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Conservation farming systems and canola

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Executive summary

Canola is now the third most important winter grain crop grown in Australia and has a four year average gross value of production of $596 million, even with the inclusion of production from the 2002/2003 drought.

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.

Research in Australia has demonstrated that wheat following canola has a 20% yield benefit over wheat following wheat. This could provide an additional 500,000 tonnes to the national wheat crop.

Weeds are a significant issue for canola growers. Brassica weeds (including wild radish and wild mustard) are not able to be controlled in conventional canola cultivars.

As well as competing with the crop, some Brassica weeds contain unacceptable levels of erucic acid and glucosinolates that contaminate canola seed.

In addition to conventional canola, Australian farmers grow two conventionally-bred herbicide tolerant types: TT (triazine tolerant) canola and IT (imidiazolinone tolerant) canola.

The introduction of two lines of genetically modified (GM) canola with tolerance to either Roundup® or glufosinate-ammonium herbicides will give farmers other weed control options.

Most importantly, GM canola will allow farmers to sow earlier, achieve better weed control when compared to current canola weed control systems and avoid the inherent yield and oil penalties associated with TT canola.

Based on a scenario of GM canola replacing 50% of TT canola and 40% of conventional canola, and with an additional 160,000 hectares of canola plantings because of the new technology, it could be estimated that:

- an extra 200,000 hectares of canola would be grown under direct drilling or minimum tillage
- 640 tonnes less triazine herbicide would be used each year
- average Australian canola yields would increase from 1.27t/ha to 1.38 t/ha, with an increase in canola production estimated at 295,000 tonnes annually
- wheat production would increase by 64,000 tonnes on the additional canola area.

This increase in canola and wheat production would be worth $135 million to the Australian grains industry.

The increased production could be achieved while making the canola industry more sustainable through better integrated weed management and soil conservation practices.

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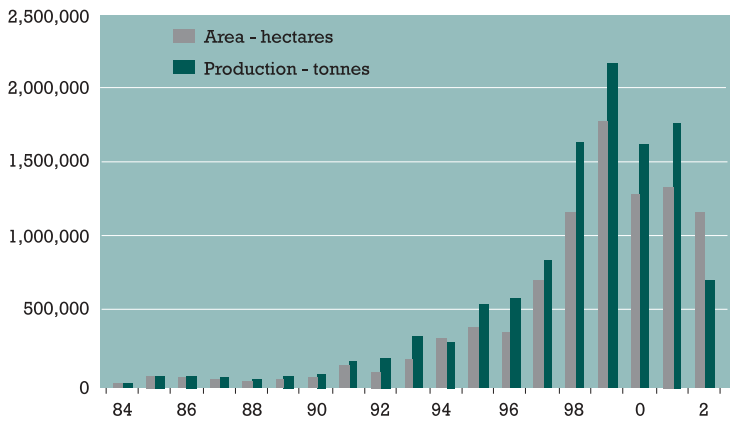
Introduction

Rapeseed (*Brassica napus*) has been grown in Asia and Europe for over 4,000 years, with its original use as a lighting oil (Bunting 1986). The oil extracted from the seed was used as a marine lubricant during the wars, and it was not until new quality types were developed in the 1950s in Canada that the crop became widely grown (Colton and Potter 1999). New rapeseed types were bred with low erucic acid in the oil and with a meal (seed with the oil extracted) suitable for use by intensively housed animals. The term canola now indicates a particular quality type (edible oil) of rapeseed with less than two per cent erucic acid and less than 30 micromoles per gram of glucosinolates in the meal (Canola Council of Canada 2002). Other species of Brassica, such as mustard (*Brassica juncea*) and Polish rape (*Brassica rapa*) are also grown commercially to produce similar oils.

Although canola was produced in Australia during the early 1970s, the fungal disease blackleg (*Leptosphaeria maculans*) caused growers to lose confidence in imported cultivars (Colton and Potter 1999). Breeding programs in Victoria, Western Australia and New South Wales produced the first blackleg tolerant canola types in 1980. More recently, an alternative source of blackleg resistance was identified from field populations of *Brassica sylvestris* and transferred via hybridisation, embryo rescue and chromosome doubling into *Brassica napus*. These genes are available in the 'Surpass' lines at present produced by Pacific Seeds (Easton 2001).

Up until the mid-1990s, seed yields were still relatively low, approximately 50% of wheat yields, and further genetic improvement along with the use of fertilizer nitrogen and liming, took canola to approximately 60% of wheat yields by the early 1990s. Potter et al. (1989) reviewed the impact of genetic improvement from 1981 up until 1989. During that time, seed yield increased by 29%, blackleg resistance was at higher levels and plants became shorter and less prone to lodging. Oil and meal quality also improved to consistently meet canola quality standards.

Figure 1: Area sown and production of canola, 1984 to 2002 (sources ABARE crop reports, AOF 2003).



Between 1991/92 and 1999/2000, the area planted to canola in Australia grew from about 100,000 hectares to 1.9 million hectares with production increases from 200,000 tonnes to 2.4 million tonnes **(Figure 1)**.

This rapid expansion challenged the industry to change from supplying a domestic crushing market to an export focus, with approximately 80% of production exported in 2000. New markets for Australian canola were developed in Japan, Bangladesh, Mexico and recently China (Nelson et al. 2001).

Since 2000, the area sown to canola has declined, mainly due to a series of late breaks to the seasons and improved wheat prices. The drought in 2002 has reduced canola production by 65% nationally, with New South Wales suffering the largest decline, down 87% (ABARE 2003).

Much of the variation in area planted since 1995 has been in Western Australia which rose to almost 1 million hectares in 1999/2000, but since then has been around 300,000 to 500,000 hectares (Carmody et al. 2001).

Nelson et al. (2001) reviewed the future of markets and prices for canola across several scenarios and in their baseline estimate concluded that canola production area would return to over 1.6 million hectares by 2010, and overall canola production would rise to 2.4 million tonnes. The scenario projections then depended on domestic policy in the United States and European Union which impact on world wheat prices, which in turn will largely determine the amount of canola produced in Australia.

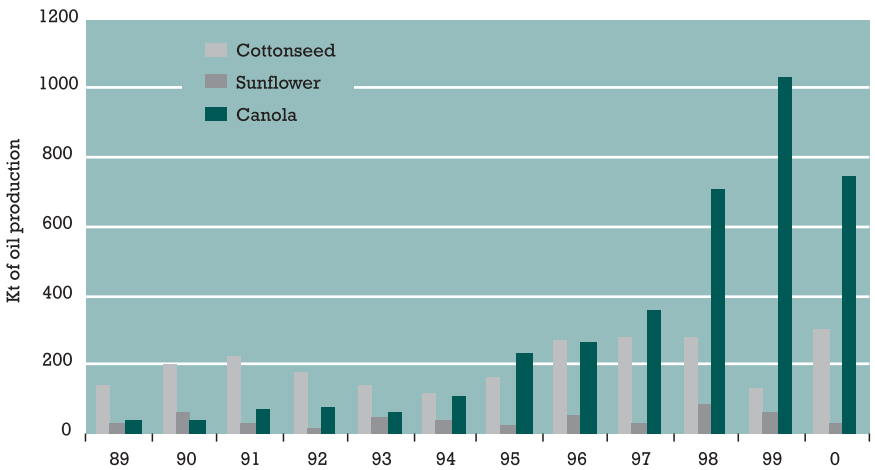
Since 1980, cottonseed production – a co-product of the cotton industry - also increased but canola overtook cottonseed in tonnage crushed by 1997, and due to the much higher oil content of canola, actually overtook cottonseed oil production in 1995 **(Figure 2)**. A significant factor in the growth of the domestic market for canola oil is due to the nutritional benefits associated with the particular fatty acid composition (Clifton 1999).

In summary, the canola industry has become a significant sector of Australian agriculture. The average for gross value of canola production from 1999 to 2002 was $666 million (ABARE 2002).

Even in drought affected 2002/3, approximately 730,000 tonnes of canola was produced (AOF 2003). World prices have been buoyant and ABARE (2003) indicative prices for the last quarter of 2002 and first quarter of 2003 averaged $512/t (at Port Melbourne), which gives Australian canola production an estimated value of $374 million for 2002, making it the third largest winter grain crop in Australia behind wheat and barley (ABARE 2003). The current and future development of the industry is based on the breeding of better varieties, improved agronomy and the continued collaboration between all industry sectors.

The objective of this paper is to discuss the impact of the adoption of new gene technologies on farming systems, with particular respect to the impact on farm profitability and conservation farming.

Figure 2: Oil production from the principal oilseed crops grown in Australia (ABS 2003).



The new technology

The Australian grains industry has rapidly adopted new technologies. Donald (1965) produced some trend lines in Australian wheat yields between 1860 and 1960, and these trends were continued and then extrapolated by Angus (2001) **(Figure 3)**. These authors noted that particular innovations have led to increased wheat yields, and Angus (2001) proposed that the most recent increases were due to the break crop benefits of broadleaf crops, particularly canola, as well as the increased use of nitrogen fertilizers.

Figure 3 shows that the adoption of canola during the past decade was a significant innovation for the whole of the Australian grains industry. Even though canola is only ten per cent of the wheat area, it is approximately 40% of the area cropped to non-cereals in temperate Australia (ABARE 2003) and as such provides an excellent break crop between cereal crops. Grain growers have readily adopted canola production systems, not just because canola provided good returns in its own right but also because it assists in raising the yield of other crops.

There are currently two distinct canola agronomic systems used in Australia; conventional canola, and canola with a conventionally-bred herbicide tolerance.

The proposed release of canola cultivars genetically modified (GM) to confer herbicide tolerance will give Australian growers more herbicide tolerant canola options. Applications for the commercial release of two GM canola cultivars are currently before the Office of the Gene Technology Regulator (OGTR).

The new technology

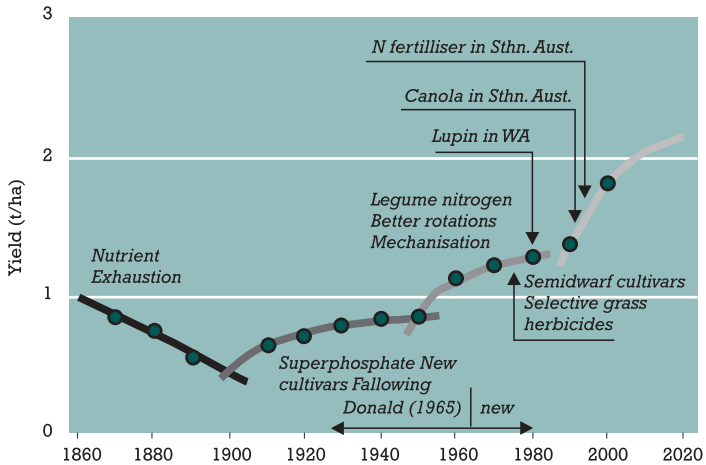
Canola's benefit as a break crop has been a major factor leading to a jump in average Australian wheat yields over the past decade.

Weeds are a major problem and a limiting factor to the use of a canola in a rotation.

Australian growers currently have two agronomic systems for controlling weeds: conventional canola and two types of conventionally-bred herbicide tolerant canola (TT and IT).

The two proposed GM canola varieties with herbicide-tolerant characteristics (Roundup Ready® tolerant and glucosinolate-ammonium tolerant) being considered by the Office of the Gene Technology Regulator will provide growers with additional weed control and production system options.

Figure 3: Decadal Australian wheat yields with notes on trends (Donald 1965, Angus 2001) from *Aust. J. Exp. Agr.* (2001), 41, 277-288.



Conventional canola

Perhaps the major weakness in conventional canola production systems is the limited opportunity for broadleaf weed control. Prior to 1993, there were no post-emergence herbicides for the control of weeds such as wild radish (*Raphanus raphanistrum)*, muskweed (*Myagrum perfoliatum*) and charlock (*Sinapis arvensis*) in canola crops (Sutherland 1999). There are several group A herbicides registered for grass weed control, and a group I herbicide (clopryralid) for control of various *Asteraceous* weeds. In addition, robust weed control has been routinely provided to canola and other crops by the pre-emergence use of the group D herbicide, trifluralin.

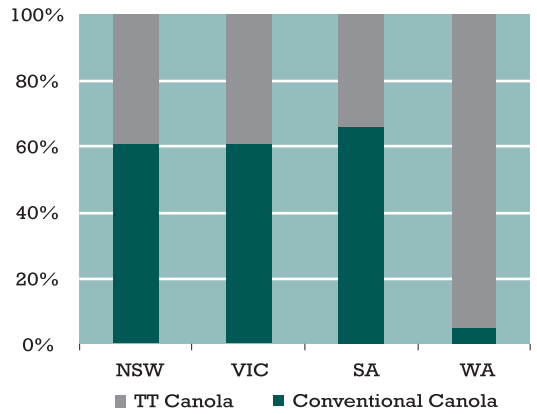
Despite these control options, the pressure of particular weeds and need for lower costs have led to the inclusion of various herbicide tolerance traits into canola and varieties with these traits have been widely adopted in Australia (Preston 2003).

Conventional canola varieties are susceptible to particular triazine (group C), sulfonyl urea and imidazolinone (group B) and most other broadleaf herbicides used in grain production. The presence of residues of herbicides is now a major factor determining the position of crops within a rotation. For example, the plant-backs from the prior crop can vary from nine months (simazine) to 34 months (imazethapyr), which restricts crop selection following the use of these herbicides. As well, there is widespread weed resistance to group A and group B herbicides through grain producing areas (Heap 2002). **Appendix 1** describes commonly used canola herbicides and their resistances management groups.

TT Canola

Triazine-tolerant (TT) canola varieties were the first herbicide tolerant (HT) crops in Australia with the release of the cultivar Siren in 1993 (Colton and Potter 1999). Triazine herbicides are widely used in pulse crops and for winter cleaning of pastures prior to the cropping phase (Gill and Holmes 1997). The adoption of the TT canola variety Karoo contributed to much of the production increase in Western Australia, where area sown went from 95,000 hectares to 950,000 hectares between 1996 and 1999. By 1999, Karoo comprised about 90% of the area sown in Western Australia (Carmody et al. 2001). TT cultivars make up less than one per cent of the area grown in North America but about 55% of the area sown in Australia **(Figure 4)**.

Figure 4: Australian canola varieties - 2002. Area under conventional canola vs TT canola.



TT canola cultivars are able to tolerate high dose rates of triazine (group C) type herbicides. This tolerance is inherited in the cell cytoplasm, which means the genes for resistance are not carried in pollen, but remain in the maternal parent. TT varieties suffer from an inefficient photosynthetic system, which leads to lower vigour, reduced growth, yield and seed oil content (Arntzen et al. 1982). Robertson et al. (2002) used a simulation modelling approach which identified a 26% lower seed yield for TT canola compared to conventional canola types in weed free situations. Despite this penalty, TT cultivars have enabled growers to use robust in-crop herbicides to control weeds that were intractable in conventional varieties. This technology has been reliable and relatively cheap, which has contributed to its widespread adoption in Australia.

IT Canola

In 2000, canola varieties (Clearfield®) with tolerance to imidiazolinone (group B) herbicides were released in Australia. This trait was induced by using mutagenisis, a traditional plant breeding technique and the varieties do not carry the inherent yield penalty of TT canola. The herbicide used with IT canola (On-Duty®, imazapic/imazapyr) has good activity on a wide spectrum of weeds although it does have residual action which may restrict crop selection.

For example, while peas, beans and chickpeas can be planted in the year after IT canola, conventional canola cannot be sown for 34 months after using On-Duty®.

In Canada, IT canola varieties comprise about 17% of the area sown (Buzza 2001), whereas, it is less than five per cent in Australia.

Resistance to group B herbicides has been identified in 15 Australian weed species, including populations of wild radish and annual ryegrass (*Lolium rigidum*) (Heap 2002). This pre-existing resistance would be likely to restrict the widespread use of IT canola in Australia. Carmody and Hashem (2001) found that the best IT lines produced higher gross margins than the best TT lines in Western Australia, although they recognised that appropriate herbicide rotation was integral to ensuring the technology remained useful to growers.

Genetically modified canola

In March 2003 there were two applications before the OGTR for general release of genetically modified canola types that incorporate particular herbicide tolerance traits. The term 'genetically modified' (GM) is used to indicate that particular 'transgenes' have been stably integrated into the genetic makeup of an organism (Green and Salisbury 1998). Two particular GM canola types are being considered.

InVigor® hybrid canola

InVigor® hybrid canola contains novel genes for tolerance to the herbicide glufosinate-ammonium and pollination control. Because of heterosis (hybrid vigour), InVigor® hybrid canola varieties have been shown to have a 10-15% yield benefit over similar open-pollinated conventional varieties in Canada (Zand and Beckie 2002). This type of GM canola was released in Canada in 1997 and now makes up approximately 12% of the planted area (Buzza 2001).

The glufosinate-ammonium tolerance presented by InVigor® hybrid canola provides a novel HT trait to growers in Australia. Glufosinate-ammonium (Liberty®) is a contact broad-spectrum herbicide, with some systemic activity. It has no significant residual activity in the soil. Glufosinate-ammonium is used as a split application post-emergence in InVigor® hybrid canola and is a group N herbicide. While there are no other registered uses in the cropping industry, Basta®, which has the same active constituent as Liberty®, is a broad spectrum herbicide used in certain vine and tree crops. This, along with its particular mode of action, means that it has a low probability of inducing resistance in weed populations. The label and weed spectrum for glufosinate-ammonium has not been released as yet, but based on the Basta® label, the spectrum of weeds controlled should provide growers with a useful weed management tool.

Roundup Ready® canola

Roundup Ready® canola contains genes that confer tolerance to the broad spectrum herbicide Roundup® or any other formulation of glyphosate registered for use on Roundup Ready® canola. The tolerant plants are protected by two enzymes, one that confers metabolism and the other that provides tolerance to glyphosate. Glyphosate is one of the most widely used herbicides in farming systems, where it is commonly used as a pre-plant knockdown. It is a broad spectrum systemic herbicide absorbed by the foliage with rapid translocation throughout the plant. It is inactivated on contact with soil and has no residual activity. The label and recommended use rates for Roundup® on Roundup Ready® canola have not yet been released, although based on current registered pre-crop uses, rates of 440-660 grams active ingredient (g ai)/ha could be expected.

The development of this HT canola will allow growers to use Roundup® in-crop. The overall performance of Roundup Ready® canola varieties will depend on the genetic background into which the HT trait is placed as well as the degree of weed control achieved with the herbicide and other agronomic benefits. In Canada, Harker et al. (2000) compared a range of herbicide tolerant canola production systems and found that weed control was usually the best where glyphosate was used. In Canada, Roundup Ready® canola varieties represent about 50% of the total canola area planted (Buzza 2001).

This HT trait has also been included in a range of other crops such as corn, cotton and soybeans which have been widely adopted in North America. For example, 68% of US soybean production now uses Roundup Ready® varieties that carry Roundup Ready® technology (Carpenter and Gianessi 2001). Roundup Ready® cotton varieties entered the Australian market for the first time in 2001/2002.

In summary, Australian canola production systems presently use at least two different weed management packages, including two particular HT canola types, TT and IT canola. Additional HT canola varieties, developed through genetic manipulation, provide opportunities for alternative crop production and weed management systems for growers. There are particular situations where each of these production systems will provide growers with the new options for enhanced canola production.

Canola and wheat

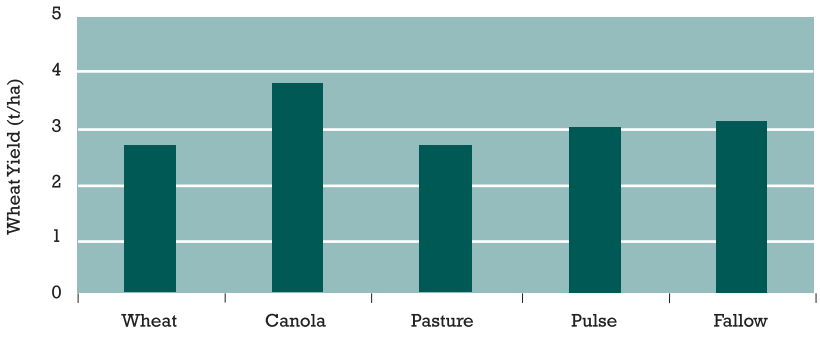
The increase in the area of canola grown in Australia has significant flow on benefits to subsequent crops – especially wheat. An outcome of the increase in canola area in eastern Australia has been an increase in the use of fertilizer nitrogen (N) and the application of lime to acid soils. These improved practices have indirectly and directly flowed through to other sectors of the grains industry. For example, many farmers who grew canola realised the need for additional N for that crop (Hocking et al. 1999), and then extended that management practice to wheat crops as well.

The rotational benefits of *Brassica* crops such as canola were recognised by farmers and researchers soon after the introduction of the crop, and it is proposed that this positive benefit was one of the major factors contributing to the rapid adoption of canola (Norton et al. 1999). Angus et al. (1989) reported a break crop effect in arid regions in New South Wales, where wheat responses to applied N were more reliable and generally greater for wheat following canola than wheat following other oilseeds.

The magnitude of the break crop effect due to canola is significant to the grains industry. **Figure 5** is derived from a Victorian survey of 226 wheat crops and shows that wheat yields were highest following canola, 3.9 t/ha, compared to wheat on pulse, 3.1 t/ha, and wheat on fallow, 3.2 t/ha (Norton et al. 1999). Angus et al. (2001) summarised the results of several crop sequence experiments across the grain producing areas of Australia and concluded that there was a mean yield increase of about 20% of wheat grown after canola compared to wheat after wheat. Similar results were seen in 14 on-farm experiments in southern New South Wales, where canola after wheat produced a 21% higher yield than wheat after wheat (Angus et al. 1999).

The nature of the break crop benefit due to wheat after canola has been the subject of research in Australia during the 1990s (Angus et al. 1991, Kirkegaard et al. 1994, Kirkegaard et al. 1998, Kirkegaard et al. 2000). In essence, the main benefit of canola would appear to be due to the control of cereal root diseases by the production of particular chemicals from the roots – termed biofumigation.

Figure 5: Wheat yield following particular crops. Results of a survey of 226 Victorian wheat crops in 1995 (Norton et al. 1999).



Although several other factors could be aiding subsequent wheat growth, such as differences in organic matter cycling (Angus et al. 2001), it is clear that canola does provide a significant benefit to subsequent wheat crops.

Angus et al. (1999) estimated that the effect of this improvement was a benefit of $147 per hectare for a two year canola/wheat rotation over a wheat/wheat rotation. Based on the yields, costs and prices they presented, 27% came from the canola, while the balance came from the subsequent wheat crop. Angus et al. (1999) noted that wheat would substitute into rotations when its price was about 60% of the price of canola. Current on-farm prices (with various discounts) for canola ($420/t) and wheat ($250/t) (ABARE 2003), place the difference between the two rotations at about $30/ha over 2 years, mainly due to the relatively high wheat price compared to canola price. A similar price ratio (60%) was estimated by Scott et al. (1999) using a whole farm linear programming framework, who concluded that when wheat was $150/t, canola would constitute 25% of cropped area on a southern New South Wales farm when canola prices rose above $340/t with a yield of around 1.8 t/ha.

Based on this information, as canola area increases, there will be a better disease break that will result in higher wheat yields, and this benefit would be of the order of an additional 0.4 t/ha in the subsequent wheat crop. Based on this, with 1.4 million hectares of canola sown, probably 90% is sown back to wheat, and then with a five year mean wheat yield of 1.93 t/ha (ABARE 2003), this disease break could account for almost half a million tonnes of wheat, with a current value of around $100 million per year.

Canola and wheat

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.

Research in Australia has demonstrated that wheat following canola has a 20% yield benefit over wheat following wheat. This provides an extra 500,000 tonnes to the national wheat crop, worth an estimated $100 million per year.

GM canola production systems

Rotations

Alemseged et al. (2001) surveyed 1000 growers in Australia and found that in the southern and western regions, 29% of growers used mixed winter crops, while an additional 55% incorporated pastures into those cropping systems. Typically, canola is planted after either a pasture phase where sheep are significant or following a cereal or pulse crop in mixed cropping rotations. Fallow cropping has significantly declined in southern Australia due to economic and environmental pressures. Fallow leaves land out of production and the bare soils typically lead to wind and water erosion. 'Summer fallow' is used in northern cropping areas, combined with stubble retention and weed control using herbicides (Felton et al. 1995). In south eastern Australia on heavy soils, O'Leary (1995) concluded that residue retention was more important than zero tillage and some tillage may be prudent for weed management. In other areas, tillage is considered more damaging and higher populations of particular weeds occur where cultivation is used (Pratley 1995).

New South Wales has the most intensive canola production systems **(Table 1)**, and some growers in the southern districts have adopted a continuous cropping canola/wheat rotation. Due to disease pressure and the appearance of new problem weeds, it is not likely that this system would remain sustainable, although canola intensities of 25% (one in four crops) on farms would be quite common in across Australia.

Weed management

Of land management issues associated with cropping, Alemseged et al. (2001) identified that farmers rank weeds as the top problem. From the same survey, farmers ranked annual ryegrass as the most difficult weed to control in southern and western cropping regions, with this weed present on 2.5 million and 3.1 million hectares respectively in each region. The presence of weeds is a significant management issue for selection of paddocks for the production of canola. Brassica weeds are not able to be controlled in conventional canola cultivars and so paddocks with low infestations are recommended (Colton and Sykes 1992). As well as competing with the crop, some Brassica weeds contain unacceptable levels of erucic acid and glucosinolates and the presence of these seeds in harvested grain can contaminate canola. In Western Australia, Alemseged et al. (2001) estimated that 2.2 million hectares were infested with wild radish.

Sutherland (1999) discussed a series of different weed management scenarios for canola. In a pasture ley system, grass weed reduction can occur in the pasture in the year prior to the canola crops, either by grazing, hay cutting or using pasture topping, which lead to an 80% yield increase in canola and 11% in the subsequent wheat crop with consequent increases in crop gross margins. Typically, trifluralin would be used pre-emergence, with clopyralid and fluazifop used to target annual Asteraceous weeds and grass weeds respectively.

Table 1: Five year averages of canola production by state (ABARE 2003), showing the proportion of triazine tolerant (TT) canola grown, canola as a proportion of winter crop area and canola as a proportion of broad-leafed winter crops (non-cereals).

State	Area (ha)	Yield (t)	%TT canola	Canola as % winter cropping area	Canola as % of non-cereals area
NSW	380,000	590,000	25	4.6	64
WA	460,000	460,000	90	4.0	27
Vic	192,000	260,000	40	5.5	33
SA	117,000	155,000	40	2.3	29
Australia	1,149,000	1,465,000	55	3.6	25

These systems enable integrated weed management (IWM) approaches across the pasture and crop phase, and where Brassica weeds are not problems, higher yielding conventional canola varieties can be used.

Because returns for livestock products were low during the 1990s, pasture phases shortened and in some systems pastures completely disappeared. Under these systems, weed control depends more on herbicides, and this dependence increases where farmers seek to minimise pre sowing mechanical weed control using cultivation. The amount of pre seeding weed control undertaken in these systems will depend on the timing of the autumn break, the amount of crop residue and the farmer's attitude to cultivation. There has been a move towards reduced cultivation and in most cases, pre sowing weed control relies on a knockdown herbicide, either glyphosate or diquat/paraquat. Due to the need to wait for weed emergence, these operations may delay sowing one or two weeks, depending on weed pressure. Many growers seek to reduce cultivation to keep ryegrass germination to a minimum and use trifluralin immediately pre sowing and incorporate this volatile herbicide by careful coverage of the inter row using particular configurations of tynes and points. Post emergence weed control is similar to the ley farming system.

Where Brassica weeds are dominant, TT canola is grown with pre-sowing and post-sowing applications of simazine and atrazine. These herbicides can be applied initially at sowing with follow-up applications as required, often with atrazine use post-emergence. Trifluralin is sometimes used pre-sowing for added ryegrass control. Because of its residual activity, late applications of atrazine in TT canola can carry over to affect subsequent wheat crops in years with dry springs and summers (Norton et al. 1999). Despite the problems of inherently lower yields and oil contents, many growers choose to use TT production systems because of the simplicity and reliability of weed control **(Figure 4)**. This system has become adopted because of the ability to sow as near to the break as possible, which is critical to a good yield particularly in dry regions (Robertson et al. 1999).

GM canola production systems

Weeds are a significant issue for canola growers. Brassica weeds (including wild radish and wild mustard) are not able to be controlled in conventional canola cultivars.

As well as competing with the crop, some Brassica weeds contain unacceptable levels of erucic acid and glucosinolates that contaminate canola seed.

GM varieties will allow farmers to sow early (on or before the break of season), and benefit from the 5 per cent per week yield advantage from timely sowing.

Better weed control will increase yields compared with both conventional and TT production systems.

Growers who move from TT production systems to GM production systems will benefit from a 20% yield advantage and increase canola oil content by 2 per cent.

GM canola should be carefully managed as part of an integrated weed management plan to avoid further development of weed resistance to herbicides.

The new technology could allow canola to be grown on an additional 160,000 hectares in the drier regions of NSW, Vic, SA and WA.

Table 2: Typical use patterns for herbicides in various canola production systems. Rates given (grams active ingredient per hectare, (g ai/ha) are indications only, actual rate depends on crop and weed growth stage and soil types.

	Pre emergence	Pre sowing Knockdown	In crop	
Conventional	Trifluralin720 g ai/ha	Glyphosate 735 g ai/ha (note 2)	Clopyralid 90 g ai/ha	Clethodim 60 g ai/ha (note 1 and 3)
TT	Simazine 1000 g ai/ha plus Atrazine500 g ai/ha	Glyphosate 735 g ai/ha (note 2)	Atrazine500 g ai/ha	Clethodim 60 g ai/ha (note 1 and 3)
IT	Trifluralin720 g ai/ha (note 1)	Glyphosate 735 g ai/ha (note 2)	Imazapic 21 g/ha plus Imazapyr 7 g ai/ha	Clethodim 60 g ai/ha (note 1 and 3)
InVigor® hybrid canola	Trifluralin720 g ai/ha (note 1)		Glufosinate-ammonium 600 g ai/ha (note 4)	
Roundup Ready® canola	Trifluralin720 g ai/ha		Roundup® - probably 440 g ai/ha glyphosate (note 4)	

Note 1: These additional applications may be used where grass weed pressure is high.
Note 2: Paraquat (200 g ai/ha) plus diquat (170 g ai/ha) may be substituted for glyphosate as a pre sowing knockdown.
Note 3: This product is one of many potential group A herbicide options for grass weed control.
Note 4: Rates and timings have not been advised, those given here are indicative only.

IT canola production systems use OnDuty®, applied at the 2-3 leaf stage in the crop, which replaces the use of simazine/atrazine in TT canola. Grass weed control can be supplemented in both TT and IT systems using a group A herbicide. Sutherland (1999) considered that IT systems were likely to be limited in scope, mainly because of the widespread group B resistance in wild radish particularly in Western Australia. Hashem et al. (2001) reported that chlorsulfuron resistance was common in radish in Western Australia and nine per cent of these populations showed cross resistance to OnDuty®.

Some typical herbicide use patterns for different production systems are shown in **Table 2**. Local rates and product configurations will vary between districts, and the use patterns given here are indicative only.

Herbicide resistance

These different production systems, and indeed all grain production systems, are challenged by herbicide resistant weeds, with resistance seen in wild radish to group B, group C and group F herbicides (Sutherland 1999), while annual ryegrass populations show resistance to groups A, B and D, as well as to group M (glyphosate) (Heap 2002, Preston 2003). Most of these resistances occur to chemicals that are used across many crops in the farming system, and especially where there is a simple mechanism for resistance, or the chemical has extended soil residual activity, and/or repeated applications of the one herbicide type occur within and between years. For example, wild radish resistant to triazines has occurred where lupins and TT canola are grown in tight rotations, both of which receive relatively high application rates of these chemicals. In the case of glyphosate, the development of resistance is correlated with high frequency of applications and few additional associated control measures such as in summer fallow no-till farming systems in northern New South Wales (Preston 2003).

GM Canola production systems

Included in **Table 2** are the expected use patterns for InVigor® hybrid canola and Roundup Ready® canola. The crop management plans developed indicate that these systems may retain trifluralin use but replace some pre-sowing treatments with in-crop herbicide use. The potential yield of new varieties that come with various herbicide tolerances will continue to increase

due to improvement in germplasm, better blackleg tolerance and improved agronomy (Salisbury and Wratten 1999), irrespective of the impact of the herbicides. Nelson et al. (2001) suggested that the conservative rate of increase for canola production between 2000 and 2010 would be about 1.5 per cent per year.

InVigor® hybrid canola

It should be noted that the use of InVigor® hybrid canola varieties is not necessarily tied to the use of glufosinate-ammonium. Conventional weed control methods could be used with InVigor® hybrid canola cultivars. As new crop varieties in their own right, InVigor® hybrid canola types may find grower acceptance due to the anticipated yield benefit due to heterosis. In fact, Hyola 60, which is a conventionally bred hybrid, is ranked in the top few high yielding varieties in Victoria (Bedggood and Bedggood 2003). Bayer CropScience (2003) has indicated that yield advantages of 10-20% can be expected, which is in-line with estimates reported from Canada (Zand and Beckie 2002).

Glufosinate-ammonium (Liberty®) is a broad spectrum herbicide that can be used in-crop with InVigor® hybrid canola. It has no other uses in grain production systems, but is registered in Australia as the horticultural product Basta®. The herbicide is used as a single or split application in-crop for grain producers, which allows growers to sow dry or at the first rains and delay control until weeds emerge in-crop. This will enable more canola to be sown early, as well as encouraging the sowing of canola in no-till situations. If grass weed pressure is high, growers may need additional herbicides such as trifluralin and a grass-selective herbicide. Glufosinate-ammonium is not suited to situations where wild radish pressure exists. In essence, the use of InVigor® hybrid canola with glufosinate-ammonium will remove the need for the pre-sowing glyphosate or SpraySeed® knockdown and post-emergence broadleaf weed control such as clopyralid. Performance of the herbicide is lower under cooler (<10°C), low light intensity and low relative humidity conditions (Petersen and Hurle 2000) so it is likely to be important that the herbicide is used early in growth in Australian production systems.

Roundup Ready® canola

Roundup® (glyphosate) is currently used in canola production systems as a pre-sowing knockdown, and the development of Roundup® tolerance in canola will permit this chemical to now be used in-crop. There are many possible configurations as to how it could be deployed, with one example being that Roundup® is used as a single application used in the 1-4 leaf crop stage, with or without pre-emergent use of trifluralin (Calderwood 2003), depending on weed pressure. Systems using multiple applications of glyphosate and no other control measures (e.g. summer fallow no-till) are at high risk of the evolution of glyphosate resistant ryegrass. The use of an additional in-crop Roundup® application is likely to exacerbate that development and so the technology may not be appropriate in that situation if glyphosate is used as the only means of weed control. In most other current production systems, it is likely that Roundup Ready® canola will provide sufficient benefits to become a significant proportion of the total canola area sown. It is almost impossible to predict that area, but it is likely that Roundup Ready® canola could take over a significant proportion of the area currently using TT canola, as well as some of the area currently sown to conventional and IT canola varieties.

Potential benefits for using GM systems

Early sowing

Growers seek to sow canola as early as possible, due to the strong relationship between sowing date and yield (Robertson et al. 1999), estimated to be of the order of two to five per cent of yield per week of delay. Farré et al. (2002) identified that yield reductions were of the order of two, six and nine per cent for high, medium and low rainfall areas in Western Australia. As well as yield benefits due to earlier sowing, seed oil content is also higher when the crop is sown earlier, because seed growth occurs under cooler conditions which favour oil accumulation (Pritchard et al. 2000).

Current canola production systems using conventional canola usually incorporate a pre-sowing knockdown application of either glyphosate or diquat/paraquat. This is applied following the opening rains and once weeds have germinated and emerged, because neither herbicide has soil residual action. An alternative is to use soil residual chemicals such as trifluralin, which require incorporation. These have the potential to delay seeding unless used as 'incorporated by sowing'. One of the attractions of the use of TT canola is that simazine and atrazine can be applied immediately prior to sowing and sowing can occur at the break of the season. Similarly, IT canola can be sown early, and weed control delayed until the crop and weeds emerge.

In all current canola production systems, grass weed control may be required and typically clethodim is used post-emergence, although there are several other herbicides available.

Both InVigor® hybrid canola and Roundup Ready® canola will enable growers to sow dry (that is, before the autumn break) or as soon as the rains occur, and then come back in with effective in-crop weed control using either Roundup® or glufosinate-ammonium. Most growers currently using TT canola, especially in Western Australia, are able to sow at the break, so this benefit would not apply to TT systems. Where conventional production systems are used, the swing to GM technology removes the need for pre-sowing control and this could achieve a five per cent yield benefit due to one week earlier sowing.

Improved weed control

Aside from the increased target range for InVigor® hybrid canola and Roundup Ready® canola, the fact that the associated chemicals can provide very early in-crop weed control will provide more effective weed control and reduce competition between the crop and weeds. Canola, especially low vigour varieties (for example, TT types) are poor competitors particularly prior to canopy closure (Colton and Sykes 1992), and may not recover from this competition (Lythgoe et al. 2001). Similarly, hybrid cultivars display higher vigour than open-pollinated types and were more able to cope with lower seeding rates, and early weed removal became more important where densities were lower (Clayton et al. 1999).

Johnson et al. (2002) reported that in Canada where glyphosate was used with conventional canola in minimum tillage systems the best yields and weed control occurred the later that glyphosate could be applied. By extension, it would seem reasonable that applications in Roundup Ready® canola could raise the level of weed control even further. Harker et al. (1999) reported that delaying herbicide application in Roundup Ready® canola even for two or three weeks gave significantly lower yields, with the best timing one week after crop emergence. In Australia, Stanton et al. (2001) reported that for ryegrass removal, early post-emergence timing of Roundup® application in Roundup Ready® canola provided more effective control of this problem weed than conventional and TT production systems. From Europe, Pilorge and Lircovich (1999) reported that a single application of either glyphosate or glufosinate-ammonium over the relevant GM canola varieties produced weed control levels equal to or superior to classic post-emergence treatments. The benefit here is difficult to assess, as there are no data on the current magnitude of weed impacts on canola, although a five per cent improvement could be expected for vigorous conventional varieties and ten per cent for TT varieties. Data from Monsanto experiments suggests that Roundup Ready® canola gives the potential for five per cent better weed control than conventional canola and 15% than TT canola, with a total yield benefit of 15% to 20% over conventional or TT production systems (Calderwood 2003).

Reduction in the use of TT canola

Despite its widespread use, TT canola systems have inherent yield penalties of 20% and a two per cent decrease in oil content when compared to other types of canola (Arntzen et al. 1982). With around 55% of the Australian canola crop carrying this penalty, the benefit of replacing TT varieties with GM canola technology would provide a benefit at least equal to the existing penalty. The performance of GM canola cultivars in Canada is reported to be around ten per cent higher than conventional varieties, although this higher yield would be an integration of genetic improvement, earlier seeding and better weed control (Serecon Management Consulting & Koch Paul Associates, 2001).

The lower oil content of TT canola is a significant problem for Australian exporters, particularly canola from Western Australia where TT canola is dominant. Western Australia has met the 40% domestic standard in recent years, but the export standard for seed oil content is 42% and to consistently meet this will be an ongoing challenge. The increase in oil content brings growers a 1.5 per cent price bonus (or deduction) for each one per cent increase (or decrease) in oil content above (or below) the export standard. The replacement of some proportion of TT canola with any other canola that does not carry the oil content penalty will assist the market remain competitive as well as providing growers with a price premium of three per cent where TT canola is replaced by GM HT canola.

Integrated weed management

The occurrence of weed resistance to particular herbicides is largely a consequence of reliance growers and agronomists have placed on particular chemicals and modes of weed control. If one control method is used – irrespective of whether it is chemical or physical, over time, the weed spectrum changes to more tolerant species that then require the use of other weed management practices (Shaner 2000). Integrated weed management (IWM) seeks to use different approaches to reduce the impact of weeds, and options used by growers include alternative chemicals, enhancing crop competitiveness and mechanical methods (Llewellyn 2002). The use of glufosinate-ammonium in particular will give growers new chemistry that is not used in other grain crops or pastures, and so should provide control of annual ryegrass, including ryegrass with multiple resistances.

As of 2002, there were 34 populations of annual ryegrass (*Lolium rigidum*) that have resistance to glyphosate (Preston 2003) across Australia. Most of these resistant populations are confined to no-till and chemical fallow production systems and have not spread widely into grain cropping (Preston 2003). The fact that glyphosate resistant ryegrass is present clearly indicates that growers will need to adopt IWM within Roundup Ready® canola.

The proposed Resistance Management Plan model for managing Roundup Ready® canola takes this into account and outlines proactive IWM and risk assessment. The need for these integrated management plans is shown by the work of Diggle et al. (2002). These authors predicted that if glyphosate was used only as a knockdown and in-crop over Roundup Ready® canola, ryegrass resistance would occur more quickly than if an alternative chemical (SpraySeed®) was used as the knockdown. Similarly, Schmidt and Pannell (1996) found that the most profitable and sustainable system using (theoretical) herbicide tolerant lupins would occur where herbicide tolerance was combined with other technologies such as weed seed collection and destruction.

It is clear that when GM technologies are used by Australian growers that weed spectra will change. The introduction of TT canola systems was seen by some growers and agronomists as a 'silver bullet' but the survey by LeMerle et al. 2001, showed that weed survival occurred under TT canola and new weed flora developed. Similarly, in Canada, weed populations have changed due to the use of herbicide tolerant crops (Derksen et al. 1999). No single weed management tool will provide on-going control of weeds in crops, but the judicious use of a range of integrated strategies should minimise the impact of weeds. It is most likely that strategies will change as the technology becomes used, and what is common practice now may alter as new weeds adapt to the altered crop ecology. As noted by Locke et al. (2002), changes in patterns of tillage, planting systems and other management strategies can alter the soil environment and lead to shifts in weed populations.

Increased rotational flexibility

Herbicide residues are significant features in determining crop rotations (Norton et al. 1999). Clopyralid, simazine and atrazine are moderately persistent, while imazapic and imazapyr are highly persistent. The latter has re-cropping intervals of up to 34 months for crops such as conventional canola. Because of this, these chemicals impose restrictions on crop selection following their use.

Neither glyphosate nor glufosinate-ammonium are likely to affect subsequent crops as both show little persistence. The half-life of glufosinate-ammonium is 7-14 days in moist soil while glyphosate is rapidly bound to soil particles and quickly rendered inactive. Because of this growers are able to delay crop selection as close as possible to the season break without locking a paddock into a particular crop because of the pre sowing herbicide used. Similarly, in the event of a crop failure, there would be no restriction on the type of crop that could be replanted into that paddock.

Increased production area

Much of the development in the area of canola sown over the past five years has been in the drier regions of the grain producing areas (Colton 2001, Burton et al. 2001, and Carmody et al. 2001). These dry areas suffer the highest penalty to late sowing (Farré et al. 2002) and so if better weed control can be obtained earlier, further expansion of canola production into these regions is likely. Based on current trends, the additional areas of canola planted in the dry regions (<350 mm) of each state could add an extra 20,000 hectares in the Victorian Mallee, 100,000 hectares in Western Australia, 20,000 hectares in the South Australian Mallee and Eyre Peninsula regions, and 20,000 hectares in western New South Wales (e.g. Coonamble, Nyngan, Condobolin and Deniliquin). This represents a total of 160,000 hectares, which is drawn from the estimates of Carmody et al. 2001, Potter and Stanley 2001, Burton et al. 2001 and Colton 2001 of the amount of canola expansion into dry regions. The Grains Research and Development Corporation has targeted research into improved agronomy in these regions to assist with this expansion in the southern (Potter et al. 2001) and western (Addison and Carlton 2002) regions. Even with the relatively low yields, total canola production from these regions could total 160,000 tonnes. The magnitude of these increases is reasonably conservative given that already Australia has proven that 1.8 million hectares can be grown **(Figure 1)**, while Potter et al. (1999) estimated that potentially between 2.5 and 3.5 million hectares could be grown.

As well as enhancing production options in low rainfall areas, it may be that control of intractable weeds can return grain production to paddocks where it has become unviable.

In addition to the higher profitability of the canola crop, canola will have a significant impact on the subsequent yield of wheat crops through the break crop effect. Therefore, as well as the additional area of 160,000 hectares of canola, a 20% disease break could flow through to wheat grown on this land. This could provide an additional 64,000 tonnes of wheat with a net value of $13 million annually.

Summary

Current canola production systems have evolved in response to local soils and climate, profitability relative to other crops, and weed pressures. Production systems try to integrate a range of weed management options to meet the changes in weed flora encountered with canola and other crops. The introduction of GM canola, with herbicide tolerance, will provide growers with an additional tool for IWM. These technologies offer growers the opportunity to sow earlier, achieve better weed control, avoid the inherent yield and oil content penalties associated with TT varieties and avoid being locked into particular crop sequences due to residual herbicides.

Conservation farming and canola

Conservation farming has many definitions, but Wilhelm (2002) suggested that it encompassed production systems that retain stubble, have a low number of minimum disturbance tillage passes, with good rotations that lead to low use of farm chemicals. Australia has diverse production systems used for grain production, and over the past 20 years there has been a consistent move towards conservation cropping systems. Production systems represent a continuum starting with totally mechanical seedbed preparation through reduced tillage and minimum tillage through to no-till. Ward et al. (1987) noted that this change came about because farmers found it of economic benefit to use herbicides pre-crop and in-crop to control weeds. Similarly, the benefit of retaining crop residues has led to its widespread adoption as well. In 1999, surveys indicated that the extent of conservation farming practices showed that 79% of farms retain stubble and 60% of crops were grown using direct drilling or minimum tillage (ABARE 1999). No figures on stubble retention were collected in a later survey, although across Australia just three years later, 81% of all crops were sown using direct drilling (nil cultivation) or minimum tillage (one or two cultivations) (Connell and Hooper 2002). Across Australia over a five year average, this represents 16 million hectares of minimum tillage in southern Australian winter cropping systems (ABARE 2003).

Despite its small seed size, there is no particular reason why canola should not be direct drilled, and it is grown successfully under this system in many areas. Although the amount of canola direct drilled is not known, TT canola is often direct drilled, especially where it follows a cereal or pulse and provided the soil is well structured root growth is not affected (Almond et al. 1986). In higher rainfall areas, some cultivation may be used prior to the sowing of conventional canola to reduce weed burdens and create better soil tilth. With 59% of crop rotations using pasture (Alemseged et al. 2001), there is a real opportunity for an increase in the area of canola grown using direct drilling or reduced cultivation if weed management options can be improved such as by the use of effective broad-spectrum weed control in crop.

Conservation farming and canola

No-till and minimum tillage farming systems (direct drilling) increase soil carbon, reduce run-off and reduce soil loss through erosion.

GM canola is expected to increase the area of canola grown under no-till or minimum tillage farming systems by 200,000 hectares.

640 tonnes less triazine herbicides are likely to be used each year.

There are reports of poor growth of canola when sown into wheat stubble, particularly if the stubble covered the seeding rows (Bruce and Ryan 2001). Using sowing equipment that moves the stubble aside can relieve some of the problem, although using highly vigorous cultivars could also aid in establishment. The improved vigour of InVigor® hybrid canola and Roundup Ready® canola over TT cultivars would be beneficial under these conditions although the magnitude of the benefit is difficult to assess.

Table 3 presents an estimate of the area of canola grown under direct drilling (including minimum and reduced tillage), compared to the total amount of direct drilling as a proportion of winter crops (Connell and Hooper 2002). This estimate is based on assumptions that 80% of TT canola is direct drilled and 60% of conventional canola is direct drilled in eastern states, and 95% of TT canola direct drilled in Western Australia. This table shows that canola is less frequently grown under conservation tillage practices compared to other crops.

Impact of reduced tillage/direct drilling

Tillage has been consistently associated with declining soil properties. Kirkegaard (1995) reviewed the literature from a series of long term tillage experiments in Australia and noted that the overall effects on crop yield of direct drilling were small (-0.18 to +0.06 t/ha). In particular situations, yield benefits to direct drilling can be expected, and Pratley (1995) showed that direct drilling gave significantly better yields in nine out of 11 years at Wagga Wagga.

Even though there may be factors that prevent consistent yield benefits, it is clear that soil quality improves where cultivation is reduced. For example, in a rotation experiment at Wagga Wagga, direct drilling and stubble retention reduced the losses of organic carbon (a measure of soil organic matter) (C) and nitrogen (N) compared with conventional cultivation and burning (Heenan et al. 1995). These authors found that soil C levels fell at a rate of 44 kg C/ha/year under direct drilling, but at three cultivations the rate of C loss increased to 179 kg C/ha/year. These rates vary with soil type, climate, and initial soil C and the nature of the C inflows from plant materials. Dalal and Chan (2001) indicated that the loss in soil organic matter levels vary from ten per cent to 60% over 10-80 years of cultivation, with highest rates of loss on sandy soils. No-till and stubble retention reduces the loss of organic matter in the soil.

While soil organic matter is significant in its own right, it confers on the soil particular physical properties that enable air, water and roots to move through. As soil C levels decrease, soil bulk density increases due to compaction and aggregates become less stable (Dalal and Chan 2001). The effect of these changes is to make the soil more prone to wind and water erosion. It has been consistently shown that where no-till or reduced tillage is practiced, soil structure improves, soil loss declines and water infiltration increases. For example, in South Australia, Malinda (1995) showed that retaining stubble and no-till preparation increased soil C and reduced run-off, and so reduces the loss of soil through erosion. On that site decreasing soil organic carbon from 1.6 to 1.2 per cent increased soil loss as sediment from about 300 to around 900 kg/ha.

GM canola and reduced tillage

Many growers using both conventional and TT canola would be sowing without cultivation, but early breaks, pre-drilling N fertilizers and the need to incorporate trifluralin before sowing may necessitate some cultivation. The proposed use patterns for both InVigor® hybrid canola and Roundup Ready® canola would allow growers to reduce tillage operations before sowing and rely on post emergence weed control in-crop. This will result in significant savings in tillage costs, as well as maintaining soil organic matter and soil structure.

To assess the potential impact of the adoption of GM canola on the area of direct drilled and reduced tillage crops, it is necessary to develop a scenario for the future adoption of HT GM canola. **Table 4** presents a scenario for the use of these technologies, based on the assumptions used to develop **Table 3**, with the added expectation that 80% of both InVigor® hybrid canola and Roundup Ready® canola will be direct drilled. This scenario proposes that GM technology is adopted for 50% of the TT area and 40% of the conventional areas in each state. IT canola is included with conventional canola figures. The future areas include the expansion of canola into the drier regions of the states, all of which would be GM and direct drilled. These assumptions would suggest that GM canola could take 52% of the area planted which is slightly lower than the 55% adoption rate in Canada (Serecon Management Consulting & Koch Paul Associates, 2001).

Table 3: Estimates of minimum tillage: canola compared to all crops, Connell and Hopper (2002).

State	Canola (Ha)	% canola under minimum tillage	% all crops under minimum tillage
NSW	380,000	62	71
WA	460,000	92	98
Vic	192,000	68	62
SA	117,000	68	89
Total	**1,149,000**	**76**	**81**

This change to GM canola would bring with it an additional 43,000 hectares of canola under direct drilling, plus the additional 160,000 hectares due to the expansion into dry areas. These increases are most likely to occur where early sowing is most desired in the drier parts of the grain producing regions. This is where canola production areas are expanding at present and where the soils are most fragile with the lowest organic matter content.

Reduced pesticide use

One of the most significant changes with the introduction of GM canola is the likely reduction in the use of triazines as TT canola areas decrease. Herbicide persistence in soils is a significant environmental and farm management issue. The persistence of atrazine and simazine depends on soil type (clay soils longer) and weather conditions (dry conditions longer). Atrazine is also more soluble than simazine and the use limitations on the label restrict its use to beyond 60 m from waterways. Residues of atrazine have been reported in ground waters in Western Australia (Appleyard 1995). Based on these system changes, it is reasonable to expect that TT canola area would decline from about 55% to 24% of the production area, and based on the past five years, this would result in TT canola declining by about 316,000 hectares. Consequently, around 320 tonnes less of both atrazine and simazine would be used. This would be replaced by glyphosate and glufosinate-ammonium which are lower persistence and considered of a lower environmental impact.

An additional benefit from the reduction of atrazine use (and some other chemicals) is the reduction in selection pressure for resistance to those chemicals, which will extend their useful life in farming systems.

Canadian experience with the introduction of GM Canola

Canada was one of the first places where GM canola was commercialised. InVigor® hybrid canola and Roundup Ready® canola were released in 1997, and growers have embraced the opportunities presented by an alternative form of weed management **(Figure 6)**. By 2001, 55% of the production area was genetically modified, with a further 15% IT (Buzza 2001). The impact of this technology was evaluated by Serecon Management Consulting & Koch Paul Associates on behalf of the Canola Council of Canada (Serecon Management Consulting & Koch Paul Associates, 2001) who surveyed 650 growers.

From that survey, the key reason that growers indicated for adopting GM canola was easier and better weed control, and 80% of adopters indicated that weeds were more effectively managed. A barrier to non-adopters of GM canola was the cost of the technology.

Against this higher cost was a ten per cent yield advantage over conventional varieties, and growers attributed this to improved weed control, earlier sowing and higher yielding varieties. Another feature identified was that growers using GM canola with herbicide tolerance had reduced the amount of cultivation, with a net benefit of a million hectares of canola planted with less cultivation, which in turn led to a fuel saving of over 30 million litres **(Table 5)**. With the change in herbicide use, growers using GM canola use less herbicide than growers of conventional canola. Overall, herbicide reduction due to the use of GM canola was estimated at 6,000 tonnes in 2000. The surveys estimated that the economic outcome from the adoption of GM canola was a $C14/ha increase in profit, as calculated by a gross margin over conventional canola.

Table 4: **A scenario for the future adoption of direct drilling (DD) using canola, based on the introduction of GM canola (note that figures are rounded).**

	A Future Adoption Scenario				
State	Area (ha)	%TT	%GM	%DD	Increased ha under DD
NSW	400,000	12	45	72	43,000
WA	560,000	37	58	94	106,000
Vic	210,000	18	49	75	29,000
SA	140,000	17	52	77	25,000
Total	**1,310,000**	**24**	**52**	**81**	**203,000**

Experience with Roundup Ready® from other crops

As indicated earlier, Roundup Ready® technology has been widely adopted in both North and South America, with the USA hosting approximately 68% of the global transgenic crops (Reddy 2001). Carpenter and Gianassi (2001) reviewed the impact of GM technology generally and estimated that the use of herbicide tolerant cotton has led to a reduction in the amount of herbicide used as well as an increase in the area of cotton direct drilled. In herbicide tolerant soybean, these authors estimated that weed control costs declined by $US216 million in 1999.

Australia has grown GM (INGARD®) cotton since 1996, and adoption of this crop with inbuilt protection against *Heliocoverpa* caterpillars has seen it grow to around 30% of plantings. Roush (2001) noted that this technology has reduced pesticide use in cotton by 50% between 1999 and 2001. ACIL (2000) reported that cost savings to growers net of licence fees averaged $96/ha. Roundup Ready® cotton in Australia was released in 2001/2002 and the technology accounts for 38% of the cotton area planted in Australia (O'Neill 2003). This report indicated that in Australia, there was a reduction in tillage associated with the uptake of Roundup Ready® cotton. This is similar to the impact of Roundup Ready® canola in Canada, and in other crops in the US and Argentina (Carpenter and Gianassi 2001). Balwin and Baldwin (2002) noted that speed of acceptance of GM technology by US farmers indicates that from a weed management standpoint, the technology is superior to traditional weed control technology.

Figure 6: GM canola in Canada (1995 - 2002). GM Canola vs Non GM Canola (Source: Canola Council of Canada).

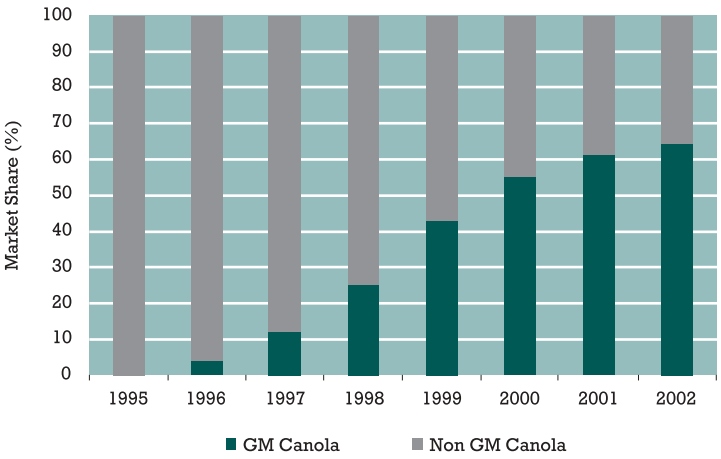


Table 5: Canadian GM Canola vs non GM Canola Impact Study (1997 - 2000) (Source: Canola Council of Canada).

Benefit	Evaluation Parameter
Herbicide use	• 40% reduction in herbicide cost • Reduction of 6,000 tonnes of herbicide applied in 2000
Reduced cultivation	• Fewer cultivation passes, estimate of 50% reduction • 1.05 million hectares with fewer cultivation passes
Low fuel use	• Reduction in total field operations, resulted in a reduction of 31.5 million litres of fuel use in 2000 • Fuel cost saving of $13.1 M($Can) @42c/lt ($Can)
Improved yield	• 10% increase in canola crop yield • 1.5% reduction in canola grain dockage
Improved returns	• $14.36 / ha ($Can) increase in net return (Yield x price - inputs, labour etc.)

Summary

The adoption of GM herbicide tolerant crops will allow growers to reduce tillage even further, especially in drier areas. Under the scenario developed, this could change 40,000 hectares of canola production over to direct drilling as well as bringing another 160,000 hectares of canola into production using direct drilling. This will help conserve soil organic matter and reduce soil erosion. As well, the change from TT to GM canola will reduce the use of triazine herbicides by around 640 tonnes per year.

Economic benefits

To develop a view of potential outcomes from the introduction of HT GM canola, it is appropriate to develop a scenario of the adoption of GM canola in Australia. This is not a prediction of the area that will use this technology, but represents one possible situation. Under the adoption scenario used in this report, adoption rates for GM canola are based on assumptions that GM canola will replace about 50% of the TT area, and 40% of the areas sown to conventional canola. IT canola production is assumed to remain the same. Monsanto field work claims a 10-20% yield benefit over conventional canola where Roundup Ready® canola is grown and a 20% benefit over TT canola (Calderwood 2003). This benefit is consistent with the benefits in yields reported from Canada of about ten per cent over conventional varieties ((Serecon Management Consulting & Koch Paul Associates, 2001). These are the same assumptions that were used in the estimate of the impact of GM canola on direct drilling **(Table 4)**.

Grains Industry Impact

The industry impact from GM canola would come from the aggregation of a range of benefits identified earlier. There is an underlying improvement in canola yields due to improved agronomy and cultivars of around 1.5% (Nelson et al. 2001) and the estimates below are exclusive of that trend and the changes are due to the impact of GM canola introduction alone. The factors listed here are tangible benefits that contribute directly to grain production. Other benefits such as increased rotational flexibility, increased conservation tillage and reduced use of triazines are not quantified here.

Indicative effects on average canola yields are:

- five per cent increase in yield where GM replaces conventional varieties due to earlier sowing
- eight per cent yield improvement due to better crop competition against weeds
- yield improvements of 20% over current TT cultivars
- increase in oil content of two per cent over TT cultivars
- increase in canola area sown of 160,000 hectare in dry areas.

Economic benefits

Under the proposed technology adoption scenario, canola production would increase by 295,000 tonnes.

The predicted increased area of canola production (160,000 hectares) will lead to a 64,000 tonnes increase in wheat production as the break crop benefits of canola are experienced.

Preliminary gross margin analysis, based on estimates of technology access fees, suggest GM canola will have up to a $170/ha gross margin advantage over conventional canola.

With the scenario changes indicated in **Tables 3 and 4**, the outcome would be an increase in average canola yield of 0.07 to 0.15 t/ha depending on the proportion of TT canola that GM canola replaced in each state **(Table 6)**. The production increases in tonnes are disproportional to the expected increase in yield and crop area because new canola growing areas in the drier regions would return lower yields. Across Australia, this would mean canola yields would rise from 1.27 to 1.38 t/ha (around 8 per cent). With the additional areas available for sowing, this would mean canola production could rise by around 295,000 tonnes to 1.76 million tonnes.

As well as the yield increase, the swing away from low oil content TT canola varieties towards more GM canola would result in a 0.6% increase in the oil content of all canola grown in Australia. Depending on the initial oil content, this would produce a one per cent increase in the value of the entire crop due to this increment in oil bonus.

Nelson et al. (2001) based their estimate of the impact of GM technology on yield increases of 7 per cent. They also estimate that the lower weed control costs with GM canola would give a 3 per cent overall decrease in total production costs. They used a similar adoption rate (50%) to the estimates here (52%). Their modelled conclusion was that by 2005 the canola area would increase by

6.2%, production would increase by 9.9% and exports would increase by 14.2%.

This model assumed that agronomic benefits were achieved, but that there was no segregation of GM and non-GM canola, as is the case in Canada.

Table 7 summarises the benefits that would accrue with that the adoption of GM canola to Australian agriculture with the benefits described and the adoption rates assumed. As well as the direct benefits of earlier sowing, higher yields and better weed control, there is an increase due to higher oil content and a supplementary benefit due to the inclusion of 160,000 hectares of canola into rotations.

The net increase in canola production is estimated at 295,000 t annually, and the added benefit summarised in **Table 7** is around $135 million.

On-farm benefits

The adoption of this technology will largely depend on the impact it has on the profitability of canola, per se as well as in comparison to wheat. The components of this profitability are the costs associated with adopting the technology and the increased yields provided by the technology. It is not expected that GM technology would be the most profitable option in all situations, but based on Canadian experience, under certain conditions, herbicide costs can be lower and returns higher. At present the costs to access the technology are not publicly known, but, again from Canadian experience, the total cost of weed control (additional seed and less herbicide) may be similar or even slightly higher with GM technology.

Comparative herbicide costs

Based on **Table 2**, and using costs as cited by Diggle et al. (2002), **Table 8** gives indicative costs for herbicide use with four weed management systems in canola. The system using InVigor® hybrid canola is not included, as the pricing for glufosinate-ammonium and package or seed costs for InVigor® hybrid canola, are not yet available. As indicated in **Table 2**, rates and uses will vary with soil type and weed pressures, but these figures show that Roundup Ready® canola will be a low cost herbicide management system compared to others systems available for Australian farmers. Technology agreements and seed will be additional to these costs.

Technology use agreements

Grower access to IT canola technology is already covered with an agreement between the grower and the technology provider, and this provides agreed methods for the deployment of IT canola and the associated herbicides. The Technology use agreement (TUA) for GM canola will address three key elements:

1 technology license conditions deemed by the OGTR to the technology licensee and the farmer

2 details of the National Registration Authority approved herbicide label that may pertain to the use of the herbicide (for example, resistance management strategies for implementation by the farmer)

Table 6: Summary of the impacts of the scenario tested on the yield, area sown and production of canola in Australia (values are rounded).

	Current			Future Scenario			
	Yield (t/ha)	Area (ha)	Production (t)	Yield (t/ha)	Area (ha)	Production (t)	% increase in production
NSW	1.55	380,000	589,000	1.63	400,000	650,000	10
WA	1.00	460,000	460,000	1.11	560,000	620,000	35
Vic	1.35	192,000	259,000	1.41	212,000	300,000	16
SA	1.32	117,000	154,000	1.37	137,000	188,000	22
Australia	1.27	1,149,000	1,462,000	1.38	1,309,000	1,758,000	20

3 commercial Terms and Conditions for access to the technology between the farmer and the technology provider.

At the time of publishing the costs of particular TUAs have not been announced.

Gross margin effects

A realistic assessment of the impact of GM on canola gross margins is difficult to assess without costs available for access to the technology. If the data presented by Norton et al. (1999) for the Wimmera is used as a basis, using current canola prices, and a seed cost of $40 to access the technology the comparison could be developed as shown in **Table 9**. The best test of the profitability of the system will be made once growers have access to the technology, and again, the experience from the adoption of other HT crops such as cotton, soybean and canola in North America is that growers have rapidly embraced these crops.

Summary

Based on the scenario developed, the adoption of GM canola is likely to provide significant direct benefits to the grains industry by increasing canola production through higher yields and expansion of areas available for growing canola. The benefits also flow through to enable more wheat to be produced. In the absence of complete information, it would appear that herbicide use will decrease, and herbicide costs will also decline. The combined effect of higher yields and lower costs would mean that canola profitability on-farm would be higher.

Table 7: Summary of approximate benefits estimated with the scenario presented concerning the introduction of GM canola.

Factor	Increment	Amount	Value canola @$400/t
Earlier sowing	5% where conventional varieties are replaced	0.08 t/ha over 205,000 ha = 16,000 t	$6 million
Improved weed competitiveness	8% where conventional and TT varieties are replaced	0.10 t/ha over 520,000 ha = 52,000 t	$21 million
Yield benefit over TT varieties	20% where TT varieties are replaced	0.21 t/ha over 320,000 ha = 67,000 t	$27 million
Increase in oil content over TT varieties	2% oil where TT varieties are replaced	+3% value of 342,000 t	$4 million
Increase in canola area	160,000 ha in dry areas	1 t/ha = 160,000 t	$64 million
Rotation benefit in next wheat crop	160,000 ha with 20% yield increase in wheat crop	0.4 t/ha (wheat @ $200/t)	$13 million
Total		**295,000 t of canola, plus 64,000 t of wheat**	**$135 million**

Table 8: Indicative herbicide costs ($/ha) for various herbicide use patterns in canola. No application costs are included.

Herbicide	Conventional	TT	IT	Roundup Ready® canola
Trifluralin (Pre emergence)	14.00	7.50	14.00	14.00
Glyphosate (knockdown)	7.50	13.50	7.50	
Simazine (pre emergence)				
Imazapic 21 g/ha plus imazapyr 7 g ai/ha		13.50	45.00	
Atrazine (pre and post emergence)				
Roundup® (post emergence)		18.00		7.50 (note 1)
Clethodim (post emergence)	18.00		18.00	
Clopyralid (post emergence)	17.50			
TOTAL $/ha	**57.00**	**52.50**	**84.50**	**21.50**

Note 1: This price is used only as an indicator as pricing for Roundup® for use with Roundup Ready® canola has yet to be announced. This price was derived from Diggle et al. (2002).

Table 9: An example of how costs and returns for conventional and GM canola could compare.

	Conventional	GM Canola
Expected Yield	1.8 t/ha	2.2 t/ha
Net Price $/t on farm	$400	$400
Gross Return	*$720/ha*	*$880/ha*
Seedbed preparation & Sowing	$14/ha	$14/ha
Seed costs	$15/ha	$40/ha (note 1)
Fertilizer Costs	$72/ha	$72/ha
Herbicide costs	$57/ha	$22/ha
Insecticides	$6/ha	$6/ha
Windrowing & Harvesting	$38/ha	$38/ha
Insurance	$10/ha	$10/ha
Local cartage	$10/ha	$10/ha
TOTAL COSTS	*$222/ha*	*$212/ha*
GROSS MARGIN	**$498/ha**	**$668/ha**

Note 1: A $25/ha technology access charge is included in the seed cost.

Technology management

The adoption of any new technology brings with it risks that need to be recognised and then managed to achieve a positive outcome for the economy and society as a whole. It would seem that much of the discussion of GM technology has focused on risks rather than potential benefits, but both aspects require consideration. For the introduction of GM canola, several risks have been identified and these are briefly discussed below.

Pollen movement

Even though canola is essentially self-pollinating (85-90%), some pollen from any particular canola variety will move through the environment and this can result in the adventitious presence of these traits in other canola varieties. The movement of pollen was studied when IT canola was first introduced into Australia. Pollen flow from the then isolated crops of IT canola were measured by assessing the presence of the HT trait in surrounding canola crops. Rieger et al. (2002) reported that pollen can move as far as 2.6 km. Despite the presence, the highest frequency of cross pollination measured was 0.225%, although 69% of samples tested showed no outcrossing at all. Only five samples tested had HT seedlings more than 0.1% which is at the limit of detection for the current commodity testing methods used. Based on the levels seen, these authors concluded that pollination between commercial fields occurs only at very low frequencies.

Even so, the recommendations contained in crop management plans developed by Monsanto and Bayer CropScience propose that a five metre buffer in non-GM crops adjacent to GM crops be maintained. Based on this and a comprehensive review of international research into pollen flow, the Gene Technology Grains Committee has proposed that GM and non-GM canola production systems can co-exist (GTGC 2002).

Canola volunteers

Because of the tendency of canola pods to shatter and small size of the seed, canola is likely to volunteer in subsequent crops. Despite this likelihood, canola (conventional, TT or IT) has not been identified as a significant weed in cereals or pulses in the most recent survey of cropping weeds in Victoria (Niknam et al. 2002) . If volunteers do occur in cereals, there are many options for control, including group B and C herbicides and then later in the crop, group I herbicides such as 2,4 D – a phenoxy acid. If the canola volunteers were IT, group B chemicals could not be used, while if they were TT, group C chemicals would not be effective. In both cases, a group I herbicide would be appropriate. Weed management in Canadian cropping systems generally provides adequate control of volunteer canola but there are low density populations reported in some crops (Légère et al. 2001). Control of canola volunteers with acquired herbicide tolerance, either with single or multiple resistances would be more an issue for control in pulses, where post emergence herbicides are limited. In such situations, growers and advisors would need to consider current integrated weed management techniques such as using pre sowing knockdown herbicides, pre emergence herbicides, cultivation or strategic crop selection. Other aspects to consider in volunteer management would be to reduce weed build up by efficient harvesting, as well as leaving paddocks uncultivated for four weeks following harvesting so that induced dormancy is minimised (Pekrun et al. 1998).

Gene transfer

A further concern expressed is the potential for herbicide tolerance genes to become introgressed into weeds with the potential development of weeds with herbicide tolerance traits. This area was reviewed recently and the authors indicated that it was unlikely that herbicide tolerance genes would be stable in weed populations if herbicides were not used to control them (Glover 2002). While there is a possibility of transfer of genes between different cultivated Brassica species, the potential for hybridization in the field, introgression of the HT trait and then stable expression in the progeny of weeds is considered a very low and manageable risk (Green and Salisbury 1998).

Resistance management plans

While the potential for resistance to glufosinate-ammonium is very low, the evolution of glyphosate resistant weed populations has already occurred in certain Australian cropping systems (Heap 2002). It is clear that, irrespective of the use of any particular HT canola production system, there is a need to implement IWM procedures in all crops to ensure that herbicides remain a component of our farming systems. Ralph (n.d.) has developed a resistance plan to be used with Roundup Ready® canola, and the procedures in that plan aim to reduce the level of weed pressure as well as reduce the frequency of glyphosate used in rotations. It has been shown that sustained use of glyphosate or virtually any herbicide used intensively, will select for weeds resistant to the chemical (Diggle et al. 2002). Using a range of techniques, including the use of trifluralin pre sowing, is likely to maintain the level of resistance in weed populations to manageable levels.

Crop management plans

Both Bayer CropScience and Monsanto Australia have developed crop management plans for their products. These plans explain the stewardship program for the commercialisation of the technologies and cover areas such as best management practice for the use of IWM with either InVigor® hybrid canola or Roundup Ready® canola. These plans were reviewed through industry consultation and the response from growers and advisors was that the plans provided farmers information appropriate to the management of the technologies (Norton 2002).

Market access and trade

A significant issue for the Australian canola industry is to assess the implications of the adoption of GM canola. The Australian Productivity Commission (Stone et al. 2002) used models to predict the impact of GM technology adoption in Australia on trade. They predicted that the share of GM canola production will increase in Australia due to local productivity gains. When comparing export performance of Australia and its major competitors, it was apparent that there would be little export growth if GM crops were not adopted. The overall conclusion was that if Australia does not adopt GM technologies for canola, its competitiveness will decline as our trading partners expand their use of these technologies.

Summary

There are several risks associated with the introduction of GM canola, and based on the work reviewed here, these risks are considered to be manageable, so that the benefits can be realised by Australian farmers and the economy.

Appendix 1

Herbicides, resistance management groups, modes of action and examples of products used in association with canola production systems (Avcare 2000).

Herbicide	Resistance Group	Types	Model of Action	Example
Clethodim	A	Cyclohexanedionone (“dims”)	Inhibitors of acetyl coenzyme A carboxylase	Select®
Fluazifop	A	Aryloxyphenoxypropr ionates (“fops”)	Inhibitors of acetyl coenzyme A carboxylase	Fusilade®
Imazethapyr	B	Imidiazolinone	Inhibitors of acetolactate synthase	Spinnaker®
Imazapic/imazapyr	B	Imidiazolinone	Inhibitors of acetolactate synthase	On-Duty®,
Simazine	C	Triazine	Inhibitors of photosynthesis at photosystem II	Gesatop®
Atrazine	C	Triazine	Inhibitors of photosynthesis at photosystem II	Gesaprim®
Trifluralin	D	Dinotroaniline	Inhibitors of tubulin formation	Treflan®
2,4 D	I	Phenoxy	Disrupters of cell growth	Amicide®
Clopyralid	I	Pyridine	Disrupters of cell growth	Lontrel®
Diquat/Paraquat	L	Bipyridyl	Inhibitors of photosysnthesis at photosystems	Sprayseed®
Glyphosate	M	Glycine	Inhibitors of EPSP	Roundup®
Glufosinate-ammonium	N	Glycine	Inhibitors of glutamine synthesis	Basta®, Liberty®

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