Curtin
University of Technology

EVALUATION OF THE ENVIRONMENTAL AND ECONOMIC IMPACT OF ROUNDUP READY® CANOLA IN THE WESTERN AUSTRALIAN CROP PRODUCTION SYSTEM

Curtin University of Technology (Muresk) Technical Report (11/2009)

EVALUATION OF THE ENVIRONMENTAL AND ECONOMIC IMPACT OF ROUNDUP READY® CANOLA IN THE WESTERN AUSTRALIAN CROP PRODUCTION SYSTEM

Curtin University of Technology (Muresk) Technical Report (11/2009)

Dr James Fisher and Dr Peter Tozer

Evaluation of the environmental and economic impact of Roundup Ready® canola in the Western Australian crop production system

Curtin University of Technology (Muresk) Technical Report (11/2009)

First Published in 2009 by
Curtin University of Technology
Muresk, School of Agriculture and Environment
Northam
WA 6401
Australia

ISBN: 978-0-9807333-0-3

Authors

This report was prepared for Curtin University of Technology by:

Dr James Fisher
Désirée Futures
York WA, Australia 6302
Email james@desireefutures.net.au

and

Dr Peter Tozer
PRT Consulting
Armidale NSW, Australia 2350
prt_consulting@live.com.au

About the authors

Dr James Fisher's research experience covers a range of aspects of agricultural systems including season and crop production, soil acidity, plant nutrition and sheep production, as well as modelling the responses and predicting the performance of these systems. He has experience in field research in animals, plants and soils, building and using computer models of systems and their components (e.g. budgeting soil acidity and simulation models), and scenario planning and social research. He is a resident of the wheatbelt region of Western Australia and has a passionate interest in the development of this area.

Dr Peter Tozer's previous research includes using economic analyses to identify efficiencies in dairy production systems in the United States, farming systems research in Australia and the United States, grazing systems research in the United States and Australia, and real options studies of investments in grazing and precision agriculture in Western Australia.

Acknowledgements

The authors would like to acknowledge Prof. Robert Belford for his helpful comments on the scope of the study and early drafts of this report, Cameron Weeks of Planfarm Geraldton for his advice on canola production systems in Western Australia, Dr James Neilsen of Monsanto Australia Ltd for providing raw data from the commercial canola trials conducted in New South Wales and Victoria and Pauline Gazey of Science with Style for her design work to produce the finished report.

This work was carried out with funding from Monsanto Australia Ltd.

Contents

Executive summary

The wheatbelt of Western Australia delivers around half of the nation's annual grain production. In this zone, canola is important as a break crop, with 5–12% of the area (400–800 000 ha) planted to the oilseed over the past ten years (ABARE 2009). The area planted to canola varies with seasonal conditions and profitability relative to cereal crops. Farmer decisions to plant canola are impacted by challenges from weeds and disease, especially blackleg, and the profitability of the crop. Production of canola in this zone would benefit from technology that increases profitability through increased yield, decreased cost, or a combination of the two.

This report presents the results of an analysis of some of the potential economic and environmental impacts at the farm level of Roundup Ready® canola in Western Australia. The analysis considered projected yields and costs, patterns of herbicide use and fuel use (and associated greenhouse gas production). A partial budget approach using a case study for a "typical" farm size and rotation for cropping businesses in Western Australia was used in the economic analysis. Cropping systems were modelled for each of the three rainfall zones; low (250–325 mm), medium (325–450 mm) and medium-high (450–750 mm). The herbicide application data from commercial trials in New South Wales and Victoria were modified to represent Western Australian production and were then used to estimate farm-level environmental impacts based on an environmental impact quotient (EIQ) field rating and farm fuel use based on the number of applications. An estimated Environmental Impact (EI) for each canola system was calculated using the product of the EIQ field rating for each herbicide.

Results showed that the profitability of Roundup Ready® canola was equal or superior to triazine tolerant canola (the canola system most commonly used in Western Australia) and comparable to conventional and Clearfield® canola. The estimated environmental impact of Roundup Ready® canola was less than half than (43%) that of triazine tolerant canola. The fuel use and related greenhouse gas production were slightly lower (5–6% and 1–2% respectively) than the other three systems.

Overall, this analysis suggests that Roundup Ready® canola will be as profitable or more profitable than triazine tolerant canola with a reduced environmental impact and slightly reduced fuel use. The importance of managing any implementation of the technology to ensure that it will remain a viable tool are discussed.

Background

Canola in Western Australia

Canola is an important crop in Western Australia and is considered to be the most successful of the four main break crops—lupin, canola, field pea and oat—that are grown commercially in the State (Amjad 2008; Carmody and Pritchard 2009). In the last ten years, 400–800 000 ha of the approximately 7 million ha of crop in the Western Australian wheatbelt has been sown to canola. Production of canola peaked at 963 000 tonnes (from 879 000 ha) in 1999 (ABARE 2009). Since that time the area planted to canola has roughly halved with average annual production over the past five years of 440 000 tonnes, valued at around $200 million per annum (Amjad 2008). Canola is grown across all of the rainfall zones of the Western Australian wheatbelt, but it has been most successful in the southern high rainfall areas while being less so in the lower rainfall areas (due to a lack of adapted cultivars) and the northern wheatbelt (due to diamondback moth infestations) (Carmody and Pritchard 2009).

Farmers in Western Australia grow break crops primarily for the rotational benefits of disease and weed control and, in the case of lupin, for nitrogen input (Carmody 2009). The benefits of having canola in the farming systems are to provide more flexibility in controlling broadleaf weeds, combating herbicide resistance, controlling cereal root diseases and increased yields of the following cereal crop. Canola provides cropping farmers with an alternative to cereals and pulses that is profitable in addition to rotational benefits, such as breaks from continuous cereal phases and weed or pest control mechanisms. While it is a cash crop, a recent survey of growers found that the most important factors in growers' decision to plant canola were "weed control (81%), cereal root disease (80%), herbicide rotation (74%), profitability of following crop (69%) and diversification of farming system (56%)" (Carmody and Pritchard 2009).

Canola is considered to be a high input and high management crop, and hence high risk, due to its nutritional requirements, the inputs required for pest control (diseases, weeds, and insects) and susceptibility to frost (Oilseeds WA 2006). The area planted to canola is limited by sowing opportunities as well as challenges from weeds and disease, especially blackleg, and the profitability of the crop. Western Australian farmers consider seasonal rainfall to be the greatest constraint to growing canola (63% agreement), which is a combination of sowing opportunities and dry finishes reducing quality, with factors such as soil constraints, climate change, commodity prices, cost of production and susceptibility to disease each having 20–25% agreement (Carmody and Pritchard 2009). Production of canola in Western Australia would benefit from cultivars that perform better in low rainfall zones or dry seasons and also from technology that increases profitability through increased yield, decreased cost, or a combination of the two.

Canola cultivars currently available in Western Australia include non herbicide-tolerant (conventional) and herbicide-tolerant

"Weed control... is a major limiting factor to canola growth and eventual yield (Oilseeds WA 2006). This factor, combined with the development of herbicide-resistant weeds, means that more than 90% of canola grown in Western Australia is from herbicide tolerant lines; either triazine tolerant or Clearfield (imidazolinone tolerant)... the majority of this 90% is triazine tolerant canola"

lines. Weed control, especially in the early stages of the crop, is a major limiting factor to canola growth and eventual yield (Oilseeds WA 2006). This factor, combined with the development of herbicide-resistant weeds, means that more than 90% of canola grown in Western Australia is from herbicide tolerant lines; either triazine tolerant or Clearfield® (imidazolinone tolerant) (Amjad 2008; Hashem 2008). As ryegrass has developed widespread cross-resistance to the imidazolinone herbicides, the majority of this 90% is triazine tolerant canola (Hashem 2008). Conventional canola is only grown in situations of low weed burdens and little herbicide resistance.

Triazine tolerant canola is able to tolerate high levels of triazine herbicides (atrazine or simazine) applied at the seedling stage. Triazine tolerance is a naturally occurring mutation in a single amino acid of the chloroplast protein that is responsible for binding triazine herbicides (Hirschberg and McIntosh 1983; Vaughn 1986). This modified photosynthesis system in triazine tolerant cultivars means that they are not affected by triazine herbicides. The herbicide-tolerance has a fitness cost and triazine tolerant canola cultivars have reduced growth and yield (commonly 5 to 10%) compared to other types of canola, (Hashem 2008; Oilseeds WA 2006). Clearfield canola has gene variants with altered acetohydroxyacid synthase (AHAS) enzyme that is less sensitive to imidazolinone herbicides (Tan *et al.* 2006). Imidazolinone tolerant crops have been developed by selecting variants that occurred naturally or were induced by chemical mutagenesis.

Weed control can represent a major challenge to canola, particularly during the seedling stages. With herbicide-resistant weeds now common throughout Western Australia (Hashem 2008), herbicide-tolerant canola provides important weed control options. Triazine tolerant canola provides an alternative option for managing grass weeds that have developed resistance to the Group A (ACCase) and Group B (sulfonylurea) herbicides, especially annual ryegrass, brome grass and wild oat. Similarly, Clearfield canola enables the use of the imidazolinone herbicides for the control of broadleaf and grass weeds. However, there are potential negative impacts on the following crop after the canola from the residual action of triazine and imidazolinone herbicides. In addition, weed populations, particularly ryegrass and wild radish, are developing resistance to these herbicides (Hashem 2008; Heap 2009; Owen and Zelaya 2005; Peltzer *et al.* 2009).

The introduction of Roundup Ready® canola could provide another option for weed control in canola systems in Western Australia through the use of post-emergent, broad spectrum control. Roundup Ready canola has gene variants with altered 5-enolpyruvylshi-kimate-3-phosphate synthase (EPSP synthase) that is less sensitive to glyphosate (common to all glyphosate-resistant crops) and a gene that codes for a glyphosate oxidoreductase (GOX, which is specific to glyphosate-resistant canola) (Tan *et al.* 2006). Unlike Clearfield canola, the gene modification in Roundup Ready canola was brought about by transgenic techniques rather than mutagenesis. In considering the potential impact of Roundup Ready canola in Western Australia it is useful to consider experiences elsewhere. Numerous reviews of GM crops and GM canola have been produced and these papers are summarised briefly to provide background and context for the current study.

Experiences with Roundup Ready® canola

Global distribution of genetically modified crops

Genetically modified (GM) crops have been adopted rapidly by farmers in major grain exporting countries across the world. James (2003) reported that in the five-year period between 1996 and 2000 the area sown to GM crops increased by more than twenty-five times with adoption being "...the highest for any new technology by agricultural industry standards". They are now grown in 23 countries across the world. The main countries growing GM crops in 2007 were the United States of America (50%), Argentina (17%), Brazil (13%), Canada (6%), India (5%), China (3%), Paraguay (2%) and South Africa (2%) (Acworth *et al.* 2008; James 2007).

Soybean, maize and cotton are the main GM crops, accounting for 51%, 31% and 13% of global GM plantings respectively (James 2007). Canola is a small proportion of the area sown to GM crops with only an estimated 5.5 million hectares grown in 2007. This represents only about 4% of the total area of GM crops, but is 18% of the global rapeseed production of over 30 million hectares (FAO 2007). Prior to 2008 only the United States of America and Canada produced GM canola, with 87% of the canola in Canada being GM in 2007 (James 2007). In 2008 moratoria on the production of GM canola were lifted in New South Wales and Victoria and an estimated area of 41 000 ha (3% of the national canola crop (ABARE 2009)) was planted to GM in 2009.

International experience

Several papers have reviewed the impact of GM crops since they were first introduced (Brookes and Barfoot 2005; Brookes and Barfoot 2008; Brookes and Barfoot 2009; Dill 2005; Dill *et al.* 2008; Duke 2005; Gianessi 2005; Gianessi 2008; James 2003). These reviews focus on the farm-level impacts and generally present the results on a national basis for each of the main GM crops. It is not the intention of this report to 'review the reviews', but instead to present some of the main findings of these papers; particularly those related to GM canola.

James (2003) attributed the rapid increase in the area sown to GM crops to the "significant and multiple benefits" for large and small-holder farmers in both industrial and developing countries. The main benefits he attributed to this technology were improved yields due to improved pest and weed control, reduced pesticide use, decreased input costs and increased flexibility. This conclusion is broadly supported by other authors (Dill 2005; Dill *et al.* 2008; Duke 2005).

Brookes and Barfoot reviewed the socio-economic and environmental impacts of GM crops at nine, ten and twelve-year intervals since their first introduction and concluded that GM crops had a positive impact on farm income (Brookes and Barfoot 2005; Brookes and Barfoot 2008; Brookes and Barfoot 2009). This was attributed to increased production and lower costs. However, it was noted that there was variation in the experience at the local level (Brookes and Barfoot 2009).

Part of the reason for such local variation in farm profitability is that decreased input costs associated with GM crops need to be balanced against possible increased costs due to higher seed costs and technology fees (Gianessi 2005; Gianessi 2008). Fulton and Keyowski (1999) incorporated these aspects into an economic model of farmer benefits from adopting GM canola in Canada which incorporated differences in farms, including local climate, soil types, length of season and management. Their conceptual model suggested that herbicide-tolerant canola would be more profitable under a reduced tillage system. These results have been borne out by the experiences with GM crops and herbicide-tolerant canola in particular.

Any discussion of the impacts of GM canola must focus on Canada and the United States. Prior to 2008, these were the only two countries growing the crop commercially. Both glyphosate-tolerant and glufosinate-tolerant canola have been grown, although Roundup Ready canola (glyphosate-tolerant) dominates in Canada. Analysis of the farm-level impacts of herbicide-tolerant canola has examined yield, cost of production, profitability, and herbicide use. For simplicity and brevity, the results presented here will focus on the Canadian experience, but the impacts in the United States have been similar, as would be expected given the proximity of the two countries and the similarities in the production systems on the Canadian prairies and Mid-West of the United States (Brookes and Barfoot 2009; Gianessi 2008).

In Canada, herbicide-tolerant canola initially enjoyed a yield advantage of over 10% compared with conventionally-bred cultivars (Brookes and Barfoot 2009). Over time this difference has disappeared as yield for conventionally-bred canola (principally Clearfield, imidazolinone tolerant cultivars) has increased, thanks to the development of hybrid lines. Adoption of GM canola has decreased the cost of production due to reduced expenditure on herbicides, but this has been offset or nearly offset by technology costs. Overall the profitability of GM, herbicide-tolerant canola in Canada has been estimated to be $23–$61/ha higher than Clearfield, imidazolinone tolerant canola (Brookes and Barfoot 2009). A survey of Canadian canola growers that was conducted in 2000 (http://www.canolacouncil.org/gmo_toc.aspx) indicated that the glyphosate-resistant system provided at least $15/ha more profit compared with conventional systems (Canola Council of Canada, cited by Gianessi 2008).

The preceding production and economic factors that are attributed as benefits from growing herbicide-tolerant canola are what is generally identified by growers as their reasons for adopting and continuing to use the technology. For example, James (2007) cited the aforementioned survey conducted by the Canola Council of Canada which reported that Canadian canola growers chose GM varieties “for easier and better weed control, better yields, higher returns and more profit, to reduce costs and to clean up fields”.

In addition to economic benefits, reductions in herbicide use and the estimated environmental impact have been associated with the adoption of herbicide-tolerant canola in both Canada and the United States (Brookes and Barfoot 2009). Overall, the volume of herbicide applied has been estimated to be 13.9% lower for GM, herbicide-tolerant canola compared with imidazolinone tolerant canola with a reduction in the environmental impact (as estimated using the Environmental Impact Quotient (Kovach *et al.* 1992)) of 25.8%.

"...Duke (2005) concluded that the overall quantity of herbicide used in GM, herbicide-tolerant crops is not much different to conventional crops. However, the substitution of the soil-applied, long residual, pre-emergent herbicides used with conventional crops with the foliar- applied, post-emergent herbicides used in GM crops means that application can be made only if, where and when they are needed."

Looking at the broader picture, Duke (2005) concluded that the overall quantity of herbicide used in GM, herbicide-tolerant crops is not much different to conventional crops. However, the substitution of the soil-applied, long residual, pre-emergent herbicides used with conventional crops with the foliar-applied, post-emergent herbicides used in GM crops means that application can be made only if, where and when they are needed. In addition, the herbicides used with GM crops are more environmentally benign in the soil and have shorter half-lives than those they replace (Duke 2005).

Another important benefit that is associated with the use of GM crops is the ability to adopt minimum- or no-tillage techniques, with the associated benefits of timeliness of sowing, improved crop water use, reduced fuel use, reduced soil erosion and potential build-up in soil organic matter (Brookes and Barfoot 2009; Duke 2005). The compatibility of GM crops with minimum- or no-tillage was one of the important factors in determining the likely profitability of the adoption of GM canola (Fulton and Keyowski 1999).

Brooks and Barfoot (2009) identified the increased reliance on a limited range of herbicides in GM crop production as a major concern. It is well known that herbicide resistance develops more rapidly in situations with increased selection pressure, such as use of a single herbicide (Owen 2008; Owen and Zelaya 2005). Kleter *et al.* (2008) highlighted this risk in a review glyphosate-tolerant (GR) crops in Europe. Using data from trials and the heretofore limited commercial production (only soybean in Romania), they concluded that “favourable environmental effects of the glyphosate-containing herbicide regimes on

GR crops appear feasible, provided appropriate measures for maintaining biodiversity and prevention of volunteers and gene flow are applied."

Australia

GM cotton and GM carnation has been produced in Australia since 1996. The introduction of insect-resistant and herbicide-tolerant, GM cotton has not been estimated to have impacted on the yield of the national crop, but is attributed to reduced pesticide and labour costs, and hence lower input costs (Acworth *et al.* 2008; Brookes and Barfoot 2009). More than 90 per cent of Australian cotton is now planted to GM varieties.

Roundup Ready canola was not grown commercially in Australia prior to 2008, and then only in New South Wales and Victoria. As the 2009 crop in those two states and the trials in Western Australia are yet to be harvested, discussion of the Australian experience with GM canola relates to one year of commercial crops as well as field trials and desktop analyses carried out prior to 2008.

The potential impact of the introduction of GM crops, including herbicide-tolerant canola, in Australia has been reviewed by several authors (Acworth *et al.* 2008; Holtzapffel *et al.* 2008; Ironfield and Barber 2007; Norton and Rush 2007; Norton 2003). In the absence of detailed local data, projected impacts of herbicide-tolerant, GM canola have been based on experiences in Canada and the United States. These are direct impacts of increased yields (of 8–38%), decreased herbicide use (by up to 40%), decreased input costs (by up to 25%) and seed costs (of $50–80/ha) and indirect impacts of improved quality, improved timeliness, reduced environmental impacts, increased health and safety, increased herbicide rotations and a requirement for improved harvest hygiene and post-harvest segregation.

Norton (2003) reported that the farm-level benefits of introducing GM canola in Australia would be earlier sowing, better weed control (compared with currently available canola cultivars) and increased yield and improved quality (due to removing the inherent yield and oil penalties associated with triazine tolerant canola). He performed an analysis based on a substitution of 50% of current triazine tolerant canola and 40% of conventional canola in Australia with GM canola. Based on this he estimated Australia-wide benefits of an increase of 200 000 hectares in canola grown under direct drilling or minimum tillage, a reduction of 640 tonnes in the amount of triazine used each year, increased canola production of 295 000 tonnes annually (based on an 8% increase in yield), increased wheat production of 64 000 tonnes due to the increased area of canola and a net benefit to the Australian grains industry of $135 million.

Acworth *et al.* (2008) utilised ABARE's general equilibrium model of the Australian economy (Ausregion) to estimate the potential economic impacts of cultivating more GM crops (canola, soybean, maize, wheat and rice) in Australia. The economic impacts were calculated as change in gross regional product (GRP) compared to the reference case of no adoption. Under the 'canola-only scenario' (i.e. adoption of only GM canola), projected economic benefits were $273 million (in 2006-07 dollars) over 10 years for the 'Rest of New South Wales' region (that is, New South Wales excluding the Murray Catchment Management Area), $180 million for Western Australia and $115 million for South Australia. In this analysis, delaying adoption for five years lead to foregone benefits of $97 million (in 2006-07 dollars) for Western Australia and $66 million (in 2006-07 dollars) for South Australia. These values are considered to be at the upper end of estimates for GM canola as the authors assumed a yield increase of 10%, net cost reductions of 2.4% for material cost and 3.8% for labour and an adoption rate of 100%.

In Western Australia, previous modelling of weed control and associated profitability with Roundup Ready canola compared with triazine tolerant canola suggested a small increase in profit associated with the former (Diggle *et al.* 2002). In this analysis it was assumed that there would be poorer control of ryegrass under triazine tolerant canola and of wild radish with Roundup Ready canola. No technology cost was included. The risk of the development of herbicide-resistant weeds due to continued use of the same herbicide was a threat in each system.

Similarly, Monjardino and her colleagues (2005) concluded that profitability would increase (by up to $33/ha) from the use of Roundup Ready canola, due to improved weed control and lower costs compared with triazine tolerant canola. They conducted a desktop study comparing weed control in the two systems using the Resistance Integrated Management model. They cautioned of the likely increase in the development of glyphosate-resistant weeds with increased use of glyphosate in the Roundup Ready canola system (Neve, *et al.* 2004; Owen and Zelaya 2005).

The yield of Roundup Ready canola cultivars in National Variety Testing trials that were conducted at Forbes (New South Wales) and Horsham (Victoria) in 2008 did not differ from the site mean yield (Pritchard and Marcroft 2009). There was a range in the performance of the cultivars of each of the different types of canola. The highest yielding Roundup Ready varieties were not significantly different from the highest yielding triazine tolerant or Clearfield varieties. These results were mirrored at demonstration sites across New South Wales and Victoria where the yields of the different canola systems were either the same, or the same for all systems apart from conventional canola (which was the highest). The yields at most of the sites were low due to the dry season in these areas in 2008.

Grower experiences with Roundup Ready canola during the first year of commercial production in 2008 were reviewed by Pritchard and Marcroft (2009). In 2008, Roundup Ready canola was grown on 9 600 ha by 108 growers in New South Wales and Victoria. Growers reported a number of positive features of the technology including weed control, simplicity of the system, herbicide benefits (use of cheaper and safer herbicides, able to reduce the use of selective herbicides in the rotation), compatibility with no-till and higher yields and gross margin (in some cases). The problems that were identified with the system were the poor performance of the cultivars (which was attributed to the fact that selection in Australian environments had slowed or ceased since 2004), problems with the availability of seed and increased anxiety associated with the actions of pressure groups.

"The above discussion indicates that farmers in Western Australia are likely to benefit from increased yields, decreased costs and reduced herbicide use (or at least use of herbicides with reduced toxicity and residual soil effects) if Roundup Ready canola is released for commercial production."

"The aim of the report is to present results of a quantitative, objective analysis of the potential impact of Roundup Ready canola in Western Australian farming systems."

The above discussion indicates that farmers in Western Australia are likely to benefit from increased yields, decreased costs and reduced herbicide use (or at least use of herbicides with reduced toxicity and residual soil effects) if Roundup Ready canola is released for commercial production. This report presents the results of an economic and environmental analysis of the farm-level impacts of Roundup Ready canola in broadacre farming systems in Western Australia. The analysis incorporates projected yields and patterns of herbicide use (modes of action, timing and quantities) to estimate gross margins, environmental impact and fuel use (and associated greenhouse gas production) for canola production systems. The aim of the report is to present results of a quantitative, objective analysis of the potential impact of Roundup Ready canola in Western Australian farming systems.

Economic and environmental analyses

Introduction

An economic and environmental analysis of the farm-level impacts of Roundup Ready canola in broadacre farming systems in Western Australia was conducted using production data adapted from Australian commercial trials of the different canola production systems and inputs based on those used in three broad rainfall zones of Western Australia (low, medium and high-medium rainfall). The analysis compared the impact of different canola production systems on total cropping gross margins and the estimated environmental impacts for each system. The impact of Roundup Ready canola was compared principally with triazine tolerant canola, the main conventionally-bred, herbicide-tolerant canola system that is in use in Western Australia currently. Data for non herbicide-tolerant, conventional and imidazolinone tolerant (Clearfield) canola are presented for completeness. The aim of the analysis was to provide quantitative and objective data of the potential impact of Roundup Ready canola in Western Australian farming systems.

Method

Economic analysis

There are numerous ways to measure the impact of new techniques or technologies on farming systems, including benefit-cost analysis, partial budgets, or whole-farm budgets. In this analysis a partial budget approach was taken whereby only the cropping system of the business was included in the analysis. Any livestock system was assumed to be constant, hence any impacts on livestock of changes in crop production were disregarded. Also, the analysis was undertaken using a case study approach for a “typical” farm size and rotation for cropping businesses in Western Australia. Three different cropping systems were modelled based on rainfall zones; low (250–325 mm), medium (325–450 mm) and medium-high (450–750 mm) rainfall.

It was assumed that the farm system, in which the canola is incorporated, is 3 200 ha, of which 70% is in crop at any one time. The remaining 30% is in fallow or non-arable. For simplicity three crops are included in the rotation, cereal, canola, and lupin. As mentioned in the background, lupin is one of the break crops used in Western Australian cropping systems as a source of nitrogen and for stored animal feed. In the sample systems used in the analysis, the level of canola and lupin was 10% or 20% of the area cropped (the average and upper proportions of these crops found from a recent survey-modelling study (Robertson *et al.* 2009)). The remainder of the cropped area is cereal crops. For simplicity this was assumed to be wheat, as wheat and barley prices and yields are highly correlated. The gross margin was fixed for lupins at $70/ha, while that of wheat varied based on several assumptions regarding location and rainfall. In the medium and medium-high rainfall zones the average wheat yield was 3 t/ha with a standard deviation of 0.56 t/ha. In the low rainfall zone wheat yield was 1.5 t/ha with a standard deviation of 0.25 t/ha. The wheat price was based on the average real price over the past 10 years.

Until 2009 genetically modified crops, including Roundup Ready canola, could not be sown in Western Australia, therefore yield and other performance data for these crops in Western Australia are not available. Detailed commercial trial data from farms in other regions of Australia (New South Wales and Victoria) were used in the analysis (previously summarised in Pritchard and Marcroft 2009; Slatter and MacLennan 2009). These data included yield and oil percentage for the different canola production systems. The data were modified to suit the three different cropping zones in Western Australia. This adaptation was done by using the Roundup Ready canola yield as the basis and adjusting the yields for the other systems to maintain the same relative yields as the trial data (Table 1). The yields that were used for Roundup Ready canola were based on five-year averages from the top 25% of commercial growers in each of the three rainfall zones (Farmanco 2008; Planfarm : BankWest 2009). On this basis, the Roundup Ready canola yield was assumed to be 0.8 t/ha for the low rainfall zone, 1.2 t/ha for the medium rainfall zone and 1.5 t/ha for the medium-high zone. The yields used in this analysis are comparable to those used in recent modelling of the optimal area of break crops on farms in Western Australia (Robertson *et al.* 2009).

Fertiliser and chemical application rates and types were derived from practices and farm plans common in each of the production zones, and differ somewhat to those used in the commercial trial reports provided. These data may be modified after the 2009 trials in Western Australia are complete and more is known about the chemical or fertiliser types and application rates. In the analysis herbicide applications were made assuming similar practices to those reported in the commercial trial data but adapted for the Mediterranean-type climate of Western Australia, i.e. at least one pre-sowing knockdown spray using treflan, atrazine or glyphosate was applied in each system.

Price data for inputs was fixed at 2009 prices as these were known for certain. Output prices are uncertain and, given prices for last year's crop and expectations of price for the current crop, prices were assumed to differ from 2008. A series of prices was derived using world prices adjusted for average exchange rates. In this derived series the average price for 42% oil canola was $475/t with a standard deviation of $40/t. Adjusting for transport and other costs the farm gate price of canola was assumed to be $445/t. However, premiums and deductions for estimated oil content were calculated as ±1% of seed value for each ±1% oil content difference from 42% oil (Table 1).

Machinery use was adjusted to account for different operations in the different systems (Table 1). Conventional systems undertook more operations, due to higher chemical applications than any of the other systems. The Roundup Ready system had lower machinery costs due to the lowest number of chemical applications.

Table 1 Machinery costs, adjusted canola yields, and oil percentages for each canola system used in the analysis.

The chief basis of comparison is triazine tolerant canola as it is the majority of canola currently grown in Western Australia.

Cropping System	Triazine tolerant	Roundup Ready®	Clearfield®[2]	Conventional[1]
Machinery cost ($/ha)	$128.49	$119.59	$128.49	$137.38
Yield in Low Rainfall Zone (t/ha)	0.68	0.8	1.02	0.73
Yield in Medium Rainfall Zone (t/ha)	1.02	1.2	1.37	1.07
Yield in Med–High Rainfall Zone (t/ha)	1.28	1.5	1.71	1.34
Oil content (%)	37.28	39.36	38.36	38.10

[1]non herbicide-tolerant
[2]imidazolinone tolerant

One set of benefits not included in the analysis is the potential reduction in costs due to different weed management options implicit in each technology. These costs are not included as it was extremely difficult to estimate these benefits with the data available. Also, the benefits from improved weed control may not be allocated to the canola gross margin but may be allocated to a different enterprise, e.g. the cereal or livestock enterprise.

Gross margins and total gross margin models were developed in EXCEL and stochastic simulation models, using Crystal Ball 2000, were run over 10 000 iterations to measure the mean and standard deviation of the different production systems and crop rotations.

Environmental impact

The herbicide application data from the commercial canola trials in New South Wales and Victoria which had been modified to represent Western Australian production were used to estimate farm-level environmental impacts based on an environmental impact quotient field rating and farm fuel use. Kovach *et al.* (1992) developed an environmental impact quotient (EIQ) that provides a simple, transparent method for assessing the estimated impacts of pesticide applications under different management techniques. The EIQ estimates the combined risk to farm workers, consumers, and the environment for a specific pesticide as an EIQ value for that pesticide. The EIQ provides a consistent and fairly comprehensive measure to contrast and compare the impact of various pesticides on the environment and human health. Readers should however note that the EIQ is an indicator only and does not take into account all environmental issues and impacts. The Integrated Pest Management team at Cornell University publish an up-to-date listing of EIQ values for current pesticides (http://nysipm.cornell.edu/publications/eiq/default.asp). The EIQ has been used in other studies comparing herbicide-resistant GM crops and other systems (e.g. Brookes and Barfoot 2009; Knox *et al.* 2006) thus providing a good basis of comparison with the current study.

An estimated Environmental Impact (EI) for each canola system was calculated using the EIQ field rating for each herbicide, which is calculated as the product of the EIQ and the application rate on an active ingredient basis. The input data came from commercial canola trials in New South Wales and Victoria conducted in 2008 and were modified to represent Western Australian production levels (as described above). Three of the common herbicide regimes that had been used in the trials of each system were used in the analysis. The EI was determined as the sum of the EIQ field ratings for each herbicide regime for each system. An average for each system was also calculated.

The Farm Fuel Calculator (Bowling *et al.* 2008; Salam *et al.* 2009) was used to estimate the fuel use and greenhouse gas production for each canola production system based on the number of herbicide applications for each. Values were calculated for the canola phase only and were based on a soil with 8% clay content, default settings for machinery power (105 kW pre-em., 150 kW post-em. and 250 kW seeding), speed (28 km/h) and boom size (33.5 m) and a direct harvest.

Results

"In the medium and medium-high rainfall systems Roundup Ready Canola consistently generated higher total gross margins than the triazine tolerant system, while those in the low rainfall zone were slightly lower. However, there was no significant difference… in economic terms in any of the rainfall zones…"

The general results show that the Clearfield technology generates higher total gross margin in all cases than the other three canola producing technologies (Table 2). This is due to the higher yields generated by the Clearfield method in the commercial trial data used in this study. The gross margin of the conventional system was higher than that of either the triazine tolerant or Roundup Ready canola; however the variance of the conventional system was also higher than any of the other systems, including Clearfield. This may have been as a result of the low number of observations for the conventional system in the trial data. In the medium and medium-high rainfall systems Roundup Ready canola consistently generated higher total gross margins than the triazine tolerant system, while those in the low rainfall zone were slightly lower. However, there was no significant difference between the triazine tolerant and Roundup Ready canola in economic terms in any of the rainfall zones, for either the 10% or 20% canola area models.

The variance of total gross margin for the Roundup Ready and triazine tolerant systems were typically much lower than for either the conventional or Clearfield systems. However, when compared on a coefficient of variation basis the three non-conventional systems are relatively equal.

The EIQ is similar for each of the herbicides used in the four canola production systems (Table 3). As there was no value published for haloxyfop this was given an average EIQ (20) based on the published toxicity information. The knockdown herbicides have a higher EIQ field use rating due largely to the

Roundup Ready compared with triazine tolerant canola:

- **environmental impact 135% lower;**
- **fuel use 5% lower;**
- **greenhouse gas production 1% lower.**

higher application rates and these values are reflected in the EI for each canola production system.

The estimated EI of the triazine tolerant canola system was on average more than double that of Roundup Ready canola and nearly four times that of the other two systems. The Clearfield canola system had the lowest estimated EI, being on average 95% of the conventional and 60% of the Roundup Ready systems (Table 3).

With effective weed control from either one to three spray operations, Roundup Ready canola required slightly less fuel and produced slightly less carbon emissions than the other systems (Table 4). The estimated fuel use of Roundup Ready canola was on average 5% lower than the triazine tolerant canola systems (Table 5). The Roundup Ready system also used less fuel than the conventional system (6%) and the Clearfield system (5%).

Table 2 Summary of total gross margins for different levels of canola in the crop rotation (10% and 20%) and different yields due to rainfall zone.

The chief basis of comparison is triazine tolerant canola as it is the majority of canola currently grown in Western Australia. It was assumed that the farm system is 3 200 ha, of which 70% is in crop at any one time.

Rotation System		Triazine tolerant	Roundup Ready®	Clearfield®[2]	Conventional[1]
Low Rainfall Zone					
10% canola, 0.8 t/ha canola	mean	$160,184	$159,957	$168,075	$165,565
	s.d.	$76,853	$78,402	$79,836	$88,847
20% canola, 0.8 t/ha canola	mean	$143,707	$143,254	$159,489	$154,470
	s.d.	$97,642	$101,618	$106,971	$131,721
Medium Rainfall Zone					
10% canola, 1.2 t/ha canola	mean	$390,118	$397,066	$414,600	$406,325
	s.d.	$178,323	$182,753	$192,584	$220,168
20% canola, 1.2 t/ha canola	mean	$397,579	$401,053	$409,820	$405,683
	s.d.	$154,002	$155,079	$158,724	$166,923
Medium-High Rainfall Zone					
10% canola, 1.5 t/ha canola	mean	$408,746	$415,615	$427,789	$416,588
	s.d.	$159,150	$160,359	$163,942	$177,361
20% canola, 1.5 t/ha canola	mean	$412,451	$426,189	$450,537	$428,135
	s.d.	$194,885	$200,535	$211,726	$250,342

[1]non herbicide-tolerant
[2]imidazolinone tolerant

Table 3 Product details, application rate, environmental impact quotient (EIQ) and EIQ field use rating for herbicides applied to canola crops in comparative trials conducted in New South Wales and Victoria in 2008 with rates adjusted for production levels in Western Australia.

Product name	Active ingredient	Active ingredient concentration (g/L or g/kg)	Application rate (L/ha)	EIQ (of the active ingredient)	EIQ field use rating (active ingredient applied basis)
Roundup PowerMAX®	glyphosate	540	0.8	15.33[2]	6.62
Roundup Ready® Herbicide	glyphosate	690	0.9	15.33[2]	9.52
Atrazine	atrazine	600	1.1	22.85	15.08
Select®	clethodim	240	0.19	17	0.78
Simazine	simazine	900	2	21.51	38.72
Intervix®[1]	imazamox	33	0.4	19.5	0.39
	imazapyr	15		22.3	
Lontrel™	clopyralid	300	0.08	18.1	0.43
Treflan™	trifluralin	480	1	18.8	9.02
Dual Gold	S-metolachlor	960	0.25	22	5.28
Verdict™	haloxyfop	520	0.1	20	1.04

[1]Intervix® contains both imazamox and imazapyr. The active ingredient concentration and EIQ in the table are for the two active ingredients, while the application rate and EIQ field rating is for the formulated product.

[2]EIQ value revised December 2009 (D. Marvin, NYS Integrated Pest Management Program—Cornell University, personal communication, 17th December 2009).

Table 4 Estimated environmental impact (EI) for four different canola production systems in Western Australia.

Calculations are based on pre-emergent and post-emergent application rates of herbicides and the environmental impact quotient (EIQ, from Table 3) for each. The estimated use is the proportion of paddocks under each system receiving each herbicide regime. These proportions were used to calculate the weighted average EI for each. The Average EI is the simple arithmetic average of the three values. The chief basis of comparison is triazine tolerant canola as it is the majority of canola currently grown in Western Australia.

System	No.	Pre-emergent	Post-emergent	Environmental Impact (EI)	Estimated use (%)	Average EI	Weighted average EI
Triazine tolerant	1	Atrazine, Simazine	Select®	54.6	45	44.4	40.3
	2	Atrazine	Select®	15.9	40		
	3	Treflan™, Atrazine	Simazine	62.8	15		
Roundup Ready®	1		Roundup[3]	9.5	32	19.9	16.4
	2		Roundup, Roundup	19.0	63		
	3	Treflan™	Roundup, Roundup	28.1	5		
Clearfield®[1]	1	Roundup[3]	Select®, Intervix®	12.1	30	14.2	14.8
	2	Treflan™	Select®, Intervix®	10.2	30		
	3	Treflan™	Intervix®, Roundup	20.4	40		
Conventional[1]	1	Treflan™	Select®, Lontrel™	10.2	45	11.9	10.8
	2	Treflan™	Verdict™, Lontrel™	10.5	45		
	3	Treflan™	Select®, Dual Gold	15.1	10		

[1]imidazolinone tolerant
[2]non herbicide-tolerant
[3]'Roundup' refers to Roundup Ready® Herbicide in the Roundup Ready® system and Roundup PowerMAX® in all others.

Table 5 Estimated fuel use and greenhouse gas emissions for four different canola production systems in Western Australia.

Values are for the canola phase only and were calculated using the Farm Fuel Calculator by varying the number of spray operations. The weighted averages were calculated using the estimated proportion of paddocks under each system receiving each herbicide regime (from Table 4). The chief basis of comparison is triazine tolerant canola as it is the majority of canola currently grown in Western Australia.

System	No.	No. spray operations	Fuel use (L/ha)	Weighted average fuel use (L/ha)	Carbon emissions (kg)	Average emissions (%)
Triazine tolerant	1	2	8.92	8.92	295	101
	2	2	8.92		295	
	3	2	8.92		295	
Roundup Ready®	1	1	8.92	8.43	286	100
	2	2	8.20		295	
	3	3	8.20		304	
Clearfield®[1]	1	2	8.92	8.92	295	102
	2	2	8.92		295	
	3	3	8.92		304	
Conventional[2]	1	2	8.92	8.99	295	101
	2	2	8.92		295	
	3	3	9.64		304	

[1]imidazolinone tolerant
[2]non herbicide-tolerant

Discussion

"Roundup Ready canola compares positively to triazine tolerant canola in Western Australian farming systems... In gross margin terms Roundup Ready canola was found to be comparable to triazine tolerant canola (and also to conventional and Clearfield canola)...

Roundup Ready canola compares positively to triazine tolerant canola in Western Australian farming systems. From an economic perspective Roundup Ready canola is a competitive enterprise. In gross margin terms Roundup Ready canola was found to be comparable to triazine tolerant canola (and also to conventional and Clearfield canola). While the gross margin for Roundup Ready canola in the medium and medium-high rainfall zones was higher than that for triazine tolerant canola, the large variance in margin meant that none of the differences were significant. This large variance of gross margins highlights the impact of seasonal variability on yield and hence profitability, irrespective of the herbicide system. Better estimates of the economic performance will be able to be made using the data from the comparative canola trials currently being conducted in Western Australia.

The environmental analysis showed that Roundup Ready canola was significantly less impacting than triazine tolerant canola, which is the principal system for producing canola in Western Australia at present (Oilseeds WA 2006). The estimated environmental impact of Roundup Ready canola was less than half than that of triazine tolerant canola. This is an important benefit from the Roundup Ready system that comes about due to the use of relatively environmentally benign, foliar applied post-emergent herbicide in place of high residual, soil applied herbicide. Removal of soil-applied, residual herbicides takes away a factor that may have a negative impact on following crops (Hashem 2008). Also, this change in the type of herbicide used makes the system more attractive to farmers and was one of the benefits identified by growers who took part in commercial trials in eastern Australia in 2008 (Pritchard and Marcroft 2009).

The environmental analysis showed that Roundup Ready canola was significantly less impacting than triazine tolerant canola, which is the principal system for producing canola in Western Australia."

In addition to the lower estimated environmental impact, Roundup Ready canola required slightly less fuel use and so produced slightly less carbon emissions compared with triazine tolerant canola (and in fact all other systems). This result is on the basis of effective weed control being achieved from one or two, post-emergent sprays in 95% of cases. The differences between the systems in these aspects is small and must be assessed in the context of the small contribution of on-farm fuel use to Australia's overall greenhouse gas emissions (Garnault 2008). As with the economic analysis, a more accurate estimate will be able to be completed once data are available from the nineteen GM canola trials being carried out in Western Australia in 2009. The main impact of fewer spray operations and lower fuel use is in reduced input costs for Roundup Ready canola, as discussed in the preceding economic analysis.

The calculations of fuel use and associated greenhouse gas production did not consider insecticide spray applications. Roundup Ready Herbicide and some of the herbicides that are commonly used with triazine tolerant and imidazolinone tolerant canola (e.g. Intervix and Select) are currently registered for mixing with a small number of the insecticides that are commonly used in canola. Such mixing of herbicides and insecticides has the potential to reduce fuel use due to fewer passes of spray vehicles. Our analysis shows that such fuel savings are likely to be small, though measurable.

The commercial trial data provided showed that Roundup Ready canola was on average 15% higher yielding than triazine tolerant canola. Although the chemical and machinery costs for Roundup Ready canola were lower, the trait fee somewhat offset these savings. In the low rainfall areas, the combined impact of lower absolute yields, yield variability and the trait fee was sufficient to result in no difference in gross margin between the Roundup Ready and triazine tolerant canola. Yield differences of 8–38% have been reported from trials in other states of Australia (Acworth *et al.* 2008), while results from company trials in Western Australia in 2000 (a dry year) found Roundup Ready canola had higher yield (approximately 13%) compared with triazine tolerant canola (Ralph and Kruithoff 2004). While there is little doubt that Roundup Ready canola can be as profitable as triazine tolerant canola in the Western Australian environment, yield differences would need to be at the upper end of the observed range in order to offset the trait fee and to make the crop more profitable. The importance of trait fee in this analysis is similar to other studies (Fulton and Keyowski 1999; Gianessi 2008). Ultimately the level of this fee is a commercial decision, but the sensitivity of the profitability of Roundup Ready canola to this cost, particularly at the relatively low yields in the Western Australian farming system, needs to be stressed.

"While there is little doubt that Roundup Ready canola can be as profitable as triazine tolerant canola in the Western Australian environment, yield differences would need to be at the upper end of the observed range in order to offset the trait fee and to make the crop more profitable."

Norton (2003) concluded "while canola is an important crop in its own right, its beneficial effect on wheat yields as part of a rotation, make it a critically important crop for the winter cropping belt of southern Australia." The Roundup Ready technology also has the ability to reduce weed burdens in the current crop and in subsequent crops. Although current Western Australian-based research is not available, older data from trials in WA showed that wheat yields in the year after Roundup Ready canola was between 50 and 400 kg higher than the yields from the triazine tolerant weed management system. This difference in yields represents a $12.50 to $100 positive benefit to the Roundup Ready system. These are of a similar magnitude to previous workers where the benefit of canola to following cereal crops was estimated as 20% yield gains from removal of herbicide resistant ryegrass adding $15–20 per hectare in a cropping programme in which canola made up 10% of the crop (Oilseeds WA 2006).

Another factor to be considered that is at present unpriced is the potential reduction in herbicide costs in the subsequent wheat crop due to lower burdens. Improved weed control across a wheat-canola-wheat-pea rotation incorporating Roundup Ready canola has been reported in Canada (Harker *et al.* 2004). One way to estimate the cost saving associated with improved weed control and hence reduced herbicide application would be to consider the value of chemicals not used, approximately $5–$10/ha, and a machinery cost saving of approximately $8–$10/ha, giving a further potential saving of $13–$20/ha.

"One way to estimate the cost saving associated with improved weed control and hence reduced herbicide application would be to consider the value of chemicals not used, approximately $5-$10/ha, and a machinery cost saving of approximately $8-$10/ha, giving a further potential saving of $13-$20/ha."

As mentioned above, the EI of each of the canola systems is determined principally by the pre-emergent herbicide that was used. Maintenance of the effectiveness of these chemicals in the face of herbicide-resistant weeds is a major concern for the long-term viability of any system (Hashem 2008; Heap 2009; Owen and Zelaya 2005; Peltzer *et al.* 2009). Herbicide resistance is more likely with a system, such as herbicide-tolerant crops, that is largely built around the use of a single herbicide (Diggle *et al.* 2003; Diggle *et al.* 2009; Werth *et al.* 2008).

Duke (2005) identified four types of weed shifts that may occur with herbicide-tolerant crops; changes in the weed spectrum, selection for resistant weeds, herbicide-resistant crop plants as weeds in other crops and the movement of transgenes to weeds. The first three are issues in any weed management programme as both the population of a single weed and the spectrum of weeds in an area will change in response to a weed management technique; be it herbicide, tillage, burning, seed-catching or some other technique.

The movement of transgenes to weed populations is presented as a the 'disaster scenario' associated with the release of herbicide-tolerant GM crops. However, the flow of genes *per se* is also not limited to GM crops (Mallory-Smith and Zapiola 2008). They noted that gene-flow occurs naturally and can be associated with pollen, seed or vegetative propagules. Examples of gene flow from GM crops to wild relatives, while rare, have been recorded (Légère 2005; Mallory-Smith and Zapiola 2008; Messean *et al.* 2007; Owen 2008). It is important that knowledge of the mechanisms of gene flow (Mallory-Smith and Zapiola 2008), international experiences with escaped herbicide-resistant individuals (Johnson *et al.* 2009; Knispel *et al.* 2008) and segregation of GM and non-GM crops (Coléno *et al.* 2009) are taken into account when formulating and implementing management guidelines for the growth of GM canola in Australia.

There is awareness of these important issues in the industry. Monsanto requires that all growers and agronomists who use or advise on their Roundup Ready technology are appropriately trained and that each paddock undergoes a herbicide resistance assessment as part of their crop management plan (Ralph and Kruithoff 2004; Wells and Slatter 2009). These requirements are admirable and important, but they alone will not be sufficient to reduce the risk of increased glyphosate-resistant weeds due to the use of Roundup Ready crops. Only a genuine, integrated weed management programme will achieve this aim. To quote farm consultant John Stuchbery, "the incidence of resistance to glyphosate is on the rise and there is no doubt that this will be exacerbated if Roundup Ready technology is misused. It is essential that growers and advisers adhere to the guidelines outlined in the Roundup Ready technical manual and the Paddock Risk Assessment and Management Option Guide (PRAMOG) and adopt integrated weed management practices to minimise this risk" (Pritchard and Marcroft 2009).

A large part of the estimated environmental benefit of the adoption of GM crops in the United States and Canada is attributed to the herbicide-tolerant technology facilitating the adoption of reduced or no-tillage cropping with its associated benefits such as reduced fuel use, improved timeliness of sowing, greater soil cover and potential build up of organic matter (Brookes and Barfoot 2009). This same benefit will not occur in Western Australia where reduced tillage has been practised at an increasing rate since the 1980s and is now so widely adopted that it is estimated that 75–97% of all crop production across the entire cropping area is carried out using no-till (D'Emden and Llewellyn 2004; D'Emden, *et al.* 2009). That said, herbicide-tolerant crops have a good 'fit' with no-till, so their implementation would be a useful tool for farmers using no-till in Western Australia. In fact, "ideal for no-till" was one of the benefits attributed to Roundup Ready canola by growers who took part in commercial trials in eastern Australia in 2008 (Pritchard and Marcroft 2009).

"...herbicide-tolerant crops have a good 'fit' with no-till, so their implementation would be a useful tool for farmers using no-till in Western Australia. In fact, "ideal for no-till" was one of the benefits attributed to Roundup Ready canola by growers who took part in commercial trials in eastern Australia in 2008 (Pritchard and Marcroft 2009)."

Further research

This study has identified several areas for further research.

- **Data from Western Australian farming systems**

There is a paucity of data on Roundup Ready canola in Australia and particularly in Western Australia. The analyses carried out for this report were done by adapting data from eastern Australia based on local knowledge, experience and published production and inputs. Clearly such analyses would benefit from access to data collected in the local environment. This will be partly addressed when the data from the 2009 commercial trials that are being conducted in Western Australia are available. These data will provide one year of comparisons of Roundup Ready canola and other canola systems from a limited range of sites and environments. What is really needed is a set of well-designed trials that are aimed at the quantification of impacts of various canola systems in rotations, particularly on following cereal crops. Such information, combined with economic and bio-physical modelling would enable a full analysis of the impacts of Roundup Ready canola in the farming system and would also help to answer specific research questions and to identify gaps in knowledge.

- **Yield improvements in Roundup Ready canola**

The available data as well as grower comments suggest that there is a need to improve the yield (and quality) of currently available Roundup Ready canola cultivars. With the lifting of the moratorium in eastern Australia it is expected that breeding and selection of cultivars for improved yield and production traits in the 'local' environment will proceed apace. There are positive signs of the potential for fairly rapid progress in this area as field testing carried out in 2008 indicated yield gains of 10–20% over existing Roundup Ready canola (Cowling 2009; Pritchard and Marcroft 2009). A particular need for large parts of the Western Australian wheatbelt as well as northern and western South Australia, western Victoria and western New South Wales is for canola cultivars, or other oilseeds, that are better adapted to low rainfall environments.

- **Integrated weed management programme**

As discussed above, the risk of increased development of glyphosate-resistant weeds is a very real one if production of Roundup Ready canola is not managed carefully. This will only be possible with the development and implementation of integrated weed management programmes in canola systems. This will require multiple control techniques that are applied across time and space and only in conjunction with clear thresholds of action and inaction. The alternative is to view the Roundup Ready technology in a similar manner to the way new herbicides have been used in the past, i.e. as a technology that will have a limited lifetime and will be discarded when it is no longer effective. It would seem to be a far better use of the time and effort that has gone into developing the technology to aim to sustain it over the medium- to long-term.

Conclusion

The analysis presented in this report provides an objective assessment of some of the farm-level impacts of Roundup Ready canola in Western Australian farming systems. The results suggested that Roundup Ready canola will be as profitable or more profitable than triazine tolerant canola with a reduced environmental impact and slightly reduced fuel use. This ex-ante analysis used the best available data at the time of writing. Further analyses, based on data from trials conducted in Western Australia will enhance this work.

It is important, should the current moratorium in Western Australia be lifted completely, that Roundup Ready canola is implemented not as a 'silver bullet' technology, but as another tool for farmers to use to make their systems more profitable and sustainable. The use of the technology needs to be couched in terms of clear conditions of use to ensure that it will still be a viable tool ten years from now and that potential negatives are minimised.

References

ABARE (2009) Australian Crop Report: WA 1998-2009. Report number 151. (Australian Bureau of Agriculture and Resource Economics: Canberra, ACT)

Acworth, W., Yainshet, A. and Curtotti, R. (2008) Economic impacts of GM crops in Australia. ABARE Research Report 08.4. 35 pp. (Commonwealth of Australia: Canberra, ACT)

Amjad, M. (2008) Canola variety guide Western Australia 2008. Farmnote 287. 3 pp. (Department of Agriculture and Food, Western Australia: Perth, WA)

Bowling, J., Short, N., Riethmuller, G., Fisher, J. S. and Salam, M. U. (2008) How much fuel does your farm use for different management operations? In Proceedings of the 14th Australian Society of Agronomy Conference, Adelaide, SA,

Brookes, G. and Barfoot, P. (2005) GM Crops: The Global Economic and Environmental Impact—The First Nine Years 1996–2004. AgBioForum 8, 187-196.

Brookes, G. and Barfoot, P. (2008) Global Impact of Biotech Crops: Socio-Economic and Environmental Effects, 1996-2006. AgBioForum 11, 21-38.

Brookes, G. and Barfoot, P. (2009) GM crops: global socio-economic and environmental impacts 1996- 2007. 128 pp. (PG Economics Ltd: Dorchester, UK)

Carmody, P. (2009) 2008 break crops survey report. In Crop Updates, Perth, WA, pp. 16–19. (Department of Agriculture and Food, Western Australia).

Carmody, P. and Pritchard, I. (2009) Attitudes of Western Australian wheatbelt growers to ‘Break Crops’. In Crop Updates, Perth, WA, pp. 20–25. (Department of Agriculture and Food, Western Australia).

Coléno, F., Angevin, F. and Lécroart, B. (2009) A model to evaluate the consequences of GM and non-GM segregation scenarios on GM crop placement in the landscape and cross-pollination risk management. Agricultural Systems 101, 49-56.

Cowling, W. (2009) Performance of Canola Breeders Roundup Ready® canola hybrid CHYB-166 in 2008. In Crop Updates, Perth, WA, pp. 184-185. (Department of Agriculture and Food, Western Australia).

D’Emden, F. H. and Llewellyn, R. S. (2004) No-till adoption and cropping issues for Australian grain growers. In Proceedings of the 4th International Crop Science Congress, Brisbane, QLD, (Australian Society of Agronomy).

D’Emden, F., Llewellyn, R. and Flower, K. (2009) Is the no-till revolution complete in WA? In Crop Updates, Perth, WA, pp. 304-307. (Department of Agriculture and Food, Western Australia).

Diggle, A., Neve, P. and Smith, F. (2003) Herbicides used in combination can reduce the probability of herbicide resistance in finite weed populations. Weed Research 43, 371-382.

Diggle, A., Peek, C., D’Emden, F., Evans, F., French, B., Grima, R., Harburg, S., Hashem, A., Holmes, J., Lemon, J., Newman, P., Paterson, J., Penny, S. and Portmann, P. (2009) The implications of GM glyphosate resistant lupin. In Crop Updates, Perth, WA, pp. 186-191. (Department of Agriculture and Food, Western Australia).

Diggle, A., Smith, P., Neve, P., Flugge, F., Abadi, A., Powles, S. and Eksteen, D. (2002) Role for Roundup Ready canola in the farming system. In Crop Updates, Perth, WA, pp. 70-72. (Department of Agriculture and Food, Western Australia).

Dill, G. M. (2005) Glyphosate-resistant crops: history, status and future. Pest Management Science 61, 219-224.

Dill, G. M., CaJacob, C. A. and Padgette, S. R. (2008) Glyphosate-resistant crops: adoption, use and future considerations. Pest Management Science 64, 326-331.

Duke, S. O. (2005) Taking stock of herbicide-resistant crops ten years after introduction. Pest Management Science 61, 211-218.

FAO (2007) FAOSTAT: Food and Agricultural commodities production—crops. Food and Agriculture Organization of the United Nations http://faostat.fao.org/site/567/default.aspx

Farmanco (2008) Profit Series : benchmarking the top performers in agriculture. 104 pp. (Farmanco: Mundaring, WA)

Fulton, M. and Keyowski, L. (1999) The producer benefits of herbicide-resistant canola. AgBioForum 2, 85-93.

Garnault, R. (2008) The Garnaut Climate Change Review. Cambridge University Press, Port Melbourne, Victoria. 680 pp.

Gianessi, L. P. (2005) Economic and herbicide use impacts of glyphosate-resistant crops. Pest Management Science 61, 241-245.

Gianessi, L. P. (2008) Economic impacts of glyphosate-resistant crops. Pest Management Science 64, 346-352.

Harker, K., Clayton, G., O'Donovan, J., Blackshaw, R. and Stevenson, F. (2004) Herbicide timing and rate effects on weed management in three herbicide-resistant canola systems. Weed Technology 18, 1006-1012.

Hashem, A. (2008) Weed control in herbicide-tolerant canola. Farmnote 291. 4 pp. (Department of Agriculture and Food, Western Australia: Perth, WA)

Heap, I. M. (2009) The international survey of herbicide resistant weeds. www.weedscience.com

Hirschberg, J. and McIntosh, L. (1983) Hirschberg and McIntosh. Molecular basis of herbicide resistance in Amaranthus hybrids L. Science 222, 1346-1349.

Holtzapffel, R., Mewett, O., Wesley, V. and Hattersley, P. (2008) Genetically modified crops: tools for insect pest and weed control in cotton and canola. 81 pp. (Bureau of Rural Sciences: Canberra, ACT)

Ironfield, D. and Barber, M. (2007) GM Canola: An Information Package. 159 pp. (Prepared for the Department of Agriculture, Fisheries and Forestry: Canberra, ACT)

James, C. (2003) Global review of commercialized transgenic crops. Current Science 84, 303-309.

James, C. (2007) Global Status of Commercialized Biotech/GM Crops: 2007. ISAAA Brief No. 37. 143 pp. (ISAAA: Ithaca, NY)

Johnson, W., Davis, V., Kruger, G. and Weller, S. (2009) Influence of glyphosate-resistant cropping systems on weed species shifts and glyphosate-resistant weed populations. European Journal of Agronomy 31, 162-172.

Kleter, G. A., Harris, C., Stephenson, G. and Unsworth, J. (2008) Comparison of herbicide regimes and the associated potential environmental effects of glyphosate-resistant crops versus what they replace in Europe. Pest Management Science 64, 479-488.

Knispel, A., McLachlan, S., Van Acker, R. and Friesen, L. (2008) Gene Flow and Multiple Herbicide Resistance in Escaped Canola Populations. Weed Science 56, 72-80.

Knox, O. G. G., Constable, G. A., Pyke, B. and Gupta, V. V. S. R. (2006) Environmental impact of conventional and Bt insecticidal cotton expressing one and two Cry genes in Australia. Australian Journal of Agricultural Research 57, 501-509.

Kovach, J., Petzoldt, C., Degnil, J. and Tette, J. (1992) A method to measure the environmental impact of pesticides. New York's Food and Life Sciences Bulletin 139, 1-8.

Légère, A. (2005) Risks and consequences of gene flow from herbicide-resistant crops: canola (Brassica napus L) as a case study. Pest Management Science 61, 292-300.

Mallory-Smith, C. and Zapiola, M. (2008) Gene flow from glyphosate-resistant crops. Pest Management Science 64, 428-440.

Messean, A., Sausse, C., Gasquez, J. and Darmency, H. (2007) Occurrence of genetically modified oilseed rape seeds in the harvest of subsequent conventional oilseed rape over time. European Journal of Agronomy 27, 115-122.

Monjardino, M., Pannell, D. and Powles, S. (2005) The economic value of glyphosate-resistant canola in the management of two widespread crop weeds in a Western Australian farming system. Agricultural Systems 84, 297-315.

Neve, P., Sadler, J. and Powles, S. (2004) Multiple herbicide resistance in a glyphosate-resistant rigid ryegrass (Lolium rigidum) population. Weed Science 52, 920–928.

Norton, R. M. and Roush, R. T. (2007) Canola and Australian Farming Systems 2003 - 2007. 10 pp. (The University of Melbourne: Melbourne, VIC)

Norton, R. (2003) Conservation farming systems and canola. 35 pp. (The University of Melbourne: Melbourne, VIC)

Oilseeds WA (2006) Growing Western Canola: An overview of canola production in Western Australia. Oilseeds Industry Association of Western Australia, Belmont, WA. 53 pp.

Owen, M. D. (2008) Weed species shifts in glyphosate-resistant crops. Pest Management Science 64, 377-387.

Owen, M. D. and Zelaya, I. A. (2005) Herbicide-resistant crops and weed resistance to herbicides. Pest Management Science 61, 301-311.

Peltzer, S. C., Hashem, A., Osten, V. A., Gupta, M. L., Diggle, A. J., Riethmuller, G. P., Douglas, A., Moore, J. M. and Koetz, E. A. (2009) Weed management in wide-row cropping systems: a review of current practices and risks for Australian farming systems. Crop and Pasture Science 60, 395-406.

Planfarm : BankWest (2009) Planfarm BankWest Benchmarks 2008–2009. 77 pp. (Planfarm Pty Ltd and BankWest Agribusiness Centre: West Perth & Wembley, WA)

Pritchard, F. and Marcroft, S. (2009) GM canola - performance and experiences in 2008:

Roundup Ready® canola grower case studies, field trial results and demonstration site activities. 31 pp. (Grains Research and Development Corporation: Barton, ACT)

Ralph, A. and Kruithoff, D. (2004) The Benefits of Roundup Ready® canola for Western Australian Farming Systems. In Crop Updates, Perth, WA, (Department of Agriculture and Food Western Australia).

Robertson, M., Lawes, R., Sands, R., White, P., Byrne, F. and Bathgate, A. (2009) The area of break crops on farm: What farmers are doing compared to estimates based on maximising profit. In Crop Updates, Perth, WA, pp. 30-35. (Department of Agriculture and Food, Western Australia).

Salam, M. U., Riethmuller, G. P., Maling, T., Short, N., Bowling, J. and Fisher, J. (2009) Farm Energy Calculator. 38 pp. (Rural Industries Research and Development Corporation: Canberra, ACT)

Slatter, M. and MacLennan, A. (2009) Nufarm Roundup Ready® Canola Systems Trials—2008. In Crop Updates, Perth, WA, pp. 192-193. (Department of Agriculture and Food, Western Australia).

Tan, S., Evans, R. O. and Singh, B. (2006) Herbicidal inhibitors of amino acid biosynthesis and herbicide-tolerant crops. Amino Acids 30, 195-204.

Vaughn, K. C. (1986) Characterization of triazine-resistant and -susceptible Isolines of canola (Brassica napus L.). Plant Physiology 82, 859–863.

Wells, A. and Slatter, M. (2009) Roundup Ready® canola—2008 limited commercial release. Getting the system right. In Crop Updates, Perth, WA, pp. 194-197. (Department of Agriculture and Food, Western Australia).

Werth, J. A., Preston, C., Taylor, I. N., Charles, G. W., Roberts, G. N. and Baker, J. (2008) Managing the risk of glyphosate resistance in Australian glyphosate- resistant cotton production systems. Pest Management Science 64, 417-421.