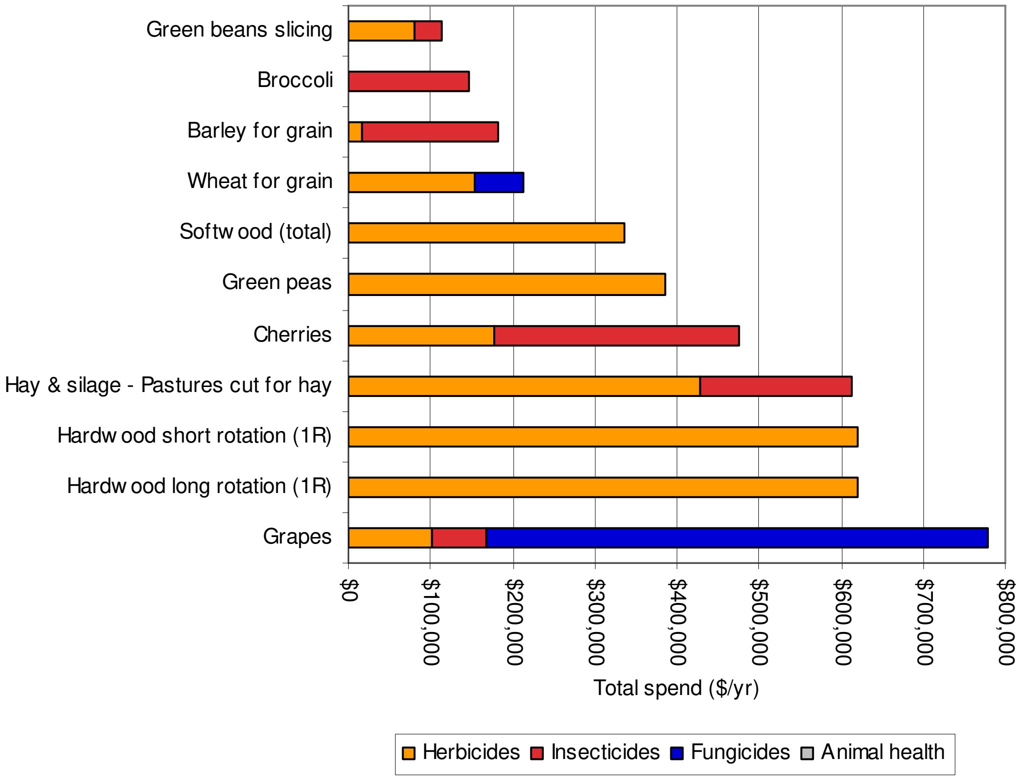


Figure C.4 The modelled results of the total chemical pesticide inputs to grow the crops shown in the zone.

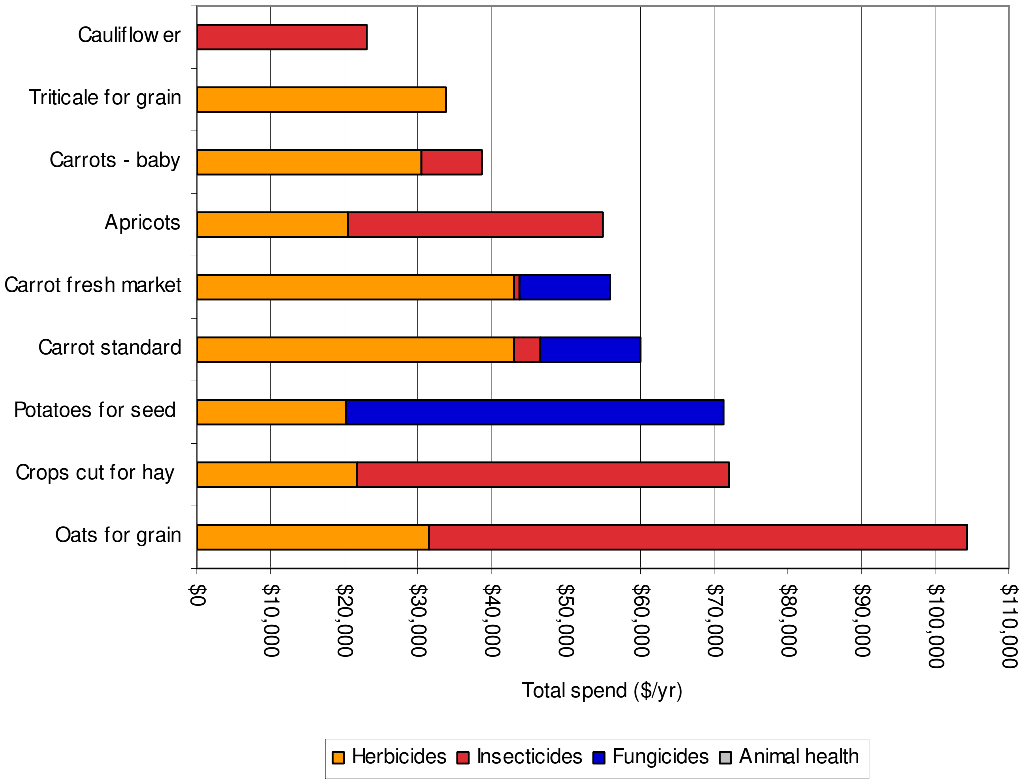


Figure C.5 The modelled results of the total chemical pesticide inputs to grow the crops shown in the zone.

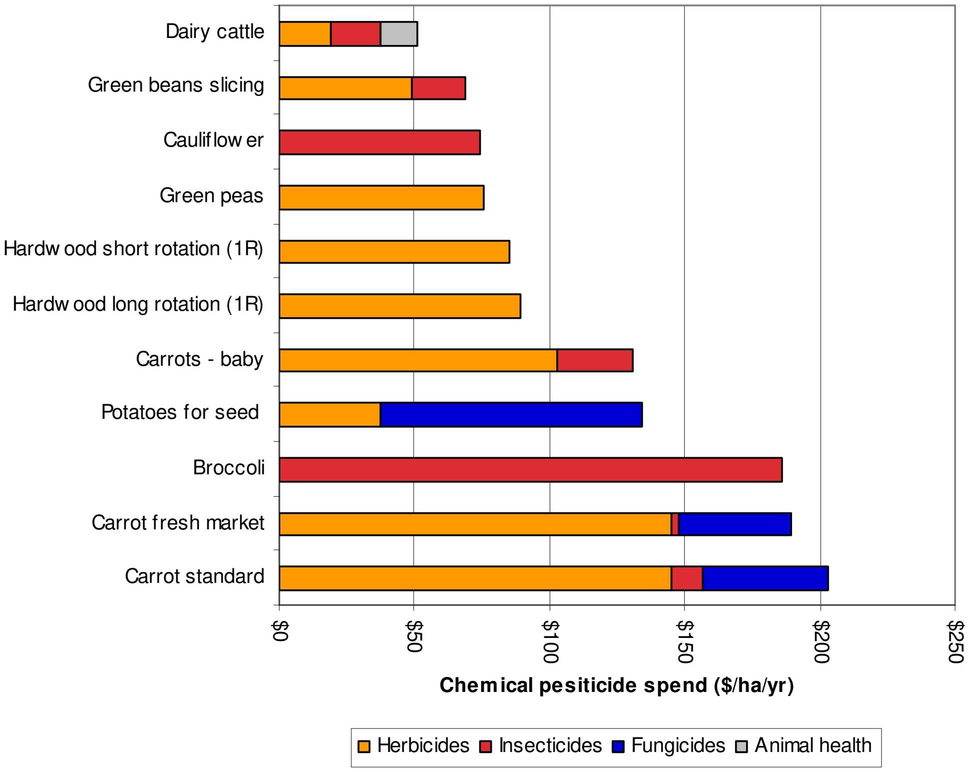


Figure C.6 The modelled results of the per hectare chemical pesticide inputs to grow the crops shown in the zone.

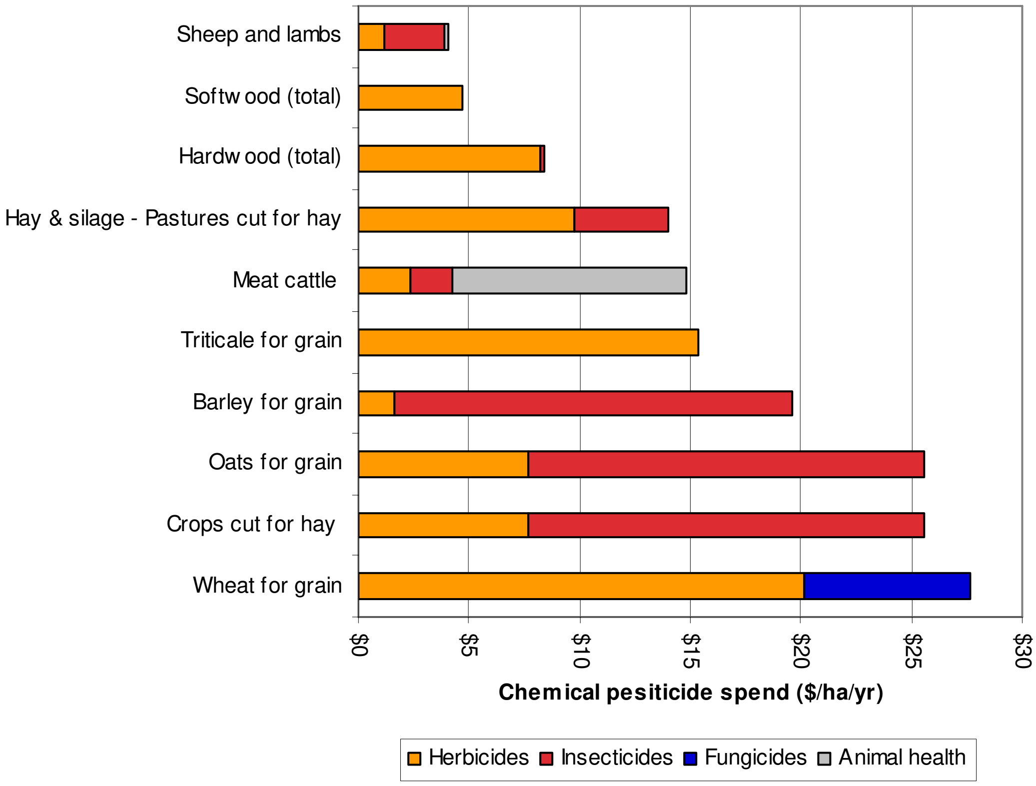
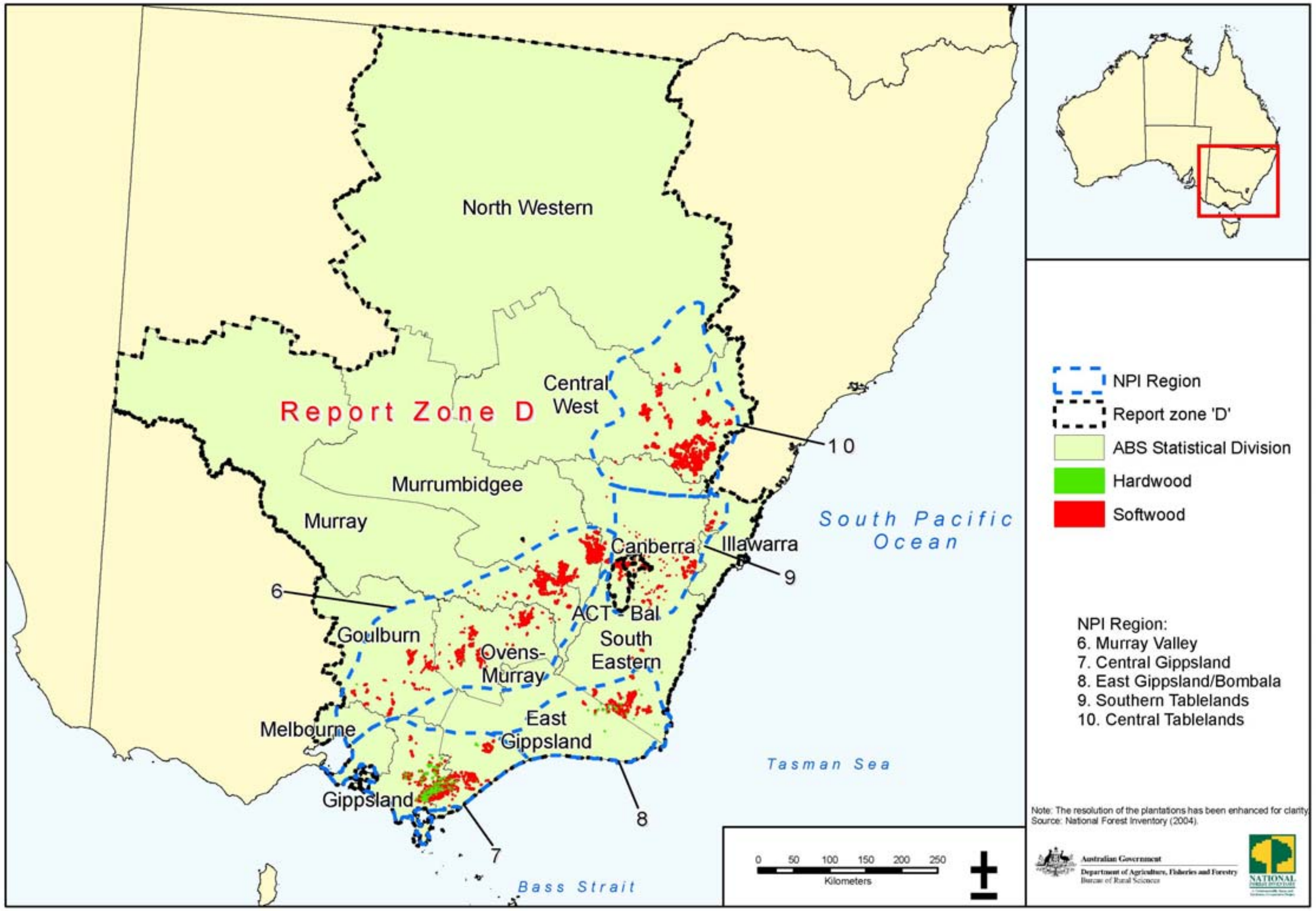


Figure C.7 The modelled results of the per hectare chemical pesticide inputs to grow the crops shown in the zone.

Zone D details

- Map D shows the areas covered by Zone D and defines the NFI zones and the ABS SD's;
- Figures D.1 to D.3 show the area of each land use in the zones based on the NFI (Parsons *et al.*, 2006) and ABS data (ABS, 2006);
- Figures D.4 to D.6 show the estimated total chemical pesticide use for each of the land uses shown;
- Figures D.7 to D.8 show the per hectare chemical pesticide use for each of the land uses shown.



Note: The resolution of the plantations has been enhanced for clarity.
Source: National Forest Inventory (2004).

Map D An outline of the area covered by Zone D. The map shows the NFI zones and the ABS SD's (prepared by NFI, 2006)

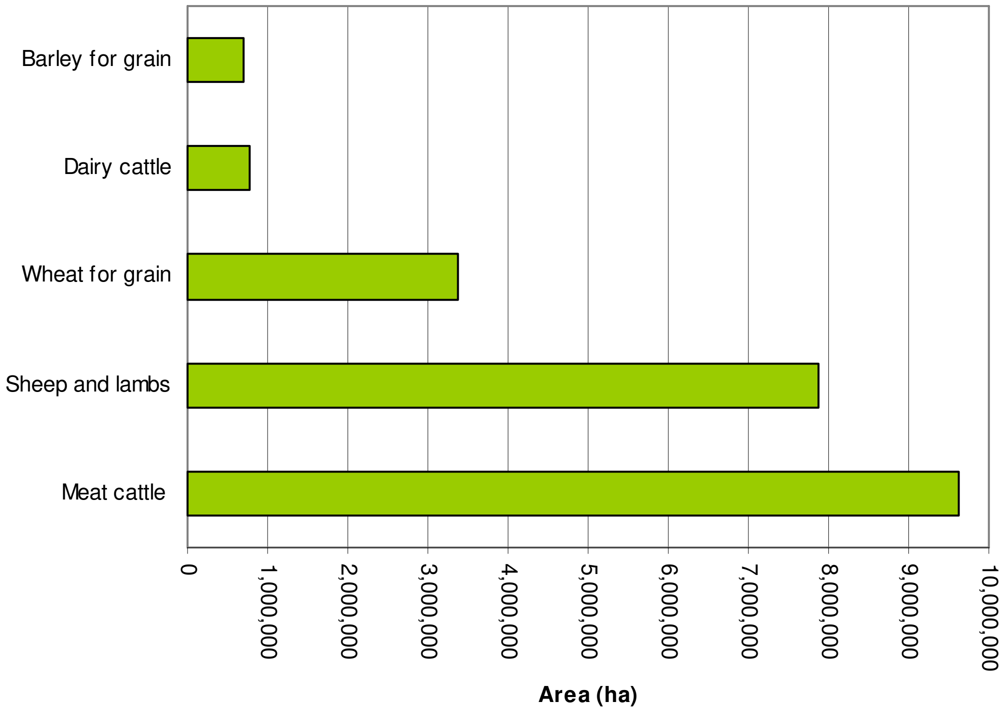


Figure D.1 A breakdown of the zone land use based on ABS (2006a) and Parsons *et al.* (2006).

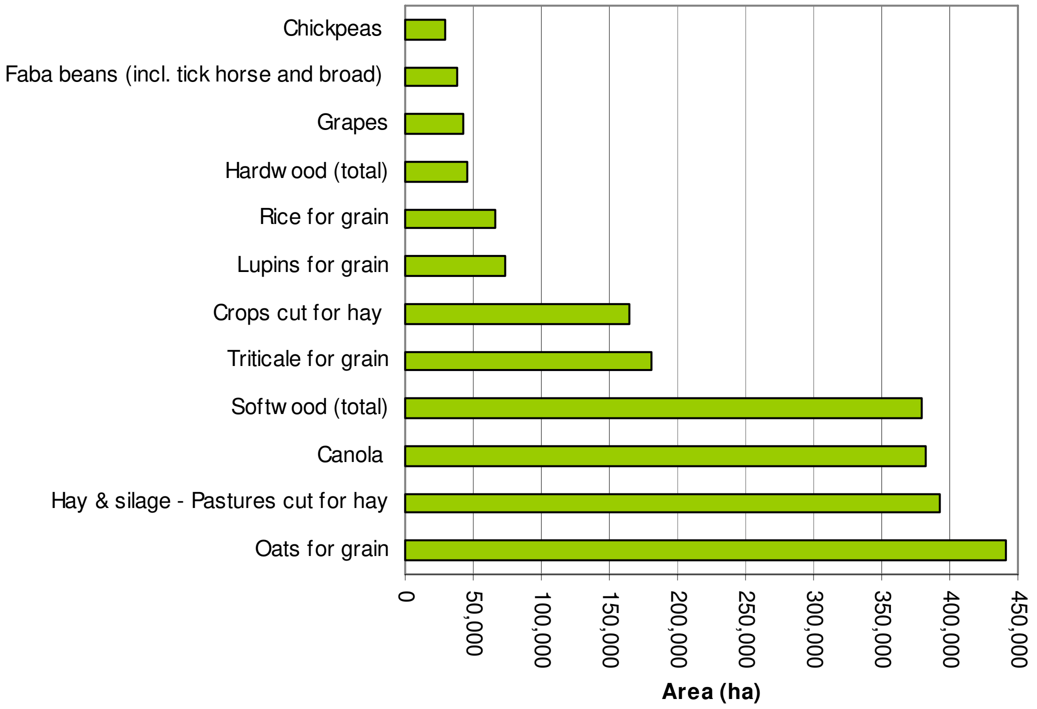


Figure D.2 A breakdown of the zone land use based on ABS (2006a) and Parsons *et al.* (2006).

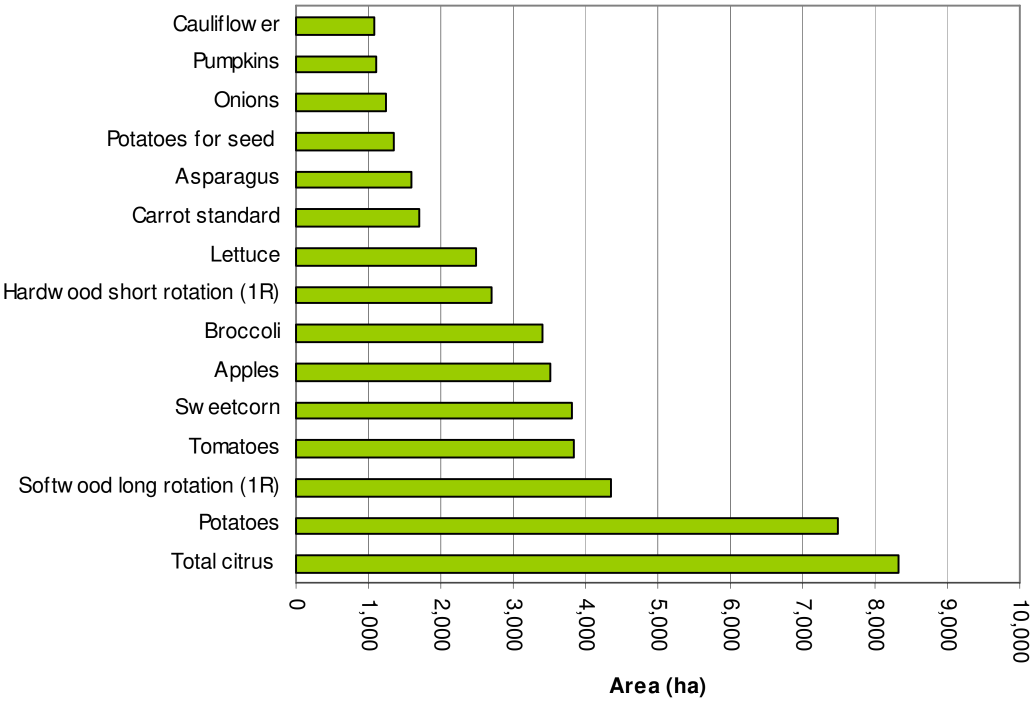


Figure D.3 A breakdown of the zone land use based on ABS (2006a) and Parsons *et al.* (2006).

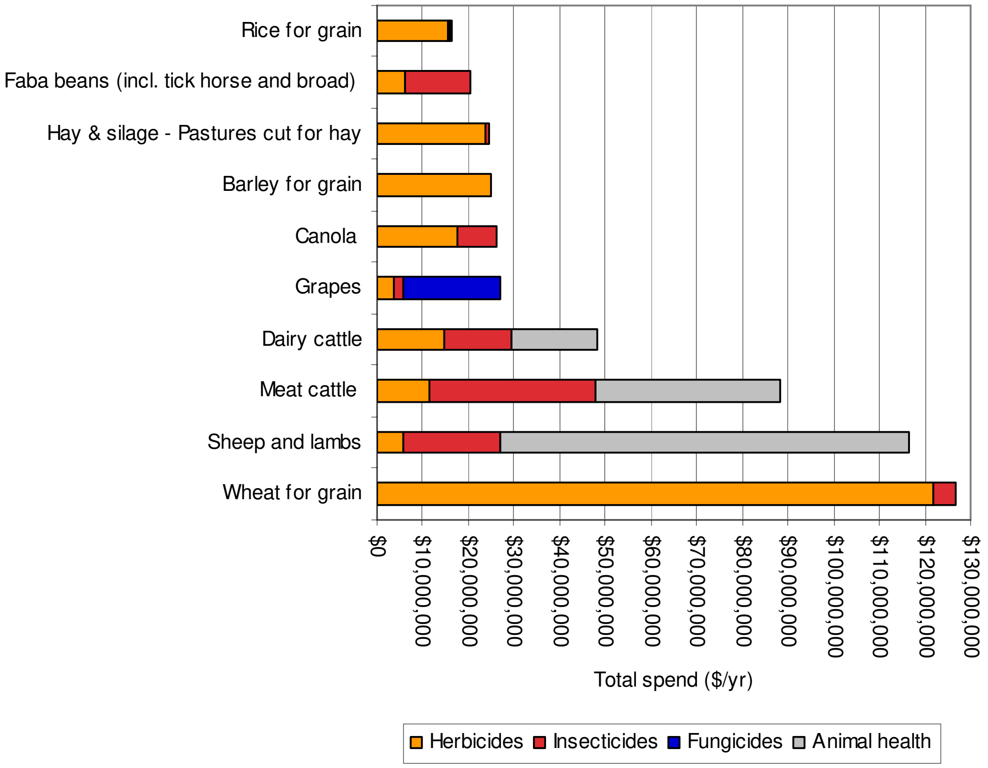


Figure D.4 The modelled results of the total chemical pesticide inputs to grow the crops shown in the zone.

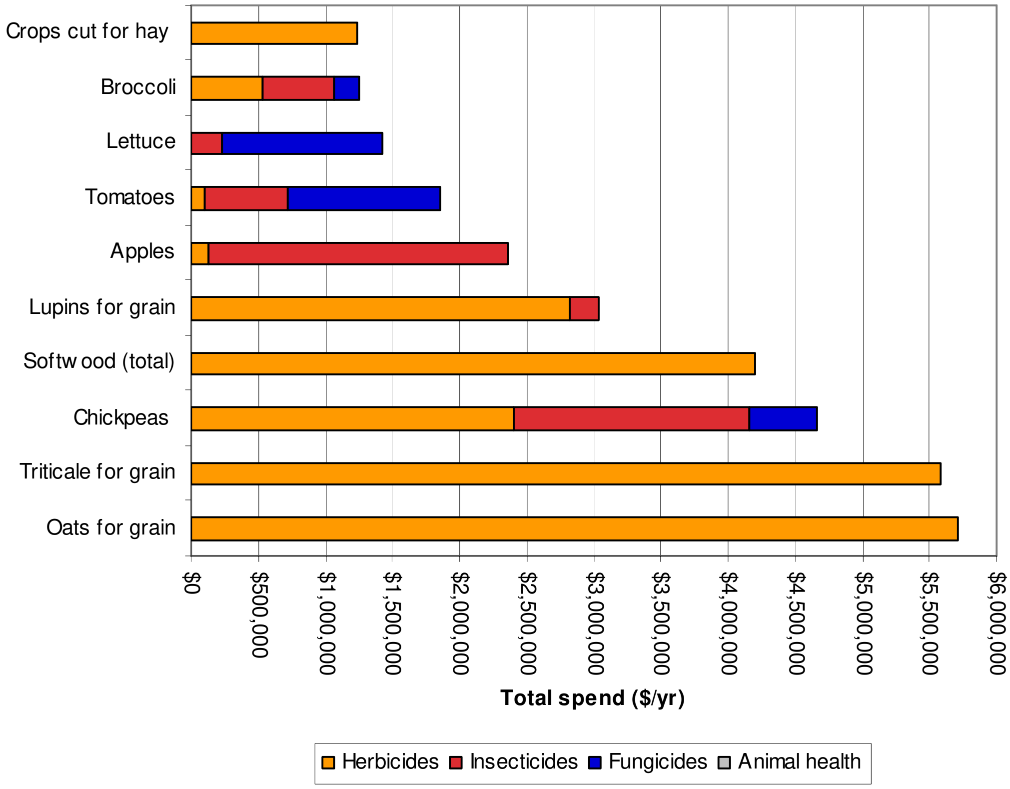


Figure D.5 The modelled results of the total chemical pesticide inputs to grow the crops shown in the zone.

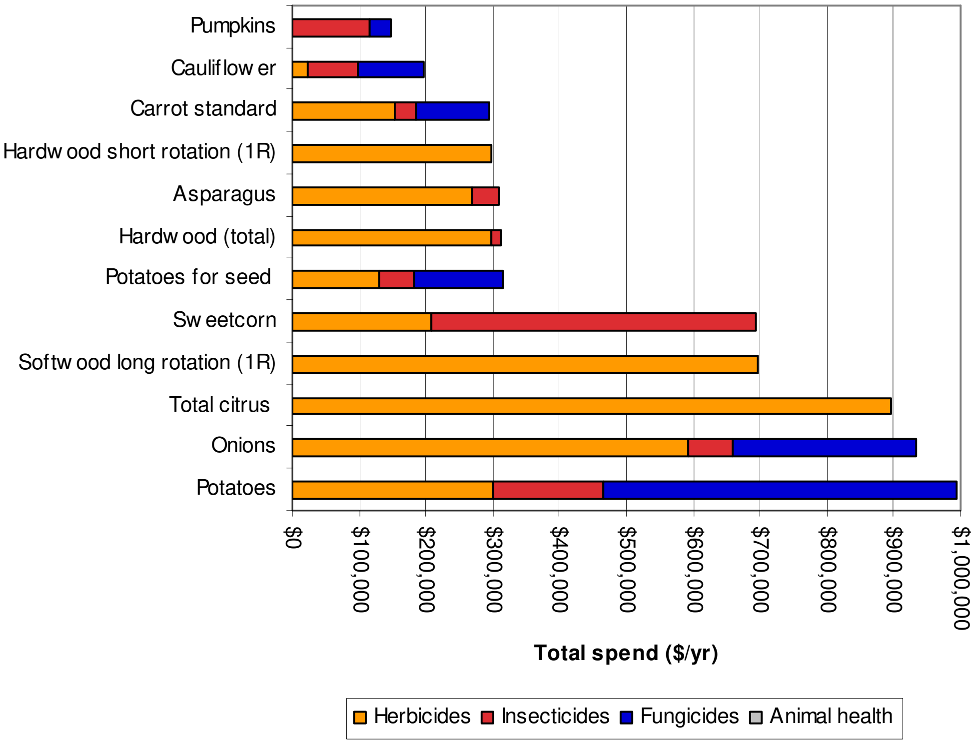


Figure D.6 The modelled results of the total chemical pesticide inputs to grow the crops shown in the zone.

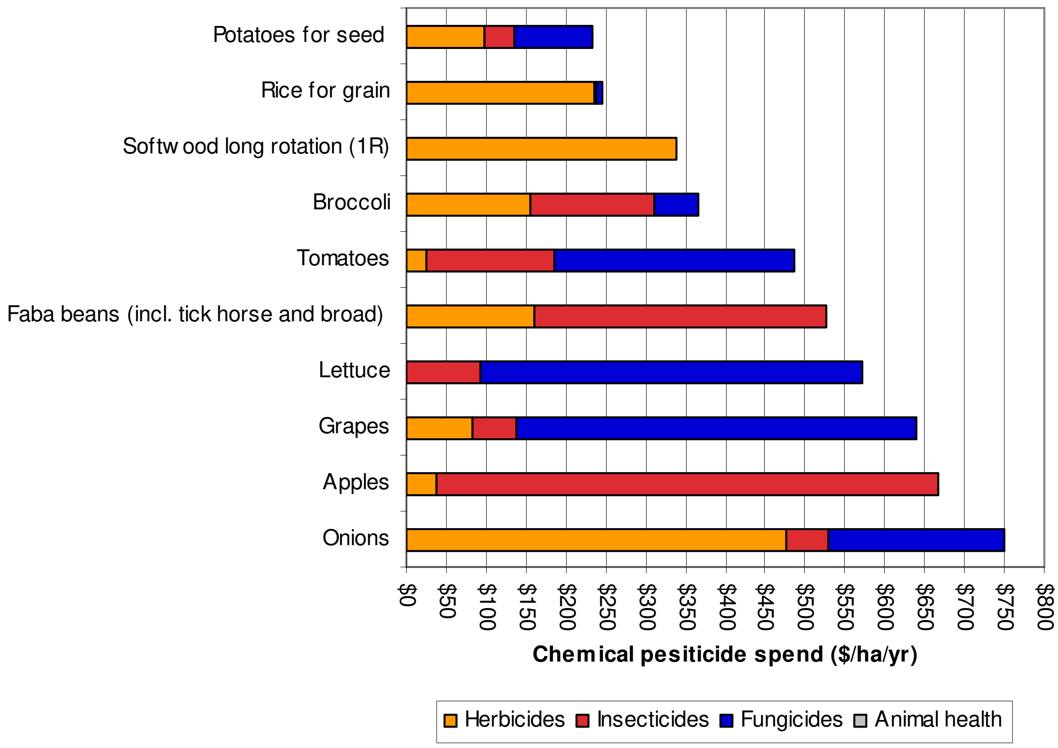


Figure D.7 The modelled results of the per hectare chemical pesticide inputs to grow the crops shown in the zone.

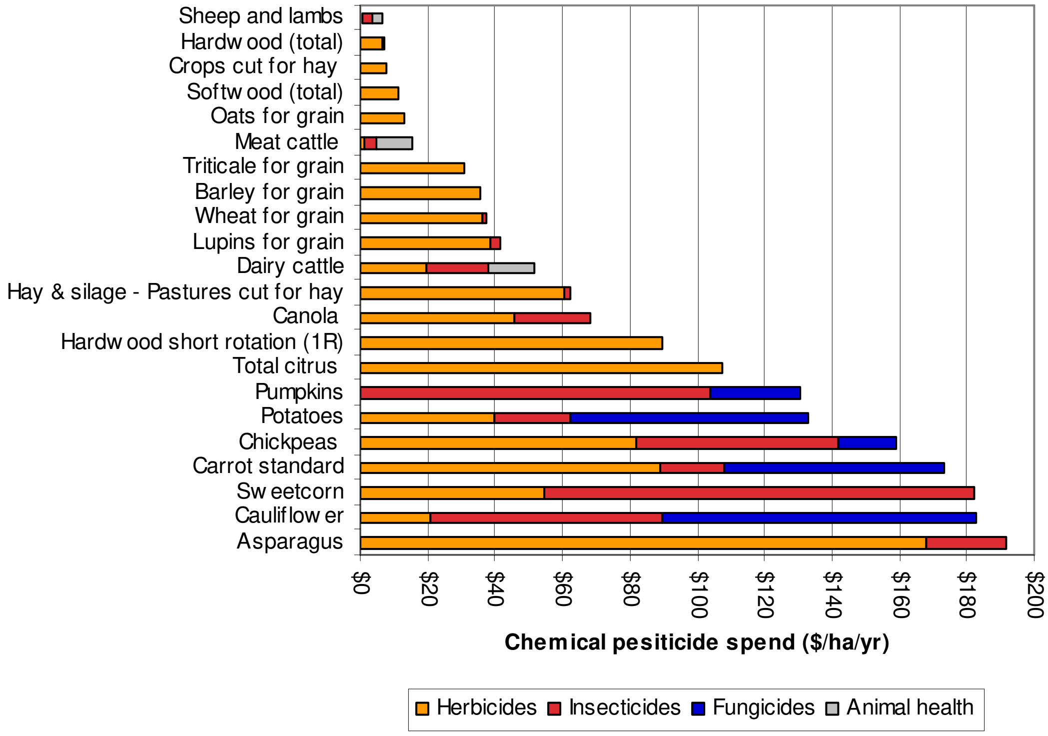
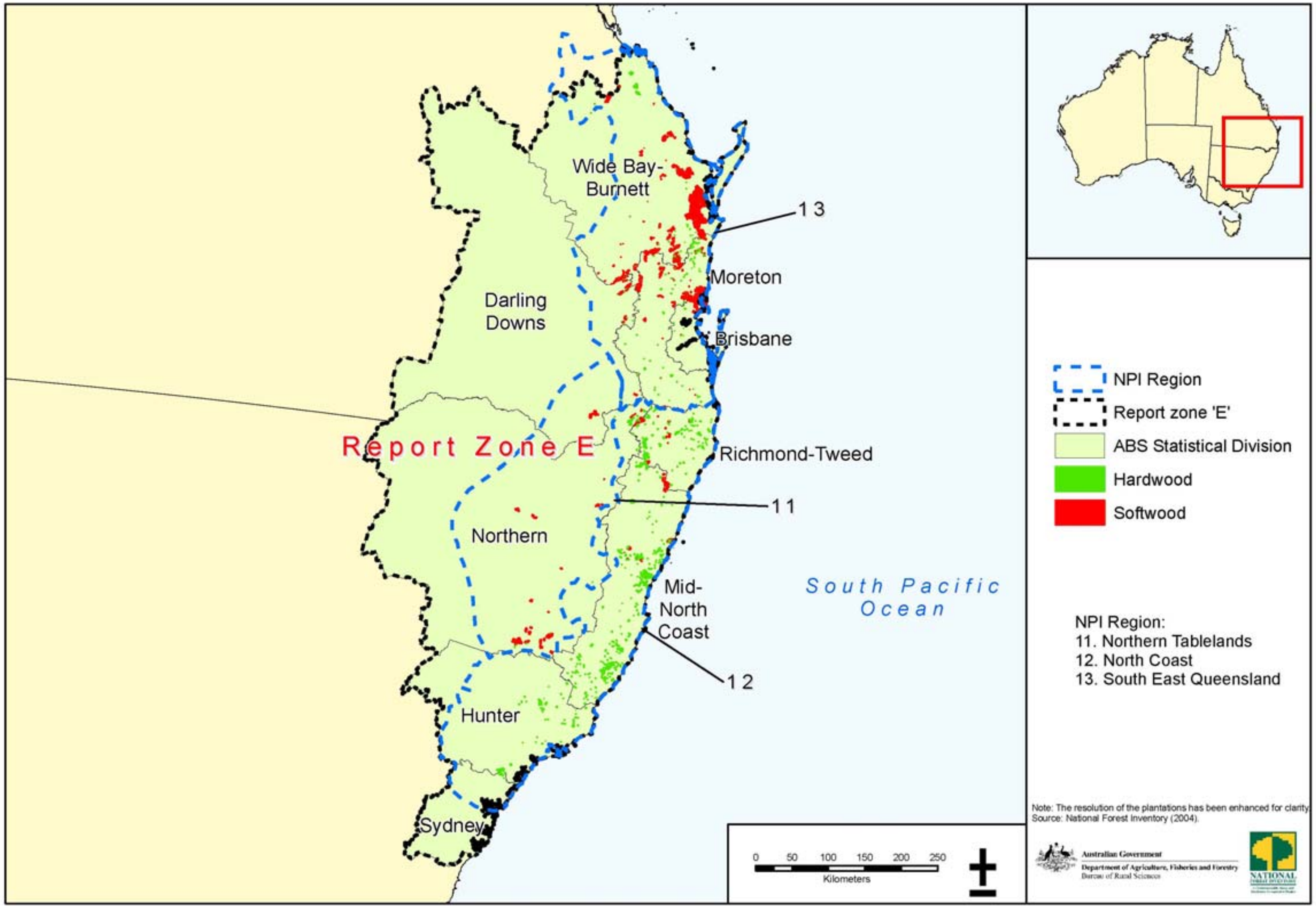


Figure D.8 The modelled results of the per hectare chemical pesticide inputs to grow the crops shown in the zone.

Zone E details

- Map E shows the areas covered by Zone E and defines the NFI zones and the ABS SD's;
- Figures E.1 to E.3 show the area of each land use in the zones based on the NFI (Parsons *et al.*, 2006) and ABS data (ABS, 2006);
- Figures E.4 to E.6 show the estimated total chemical pesticide use for each of the land uses shown;
- Figures E.7 to E.8 show the per hectare chemical pesticide use for each of the land uses shown.



Note: The resolution of the plantations has been enhanced for clarity.
Source: National Forest Inventory (2004).

Map E An outline of the area covered by Zone E. The map shows the NFI zones and the ABS SD's (prepared by NFI, 2006)

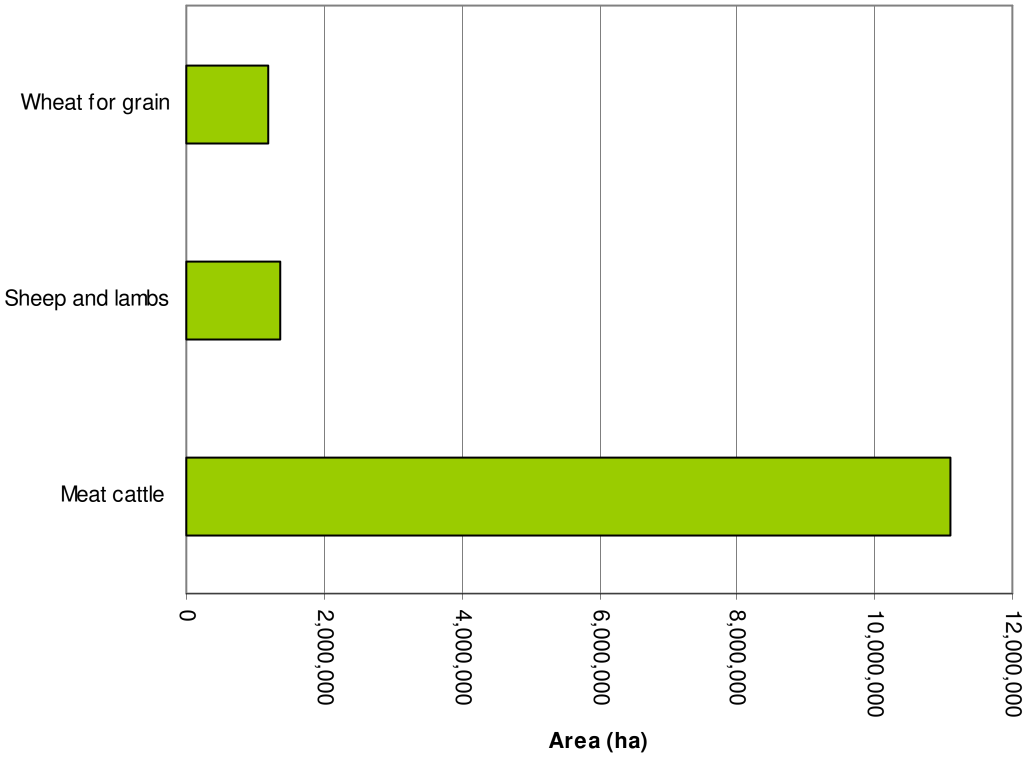


Figure E.1 A breakdown of the zone land use based on ABS (2006a) and Parsons *et al.* (2006).

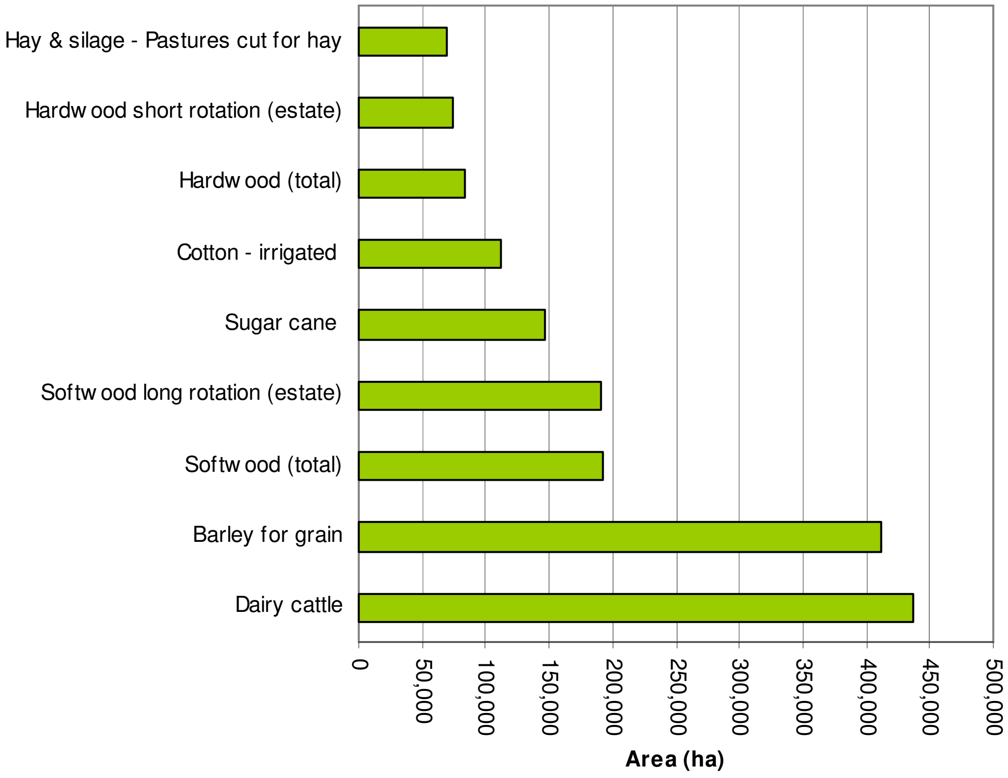


Figure E.2 A breakdown of the zone land use based on ABS (2006a) and Parsons *et al.* (2006).

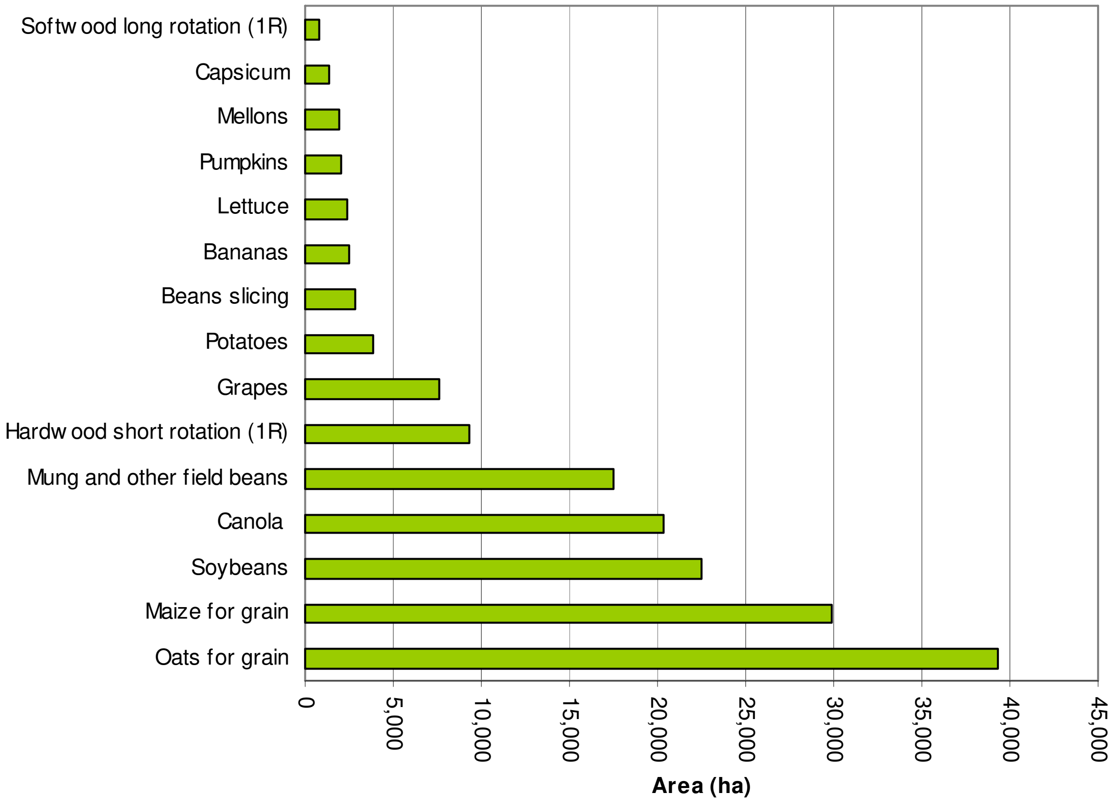


Figure E.3 A breakdown of the zone land use based on ABS (2006a) and Parsons *et al.* (2006).

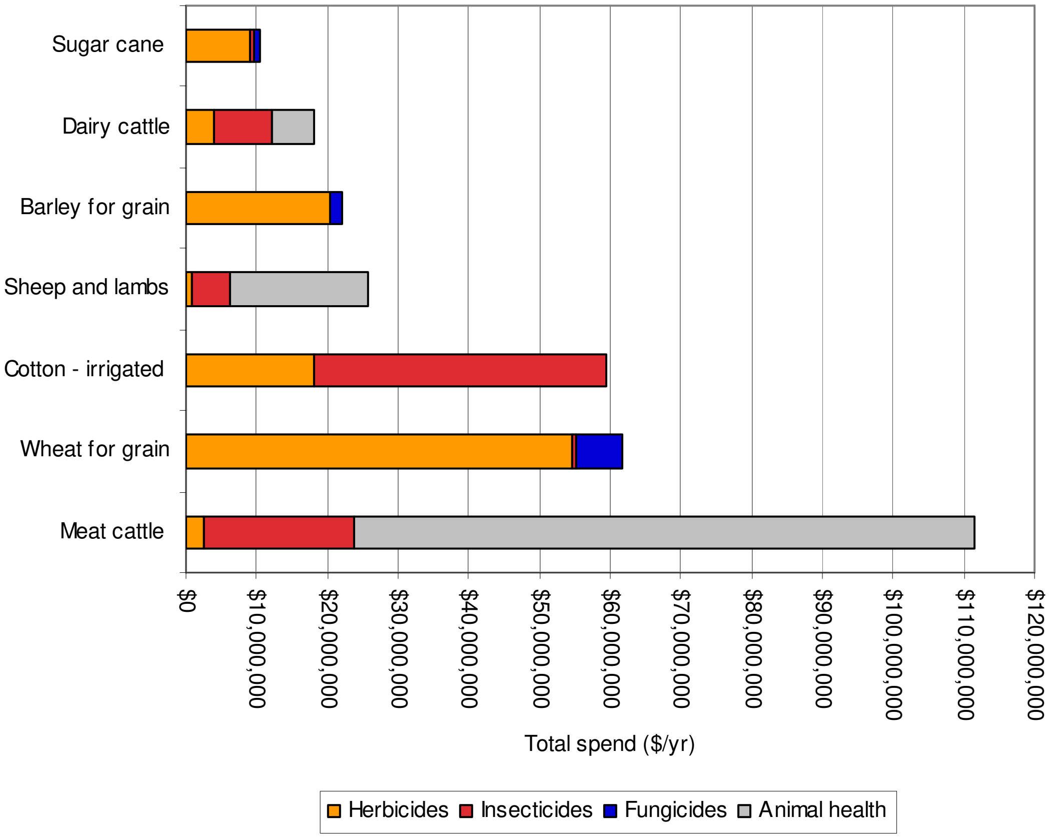


Figure E.4 The modelled results of the total chemical pesticide inputs to grow the crops shown in the zone.

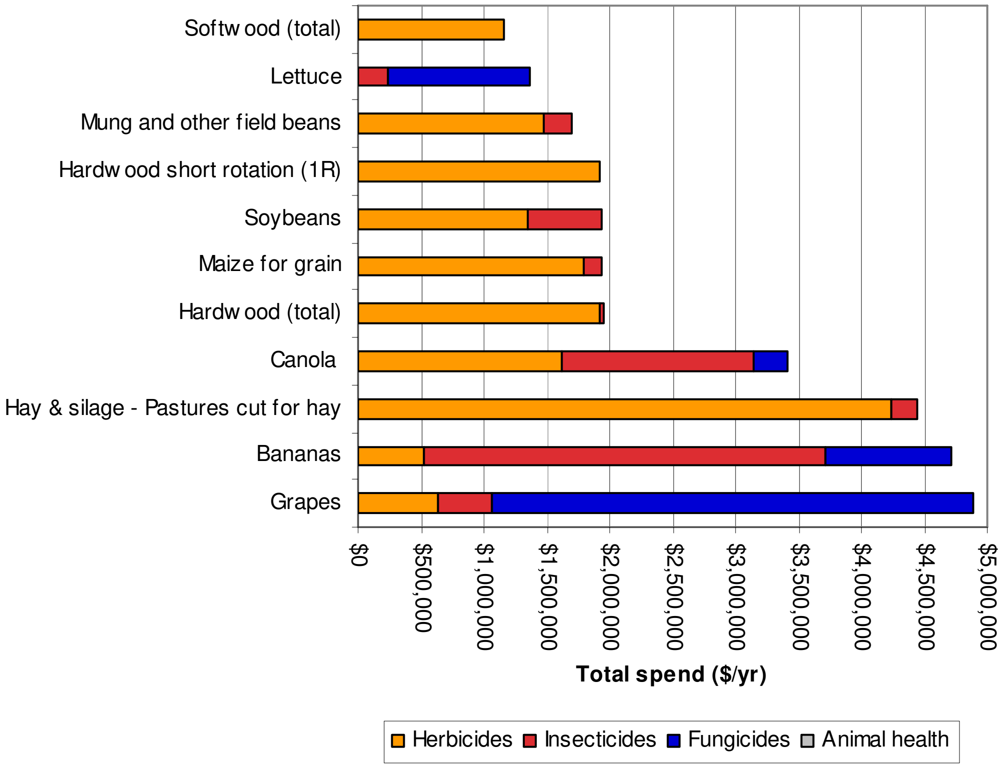


Figure E.5 The modelled results of the total chemical pesticide inputs to grow the crops shown in the zone.

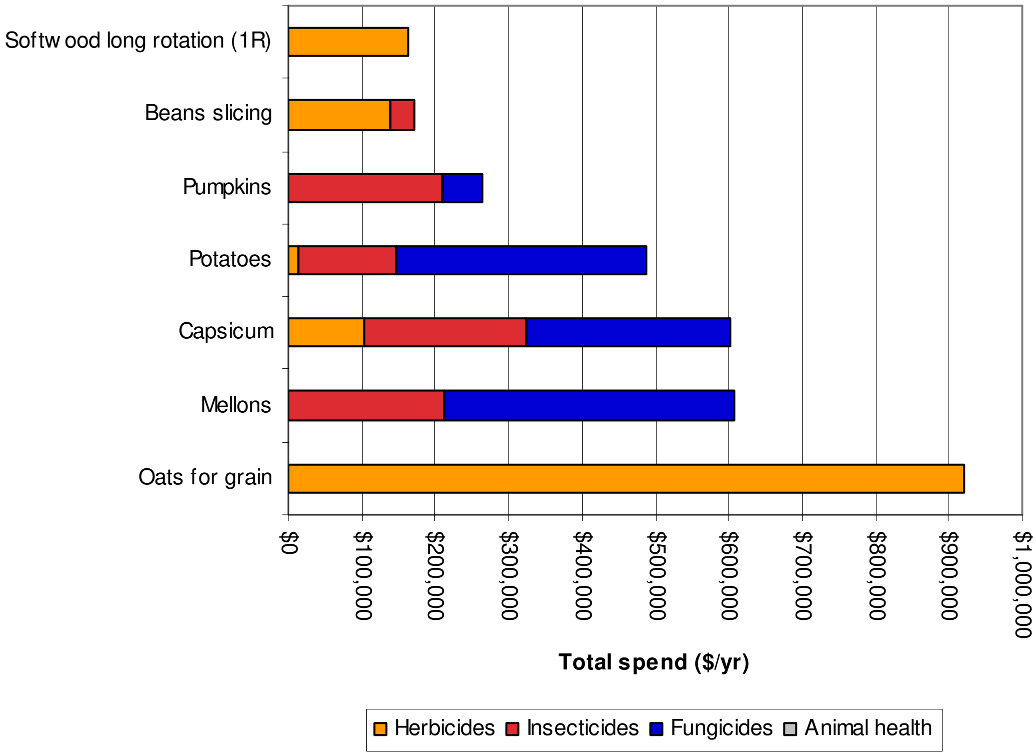


Figure E.6 The modelled results of the total chemical pesticide inputs to grow the crops shown in the zone.

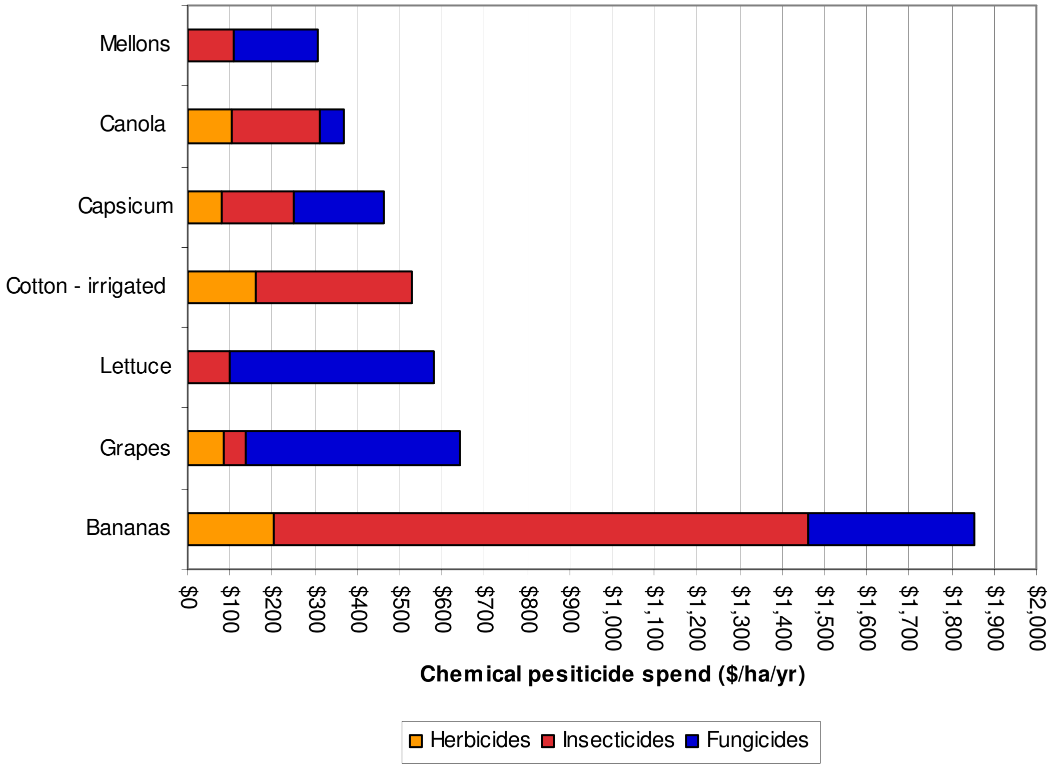


Figure E.7 The modelled results of the per hectare chemical pesticide inputs to grow the crops shown in the zone.

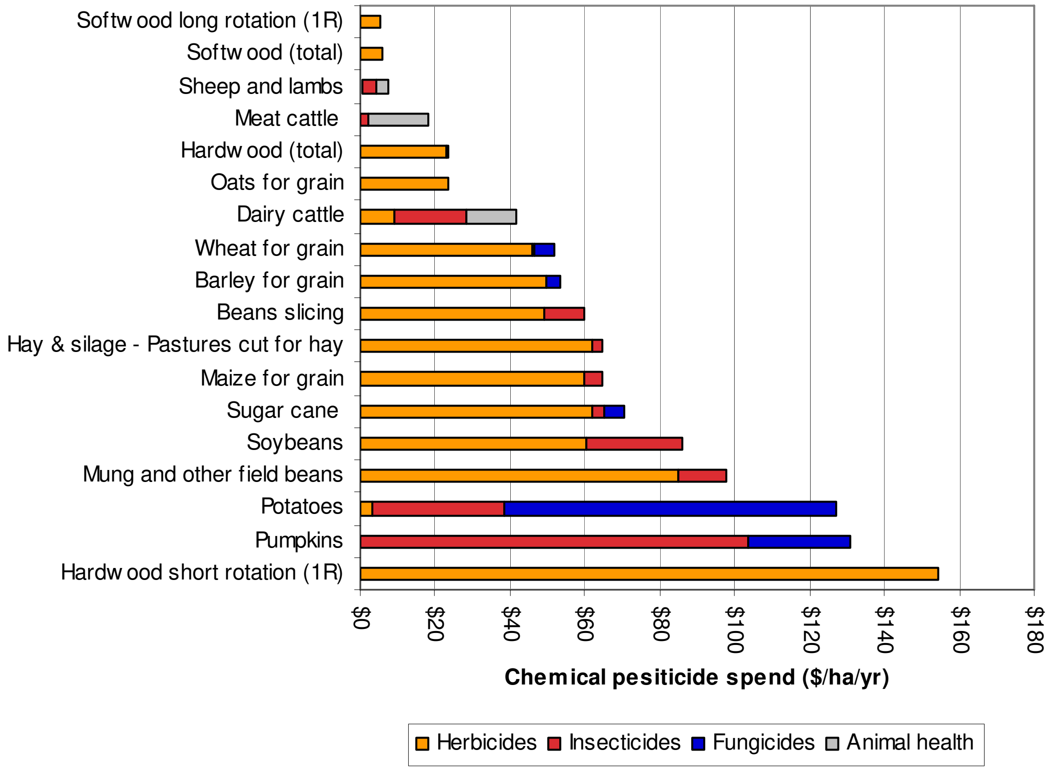
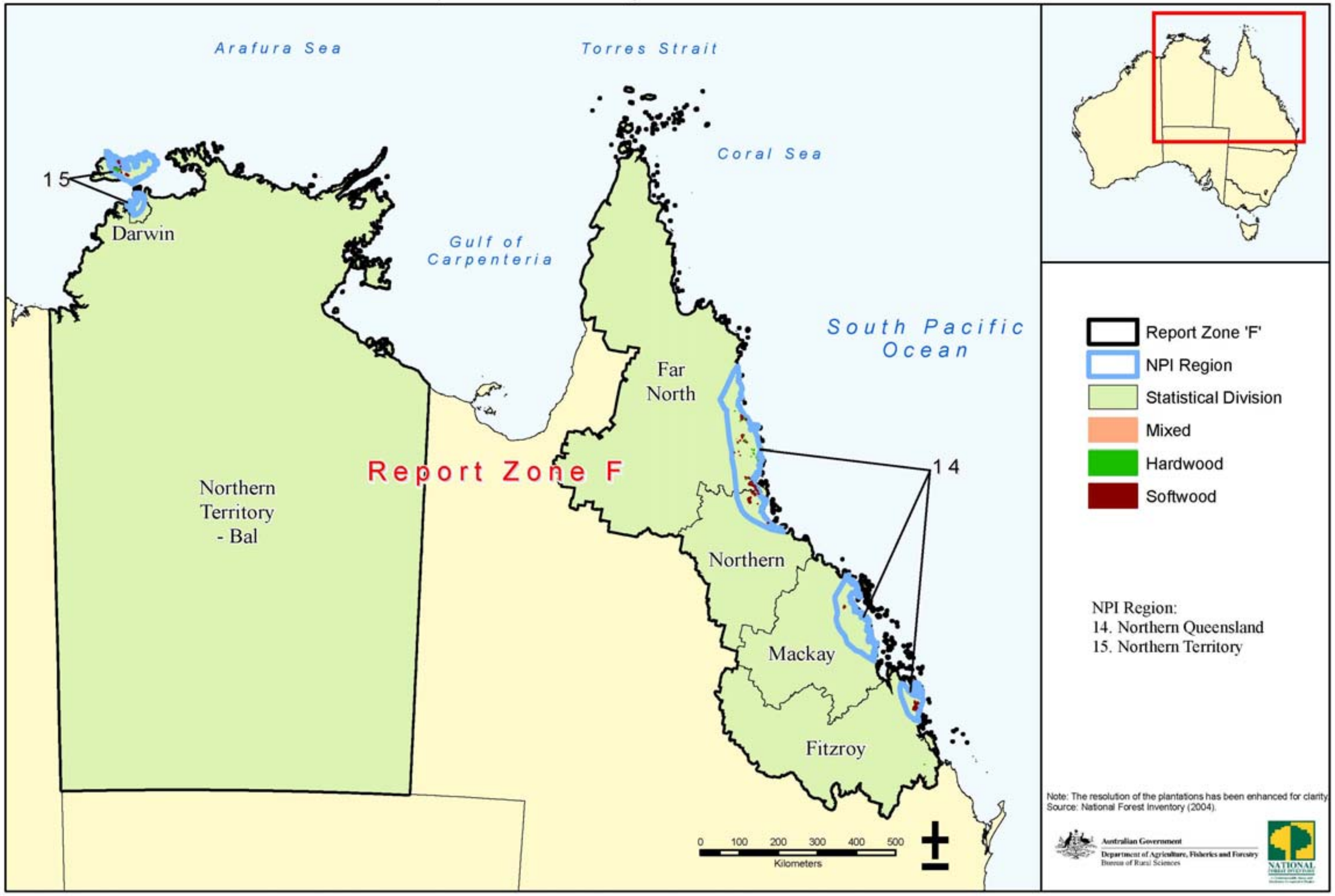


Figure E.8 The modelled results of the per hectare chemical pesticide inputs to grow the crops shown in the zone.

Zone F details

- Map F shows the areas covered by Zone F and defines the NFI zones and the ABS SD's;
- Figures F.1 to F.3 show the area of each land use in the zones based on the NFI (Parsons *et al.*, 2006) and ABS data (ABS, 2006);
- Figures F.4 to F.6 show the estimated total chemical pesticide use for each of the land uses shown;
- Figures F.7 to F.8 show the per hectare chemical pesticide use for each of the land uses shown.

Report Zone F- NPI Regions and Statistical Divisions



Note: The resolution of the plantations has been enhanced for clarity.
Source: National Forest Inventory (2004).

Map F An outline of the area covered by Zone F. The map shows the NFI zones and the ABS SD's (prepared by NFI, 2006)

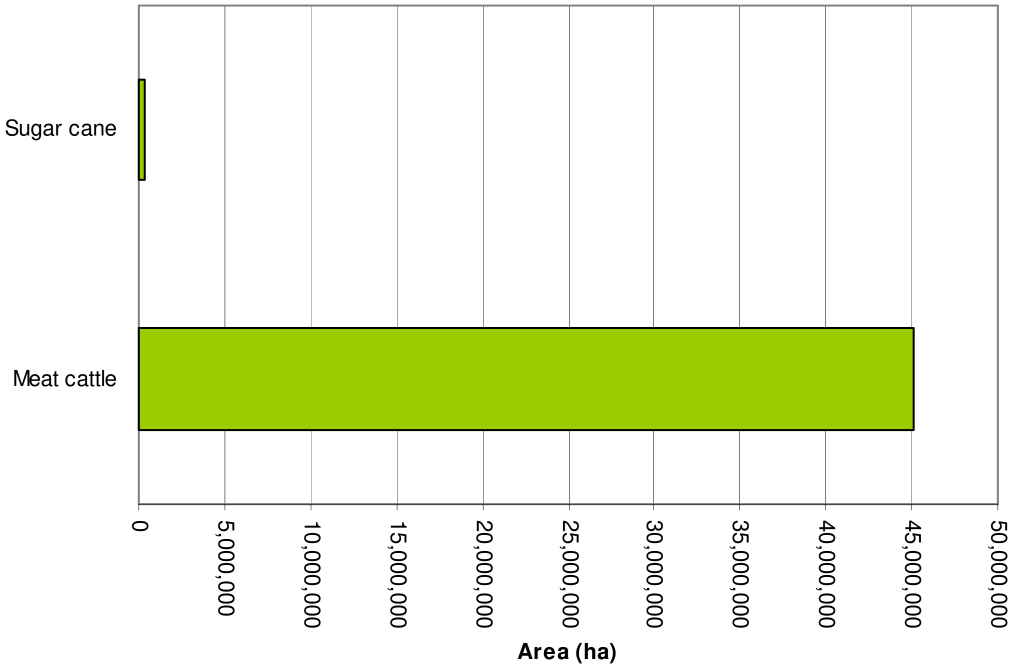


Figure F.1 A breakdown of the zone land use based on ABS (2006a) and Parsons *et al.* (2006).

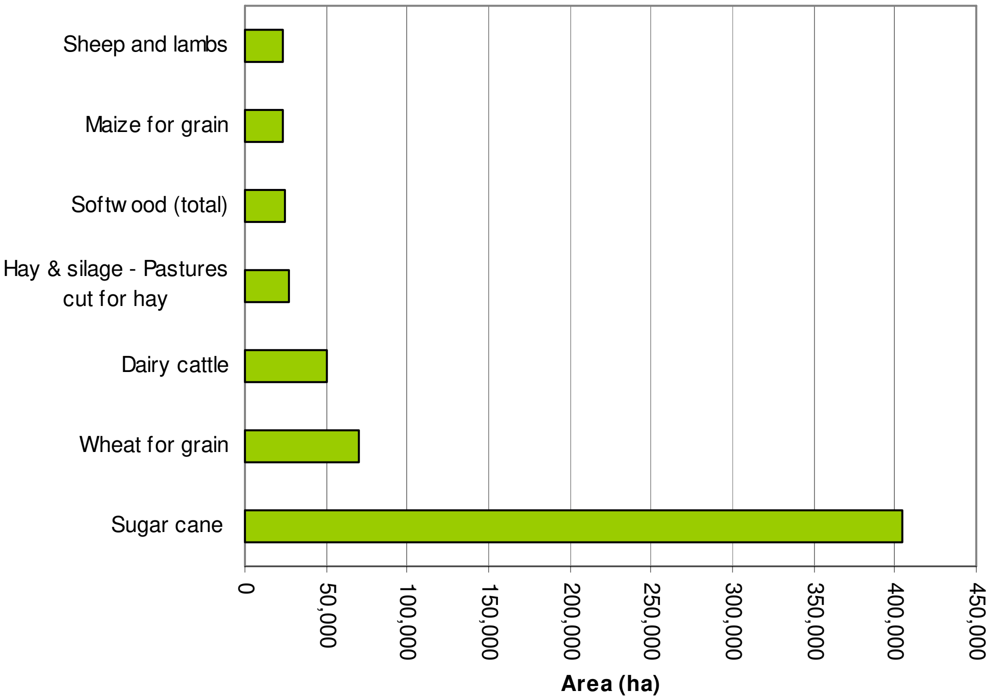


Figure F.2 A breakdown of the zone land use based on ABS (2006a) and Parsons *et al.* (2006).

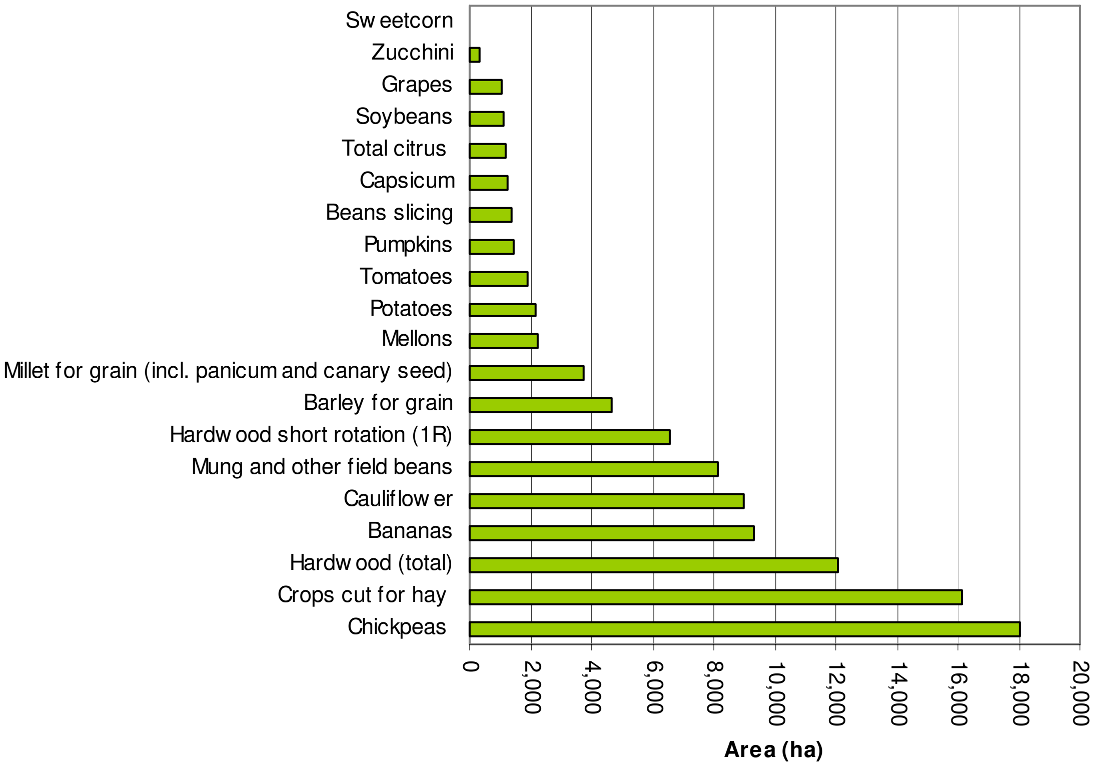


Figure F.3 The modelled results of the total chemical pesticide inputs to grow the crops shown in the zone.

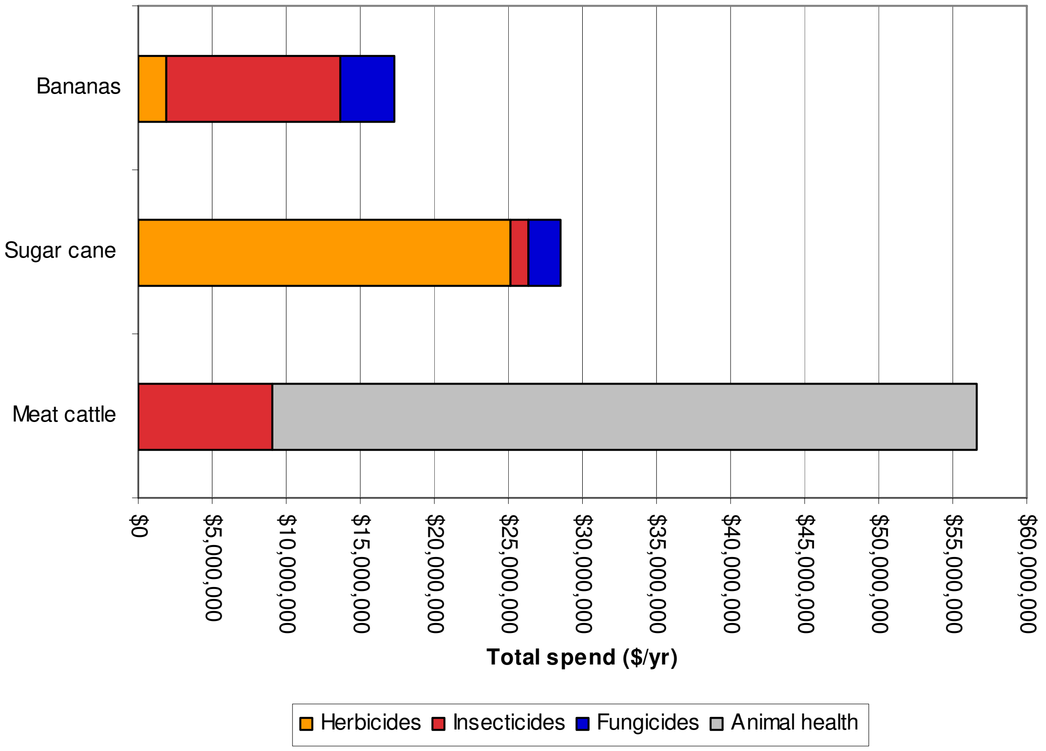


Figure F.4 The modelled results of the total chemical pesticide inputs to grow the crops shown in the zone.

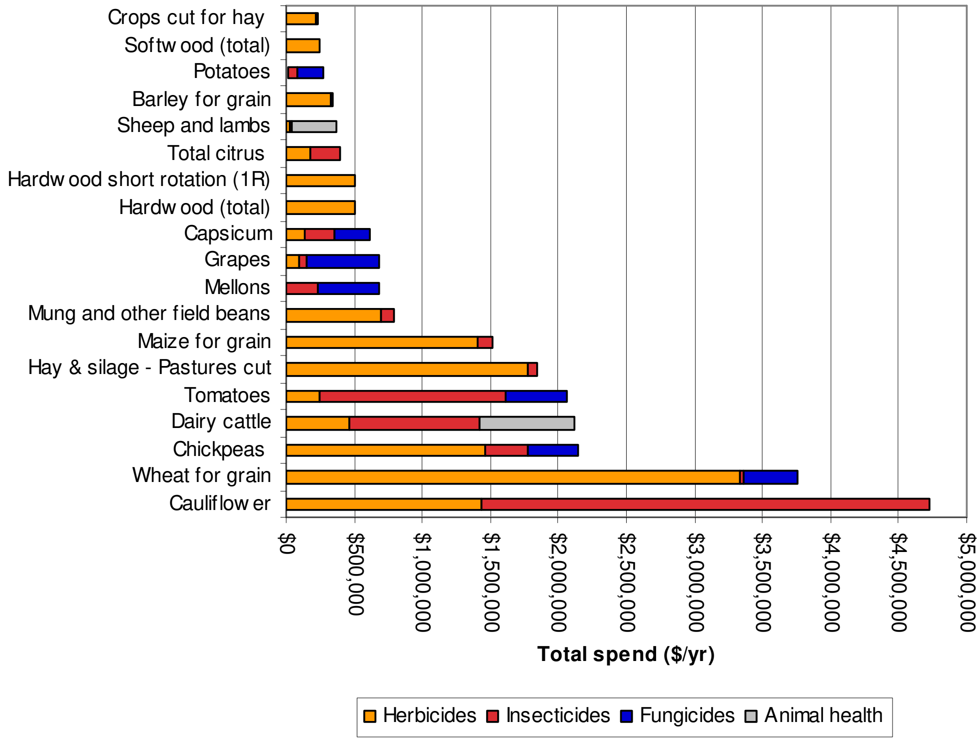


Figure F.5 The modelled results of the total chemical pesticide inputs to grow the crops shown in the zone.

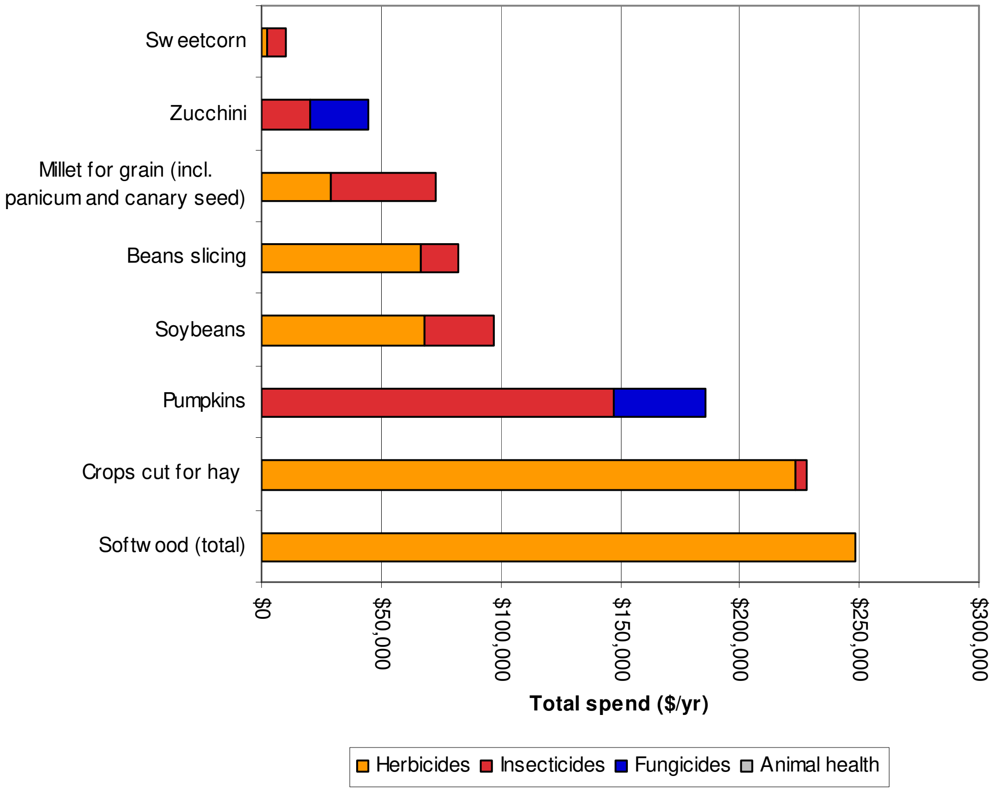


Figure F.6 The modelled results of the total chemical pesticide inputs to grow the crops shown in the zone.

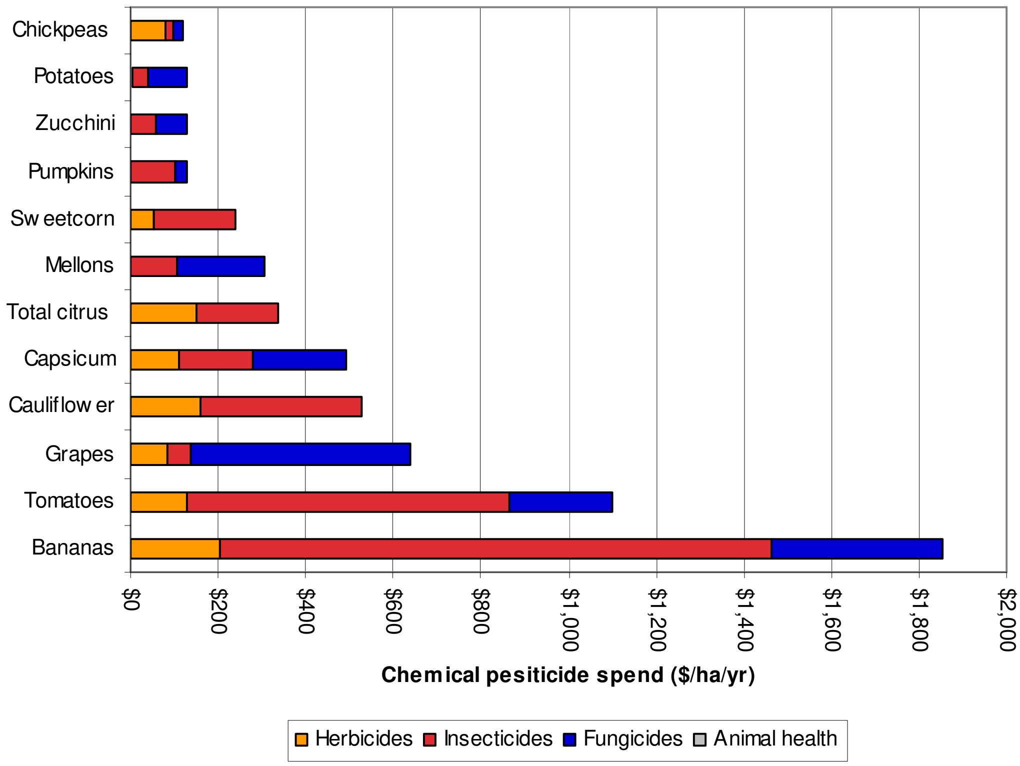


Figure F.7 The modelled results of the per hectare chemical pesticide inputs to grow the crops shown in the zone.

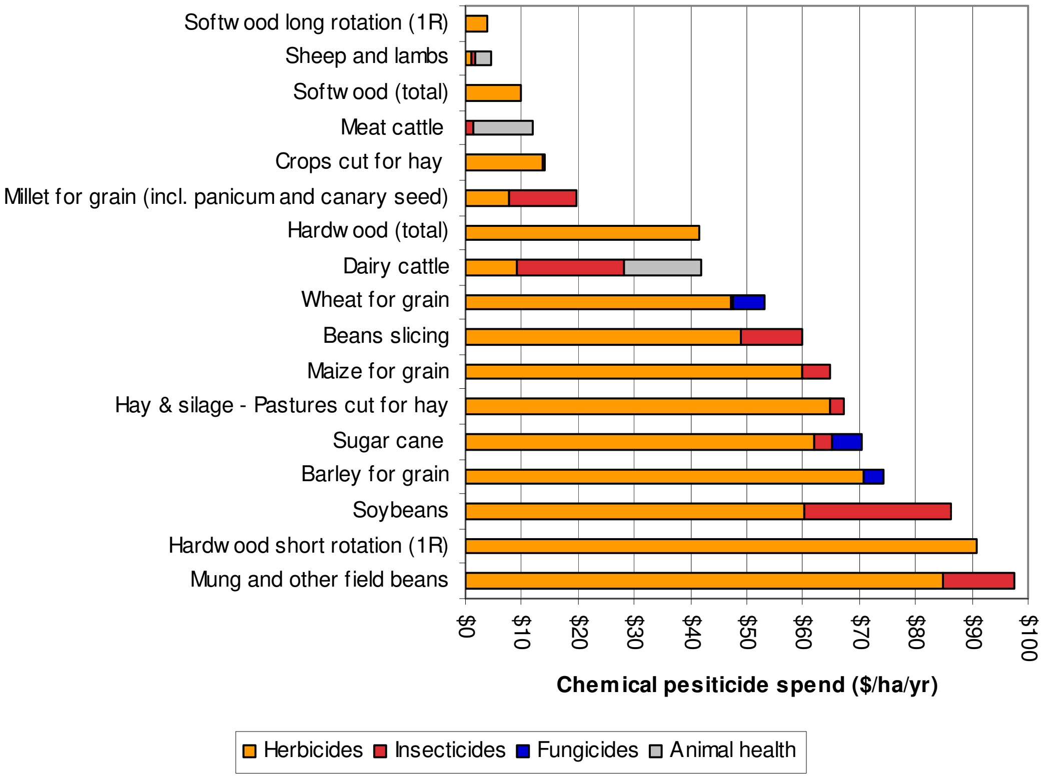


Figure F.8 The modelled results of the per hectare chemical pesticide inputs to grow the crops shown in the zone.

Acknowledgements

The authors wish to acknowledge assistance in preparing this report: industry survey participants; Mark Parsons, Mijo Gavran and Robert Dillon of the National Forest Inventory for preparation of zone mapping; Paul Curtis of the Australian Bureau of Statistics for assistance with and the provision of ABS data sets; the many industry contacts who provided a valuable checks of the information generated by this study.