An Environmental Safety Assessment of Roundup Ready® Wheat: Risks for Direct Seeding Systems in Western Canada.

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Executive Summary

Roundup Ready® wheat is a novel product for which unconfined release in Canada is pending. The unconfined release of this product will threaten the sustainability of reduced tillage cropping systems in western Canada and as such it will pose a risk to the environment and natural resource conservation on managed ecosystems (farms) in western Canada.

Reduced tillage provides significant and measurable environmental, resource conservation and economic benefits to farms in western Canada, and it is being recognized by Agriculture and Agri-Food Canada as a method for carbon sequestration and a means of helping Canada to meet Kyoto protocol targets for greenhouse gas emission reduction. Over the past decade there has been a significant trend towards reducing tillage on farms in western Canada. Low-disturbance direct seeding is the most rapidly growing reduced tillage system in western Canada, and this system is agronomically and economically dependent upon glyphosate (e.g. Roundup) for pre-seeding weed control.

After the commercial release of Roundup Ready canola in western Canada the movement of the transgene conferring Roundup resistance among canola crops was significant. This transgene movement was facilitated by a number of factors which in combination created a transgene bridge for the Roundup Ready trait in canola. In relation to this transgene bridge one factor that facilitated the transgene movement and that was unique to Roundup Ready canola was the extensive use of glyphosate (Roundup) in western Canadian cropping systems. The use of glyphosate created a selective advantage (positive fitness value) for Roundup Ready canola volunteers versus non-Roundup Ready canola volunteers. This selective advantage quickly increased the frequency of the Roundup Ready transgene within the volunteer canola population in western Canada. The Roundup Ready trait has now been found in a high proportion of non-Roundup Ready pedigreed canola seedlots. Extraordinary efforts would be required in the current canola production system to contain the Roundup Ready trait

When the Roundup Ready trait moves among canola crops it becomes impossible for farmers to know if their volunteer canola population will contain Roundup Ready volunteers, even if they have not previously grown Roundup Ready canola. If Roundup Ready volunteer canola is present, pre-seeding weed control in low-disturbance direct seeding systems requires the addition of another herbicide which adds cost to the production system and herbicide load on the environment. Because of the Roundup Ready transgene bridge in canola in western Canada, the added cost and herbicide load is borne by both adopters and non-adopters of Roundup Ready canola.

If Roundup Ready wheat was grown under unconfined conditions in western Canada the trait would move from wheat crop to wheat crop in a fashion similar to that seen in canola. The factors combining to form the Roundup Ready transgene bridge in canola will be similar for Roundup Ready wheat. This includes the factor that was unique to the Roundup Ready trait in canola; the extensive use of glyphosate in cropping systems in western Canada which would create a selective advantage for Roundup Ready volunteer wheat over non-Roundup Ready volunteer wheat. As in canola, this factor will make it difficult to contain the Roundup Ready trait within given wheat fields.

For low-disturbance direct seeding farmers, controlling volunteer Roundup Ready wheat volunteers will require the addition of another herbicide to the pre-seeding application. This will add more cost and more herbicide load on the environment. The cost to control volunteer Roundup Ready wheat volunteers will be higher than the cost to control volunteer Roundup Ready canola. Because of the eventuality of a Roundup Ready transgene bridge in wheat, the additional cost and additional herbicide load will be borne by both adopters and non-adopters of Roundup ready wheat.

Adding cost, complexity and herbicide load to pre-seeding weed control in low-disturbance direct seeding cropping systems will threaten the sustainability of these systems for all farmers in western Canada. This, in turn, will threaten farmers' ability to capture the environmental, resource conservation and economic value of low-disturbance direct seeding. The release of more than one widely-grown Roundup Ready crop in western Canada would magnify and accelerate these effects.

Because of the dependence of low-disturbance direct seeding on glyphosate, the movement of the gene conferring glyphosate resistance has greater agronomic implications and environmental risk than genes conferring resistance to either glufosinate (e.g. Liberty Link) or imidazolinone herbicides (e.g. Clearfield). The extensive use of glyphosate in western Canada facilitates movement of the Roundup Ready trait from crop to crop. Concerns are unique to the Roudup Ready crops because neither glufosinate nor the various herbicides used in Clearfield canola or Clearfield wheat are used as extensively as glyphosate or as low-disturbance direct seeding, spring burn-off treatments.

The release of Roundup Ready wheat also brings concerns about an increased risk of selecting for glyphosate resistant weed biotypes. These weed biotypes would also threaten the sustainability of low-disturbance direct seeding. The suitability of farm-saved wheat seed for low-disturbance direct seeding systems will be threatened because it will be difficult for farmers to keep farm-saved wheat seed free from the Roundup Ready trait. Additionally, the movement of the Roundup Ready trait among wheat crops in western Canada will create additional risk for Canadian marketers of wheat and cereal grains in meeting the requirements of the Cartagena Protocol on Biosafety which is designed to meet global environmental safety needs.

Even with the value of experience after the release of Roundup Ready canola there have been no means proposed, implemented and tested for containing the Roundup Ready trait. Industry lead stewardship plans have been suggested but they are fundamentally inappropriate as the means to achieve this end. Further research in key areas is required to create and test means for containment of this trait.

The unconfined release of Roundup Ready wheat will negatively affect the environment and limit farmers' ability to conserve natural resources on farms in western Canada. The effect that this novel product will have is unique because of the nature of the trait involved and its relationship to the way in which crops are farmed in western Canada. Under current conditions the release of Roundup Ready wheat in western Canada would be environmentally unsafe.

1. Introduction

The unconfined release of Roundup Ready wheat will pose a risk to the environment and natural resources on managed ecosystems (farms) in western Canada. The risk is related to

1. the environmental and resource conservation value direct-seeding cropping systems in western Canada provide,
2. the dependence these systems have on an inexpensive, non-selective, reliable and relatively benign herbicide such as glyphosate (Roundup) used to replace tillage for weed control prior to seeding, and
3. the threat that Roundup Ready wheat poses to the sustainability of using glyphosate for pre-seeding weed control.

The argument, in brief, is that the unconfined release of Roundup Ready wheat into western Canada will result in the movement among wheat crops (and wheat cultivars) of the transgene which confers glyphosate resistance. This transgene movement will be difficult to limit because of

1. the nature of pollen mediated gene flow in wheat,
2. the amount of wheat grown in western Canada,
3. the relative abundance and persistence of volunteer wheat in cropped fields, and
4. the common use of glyphosate in western Canadian cropping systems which increases the frequency of the gene conferring Roundup resistance within the volunteer wheat population.

Movement of the Roundup resistance transgene will lead to the general presence of volunteer Roundup Ready wheat in western Canada. This will complicate and add expense and herbicide load to current cropping practices in western Canada. Farmers who practice glyphosate dependent direct-seeding (whether or not they chose to grow Roundup Ready wheat) would be required to add another herbicide to their pre-seeding glyphosate application. The additional cost would significantly diminish the economic advantage of direct-seeding for these farmers, driving them towards high disturbance direct-seeding or conventional-tillage practices in order to achieve cost effective pre-seeding weed control. In this fashion the unconfined release of Roundup Ready wheat would create a movement among farmers towards increased tillage in western Canada.

Direct-seeding results in significant soil moisture conservation, an increase in soil organic matter and protection of the soil from wind and water erosion. A movement away from direct seeding would therefore pose a risk to the environment (soil environment) and natural resources (soil, soil organic matter and soil water) conservation on managed ecosystems (farms) in western Canada.

The argument is supported by:

1. the value of and the trend toward reduced tillage in western Canadian cropping systems,
2. experiences with the unconfined release of Roundup Ready canola in western Canada,
3. the potential for movement of the transgene conferring glyphosate (Roundup) resistance in wheat in western Canada,
4. increased risk of the evolution of glyphosate resistant weeds,

5. the potential for contamination of farm-saved wheat seed with the Roundup Ready trait, and
6. our ability to maintain segregation of Roundup Ready wheat from non-Roundup Ready wheat and implications for meeting commitments to the Cartagena Biosafety Protocol.

2. The value of and trend toward reduced tillage in western Canadian cropping systems

2.1. The value of reduced tillage

In western Canada, the adoption of reduced tillage practices is largely responsible for significantly reducing the risk of soil erosion since 1981 (Campbell 1999; McRae et al. 2000). Agriculture and Agri-Food Canada estimated that the adoption of reduced tillage practices has been primarily responsible for a 33% reduction in wind erosion risk for prairie soils in the period from 1981 to 1996. The reduced risk of wind erosion was also associated with a decline in tilled summer fallow acres that was directly related to farmers' ability to continuous crop because of soil moisture conserved through the use of reduced tillage practices (Lafond et al. 1992; McRae et al. 2000). Between 1990 and 1998 the summer fallowed acres in the brown, dark brown, and black and grey soil zones declined from 43% to 38%, 31% to 20% and 17% to 9%, respectively (Zetner et al. 1999). The decline in summer fallow acres resulting from a reduction in tillage equated to approximately 5 million additional cropped acres across western Canada in 1998 versus 1990.

Reduced tillage provides a range of benefits to farmers and the farm environment. It results in the conservation of soil moisture, uses less labour and fuel, and means fewer repairs to equipment per hectare (Lafond et al. 1992; Nagy 2001). Yields are generally equivalent to, or higher than, those under conventional tillage for traditional grains and oilseeds and special crops (Lafond and Derksen 1996; Derksen et al. 1996; Nagy 2001; Cutforth et al. 2002). In most of the soil zone regions of western Canada an adoption of reduced tillage practices leads to higher net returns. Costs of production for low-disturbance seeding systems are generally lower than for conventional tillage systems with the difference in costs primarily directly related to tillage (Nagy 2001). With reduced tillage, silt and nutrients are kept on the field and not carried off with run-off. Wildlife benefits because crop residue offers more food and cover, and earthworms and soil microbes thrive. Reduced tillage improves the long-term condition and overall health of soils (Grant 1997). In reduced versus conventional-tillage systems, proportionally more of the carbon dioxide from the atmosphere that is absorbed by plants is stored as carbon-containing soil organic matter. Reduced tillage systems leave more organic matter in the soil than conventional tillage systems, making the soil a sink for carbon, and allowing farmed soil to act as a reservoir for carbon emissions in Canada (Campbell 1999). Agriculture and Agri-Food Canada's contribution to meeting the requirements of the Kyoto protocol explicitly includes plans to increase carbon sequestration on farm lands through greater adoption of reduced-tillage practices (Agriculture and Agri-Food Canada 2003).

2.2. The trend towards reduced tillage in western Canada

Reduced tillage practices are rapidly gaining acceptance in western Canada and the acres under reduced tillage have been rapidly increasing (Campbell 1999; Statistics Canada 2002). Within Canada, low and no-till systems are most popular in western Canada as a means of conserving scarce soil water and preventing wind erosion because western Canada is generally drier than most other agro-ecoregions in Canada (Campbell 1999; Ecological Stratification Working Group 1995; Lafond et al 1992; McRae et al. 2000; Nagy 2001; Derksen et al. 2002).

2.2.1. Direct-seeding (no-tillage seeding)

In western Canada, many farmers have adopted direct-seeding (no-tillage seeding) both for practical purposes and to capture the benefits of reduced tillage (Derksen et al. 2002). With direct-seeding, farmers do not till the soil in the spring prior to seeding. Instead they seed directly into the overwintered seedbed. There are both high and low-disturbance versions of direct-seeding. With high-disturbance direct seeding, farmers use sweep type openers on their seeding equipment. The tillage action of the sweeps tends to cover the entire field surface area and generally provides sufficient pre-seeding weed control, allowing high-disturbance direct seeding farmers to forego a pre-seeding herbicide application. With low-disturbance direct seeding, farmers use narrow openers on their seeding equipment. These generally provide insufficient inter-row tillage action to achieve satisfactory levels of pre-seeding weed control. With low-disturbance direct-seeding, therefore, farmers use a pre-seeding herbicide application for weed control (Harker et al. 2003).

In Saskatchewan, there has been a steady increase in the number of acres under low-disturbance direct-seeding. In 2002, conventional tillage was practiced on only 35% of acres compared to 55% in 1995. During this same period high-disturbance direct seeding acres fell slightly from 31% in 1995 to 28% in 2002. Low-disturbance direct seeding acres rose from 15% in 1995 to 42% in 2002 (Nerbas 2003). Across the three prairie provinces it is estimated that in 2001 between 16 and 20 million acres of annually cropped land (25-30% of the annually cropped acres in western Canada) was seeded using low-disturbance direct seeding (Statistics Canada 2002; N. Harker, AAFC-Lacombe, pers. comm.).

2.2.2. Low-disturbance direct seeding depends on glyphosate

Newer and cheaper herbicides, particularly glyphosate, provide an alternative to tillage for controlling weeds and have spurred the adoption of no-till cropping (especially low-disturbance direct seeding) and chemical summer fallow (Derksen et al. 2002; Nagy 2001). Glyphosate degrades quickly without damaging earthworms or soil microbes, and without being carried in surface or ground water (Campbell 1999). The majority of direct-seeding farmers rely upon the use of glyphosate for weed control prior to seeding (Roundup is one trade name for a glyphosate based herbicide) (Thomas et al. 1999a,b,c, 2003). Glyphosate products are very effective, non-selective, systemic, non-residual (with respect to limitations on cropping and re-cropping) and relatively inexpensive. The majority of farmers practicing low-disturbance direct-seeding use 450 g ae/ha of glyphosate herbicide prior to seeding; herbicide cost for this application rate would be $4.50/acre (Manitoba Agriculture and Food, 2002). Effective low-disturbance direct-seeding is dependent on inexpensive and effective, non-selective pre-seeding herbicidal weed control. The net returns from low-disturbance seeding systems in western Canada are very sensitive to herbicide costs (Nagy 2001). There currently are no other non-selective, systemic, non-residual (with respect to limitations on cropping and re-cropping), relatively environmentally benign and relatively inexpensive herbicides registered for use in western Canada which could act as an effective substitute for glyphosate for pre-seeding weed control in low-disturbance direct-seeding systems (Friesen et al. 2003; Van Acker and Entz 2002).

3. Experiences with Roundup Ready canola in western Canada after unconfined commercial release

3.1 Movement of transgenes within the canola genome

The rate of herbicide tolerant genetically modified (GM) canola adoption in western Canada has been rapid. Roundup Ready canola constituted approximately 40% of canola acres in western Canada in 2001 (Friesen et al. 2003). At the time of unconfined commercial release of Roundup Ready canola in Canada, it was known that there was significant potential for outcrossing within the canola (*Brassica napus* L.) genome and that transgene movement from canola crop to canola crop would occur. At the time, the consequences of this transgene movement were considered to be manageable (Canadian Food Inspection Agency 1995).

The decision for unconfined commercial release was based on evidence at that time of the extent of gene flow in canola, and work after the release has shown that pollen mediated gene flow in canola can be an even greater source of genetic contamination than was predicted. Beckie et al. (2001) conducted commercial field-scale tests of pollen mediated gene flow in canola and found that outcrossing occurred to a distance of 800 m. In Australia, Rieger et al. (2002) recorded outcrossing in commercial canola (*B. napus*) fields at distances of up to 2.5 km. These studies helped explain why there were so many reported cases of farmers finding Roundup Ready volunteer canola in fields in which no Roundup Ready canola had ever been seeded (Hall et al. 2000). Farmers also suspected that some volunteer Roundup Ready canola was coming into their fields along with their certified canola seed. Friesen et al. (2003) and Downey and Beckie (2002) confirmed independently that certified pedigreed non-GM canola seedlots in western Canada were contaminated with genetically engineered herbicide resistance traits. The Canadian Seed Growers Association (CSGA) is investigating mitigation plans and adjustment to the canola seed production system to help to stem and prevent this contamination (Dale Adolphe, CSGA, pers. comm.), but it will be difficult given the effective transgene bridge that exists for the Roundup Ready trait in canola (see section 3.1.1).

Friesen et al (2003) concluded that given current knowledge of pollen mediated gene flow in *B. napus*, it is unlikely that pollen flow would cause greater than 0.1% contamination in a single generation of pedigreed seed production. Pedigreed seed crops are grown with mandatory isolation distances from sexually compatible species which limits pollen mediated gene flow. Therefore, the contamination occurring in certified canola seedlots with contamination levels greater than 0.25% was either the result of inadvertent mechanical mixing of certified seedlots during harvest or handling, or the result of contamination occurring in earlier generations of pedigreed seed production (i.e., Breeder or Foundation seed) that was not tested for or detected. Downey and Beckie

(2002) reached similar conclusions. Friesen et al. (2003) also noted that the planting of pedigreed canola seedlots that do not exceed the 0.25% contamination guideline (variety purity) for certified seed does not necessarily mean that there will be no agronomic concern the following year with regard to the unexpected presence of herbicide resistance traits in volunteer canola seedlings. Given some reasonable assumptions regarding canola seeding rates and thousand seed weight (5.5 kg/ha, 4.0 g per thousand seeds), there are approximately 1.4 million seeds planted per hectare. At the 0.25% contamination level of a herbicide resistance trait in a seedlot, there will be 3,500 resistant ‘seeds’ planted per hectare. If one-half of these seeds result in mature canola plants, which is a typical establishment rate for a commercial canola crop in western Canada, then there will be 1,750 resistant canola plants per hectare. Given a 2,000 kg/ha crop yield and harvest losses of 6% (Gulden et al., 2003), there will be 120 kg/ha of seed remaining in the field. Resistant seeds will be 0.25% of this 120 kg/ha [in the absence of selection and given equal fitness of susceptible and resistant individuals, a resistance trait will remain at approximately the same frequency in a population over time (Jaseniuk et al., 1996)]. Therefore, 300 g of resistant seed will shatter onto the soil per hectare, or 75,000 resistant seeds per hectare. If one-tenth of these seeds successfully establish a seedling the following year, there will be one herbicide resistant volunteer canola plant every 1.3 m^2. If the resistance trait is glyphosate and the farmer practices direct seeding and sprays with glyphosate alone prior to crop emergence, one surviving canola plant every 1.3 m^2 will be a weed problem. Depending on the crop planted, there may not be in-crop herbicide options that will provide satisfactory control of relatively large volunteer canola plants (large because the canola volunteers would have survived the spring glyphosate burn-off applied prior to crop emergence). If the crop planted is not as competitive as cereals (e.g., flax, lentil, or field bean), one volunteer canola plant every 1.3 m^2 may be more than a cosmetic problem and probably will cause crop yield losses (Simard and Legere 2003).

The above scenario applies to pedigreed canola seedlots that meet the cultivar purity guideline of 99.75%. Downey and Beckie (2002) acknowledged this problem and noted that even when variety purity standards are met, the sowing of a non-herbicide resistant canola variety will almost certainly result in a significant population of herbicide resistant plants within that field. The results of the seedlot contamination studies are a demonstration of the difficulty in maintaining crops free from GM trait contamination, including the Roundup Ready trait, even when they are managed within a very stringent, regulated and monitored segregation system such as the pedigreed canola seed production system.

3.1.1. A transgene bridge in canola

The spread of the transgene conferring glyphosate resistance within canola is not only related to the outcrossing potential of canola as measured by Beckie et al. (2001) and Rieger et al. (2002). More broadly, it is a function of the environmental and agronomic conditions and biological and ecological characteristics for canola as it is grown and exists in western Canada. These conditions and characteristics interact to create effective opportunities for genes to move from canola crop to canola crop; they create a gene bridge. For the Roundup Ready trait it can be called a transgene bridge. The conditions and characteristics which interact to create an effective transgene bridge for the Roundup Ready trait in canola in western Canada include:

- The large number of acres of Roundup Ready and non-Roundup Ready canola grown in all agricultural regions of western Canada.
- The relatively high frequency of canola in crop rotations in western Canada (for example, on average 1 in 4 years on any given field in Manitoba, Thomas et al. 1999c).
- The high population levels of volunteer canola in fields in western Canada (Leeson et al. 2002 a,b; Thomas et al. 1996; Thomas et al. 1998 a,b; Gulden et al. 2003).
-Volunteer canola commonly survives to flowering at significant occurrence densities in a significant proportion of fields in western Canada (Leeson et al. 2002a,b; Thomas et al. 1996).
- In low disturbance direct-seeding systems, Roundup Ready volunteer canola is selected for within the volunteer canola population, and according to population genetics theory and experience with herbicide resistant weed populations (Jaseniuk et al. 1996), this causes the frequency of the glyphosate resistance trait to increase rapidly in the volunteer canola population.
- Volunteer canola can persist until, emerge in and flower in subsequent canola crops (Simard et al. 2002; Legere et al. 2001; Leeson et al. 2002 a,b).
- Outcrossing rates in canola are relatively high from plant to plant within a commercial crop (Staniland et al. 2000).
- The current canola seed production system was designed to maintain varietal purity standards related to performance and end-use function. The system was not designed to prevent gene flow at the level required to prevent problematic appearance of the Roundup Ready trait in non-Roundup Ready varieties.

These factors combine to create an effective Roundup Ready transgene bridge in canola as both Roundup Ready and non-Roundup Ready canola are widely grown in western Canada. The result of this transgene bridge is that essentially all volunteer canola populations in western Canada likely contain some proportion of Roundup Ready volunteers, even if Roundup Ready canola was never intentionally planted in a given field. Thus farmers cannot be certain of the herbicide resistance trait status of their volunteer canola population.

Other herbicide resistant traits (glufosinate resistance and imidazolinone resistance traits in the Liberty Link and Clearfield canola systems, respectively) also move into non-herbicide resistant canola varieties (Friesen et al. 2003). However, the difference for these other herbicide resistant traits in contrast to the Roundup Ready trait is that their movement does not create agronomic and environmental problems to the same degree for farmers in western Canada. This is because, as an agronomic practice, farmers do not currently depend on glufosinate or imidazolinone herbicides for pre-seeding weed control to replace pre-seeding tillage for weed control in low-disturbance direct seeding.

3.2. Managing Roundup Ready volunteer canola

Currently, for low-disturbance direct seeding farmers in western Canada there are no suitable substitutes for glyphosate as a spring pre-seeding ("burn-off") herbicide when one considers spectrum of activity, efficacy, absence of soil residue, and cost. Consequently, those low-disturbance direct seeding farmers that expect glyphosate resistant canola volunteers (which may now be very widespread) still use glyphosate as a spring pre-seeding burn-off, but usually add an auxin-type herbicide such as 2,4-D or

MCPA to the spray tank. There are indications that in western Canada the standard pre-seeding herbicide application is becoming a two-herbicide mixture instead of a one herbicide (glyphosate) application (Don Wilkinson, Interprovincial Co-operatives, Winnipeg, MB, pers. comm.).

In addition to extra cost, and extra herbicide load on the environment, there are other concerns with tank-mixing glyphosate and an auxin-type herbicide. The auxin-type herbicides have some soil residual activity, and this soil residue can seriously injure certain sensitive broadleaf crops as they emerge such as field pea (*Pisum sativum* L.), field bean (*Phaseolus vulgaris* L.), lentil (*Lens culinaris* Medic.), chickpea (*Cicer arietinum* L.), and sunflower (*Helianthus annuus* L.) (Saskatchewan Pulse Growers, 2000). Furthermore, volunteer canola plants that emerge early in the spring are generally large, hardy, and robust at the time of spring burn-off, and therefore complete control may be difficult with alternative herbicides such as 2,4-D, MCPA, or thifensulfuron/tribenuron (Simard and Legere 2003). If there are unexpected glyphosate resistant canola volunteers, due to pollen mediated gene flow from a neighboring field or from a contaminated seed source, these become very obvious five to seven days after application of the spring pre-seeding glyphosate burn-off. Depending on the crop planted (e.g., field bean, lentil, chickpea, sunflower) applying auxin-type herbicides in-crop to the escaping glyphosate resistant canola volunteers may not be an option. Also, glyphosate resistant volunteers escaping the spring pre-seeding burn-off may be relatively large and difficult-to-control by the time alternative herbicides can be applied in-crop. Depending on surviving volunteer canola density and the crop that was sown, the resulting problem may be cosmetic or the competitive growth habit of volunteer canola may actually reduce crop yield and contribute to the glyphosate resistant canola seedbank in the soil (Friesen et al.2003).

4. The potential for movement of the transgene conferring glyphosate resistance in wheat in western Canada

4.1. Pollen flow in wheat

In plants, genes move between populations either through pollen or seed movement. Pollen movement in wheat is facilitated by wind and gravity. In wheat, anthers normally open within the floret, followed by filament elongation and extrusion of the anthers outside of the floret. A small amount of pollen is shed on the stigma within the floret, while 80% of the pollen is shed outside of the floret. Florets that have not been successfully self-pollinated will remain open and be receptive to pollen from other sources for up to 13 days after flowering (de Vries 1971). Estimates of out-crossing rates in wheat are dependent on synchrony of flowering between males and females, the presence of receptive females and the availability of single dominant nuclear genes to facilitate detection of out-crossing (Waines and Hegde 2003).

On-farm seed movement may occur in a number of ways such as through movement between fields during seeding and harvesting operations, through on-farm grain handling and storage, even by animals, or wind and water. Seed that has previously been contaminated with a GM trait through prior pollen or seed movement can contribute to the introduction of GM traits into fields that were not previously planted to a GM crop or adjacent to a GM crop. Frequency of seed movement is expected to be highly variable and difficult to predict. However, extrapolations from weed seed studies and crop mixtures may be helpful in establishing a range of values.

Hucl and Matus-Cádiz (2001) compared out-crossing rates among four wheat cultivars (Katepwa, Roblin, Oslo and Biggar) using a dominant blue aleurone trait in the pollen source to quantify out-crossing rates. Out-crossing rates varied considerably among the different cultivars (Figure 4.1). Katepwa showed the lowest level of out-crossing and Oslo showed the highest level of out-crossing. Out-crossing was reported up to 27 m from the pollen source. The pollen source plot size in this study was small ($5m^2$) and sample sizes evaluated were low (less than 700 seeds/sample). Other studies have shown that out-crossing rates in wheat fall within the range 0.1% to 10.1% (Griffin 1987; Martin 1990; Hucl 1996; Enjalbert et al. 1998, Waines and Hegde 2003).

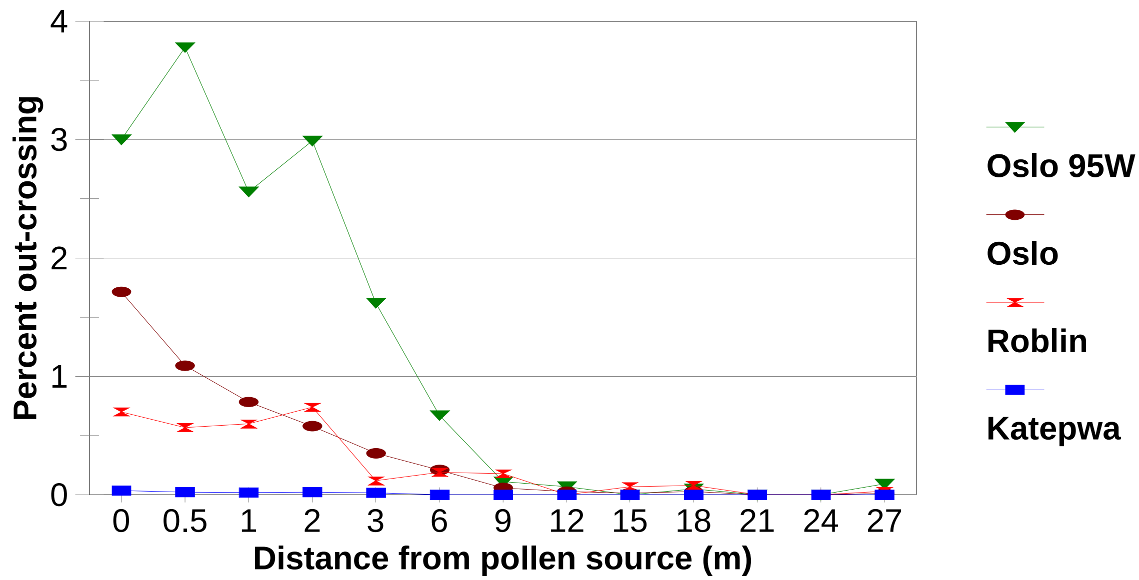


Figure 4.1. Mean out-crossing rates reported for Katepwa, Roblin and Oslo in a two year study conducted by Hucl and Matus-Cádiz (2001). Highest out-crossing rate (Oslo 95W) occurred for the cultivar Oslo in 1995 for samples collected west of the pollen source.

4.2 Influence of selection pressure on Roundup Ready transgene flow in wheat

4.2.1 Modeling gene movement in wheat populations

Brûlé-Babel et al. (2003) modeled the contamination potential of the gene conferring glyphosate resistance in commercial wheat fields within a region such as Manitoba, given average agronomic practices as defined by surveys of agronomic practice (Thomas et al. 1999c). For the purposes of their study out-crossing rates similar to Katepwa and Oslo were used to provide comparisons of high and low out-crossing rates. Although out-crossing has been reported as far as 48 m (Khan et al. 1973) and 80 m (P. Hucl, Univ. of Saskatchewan, pers. comm.) from the pollen source, levels of out-crossing are highest in the first 10 m from the pollen source. Beyond 10 m out-crossing rates tend to be quite low but can occur at low levels for a considerable distance from the pollen source (Waines and Hedge 2003). Measuring exact out-crossing rates beyond 10 m from the pollen source becomes difficult because the area from which samples must be drawn increases exponentially with distance from the pollen source. Therefore, to simplify modeling, out-crossing was assumed to occur within 10 m of the pollen source at either a level of 0.01% (similar to Katepwa in the Hucl and Matuz-Cádiz 2001 study) or 3% (similar to Oslo in the Hucl and Matuz-Cádiz 2001 study).

Basic population genetics models were used to evaluate the effect of gene flow either on its own or followed by the application of selection pressure (Hartl and Clark 1989). Similar models have been validated for herbicide resistant trait movement in wild type populations (weeds) (Jaseniuk et al. 1996) and for herbicide resistant traits moving from wheat to jointed goatgrass (*Aegilops cylindrica* Ces., Host) in Oregon (Zemetra et al. 1998). Since most GM traits are inherited as single nuclear dominant genes, this form of inheritance was modeled. The general selection equation was modified to accommodate the primarily self-pollinating nature of wheat such that following the initial gene flow event an out-crossing rate of 1% within the resulting population was used. The selection pressure used in the general selection model was set at 95% to simulate a typical herbicide efficacy rate.

Even though gene-flow rates in wheat may be relatively low when compared to crops that are primarily cross-pollinating, the levels of gene flow are sufficiently high that it will not be possible to guarantee 0% GM trait in non-GM wheat and it will likely not be possible to maintain even low levels of GM trait contamination in non-GM crops.

The vast acreage of wheat in western Canada suggests that some wheat fields will be grown adjacent to each other with very little distance separating them. Similarly, the minimum isolation distance for production of pedigreed Breeder and Select seed is 10 m and for Foundation, Registered and Certified seed is only 3 m (Anonymous 1994). Based on the out-crossing rates and distances reported above, gene flow between GM and non-GM wheat will be of concern in a production system that requires segregation of non-GM wheat from GM wheat. In the short term there is little concern of gene flow of non-GM traits to GM wheat. As a result, the main focus will be on the fate of GM traits in non-GM wheat crops and volunteers.

4.2.2 Fate of single gene flow events

When a field of GM wheat is grown adjacent to a non-GM wheat field some out-crossing may occur. The level of out-crossing will depend on the synchrony of flowering between the two fields, the level of male sterility in the non-GM wheat (i.e. degree to which receptive females are available), the non-GM cultivar, distance between the crops, and wind direction. The frequency of the GM trait in the harvested seed from the non-GM crop will be influenced by the rate of out-crossing experienced and size of the field being harvested. Since the highest level of out-crossing will occur on the field edge closest to the GM crop, it is expected that the frequency of the GM trait will be highest on the field edge of the non-GM crop and will diminish with distance from the GM crop. As the non-GM field is harvested, it is expected that the GM trait will be mixed with and diluted with the non-GM wheat from the remainder of the field. Depending on how the field is harvested the frequency of the GM trait may vary significantly from sample to sample with the highest frequency occurring in samples harvested from the areas closest to the GM wheat crop. If the harvested grain is used for seed, the GM trait may be introduced into a field that has never been near a GM wheat crop. Similarly, wheat volunteers that remain after harvest will contain the GM trait at a frequency equivalent to the out-crossing rate. The highest frequency of the GM trait in volunteers will occur in the field in areas close to the GM crop. Under situations that do not provide a selective advantage or disadvantage to the GM trait, the frequency of the trait will remain constant within the population. If volunteer population sizes are very low, the frequency of the GM trait may increase or decrease due to random genetic drift.

4.2.3 Effect of repeated gene flow events

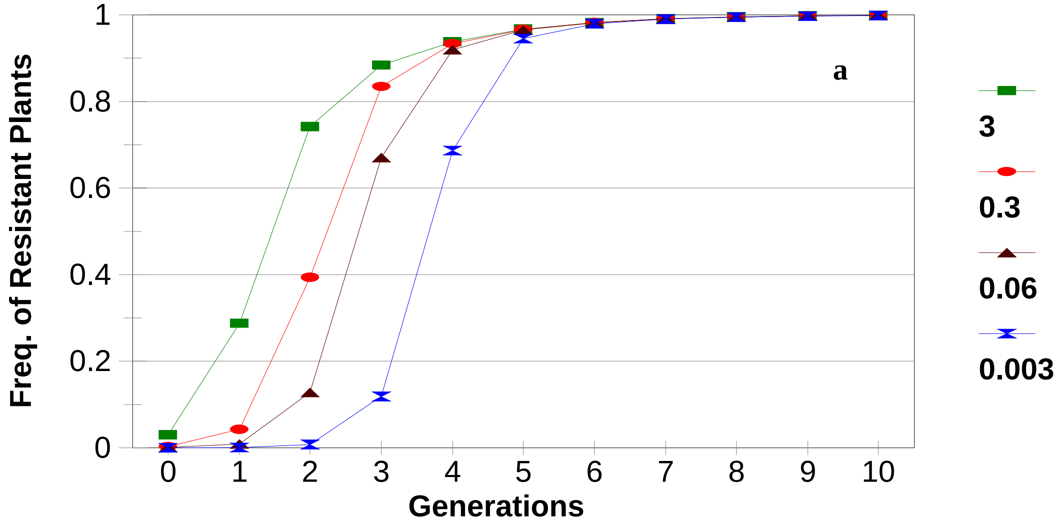
When a non-GM wheat crop is grown adjacent to a GM wheat crop over multiple generations, the frequency of the GM trait is expected to increase in the non-GM wheat crop. If no other forces are acting on the population, the rate of increase will be directly related to the level of gene flow between the two crops (Table 4.1). Maintaining GM trait contamination in non-GM wheat at a low level (0.25%, for example) would be difficult if out-crossing rates were relatively high (between 1% and 0.1%) but it would be less difficult if out-crossing rates were low. The results from Table 4.1 stress the importance of ensuring that seed supply is produced under conditions that limit the potential for gene flow between GM and non-GM wheat. Farmers that use "farm-saved" seed may need to rethink this strategy if there is a potential for gene flow from a GM wheat crop into their non-GM wheat crop. Alternatively, they may be required to modify their harvesting and seed handling procedures to limit the potential for introduction of GM wheat into their non-GM wheat seed crop (see also section 7).

Table 4.1. The effect of repeated generations of out-crossing from GM wheat to non-GM wheat on the frequency of the GM trait in a non-GM wheat population.

Generation	**% of GM plants in non-GM wheat resulting from different out-crossing rates**			
	% Out-crossing			
	1.0	**0.1**	**0.01**	**0.001**
1	1.000	0.100	0.010	0.001
2	1.990	0.199	0.020	0.002
3	2.970	0.299	0.030	0.003
4	3.940	0.399	0.040	0.004
5	4.901	0.499	0.050	0.004
Generations to exceed 0.25% GM trait in non-GM wheat	**1**	**3**	**26**	**>50**

4.2.4. Effect of selection pressure: Roundup Ready wheat

The fate of GM traits within production systems will depend on the selective advantage or disadvantage conferred by that trait within the production system. Many GM traits will not confer a significant selective advantage either within or outside of the production system. For these traits, their frequency in the non-GM wheat population will be maintained at fairly low levels related to the rate of gene flow. However, GM traits that confer a selective advantage either within the production system or outside of the production system will increase in the population with each generation in which the selection pressure is present (Waines and Hegdes 2003). Herbicide resistance or tolerance traits are an example of the type of trait that confers a selective advantage within the production system (Warwick et al. 1999). The more effective the herbicide and the more frequently it is applied, the more rapid the increase in the frequency of the GM trait in the population.



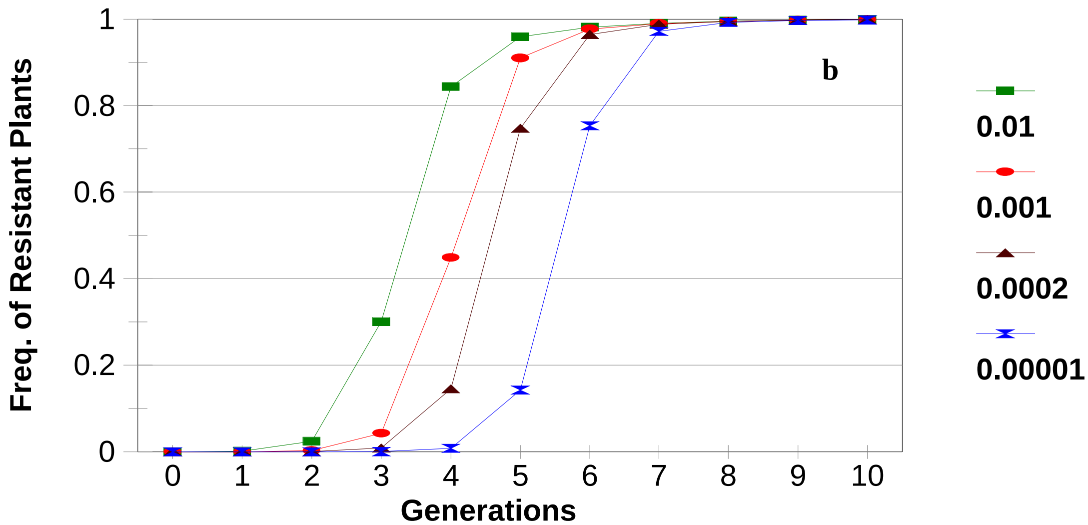


Figure 4.2. Frequency of herbicide resistant GM volunteers following application of the herbicide. The selection pressure of the herbicide is 95%. a) Initial gene flow rates range from 0.003 to 3% to simulate a cultivar such as Oslo that has a high out-crossing rate. b) Initial gene flow rates range from 0.00001 to 0.01% to simulate a cultivar such as Katepwa that has a low out-crossing rate.

Figure 4.2 illustrates the effect of selection pressure on the frequency of a GM trait in a non-GM wheat volunteer population. In this situation the GM trait is assumed to be a herbicide resistance trait such as resistance to glyphosate (Roundup Ready trait). To simulate a field situation, gene flow rates similar to those reported by Hucl and Matuz-Cádiz (2001) for Oslo (Figure 4.2a) or Katepwa (Figure 4.2b) were used as the upper and lower limits, respectively. The remaining gene flow rates simulate a situation in which gene flow occurs in the first 10 m of the field, but then a larger field area is harvested that dilutes the frequency of the GM trait by 10, 50 or 100 times. In these scenarios, it is assumed that gene flow has occurred only in the initial generation. Figure 4.2a indicates that 50% of the volunteer wheat population will be resistant to the herbicide after only 2 to 4 generations in which the herbicide is used and selection pressure is applied. Even at low initial gene flow rates, 50% of the volunteer population will be resistant after only 4 to 6 generations of herbicide treatment. This demonstrates the population genetics principle whereby the frequency of traits that have a high selective advantage in the production system increase rapidly with the application of the selective agent. The model shows that it is the selection pressure from the herbicide application that drives a rapid increase in the herbicide resistance gene frequency in the volunteer wheat population. The rapid increase in herbicide resistance gene frequency occurs regardless of initial outcrossing rate. It occurs rapidly both for varieties with high and low outcrossing rates. For herbicide resistance traits, this will have a significant impact on volunteer management, crop rotation, herbicide management, and the ability to maintain low levels of GM traits in non-GM crops. In western Canada, glyphosate use is extensive and farmers who practice low-disturbance direct seeding use glyphosate every spring for pre-seeding weed control. Low-disturbance direct seeding is currently practiced on 25-30% of the annually cropped acres in western Canada, and that percentage is rising. Therefore, in western Canada there is tremendous selective pressure for the Roundup Ready trait in volunteer wheat populations. Within common production systems in western Canada the Roundup Ready volunteer wheat will have a positive fitness advantage over non-Roundup Ready volunteer wheat and the frequency of the Roundup Ready trait will rise rapidly in the volunteer wheat population.

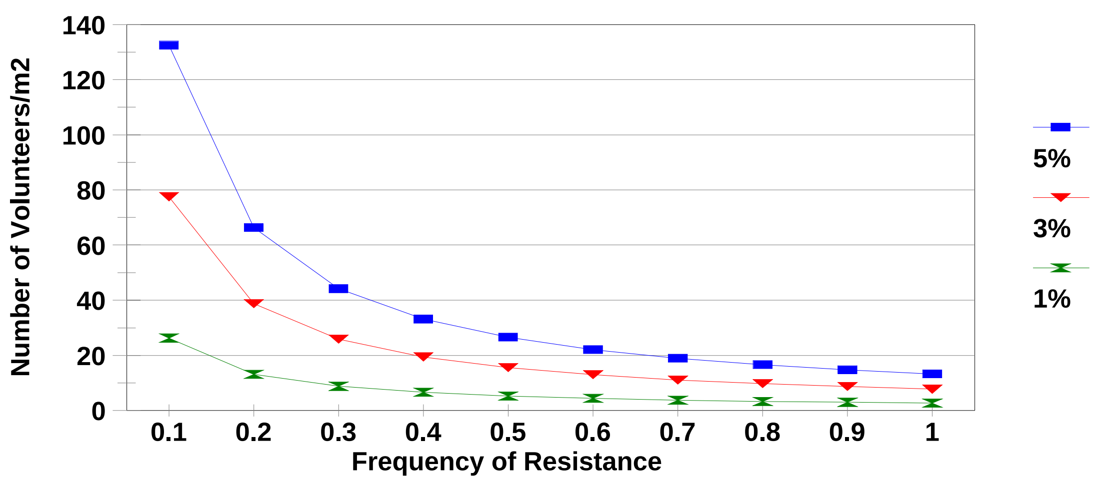


Figure 4.3. Number of volunteers that would lead to 1%, 3%, or 5% GM contamination in non-GM wheat crop sown at 250 seeds/m^2 relative to the frequency of resistant GM plants in the volunteer wheat population.

With the exception of Canada Prairie Spring wheat, current standards for pedigreed wheat seed production allow a maximum of 1 in 10,000 off-types in Breeder and Select seed and 5 in 10,000 in Foundation, Registered, and Certified seed (Anonymous 1994).

Therefore Certified seed could have a frequency of GM traits equivalent to a gene flow rate of 0.05% and still meet pedigreed seed standards. If the GM trait is glyphosate resistance, farmers in western Canada, generally, would rapidly increase the frequency of this trait within their volunteer wheat populations. The rate of increase of the Roundup Ready trait would be similar to the gene flow rate of 0.06% shown in figure 4.2a.

4.2.5. Ability to maintain minimum levels of GM traits in non-GM crops

The potential for selection to increase the frequency of GM traits in volunteer populations must be considered when trying to meet standards for non-GM crops. Figure 4.3 indicates that when the frequency of a GM trait within a volunteer wheat population is relatively high, even a small number of volunteers could make it difficult to meet non-GM standards. For example, if the frequency of a GM trait in a volunteer population is 50% and a non-GM wheat is sown into a field at a standard seeding rate of 250 seeds/m^2, as few as 6 wheat volunteers/m^2 would lead to a GM contamination rate that exceeds 1%. Similarly, 16 and 27 volunteers/m^2 would lead to contamination rates that exceed 3% and 5%, respectively. Marginet (2001) reported that pre-treatment wheat volunteer densities ranged from 1-171/ m^2, and most frequently ranged between 20-40/ m^2. Therefore, a typical density of wheat volunteers could cause concern even if the frequency of the GM trait in the volunteer population was as low as 20-30%. In addition, wheat volunteers continue to persist after control measures have been applied (Derksen and Watson 2001). In the most recent post-control survey of weeds in Manitoba, volunteer wheat was found in 15.8% of fields at an average occurrence density of 2.1 plants/m^2 (Leeson et al. 2002b).

Since pre-seed spring “burn-off” herbicides may be applied immediately before seeding and possibly before emergence of all volunteers, farmers may not be aware that there may be a high frequency of resistant Roundup Ready volunteers in their fields. If the problem is not noted prior to marketing of the grain, this could cause economic losses to the farmer as well as grain buyers. Roundup Ready wheat volunteers that are not controlled prior to seeding, or that cannot be controlled in crop, could also cause export related environmental problems for other wheat classes (i.e. other than CWRS), durum or other non-GM and non-Roundup Ready cereal crops such as barley or oat. Since wheat seed is similar in size to most small grain cereals, wheat containing the GM-Roundup Ready trait could not be easily removed from these crops (see also section 8).

4.3. The Roundup Ready transgene bridge in wheat in western Canada is similar to that witnessed in canola

In canola the Roundup Ready transgene has moved to non-Roundup Ready canola to a greater extent than might have been predicted at the time when Roundup Ready canola was released. This level of transgene movement occurred because of the significant transgene bridge that existed for the Roundup Ready transgene in canola. If Roundup Ready wheat were commercially released a Roundup Ready transgene bridge in wheat would occur that would be similar to that seen in canola because many of the factors that facilitated the transgene bridge in canola are present and similar for wheat, including:

- The great number of acres of wheat grown in all agricultural regions of western Canada.
- The relatively high frequency of wheat in common rotations in western Canada (for example, 43% of rotation in Manitoba, Thomas et al. 1999c).

- The high population levels of volunteer wheat in average fields in western Canada (Leeson et al. 2002 a,b; Thomas et al 1996).
-Volunteer wheat commonly survives to flowering at significant occurrence densities in a significant proportion of fields in western Canada (Leeson et al. 2002a,b; Thomas et al. 1996).
- In low disturbance direct-seeding systems, Roundup Ready volunteer wheat would be selected for within the volunteer wheat population and according to population genetics theory and experience with herbicide resistant weed populations (Jaseniuk et al. 1996), this would cause the glyphosate resistance gene frequency to rise in the volunteer wheat population.
- In general, wheat is as persistent as canola both in terms of quantity (density) and frequency (% of fields) and it can persist to a measurable level for up to five years (Fig. 4.4).
- Volunteer wheat can persist until, emerge in and flower in subsequent wheat crops (figure 4.4) (Beckie et al. 2001; Legere et al. 2001).
- Outcrossing rates in wheat are relatively high from plant to plant within a commercial crop (Brûlé-Babel et al. 2003; Waines and Hegde 2003). The outcrossing rates are not as high as for canola but are high enough to be significant once positive selection pressure is applied for the Roundup Ready trait in common low-disturbance direct seeding production systems in western Canada where pre-seeding glyphosate is applied each year.
- The current wheat seed production system was designed to maintain varietal purity standards related to performance and end-use function. The system was not designed to prevent gene flow at levels required to prevent problematic appearance of the Roundup Ready trait in non-Roundup Ready varieties.

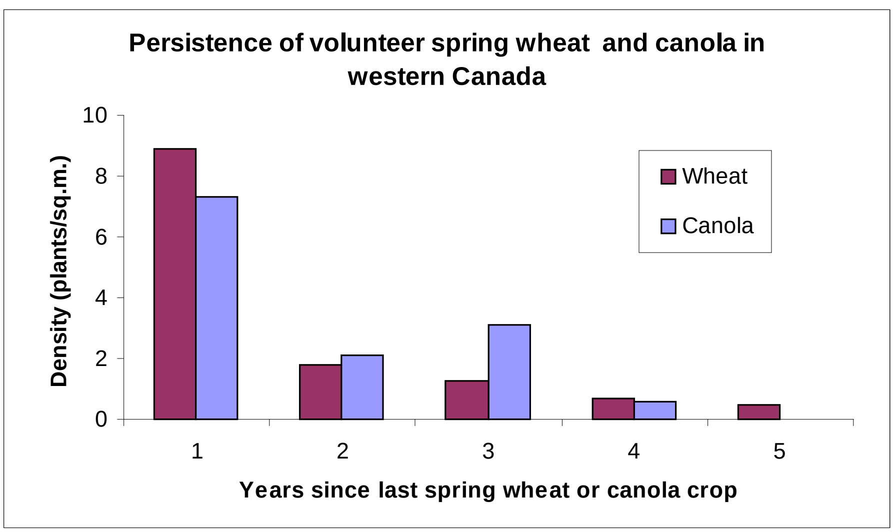


Figure 4.4. Persistence of volunteer wheat or canola in western Canada based on weed survey results from Manitoba, Saskatchewan and Alberta, adapted from Beckie et al. 2001 and Legere et al. 2001. Note: Field frequencies for wheat and canola are 31% and 35%, 15% and 20%, 10% and 15%, 10% and 8% and 9%, in years 1, 2, 3, 4 and 5, respectively.

In canola we have seen that the gene bridge for the Roundup Ready trait has resulted in the movement of the Roundup Ready gene into non-Roundup Ready certified pedigreed canola seedlots (Friesen et al. 2003, Downey and Beckie 2002). Any efforts made to keep the Roundup Ready trait discrete within Roundup Ready canola have proven insufficient, even in the pedigreed seed production systems which can be considered an intensive segregation system. Given the similarities between wheat and canola with respect to a Roundup Ready transgene bridge it is likely that current commercial and seed production management systems in wheat would be insufficient to keep the Roundup Ready trait discrete within Roundup Ready wheat. Management systems sufficient to achieve and maintain discrete segregation of the Roundup Ready trait in either wheat or canola have not yet been devised, modeled or tested.

5. The introduction of Roundup Ready wheat threatens the sustainability of low-disturbance direct seeding

5.1. Roundup Ready wheat volunteer management

Given the experience with Roundup Ready canola in western Canada and the potential for similar gene flow in wheat, volunteer Roundup Ready wheat control will be an issue for both adopters and non-adopters of Roundup Ready wheat. It is generally agreed by agronomists and weed scientists that diverse and integrated approaches to weed management are most effective. Harker et al (2003) recommended judicious crop rotation and a non-exclusive reliance on herbicides for the management of volunteer Roundup Ready wheat. CropLife Canada makes similar suggestions in their best management practices guide to herbicide tolerant volunteer crop control (CropLife Canada 2003). In this same guide, CropLife Canada repeatedly recommends the use of certified seed as a means of avoiding the adventitious presence of herbicide tolerant volunteers. For volunteer Roundup Ready canola in western Canada, this approach has proven insufficient because of seedlot contamination (Friesen et al. 2003).

Despite recommendations for non-herbicidal approaches to the management of herbicide tolerant volunteers, increasing farm size and the common use of simple crop rotations in western Canada mean that most farmers rely heavily on the use of herbicides for weed control, including the control of volunteers. In Manitoba, Saskatchewan and Alberta, 98%, 92% and 96% of all cereal fields, respectively, are sprayed with herbicides and 100%, 96% and 97% of all oilseed fields, respectively, are sprayed with herbicides (Thomas et al. 1999a,b,c). As for the management of other herbicide tolerant volunteers, the control of Roundup Ready volunteer wheat will require the addition of a herbicide to the pre-seeding glyphosate application for farmers who practice low-disturbance direct-seeding (Harker et al. 2003; CropLife Canada 2003).

Farmers who are managing Roundup Ready canola volunteers are concerned about cost and efficacy. Farmers who will be managing Roundup Ready wheat volunteers will have the same concerns. Trials are currently being conducted in western Canada to test the efficacy and reliability of control of volunteer Roundup Ready wheat using various rates of group 1 herbicides (aryloxyphenoxypropionates). Initial results look promising (Rainbolt et al. 2001; Harker et al. 2003) but there remains insufficient publicly available broad group 1 rate range efficacy data on real volunteers (those emerging from fall seed early the following spring) in areas of western Canada where spring nights can be very cold (Northwest Manitoba, the Dark Brown and Black and Grey soil zones in Saskatchewan and Alberta, and the Peace River area of Alberta) (Ecological Stratification Working Group 1995).

In addition, nothing has yet been published on the biology and ecology of volunteer spring wheat to provide information on time of emergence and length of emergence period for these volunteers (Ogg and Jackson 2001). These two factors can greatly influence pre-seeding and in-crop efficacy (Martin et al. 2001). There is also concern about increasing group 1 herbicide use in western Canadian cropping systems. There are already a high number of group 1 resistant populations of wild oat (*Avena fatua* L.) and green foxtail (*Setaria viridis* L.) across western Canada and many weed scientists recommend that farmers in western Canada limit their use of group 1 herbicides (Beckie et al 1999a, 1999b).

One non-herbicidal option that farmers could use to control volunteer Roundup Ready wheat prior to seeding is to till. Low-disturbance direct seeding farmers may be very reluctant to use this option for fear that they would lose the value they gain from their seeding and natural resource conservation approach.

5.2. Cost to control Roundup Ready volunteers

The introduction of Roundup Ready canola has altered the economics of pre-seeding weed control in low-disturbance direct-seeding systems. Although the use of Roundup Ready canola may simplify in-crop weed control in canola, in low-disturbance direct seeding systems the presence of Roundup Ready volunteer canola complicates pre-seeding weed control and it requires farmers to add additional herbicides in their pre-seeding application.

The free movement of the Roundup Ready gene in the canola genome forces both adopters and non-adopters of Roundup Ready canola to assume that a proportion of their volunteer canola plants will be Roundup Ready and so it is becoming necessary for all low-disturbance direct-seeding farmers to add 2,4-D, MCPA or florasulam to their pre-seeding weed control. This will cost all low-disturbance direct–seeding farmers an additional $1.50 - $6.00/acre depending on product used and rate (Manitoba Agriculture and Food 2002). To-date recommended rates are; 2,4-D - from 280-700 g ai/ha, MCPA - from 250-500 g ai/ha and florasulam (in PrePass) at 5 g ai/ha. The rates used depend on the crop to be seeded (higher rates of 2,4-D and MCPA have a soil residue which can be injurious to certain broadleaf crops), and the leaf stage of the volunteer canola (higher rates are recommended for volunteer canola in the 6 leaf stage versus volunteer canola in the 2-4 leaf stage) (Greuel 2003).

The control of Roundup Ready volunteer wheat in direct-seeding systems will be a problem for adopters and non-adopters of Roundup Ready wheat. Low-disturbance direct seeding farmers will need to add a group 1 herbicide to their pre-seeding herbicide to control Roundup Ready volunteer wheat. Assure II (quizalofop-p-ethyl) is the product being tested by Monsanto (Rob Bahry, Monsanto Canada, pers. comm.). This will cost all low-disturbance direct-seeding farmers an additional $6 - $12.00/acre based on Assure II rates of 18-36 g ai/ha (1/2 to full recommended rates) (Manitoba Agriculture and Food

2002). The rates required would depend on conditions at time of spraying and growth stage of volunteers.

5.3. Managing both Roundup Ready canola and Roundup Ready wheat in rotation

If both Roundup Ready canola and Roundup Ready wheat are commercially released in western Canada the management of volunteer wheat and canola will become more complicated and will require the use of additional herbicides in low-disturbance direct seeding systems. Along with adding herbicide load to the environment compared to current production systems, the requirement for additional herbicides will add cost for all low-disturbance direct seeding farmers in western Canada (Table 5.3.1). The cost of the required addition of other herbicides to the pre-seeding herbicide solution would range from $7.50 - $18.00/acres/year.

For the adopters of Roundup Ready technology there would be additional costs. If a farmer has both Roundup Ready wheat and Roundup Ready canola in rotation they will need to add additional herbicides in-crop to Roundup in the Roundup Ready canola crop to control the Roundup Ready volunteer wheat which emerges after seeding and has not been controlled prior to seeding; and in Roundup Ready wheat to control the Roundup Ready canola that emerges after seeding and has not been controlled prior to seeding. The additional in-crop herbicide cost in Roundup Ready wheat would be $1.50 - $6.00/acre (using 2,4-D or MCPA). The additional in-crop cost in Roundup Ready canola would be $6.00-$12.00/acre (using Assure II). In a typical 1 in 4 canola rotation and 1 in 3 wheat rotation this would add $2.00 - $5.00/acre/year in additional in-crop herbicide costs for farmers who adopt the use of both Roundup Ready wheat and Roundup Ready canola.

Table 5.3.1. Current estimated costs for managing Roundup Ready volunteers in low- and high-disturbance direct seeding annual cropping systems in western Canada if both Roundup Ready wheat and Roundup Ready canola are released.

Farmer Group	Additional Production Costs (dollars/acre)
Adopters of Roundup Ready Technology	
Low-disturbance direct seeding	9.50 – 21.00
High-disturbance direct seeding or conventional tillage	2.00 – 5.00
Non-Adopters of Roundup Ready Technology	
Low-disturbance direct seeding	7.50 – 16.00
High-disturbance direct seeding or conventional tillage	0.00

The introduction of Roundup Ready wheat along with Roundup Ready canola to western Canada would cause a total of $7.50 - $16.00/acre/year in additional costs for non-adopting low-disturbance direct seeding farmers. For Roundup Ready adopters who are low-disturbance direct seeding farmers the additional costs would be $9.50 -

$21.00/acre/year. For Roundup Ready adopters who do not rely on glyphosate for pre-seeding weed control (high disturbance direct seeding farmers or conventional tillage farmers) the additional costs would be $2.00 - $5.00/acre/year. In this regard, the use of more than one Roundup Ready crop within a given farmer's rotation can add additional cost and complexity to their weed control program and this would be true for all farmers, not just those practicing low-disturbance direct seeding. This is not only a concern related to the introduction of Roundup Ready wheat. There is a sharp increase in the number of acres seeded to soybeans and corn in adapted areas in western Canada, and this would include Roundup Ready varieties (Dave Kelner, Agricore United Agronomist, Winnipeg, MB, Pers. comm.). The costs outlined above are additional on-farm production management costs and they do not include potential post-farm segregation or market harm costs.

6. The introduction of Roundup Ready crops increases the risk of evolution of glyphosate resistant weeds

The evolution of glyphosate resistance within populations of weed species in western Canada is of great concern to farmers who rely on glyphosate for pre-seeding weed control in low-disturbance direct seeding systems. As with the presence of glyphosate resistant volunteer wheat and canola in western Canada, the presence of glyphosate resistant weeds in western Canada would limit farmers' ability to practice low-disturbance direct seeding. To-date there has been confirmation of resistance to glyphosate in 4 weed species; rigid ryegrass (*Lolium rigidum* Gaudin) in Australia and northern California, goosegrass (*Elusine indica* (L) Gaertn.) in Malaysia, common waterhemp (*Amaranthus rudis* Sauer.) in the Midwest United States, and horseweed (*Conyza canadensis* (L.) Cronq.) in Delaware (Ogg and Jackson 2001; Van Gessel 2001; Martinez-Ghersa et al. 2003). The latter is known as Canada fleabane in western Canada (*Erigeron canadensis* L.), a wind-dispersed winter annual considered common in zero-till fields (Watson et al. 2001). Some argue that the small number of weed biotypes to-date, worldwide that have been confirmed resistant to glyphosate after glyphosate has been used for such a long time is strong evidence that this is a herbicide to which resistance will rarely evolve (Bradshaw et al. 1997). Bradshaw et al. (1997) published their review and opinions at the same time a confirmed report of glyphosate-resistant annual ryegrass in Australia was being prepared for publication.

Roundup Ready crop use may hasten the evolution of glyphosate resistant weeds (Warwick et al. 1999). With the advent of Roundup Ready crops there has been a significant change in use pattern of glyphosate towards extensive in-crop use in addition to its traditional role in pre-seeding weed-control and for the specific control of problem perennials (Fig 6.1). There may be less chance of selecting for herbicide resistant biotypes within the populations of many common perennial weed species. For example, Canada thistle (*Cirsium arvense* L. Scop.) populations rely heavily on vegetative propagation and their populations have limited genetic diversity meaning there is less chance for a resistant biotype to exist within the populations of common perennial species like this (Heimann and Cussans 1996).

Selection for resistance is a numbers game and the likelihood for the existence of and selection for resistant biotypes increases for outcrossing species which have large and

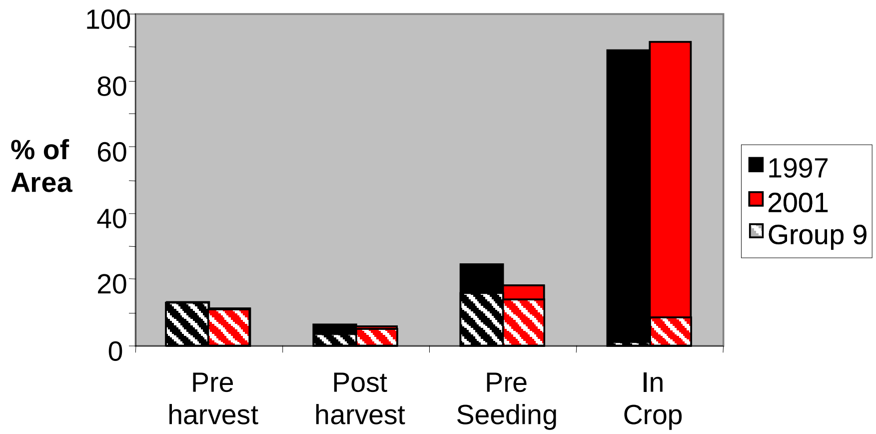


Figure 6.1. Herbicide use timing patterns for all herbicide groups in Alberta in 1997 and 2001. Note rise in group 9 (glyphosate) use in-crop. From Thomas et al. 2003.

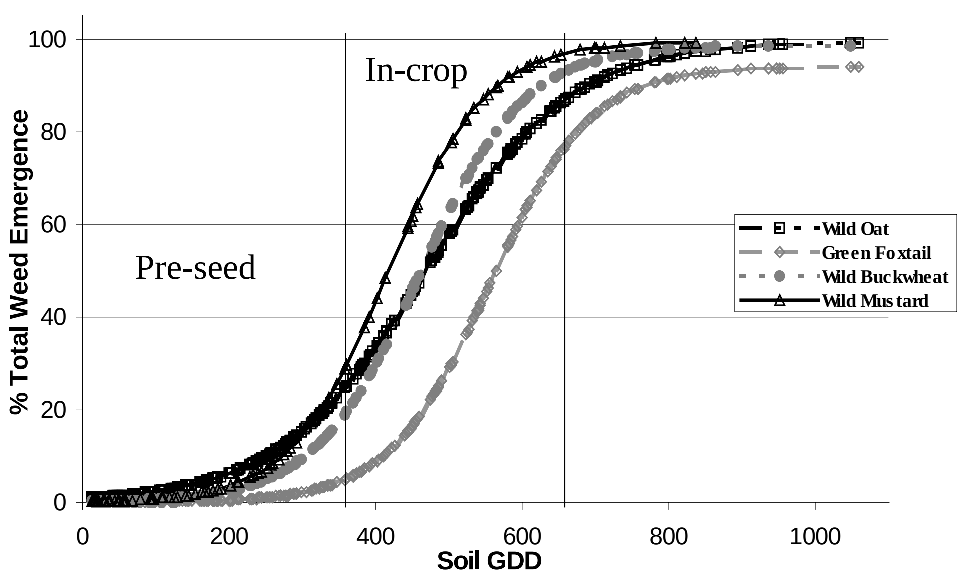


Figure 6.2. Timing of average pre-seeding weed control operations versus in- crop weed control operations (first and second vertical lines, respectively) and demonstration of proportional summer annual weed emergence at pre-seed versus in-crop timing. Soil GDD = soil growing degree days, base of 0 C. Adapted from Bullied et al 2003.

transient populations and a great amount of genetic diversity within their populations (Jaseniuk et al. 1996). Populations of common annual weed species tend to fit this criteria more so than populations of common perennial weed species. In western Canada, wild oat populations fit these criteria very well and many herbicide resistant and cross-resistant (resistant to more than one group of herbicides) biotypes of wild oat have already been selected for (Beckie et al. 1999). An increase in use of glyphosate in-crop will greatly increase the chance for successful selection for glyphosate-resistant annual weeds such as wild oat. A shift to in-crop use in addition to pre-seeding use of glyphosate will increase even more the opportunity for successfully selecting resistant weed biotypes because the in-crop control includes a much greater proportion of common annual weed population in fields in western Canada (Fig 6.2.)

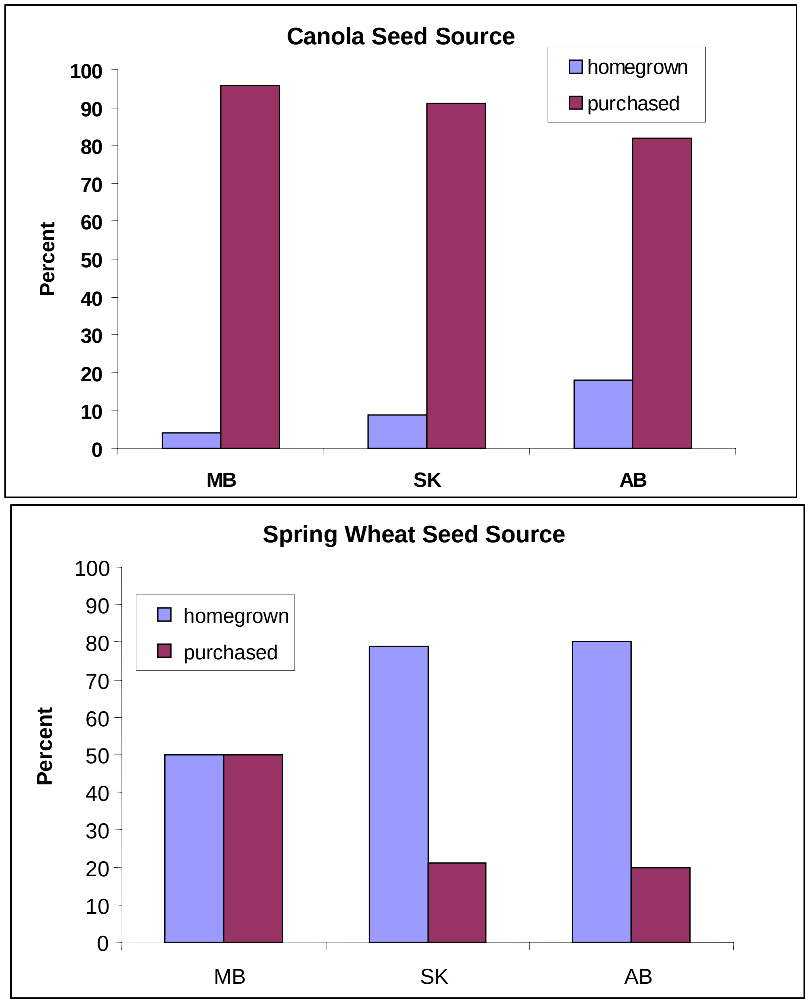


Figure 8.1. Spring wheat (excluding Durum) and canola seed source in western Canada averaged for the period 1991-97 in MB, 1990-95 in SK and 1991-97 in AB. Adapted from Thomas et al. 1999a,b,c.

7. Use of farm-saved seed

Across western Canada the majority of spring wheat seed used by farmers is home-grown. In Canada, Plant Breeder's Rights (PBR) allows for farmer's to save and use seed in such a fashion if they so chose and if they have not signed contracts preventing them from doing so (Clarke 2001). In contrast, the majority of canola seed used by farmers in western Canada is purchased certified seed (Figure 7.1). Currently, farmers are restricted by contract (Monsanto technology use agreement) from using farm-saved Roundup

Ready canola seed after having grown a Roundup Ready canola crop. If this restriction were also applied to Roundup Ready wheat it would force a very significant change in practice and change in cost for spring wheat farmers who adopt the use of Roundup Ready wheat. For farmers who do not adopt Roundup Ready wheat and who use farm-saved seed, the unconfined release of Roundup Ready wheat will make it difficult and costly for them to maintain their seed free from the Roundup Ready GM trait (see section 4.2.3). It would be critical for non-adopting low-disturbance direct seeding farmers to maintain their farm-saved wheat seed source free from the Roundup Ready trait because the presence of this trait in their seed source will threaten their ability to practice low-disturbance direct seeding and reap the environmental, resource conservation and economic benefits of this practice.

8. Our ability to maintain segregation of GM and non-GM wheat: implications for meeting commitments to the Cartagena Biosafety Protocol

Currently, the vast majority of Canadian wheat is shipped using a bulk handling system and is segregated by class, grade, protein level and, in some cases, other quality factors. As with all bulk commodity distribution systems, Canada's system has evolved to ensure that crops are stored, transported and processed in as efficient a manner as possible to minimize costs in the chain from origin to final consumption. This challenges marketers ability to provide customer guarantees that may be required to meet food labeling requirements or to maintain access to markets.

This lack of segregation ability also creates an environmental concern. Under the Cartagena Protocol on Biosafety, which the Canadian government has indicated that it intends to ratify, Canadian exporters will be required to know the level of GM material in their shipments in order to meet documentation requirements (Canadian Food Inspection Agency 2002). The Cartagena Protocol is intended to protect biodiversity in grain importing countries, with special attention given to centers of origin for key world crops such as wheat. Recently there has been evidence of transgenes escaping from corn to teosente in Mexico (Ellstrand 2001).

The segregation issue is inextricably linked to Roundup Ready wheat management issues because both are about limiting transgene movement from Roundup Ready wheat to non-Roundup Ready wheat.

9. Stewardship management plans for Roundup Ready wheat

Since the unconfined release of Roundup Ready canola in western Canada the movement of the Roundup Ready trait from Roundup Ready canola to other types of canola has added complication and cost to low-disturbance direct seeding cropping systems for both adopters and non-adopters of the technology. The appearance of the Roundup Ready trait in non-Roundup Ready pedigreed seedlots Canada was remarkable but arguably predictable. The experience with canola emphasizes the need for forward planning regarding means of containing the Roundup Ready trait as an environmental protection measure.

Stewardship plans that would accompany the potential unconfined release of Roundup Ready wheat need to address all of the concerns raised within this report. In particular they need to address the containment of the Roundup Ready trait and the overuse of glyphosate as more and more Roundup Ready crops are introduced. The plans must ensure that agronomic problems resulting from the introduction of Roundup Ready wheat do not become environmental problems. Stewardship plans need to be realistic in a number of respects. These plans must:

- be based on realistic science-based, robust and field-tested models of transgene movement in wheat in western Canada. The plans must specifically recognize that the Roundup Ready trait is particularly difficult to contain because glyphosate is used extensively for pre-seeding volunteer control in western Canada and this gives Roundup Ready volunteers a selective advantage within the volunteer population in western Canada.
- represent the reality of the biology of pollen mediated gene flow in wheat with a specific recognition of the fact that transgene flow has to be controlled at the receptor end. This poses a particular challenge for transgene containment when receptors reside in the wheat fields of a non-adopters.
- recognize that introducing more than one Roundup Ready crop to western Canada magnifies the potential negative impact of the product if it is not contained and it magnifies the complexity of managing the containment of the product.
- recognize the potential for contamination of and the potential problems associated with the contamination of other wheat classes, durum and other small cereal grains with Roundup Ready wheat.
- represent a realistic expectation of commitment from farmers to implement the plans given the reality of the vast acre, short season cropping that is common in western Canada, and the almost absolute reliance of these types of cropping systems on herbicides for weed control.

Industry-led stewardship approaches are laudable but they cannot address all problems associated with the unconfined release of a novel product such as Roundup Ready wheat. The industry can educate and encourage adherence to plans but it has limited ability to demand, monitor or enforce adherence. In the case of non-adopters the industry has no ability to demand adherence to stewardship plans. This is especially problematic for the containment of the Roundup Ready trait because its containment relies critically on management of receptor wheat crops and in many (and perhaps most) cases the receptor wheat crops will belong to non-adopters of the Roundup Ready technology.

Stewardship plans will require extensive monitoring for compliance and therefore, CFIA as the regulator and the industry need to ensure adequate resources are available to provide for realistic plans and required staffing levels. In these plans there will also be a need to deal with non-compliance and a recognition of the jurisdiction and responsibilities of various stakeholders. Given the scope and significance of potential problems that can arise from Roundup Ready transgene escape through non-compliance, issues of liability and compensation will also need to be addressed.

In this report we have demonstrated that it will be difficult to contain the Roundup Ready trait within discrete fields. The experience with movement of the Roundup Ready trait in canola shows that stewardship for containment will require stewardship plan application and adherence throughout the entire cropping system and across the entire region of western Canada. Stewardship within a given field and for a given crop alone will be insufficient to achieve containment of the Roundup Ready transgene, and to prevent agronomic problems associated with Roundup Ready volunteers from becoming widespread and causing environmental problems.

To-date in Canada, there are few examples of active voluntary industry-led stewardship plans in Canada. One example is the insect resistance management plan (IRM) for managing the sustained use of Bt corn. However, given the limited number of corn acres in western Canada, the IRM stewardship plan is an eastern Canada example that hasn't been tested in western Canada. An example relevant to western Canada is the industry-led voluntary stewardship plan for delaying the evolution of herbicide resistance in weeds. Surveys in western Canada over the past decade suggest that during the period of most rapid gain in the occurrence of herbicide resistant weed populations in western Canada when there was also an active extension effort and a voluntary industry lead stewardship program on the issue there was no decline in use of high risk herbicide groups and there was no noticeable adoption among farmers of non-herbicidal alternatives for weed control (Beckie et al. 1999 a, 1999b; Thomas et al. 2003). This example does not instill confidence in voluntary industry-led stewardship plans.

10. Summary

Reduced tillage provides significant and measurable environmental, resource conservation and economic benefits to farms in western Canada. There has been a very significant trend towards reducing tillage on farms in western Canada. Low-disturbance direct seeding is the most rapidly growing reduced tillage system in western Canada, and this system is agronomically and economically dependent upon glyphosate for pre-seeding weed control.

Experiences after the commercial release of Roundup Ready canola show that the movement of Roundup Ready transgene among canola crops is significant and that it is facilitated by a number of factors combining to create a gene bridge for the Roundup Ready trait in canola. It is difficult to limit the movement of this trait in canola and even pedigreed certified canola seedlots are commonly contaminated. If Roundup Ready wheat was granted unconfined release in western Canada the trait would move among wheat cultivars and fields in a fashion similar to that seen in canola because the factors combining to form the Roundup Ready transgene bridge in canola are similar for wheat.

When the Roundup Ready trait moves among canola crops it becomes impossible for farmers to know if their volunteer canola population will contain Roundup Ready volunteers, even if they have not previously grown Roundup Ready canola. Pre-seeding weed control in low-disturbance direct seeding systems costs more if there are Roundup Ready volunteer canola plants present. This cost is borne by both adopters and non-adopters of Roundup Ready crops. Controlling volunteer Roundup Ready wheat volunteers will cost even more than controlling Roundup Ready canola volunteers, and this cost will also be borne by both adopters and non-adopters of Roundup ready wheat.

Cost added to the pre-seeding herbicide application will threaten the sustainability of low-disturbance direct seeding in western Canada for all farmers. This, in turn, will threaten farmers' ability to capture the environmental, resource conservation and economic value of low-disturbance direct seeding.

Because of the dependence of low-disturbance direct seeding on glyphosate, the movement of the gene conferring glyphosate resistance has greater agronomic implications and environmental risk than genes conferring resistance to either glufosinate (e.g. Liberty Link) or imidazolinone herbicides (e.g. Clearfield). The extensive use of glyphosate in western Canada facilitates movement of the Roundup Ready trait from crop to crop. Concerns are unique to the Roudup Ready crops because neither glufosinate nor the various herbicides used in Clearfield canola or Clearfield wheat are used as extensively as glyphosate or as low-disturbance direct seeding, spring burn-off treatments.

The release of Roundup Ready wheat also brings concerns about an increased risk of selecting for glyphosate-resistant weed biotypes. These weed biotypes would also threaten the sustainability of low-disturbance direct seeding. The suitability of farm-saved wheat seed for low-disturbance direct seeding systems will be threatened because it will be difficult for farmers' to keep farm-saved wheat seed free from the Roundup Ready trait. Additionally, the movement of the Roundup Ready trait among wheat crops in western Canada will create difficulties for Canadian marketers of wheat and cereal grains to meet international biosafety protocol requirements; requirements which are designed to meet global environmental safety needs.

The release of Roundup Ready wheat into the current agricultural context in western Canada will threaten the environment. The release of this novel product would be environmentally unsafe.

11. Topics requiring further study

Models for effective stewardship of Roundup Ready wheat and Roundup Ready transgene containment in wheat

The need to segregate GM and non-GM wheat will require a clear understanding of the fate of the GM trait within the production system. GM traits such as the Roundup Ready trait, which confer a strong selective advantage within the production system will increase in frequency within volunteer wheat populations. The highest rate of increase will occur for GM traits that confer a high selective advantage to a selective agent that is applied frequently within the production system. Resistance to glyphosate is an example of such a trait. There is also a fundamental problem with technology adopter management plans for mitigating transgene flow, both pollen and non-pollen mediated. In the case of pollen mediated gene flow, transgene flow can only be controlled at the receptor end and for non-pollen mediated gene flow, transgene flow control is critical at the receptor end. Unfortunately, the receptor is very often not the technology adopter.

Prior to the unconfined release of Roundup Ready wheat it will be necessary to consider the sufficiency of containment and stewardship plans. This can be done using models based on robust and realistic data sets. For some factors (the efficacy of Roundup on non-Roundup Ready wheat) there already exists useful data but for some factors (such as the in-field reproductive ecology and management of volunteer wheat in common western Canadian cropping systems) there exists insufficient data. This report presented examples of the types of model that could be used to test management and containment scenarios for Roundup Ready wheat. Two key factors required in containment models would be mechanistic representations of gene flow in wheat at field scale and volunteer wheat persistence.

Gene flow in wheat

There is currently enough scientific information to suggest that gene flow in wheat will be more than sufficient to drive a Roundup Ready transgene bridge in wheat in western Canada. Current evidence of gene flow levels in wheat would be sufficient, therefore, to warrant not granting unconfined release of Roundup Ready wheat in western Canada. Waines and Hedge (2003) summarize their findings in the following statement:

" The major issue to be addressed between transgenic and non-transgenic cultivars is how to maintain cultivar purity when they are grown some distance from one another, and what should be the appropriate isolation distances to minimize mixing through gene flow. Since gene flow in wheat will occur, thresholds of acceptable levels must be established. Currently, the number of systematic studies on gene flow in wheat is too small to make any valid inferences about isolation distances between adjacent cultivars. But there is enough evidence to show that cross-pollination regularly occurs in wheat and the reproductive biology of wheat is favourable to facilitate varying degrees of gene flow in a variety of situations."

This statement demonstrates the need for practical information for the establishment of suitable isolation distances for seed production of GM and non-GM wheat. These studies need to be conducted on a field scale to simulate real world conditions. Threshold levels must also be established in order to adequately evaluate the efficacy of proposed isolation distances. The type of study conducted by Beckie et al. (2001) for canola has not been completed for wheat but it is required if we are to adequately plan for the containment of the Roundup Ready trait. It would also be important to investigate the outcrossing and persistence characteristics of all wheat cultivars not just those which may potentially become available as Roundup Ready because gene flow is about the reproductive biology and ecology of both gene donors and receptors.

Volunteer Wheat Persistence

Harker et al. (2003) have been monitoring volunteer wheat persistence at 8 sites across western Canada and although they found that volunteer wheat densities pre-seeding were very low (< 1 plant m^{-2}) in the spring of 2002 for wheat seed that had been spread in the fall of 2000, their study included only a single spring wheat cultivar (cv. "Bob White") which is not standard, suited to nor registered for use in western Canada. Persistence of canola cultivars is linked to dormancy characteristics which vary by cultivar (Gulden et al. 2000). The same is likely true for wheat cultivars (Strand 1989). Thomas and Leeson considered wheat persistence using survey data from across western Canada. Their data set represented regular registered wheat varieties grown using standard practices and their results showed that volunteer wheat can persist for at least 5 years in 5 to 10% of fields (Thomas and Leeson 2000). In a long-term crop rotation study conducted in Brandon, Manitoba, Derksen and Watson (2001) found that wheat and canola persisted in a similar manner and for at least 3 years. A more systematic and mechanistic investigation of volunteer wheat persistence is required using a realistic range of genotypes.

The effect on the environment of an increase in tillage intensity in western Canada

If Roundup Ready wheat were commercially released, the cost of volunteer Roundup Ready wheat and canola control for both adopters and non-adopters of the technology may drive low-disturbance direct seeding farmers to use tillage instead of herbicides for pre-seeding weed control. There has been no research to quantify the negative effect that an increase in tillage will have on soil quality, moisture conservation and carbon sequestration if farmers revert back to high disturbance direct seeding or conventional tillage practices and away from low-disturbance direct-seeding.

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