ASSESSING THE ECONOMIC AND ECOLOGICAL IMPACTS OF HERBICIDE TOLERANT CANOLA IN WESTERN CANADA

August 2010

Stuart Smyth,
Michael Gusta,
Peter Phillips
University of Saskatchewan

and

David Castle
University of Ottawa

Assessing the Economic and Ecological Impacts of Herbicide Tolerant Canola in Western Canada

Executive Summary

Herbicide tolerant (HT) canola was introduced in Western Canada in 1995 through an identity preserved production and marketing system, with unrestricted commercial production beginning in 1997. The subsequent adoption was relatively rapid, with 26% in the initial year, 78% by 2002 and 95% by 2007. In 2007, a producer survey was undertaken to learn more about the producer level impacts that were being observed one decade after commercialization.

The survey revealed that the new technology generated between $1.063 billion and $1.192 billion annual net direct and indirect benefits for producers over 2005-7 period, partly attributed to lower input costs and partly attributed to better weed control. One major concern in the early years following introduction was the potential for HT traits to outcross with weedy relatives or for genetically modified herbicide tolerant (GMHT) canola to become a pervasive and uncontrollable volunteer in non-canola crops, either of which would offset some producer gains. The survey largely discounts that concern. More than 94% of respondents reported that weed control was the same or had improved following the commercialization of GMHT canola, less than one quarter expressed any concern about herbicide resistance in weed populations, 62% reported no difference in controlling for volunteer GM canola than for regular canola and only 8% indicated that they viewed volunteer GM canola to be one of the top five weeds they need to control.

In addition to the economic benefits the survey identified significant environmental benefits, such as producers removing summerfallow as part of their crop rotation. The production of HT canola and the adoption of zero tillage or minimum tillage practices are two complimentary technologies, as the main challenge of this form of land management was the spread of hard to control weed populations. The adoption of HT canola varieties offered new options in weed control, allowing farmers to extend the number of years that they could go without having to till a field. Tillage has dropped from being used on 89% of canola acres in 1999. Much of the tillage associated with HT canola production has been eliminated as 64% of producers are now using zero or minimum tillage as their preferred form of weed control.

The commercialization and wide spread adoption of HT canola has changed weed management practices in Western Canada. There have been significant changes regarding the use and application of herbicides for weed control in canola. This research shows that when comparing canola production in 1995 and 2006 the toxicity of agro-herbicides applied to canola has decreased of 53%, there has been a decrease in producer exposure to chemicals of 55% and a decrease in chemical active ingredient application of 1.3 million kg. The cumulative environmental impact per hectare (EI/ha) of the top five herbicides applied in 1995 was 46,715, while the figure for the top five herbicides applied in 2006 was 29,458. If HT canola had not been developed and Canadian canola farmers continued to use previous production technologies, the amount of active ingredient applied to control weeds in 2007 would have been 38% above what was actually applied.

This report refutes the claims and accusations made by critics of agricultural biotechnology that genetically modified crops do not benefit farmers and are harmful to the environment. As this report will show, the benefits are numerous and substantial.

Table of Contents

Introduction

Genetically modified herbicide tolerant canola and mutagenesis canola both received federal regulatory approval in Canada in early 1995. The limited production acres for GMHT canola in 1995 and 1996 were managed through an identity preserved production system (IPPM) (Smyth and Phillips, 2001) as part of the seed multiplication process. The IPPM systems were discontinued in the winter of 1996-97 and unhindered producer adoption began in spring 1997. The adoption rate of HT canola has been very rapid (Table 1); Roundup Ready™ and Liberty Link™ canola GMHT varieties and the Clearfield® mutagenic HT varieties rose in six years from 26% of total production in the first year of production to 93% in 2003 .

Table 1: Adoption rate for HT canola varieties (million hectares)

Year	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Total canola acres	4.9	5.3	5.5	4.8	3.8	3.6	4.6	4.8	5.1	5.2	6.3
Roundup Ready	0.2	1.1	2.0	1.7	1.6	1.6	2.2	2.3	2.5	2.3	2.8
Liberty Link	0.4	0.7	1.0	0.7	0.6	0.6	1.0	1.5	1.7	2.1	2.5
Clearfield	0.7	0.9	1.0	1.2	0.8	0.6	1.1	0.9	0.7	0.6	0.7
Total HT	1.3	2.7	4.0	3.6	3.0	2.8	4.3	4.7	4.9	5.0	6.0
% HT	26.5%	51%	72.7%	75%	79%	77.8%	93.5%	97.9%	96.1%	96.2%	95.2%
Source: Canola Council of Canada, 2008a.											

For the last four crop seasons (2004-2007), the percentage of HT canola planted has exceeded 95%. The total number of hectares planted to canola has varied in direct relationship to the price of canola. Between 2002 and 2007, there has been a doubling of hectares devoted to canola. The movement to HT canola varieties is likely to be sustained.

Focus of the study

This study provides a detailed assessment on canola production in Western Canada. The data for this study was gather based on the 2006 crop year and provides insights into canola production, one decade following the commercialization of herbicide tolerant canola varieties. The study is comprised of four sections: economic; environmental; herbicide-use; and comparison with previous Canola Council of Canada studies.

To gather the data needed for this research project, a four page, 80 question survey was developed and distributed to agricultural producers. The time required to complete the survey was estimated to be 30-45 minutes. The survey was comprised of six major areas of focus: weed control; volunteer canola control; canola production history; specific weed control measures on canola fields and subsequent crops; crop and liability insurance; and general demographics. Open, closed and partially open questions were asked in the survey. Space was provided to enable producers to more fully explain changes within the production system to facilitate a more complete understanding of producer choices. Where a quantification of producer attitudes was required, a simple three point scale was used, which allowed for positive, neutral and negative responses. The University of Saskatchewan's Research Ethics Board approved the survey design (BEH# 06-318).

Forty thousand surveys were distributed across the three Prairie Provinces in March and April 2007. Distribution of the survey was through Canada Post's un-addressed ad-mail service providing a cluster sampling method. This allowed for a selection of farms as defined by Canada Post within the postal code system. Participant selection was based upon geographic location in five targeted regions separated by provincial boundaries and based on historic canola production levels. High production and low production regions in each of Alberta and Saskatchewan and a high production area in Manitoba were surveyed. The target population was producers having over 80 acres of cropland. Surveys were randomly distributed through the regions.

A lottery was employed to encourage completion of the survey. The lottery consisted of two draws, among eligible survey respondents, for consumer electronic goods valued at $250 each. In total 685 surveys were received with 571 meeting our population criteria. Outliers within the database were identified and removed utilizing the box plot method as developed by Tukey (1977) and outlined by NIST/SEMATECH (2006). Extreme outliers were identified based on the amount of acres treated by herbicide. Table 2 outlines the distribution of usable responses across the three Prairie Provinces and between areas of low and high canola production. While the number of respondents relative to the number of surveys distributed indicates a low response rate (1.71%) it is important to note that the Canada Post's un-addressed ad-mail service delivers surveys to all mail addresses within the identified region. There is no way to know how many households received surveys that were not farmers or did not produce canola. Therefore, the actual response rate is unknown and is most certainly greater than what can be calculated here. The important point is that the number of valid responses for a survey of this size, provides us with a confidence level of 95%.

Table 2: Distribution of usable survey responses (N=571)

	Low Production	High Production	Total
Alberta	14%	11%	25%
Manitoba	NA	16%	16%
Saskatchewan	32%	27%	59%
Total	46%	54%	100%

The demographics of the sample population are similar to the source population as reported in the Statistics Canada 2006 Farm Census (Table 3) (Statistics Canada, 2006). The average age of farmers is 52 in Saskatchewan and Alberta, and 51 in Manitoba. Our survey population has a substantially higher level of post-secondary education, where the census data identifies the percentage of producers with a university degree in Manitoba at 8%, Saskatchewan at 8% and Alberta at 9%. Average farm size of the sample population was greater than that of census data, where the average Alberta farm size was 1,055 acres, Saskatchewan 1,450 acres, and Manitoba 1,000 acres.

Table 3: Producer demographics

		Alta	Sask	Man	Total
Number of respondents to survey		144	335	92	571
Average age	sample	45-54	45 to 54	45 to 54	45 to 54
	census	*52*	*52*	*51*	52
University degree[1]	sample	14%	21%	7%	14%
	census	*9%*	*8%*	*8%*	8%
Average farm size	sample	1,652	1,743	1,357	1,656
	census	*1,055*	*1,450*	*1,000*	1,168
Average canola acres		507	476	400	470
Average experience with canola		19.3	20.6	20.8	20.3
First year with GMHT canola		1999	1999	1998	1999
Source: Survey and Statistics Canada 2006 Farm Census.					

The respondents to this survey had relatively large operations (1,622 acres), with over one-quarter of their operation dedicated to canola (Table 2). The average respondent farmed for 30 years and belonged to the 45 to 54 age group. These producers reported growing canola for an average 20 years and adopting GMHT canola first in 1999; on average they reported that they removed conventional varieties from their crop rotations by 2000.

For the 2005 and 2006 crop years, farmers reported that 48% of their acreage used Roundup Ready™ varieties, 37% used Liberty Link™ and 10% used Clearfield®. These adoption rates are consistent with the adoption rates provided by the canola industry, which identifies Roundup Ready™ market share at 44%, Liberty Link™ at 40% and Clearfield® at 11% (Anderson, 2008).

[1] The number of respondents with a university degree is substantially higher in Saskatchewan than is reflected in the census data. A variety of factors contribute to this. The farm size is larger than average and producers are slightly younger than the average, suggesting higher levels of education. This level of response may also be related to the University of Saskatchewan being the major university in the province and the only university with a College of Agriculture, hence there may be some graduate loyalty to complete surveys sent out by researchers at the University of Saskatchewan.

Section 1

Economic Benefits of Herbicide Tolerant Canola

1. Introduction

Innovation is pervasive in agriculture, but few single innovations have generated the impacts or controversy of genetic modification. Advocates and critics alike have argued and debated the economic impacts from producer adoption of genetically modified (GM) crop varieties, with a disturbing lack of empirical data. The paucity of direct producer data has had a knock-on effect on diffusion of the technology, as other nations have been unconvinced of the costs and benefits of approving and adopting the technology to their markets.

Genetically modified, herbicide tolerant (GMHT) canola has been produced in Western Canada since 1995, which provides the opportunity to undertake an extensive analysis of adoption practices and impacts. Herbicide tolerant canola was initially introduced in 1995 through an identity preserved production and marketing system (Smyth and Phillips, 2001), with unrestricted commercial production beginning in 1997. The subsequent adoption was relatively rapid, with 26% in the initial year, 78% by 2002 and 95% by 2007. There are currently three HT systems available to producers, two developed through genetic modification and one through mutagenic breeding. Agrevo's (now Bayer CropScience) Liberty Link™ and Monsanto's Roundup Ready™ varieties are commonly referred to as GMHT varieties. Pioneer Hybrid's imidazolinone-tolerant Clearfield® system was developed by mutagenesis. These technologies all allow for in-crop spraying of broad spectrum herbicides, with little or no damage to the crop HT crop,

This section examines the economic benefits of HT canola adoption reported by Western Canadian producers in a survey undertaken in 2007. Section two reviews the previous efforts to document the economic benefits of HT canola. Section three describes the methodological framework for the survey. Section 4 presents the results and analysis of the survey. The article concludes with a discussion of the impacts from HT canola and some concluding thoughts.

2. Background

Eighty-one percent of the cultivated land in Canada lies in Alberta, Saskatchewan and Manitoba and virtually all of the canola is produced there. Western Canadian farms are relatively large, averaging 1400 acres. The top three crops in 2002-7 in terms of seeded acreage were spring wheat, canola and barley. Canola acreage significantly increased after the adoption of HT varieties in 1995, rising 31% to an average of 13.9 million in 2003-8, up from an average of 10.5 million acres in 1991-5 (Statistics Canada Field Crop Reporting Series).

A series of studies have examined the impact of innovation on returns to canola producers. A number of studies between 1977 and 1998 modeled the canola sector to estimate the economic impact of the transition from rapeseed to canola (Nagy and Furtan, 1977; Ulrich, Furtan and Downey, 1984; and Ulrich and Furtan, 1985) and to provide a range of ex-ante estimates of the impact of HT on producers, consumers and the environment (Aulie, 1996; Mayer and Furtan, 1998; and Malla and Gray, 1999). All estimated significant returns from those changes, with internal rates of return estimated to be as high as 101%. All of the ex ante forecasts, however, raised the possibility that the technology could be somewhat self-limiting if the HT traits outcrossed to weedy relatives or if HT canola persisted and became an unwelcome volunteer in subsequent crops.

Beginning in about 2000, a number of scholars and practitioners attempted to assess the early returns and prospects for future returns to producers. The bulk of the producer data that was used for these studies was gathered between 1999 and 2002; one study gathered data as late as 2004. The earlier data was gathered at the peak transition period between conventional canola and HT canola and the observances from these studies provide an excellent point of reference for the results of our survey.

Phillips (2003) undertook a four year retrospective analysis of the economic impact of the introduction of HT canola. Using 1995-2000 data, Phillips estimated the broad economic impacts of HT canola on the global industry and economy, as well as the direct and indirect effects on producers. Phillips identified the effect of higher seed costs, lower herbicide costs, fewer herbicide applications, lower dockage and earlier seeding (adjusted for the yield drag in early varieties and) created a benefit of about $11.14[2]/acre by 2000. While this generated an estimated $103 million gross producer gain in 2000, farmers did not net the full amount as lower prices due to increasing supply shaved off $32 million. Net, producers were estimated to gain $70 million in 2000.

The Canola Council of Canada (CCC, 2001) published a report based on data collected in 2000 that quantified the agronomic and economic impacts associated with HT canola. Adoption of HT canola by 2001 reached 80%, which still allowed for in-field comparisons of transgenic and conventional varieties. The study identified the key producer impacts as: improved yield; slightly increased fertilizer usage; increased seed costs; decreased tillage use; improved soil moisture conservation; decreased summer fallow; improved rotation flexibility; lower dockage; and decreased herbicide inputs. Overall, the study reported that direct producer benefits per acre averaged $10.62 in 2000, yielding a net gain of about $66 million for producers.

Fulton and Keyowski (1999) noted that the adoption of an innovation depends upon the perceived usefulness and ease of use to adopters; later adopters depend on the opinions and experiences of early adopters. Mauro and McLachlan (2008) conducted a survey in

---

[2] All monetary figures are expressed in Canadian dollars.

2003 to assess producer knowledge and perceptions of GM crops and the associated risks. A mixed methodology approach was applied, with 15 producer interviews being used to develop a questionnaire. Mauro and McLachlan found in their survey that 77% of HT canola producers were satisfied with the results of HT canola. They found that the decision to adopt and to continue to use was not solely an economic decision, as only 47% of producers identified HT canola was more profitable than conventional varieties and only 21% indicated that HT canola offered higher yields. Moreover, they found that producers viewed the benefits of HT to be decreasing, at least partly due to the 38% of producers who had experienced HT volunteer canola on their land. About 80% of these producers concluded the volunteers came mainly from their own production while 8% reported finding volunteer canola that they suspected originated elsewhere. The authors' concluded that the earlier estimates of benefits of HT canola were suspect as they did not account for the increasing cost of managing this volunteer canola for producers and their neighbors.

The CCC (2005) released a second report that compiled the results from three different weed surveys conducted between 2001 and 2003, as well as the results from a 2004 producer survey that examined the management of volunteer HT canola in subsequent crops. This report provided a comprehensive review of the impact of volunteer canola as a weed and assessed the differences between the various HT canola systems. The study discovered little difference between canola systems in regards to management of volunteer canola in subsequent crops. Conventional canola producers were found to make slightly fewer pre-seed passes to apply herbicides yet tilled more than HT systems.

Studies by Phillips (2003), the CCC (2005), Beckie, *et al*., (2006) and Kleter, *et al*., (2007) found correlations between adoption of HT varieties and adoption of zero tillage systems. The CCC (2005) also found 60% of HT adopters experienced a carry-over benefit of improved weed control, which was judged to be equivalent to the cost of one herbicide application. Volunteer canola was found to be the fourth most common weed targeted by herbicide; while its was not the sole target of herbicide applications, the estimated cost of controlling for volunteer canola was determined to be around $2.00/acre. Overall, the study found the benefits of growing HT varieties to be greater than that of conventional varieties.

The data gathered and reported in the majority of these reports and surveys comes from the early part of the 1990s. Since then the level of adoption has increased substantially and the number of acres seeded to canola has doubled. The results of the two CCC reports and the Phillips paper provide a solid research base on which to build; the survey used in this study was developed from these three pieces of research. Where possible, these results are compared to our own findings.

3. Survey results and analysis

The survey asked questions that explored three major economic impacts from the adoption of HT canola: cost of weed control; control of volunteer canola; and second-year benefits and costs.

3.1 Cost of Weed Control

To determine if a change in weed control practices of Western Canadian producers has occurred, the two methods of weed control—chemical herbicide use and tillage practices—have to be examined.

Producers were asked if they have changed their chemical herbicide use over the past 10 years and 68% of respondents reported that a change had occurred. Of those reporting a change, 94% found weed control effectiveness to have improved or remained the same (Table 1.1). More than 60% of respondents reported that previously difficult-to-control weeds—such as wild mustard, stinkweed and cleavers—can now be more easily controlled. More than one-third of producers reported that control over difficult weeds in canola fields is unchanged from the situation that existed prior to the commercialization of HT canola. Just more than 5% of respondents reported weed control has become less effective. While the majority of those reporting a change in weed control after adopting HT varieties attributed the changes to the new technology, about 37% the changes in weed control were not related to adoption—other agronomic circumstances (both positive and negative) were are work.

Table 1.1: Attribution of change in weed control after adopting HT canola

Weed Control	**Change due to adoption (n = 242)**	**Change not due to adoption (n = 145)**	**Average**
Weed control less effective	5.4%	7.6%	6.2%
Weed control unchanged	34.3%	42.1%	37.2%
Weed control improved	60.3%	50.3%	56.6%

The survey found that many producers have moved to minimum or zero tillage operations[3], with over half of the respondents indicating that they no longer use tillage operations in their cropping system (Table 1.2). Nevertheless, more than 46% of producers reported that they continue to use a mix of cultivation and harrow as part of their seeding practices.

Table 1.2: Tillage operations and HT canola systems

Tillage method	**Clearfield**	**Liberty Link**	**Roundup Ready**	**Average**
	(n=40)	(n=135)	(n=154)	(n=340)
Zero-till	60.0%	53.3%	50.6%	53.5%
Cultivation	22.5%	20.0%	24.0%	21.8%
Harrow	12.5%	11.9%	9.7%	10.6%
Cultivation and Harrow	5.0%	14.8%	15.6%	14.1%
Margin of error: Clearfield® ±15.5%, Liberty Link™ ±8.4%, Roundup Ready™ ±7.9%, Total ±5.3%.				

[3] While there has been a strong movement to reduced tillage land management practices in Western Canada over the past 15-20 years, it is not possible to establish a correlation between reduced tillage and HT canola adoption. These two technologies have co-evolved and can be said to be mutually beneficial, but there is no strong correlation between the two technologies.

Land management practices added some incremental costs. In 2006, 24.7% of farmers preformed harrow operations at least once, conducting an average of 1.2 passes on 88% of their canola crop. The CCC in 1999 estimated that harrowing cost $3.50 per acre. Assuming the costs have not changed, the harrow operations on HT canola fields would be about $3.72[4] for each harrowed acre; scaled up to the entire canola production area, this would add $0.92 to the cost of the average acre seeded to canola.[5] Continuing cultivation similarly adds costs. The survey revealed that 35.9% of farmers preformed cultivation operations on their canola fields, conducting an average of 1.51 passes on 88% of their canola crop. Using the CCC 1999 estimates of $6.00 per cultivated acre, the cost of these sustained operations would add $7.98[6] for each cultivated acre; scaled up to the entire canola acreage, the average cost is $2.86 per acre of canola seeded.

Comparing the CCC (2001) survey of farmer practices in 1999 with our survey of farm practices in 2006, it would appear that the total number of tillage operations for transgenic canola dropped from 2.73 passes to 0.74 passes per acre (Table 1.3). Assuming the cost of tillage operations have remained constant since 1999 (i.e. $6.00 per acre for cultivation and $3.50 for harrowing), the expected cost of all tillage conducted on canola acres would have been reduced by $10.25 per acre or by 73%. Scaled up for the size of the canola crop in 2006, this saving would translate into $153.8 million (assuming tillage on conventional canola has remained the same).

Table 1.3: Comparison of harrowing and tillage costs: 1999 to 2006

	1999 Data		**2006 Data**
	Transgenic	**Conventional**	**All Farmers**
Cultivation Operations	**n=321**	**n=316**	**N=340**
Average number of Operations	1.79	2.63	0.48
Average cost per acre cultivated*	$10.74	$15.78	$2.86
Harrowing Operations			
Average number of Operations	0.94	0.84	0.26
Average cost per acre**	$3.29	2.94	0.92
Overall			
Average number of Operations	2.73	3.47	0.74
Average cost for all tillage operations	$14.03	$18.72	$3.78
Percent Transgenic	67%		95%
Overall Cost per acre	$15.58		$4.59
Total Acres	13.7 million acres		13.0 million acres
Overall Expenditure	$213.5 million		$59.7 million
* assuming $3.50/acre; ** assuming $6/acre			
Source: CCC (2001) for 1999 data. Margin of error on 2006 data is: cultivation 9% and harrowing 11% at the 95% confidence level.			

[4] The cost of $3.72 is determined as follows: $3.50 harrowing cost x 1.2 passes x 88% of canola acres.
[5] While not all canola acres are harrowed or tilled any more, to be able to make a comparison with the Canola Council of Canada study, we have applied the cost to all acres. Thus, allowing us to determine what changes have occurred.
[6] The cost of $7.98 is determined as follows: $6.00 tillage cost x 1.51 passes x 88% of canola acres.

Tillage is both used for seeding and for weed control. When asked explicitly about weed control measures conducted on the 2006 canola crop, 77% of producers reported they only used herbicides while 28% of producers reported they combined the use of herbicides and tillage and 7% reported they only used tillage for weed control. Use of tillage has markedly decreased since 2000, when 89% of producers reported conducting tillage operations as a form of weed control (CCC, 2000). Perhaps most importantly, weed control had long been one of the main limiting factors in more producers moving both to lower-tillage agriculture and to greater cultivation of canola. The commercialization of HT canola and the superior weed control it offers has increased the utilization of minimum or zero tillage operations. The costs of the various weed control systems are identified in Table 1.4.

Table 1.4 shows that the cost of tillage has declined however, when a comparison of financial costs is undertaken, tillage remains cheaper than herbicide weed control options. The reported cost for tillage corresponds to the per pass custom tillage rate in Saskatchewan (Saskatchewan Ministry of Agriculture, 2008). Custom tillage rates vary depending on the size of equipment and hours of annual use. The range of tillage costs in Saskatchewan for 2008-09 was $5.33-$7.79. While the reported cost of one tillage pass in Table 1.4 is $8.07 (marginally above the provincial range), this cost is for one pass of tillage equipment and in an average summerfallow year, a field would be tilled 4-6 times. Finally, tillage is typically done by the individual producer who will not have added in a cost for their time to till a field. The reality is that when environmental aspects like moisture conservation and soil erosion are factored in, the cost of tillage increases even further. Table 1.4 confirms that the producer costs drop the year following production of HT canola as respondents identify a reduction in herbicide cost for weed control of 52.7%.

Table 1.4: Cost of weed control ($C)

Weed control method	Cost of weed control on canola		Cost of weed control on subsequent crop		2 year total cost
	Sample size	Average cost	Sample size	Average cost	
Herbicide only	77	$19.61	77	$9.28	$28.89
Tillage only	15	$8.07	23	$10.58	$18.68
Herbicide and tillage	105	$13.74	31	$12.54	$26.28

Canola production has increased and producers are growing canola more frequently in their crop rotations. Critics of agricultural biotechnology cite the increased rotation as providing for the development of herbicide resistance in weed populations. The survey asked producers about their experiences in the management of herbicide resistance in weeds. Management of herbicide resistance in weeds was found by 28% of producers to have improved, 47% reported it was unchanged and 24% reported herbicide resistance in weeds was on the rise. Table 1.5 identifies examines the issue of weed populations developing herbicide resistance from HT platforms. Producers using Clearfield and Liberty Link™ canola were more likely to report a rise in herbicide resistance in weed populations; 81% of producers using Roundup Ready™ identified that herbicide resistance was the same or had become easier to control.

Table 1.5: Management of herbicide resistance in weed populations

	Clearfield	**Liberty Link**	**Roundup Ready**	**Total**
	(n=46)	(n=165)	(n=209)	(n=432)
Harder	28.3%	27.3%	18.7%	23.4%
The Same	41.3%	35.2%	50.7%	43.8%
Easier	30.4%	37.6%	30.6%	32.9%
Maximum Margin of Error at 95% Confidence Interval	*14.4%*	*7.6%*	*6.8%*	*4.7%*

Producers were specifically asked about weed control measures taken on their 2006 canola crops. The responses to this question closely reflected the responses to the question on the management of herbicide resistance in weeds, with seventeen percent reported no measures had been used to control weeds in their canola fields, 47% reported only using herbicides, 7% reported only using tillage and 27% reported the use of tillage and herbicide. No significant difference was found between the three HT systems. Producers utilizing tillage and herbicide were found to be more likely (53%) to make only one herbicide application than those only utilizing herbicide to control weeds (39%).

When questioned about herbicide applications to 2006 canola crops (Table 1.6), 43% of respondents reported a single application, 37% two applications and 12% reported three or more applications. Producer applications are consistent for in-crop spraying compared to ten years ago. Data from 1998 (CCC, 2000) indicates that 47% of producers made more than one pass, 37% make two passes and 14% made three or more passes.

Table 1.6: Herbicide weed control measures on 2006 canola crops

	Clearfield	**Liberty Link**	**Roundup Ready**	**Total**
	(n=33)	(n=112)	(n=114)	(n=259)
One Application	51.5%	45.5%	38.6%	43.2%
Two Application	30.3%	34.8%	40.4%	36.7%
Three or More	13.0%	13.5%	11.4%	12.1%
Margin of error at 95% Confidence Interval	17.1%	9.2%	9.2%	6.1%

One additional reference check was to compare the absolute and relative costs of the four potential weed control systems, individually and then as they are combined. Table 1.7 presents the comparative costs of weed control by the four canola systems: conventional; Clearfield®; Liberty Link™; and Roundup Ready™. Each system is reported in three different ways: first, the average reported cost of weed control of each system; second, the average reported cost of weed control for producers that only grew a single system in 2006; and third, the average reported cost of weed control of producers who used more than one system. While the overall and single-use cost of weed control for producers using Roundup Ready™ varieties was lower than that of other systems, producers who reported using Roundup Ready™ with other systems reported their cost of weed control significantly increased. While the relative costs were higher for Clearfield® users, the pattern was the same. In contrast, producers using the Liberty Link™ system reported their costs were higher if the system was uniquely used but dropped if other systems were combined; this may be at least partly because these producers also reported that they faced a harder time managing herbicide resistance in weed populations

Table 1.7: Mixtures of canola systems and associated cost of weed control ($C)

Canola variety	Overall	Single System	Multiple Systems
Conventional [1]	$15.40	$15.40	n/a
Clearfield [1]	$15.18	$14.89	$15.32
Liberty Link [1]	$18.05	$19.02	$16.68
Roundup Ready [1]	$13.13	$11.98	$13.82
Total [2]	$15.64	$15.45	$14.81

[1] 95% confidence level +/- 10.5% or greater.
[2] 95% confidence level +/- 7%.

3.2 Control of Volunteer HT Canola

One concern frequently cited by critics of agricultural biotechnology generally and of HT canola in particular is that volunteer HT canola could become a major in-crop weed because those varieties are difficult to control with common broad spectrum herbicides. Mayer and Furtan (1999) speculated that heavy use of a technology such as HT canola could be expected to increase the weedy potential of volunteer canola in the future. Given that producers have demonstrably planted canola with increasing frequency, it would be logical to assume that the challenges of controlling volunteer canola could be increasing. To test this concern, a section of the survey asked producers about the effect of volunteer canola on producer operations and decision-making processes.

When asked an open ended question about the top five weeds targeted by weed control measures, 92% of producers did not mention volunteer canola; the 8% of producers who did mention volunteer canola listed it as their fourth or fifth most problematic weed. When asked specifically about controlling volunteer canola, 35% responded that it required efforts to control. One might conclude from this that volunteer canola is viewed mostly as a nuisance and not a major economic drain on their operations, which coincides with the Canola Council of Canada's 2005 study. These results also support the conclusion by Beckie, *et al*., (2006) that there has been no marked change in volunteer canola as a 'weed' as a result of the transition to weed problems associated with HT systems.

Advances in control of volunteer canola appear to be keeping pace with the increase in canola acreage. When asked whether they are targeting volunteer canola, 62% of producers identified that they no more focused on volunteer canola than they were ten years ago. About 74% of respondents reported that they are able to control volunteer canola more easily or about the same as ten years ago. The 26% that find volunteer canola control to be more difficult than ten years ago also reported that they are spending more on controlling volunteer canola. Only 9% of producers reported that the loss in yields due to volunteer canola have worsened over decade.

The cost of controlling volunteer canola remained constant for 73% of producers over the past decade: Twenty-seven percent of producers reported increased costs, up an average $4.23/acre. A comparison of responses between ease of control and change in targeting revealed that 77% of those who found volunteer canola more difficult to control were spending more for targeting control measures.

When asked specifically about fields in 2006 fields that were seeded to canola in 2005, 36% reported that they did not conduct any weed control measures specifically for volunteer canola. The rest made some investments: 46% sprayed herbicides; 8% conducted tillage operations; and 11% conducted both tillage operations and sprayed herbicide. A range of herbicides were used—58% used a single herbicide application, 29% made two applications and 13% reported three or more applications. While the average reported cost of these weed control operations was $12.70/acre, many respondents noted that these weed control measures were not specifically undertaken to control volunteer canola.

There is also the possibility that HT canola could volunteer on land that was not previously seeded to canola. Twenty-two percent of producers indicated that they had conducted control measures for such occurrences, with 13% spraying herbicide, 5% tilling and 3% both spraying and tilling. Once again, while the average cost reported was $14.30/acre, many producers indicated that this cost was not solely to control volunteer canola but was directed at a number of weeds, which included volunteer canola.

One option many producers exercise is to take preventative measures to limit the potential for HT canola to volunteer in their fields. Fifty-two percent of respondents reported that they had undertaken measures to prevent volunteers—64% of them cleaned machinery between fields and 13% restricted use of HT canola on their fields through restrictive rotations or other measures. However, some larger farms have adopted the practice of growing canola every year. With three difference platforms to choose from, weeds and insects are managed and volunteers are not an issue.

One common practice in Western Canada to control for disease and volunteers has been to limit canola in the crop rotation. Crop insurance agencies in Western Canada recommend that canola be seeded on a field at most once every four years to minimize insect populations developing. While one might have assumed that the risk of volunteers might encourage farmers to lengthen their rotations, the CCC studies suggest that practice has remained relatively unchanged since 2000 (CCC, 2000 and 2005). Producers generally seed canola on the same field every 3.5 years; in 2005 and 2006 they seeded an average of 450 acres to canola. The survey identified that 41% of producers grow canola in a rotation of less than four years (Table 1.8). One reason for producers to ignore the crop insurance recommendations could be that the benefits of HT canola production are greater than the risk of having to spray an insecticide later in the crop season to control insects. The adoption of HT canola seems to have affected crop rotations in two distinct ways. First, 26% of respondents reported that their crop rotation changed as a result of adoption. Second, in addition to changing rotations, these respondents reported that over the past decade adoption of HT canola directly contributed to an additional 350 acres being seeded to canola.

Table 1.8: Field rotations with HT canola

Rotation	Percent
Every Year	0.32%
Once every 2 Years	8.83%
Once Every 3 Years	33.44%
Once Every 4 Years	48.26%
Once Every 5 Years or More	7.26%
Significant at the 95% confidence interval with a margin of error of 5.5%	

With canola grown in rotations shorter than four years, one must assume that the abiotic losses of the crop are offset by the increased security or profits from the production of HT canola. Use of a HT systems lessens the risk of biotic losses from competition between the crop and weeds, a highly likely event in this crop in Western Canada, whereas abiotic or extreme environmental conditions such as drought, flooding and frost are less likely events. Given production costs for HT canola are higher than for conventional canola (CCC, 2001), the mitigation of biotic risk and associated damage must be less than the risk and associated damage from potentially more serious but less likely abiotic stressors.

3.3 Multi-year benefits

Improvements in weed control from HT canola can have a spill-over effect on the same field from one year to the next. Producers were asked if they experienced any spill-over benefits in terms of fewer weeds or easier weed control on fields that had been previously seeded to HT canola. Fifty four percent reported a second-year benefit from the technology—63% of those reporting assigned an economic value to this benefit worth an average $15.05/acre.

Table 1.9 illustrates the range of benefits that accrue across the Prairie region. The Alberta low and high, the Saskatchewan low and high and Manitoba correspond to the previously identified levels of production. The benefits reported by Alberta low and high producers are significantly higher than for the other regions. In Saskatchewan, it is the area identified as low, in terms of canola production, that realizes the highest level of benefits. This area is along the western and southern borders of the province, areas that had little canola production prior to the commercialization of HT canola. Manitoba is lower than the other regions and the average, but not significantly. These results would tend to suggest that there may be a westward effect for the spill-over benefit.

Table 1.9: Second year spill-over benefits per acre across Western Canada ($C)						
	Alberta		Sask.		Man.	Average
	Low	high	Low	high		
Number of producers	34	25	62	66	22	226
Average	$17.86	$18.93	$14.50	$13.92	$13.05	$15.05
Lower value	$15.91	$16.40	$13.29	$12.87	$11.65	$14.40
Upper value	$19.81	$21.46	$15.71	$14.97	$14.44	$15.69
At the 95% confidence interval margin of error is 8.4% for average and 14.8% or greater for rest.						

Figure 1.1 disaggregates the average reported benefits according to the size and distribution of the benefits. While the majority of responses identified benefits in the $10-15 per acre range, one fifth of producers identified spill-over benefits that were in excess of $25/acre. Over 75% of the 54% of producers reporting spill-overs estimated the benefit to be greater than $10/acre.

Figure 1.1: Estimated spill-over benefits per acre

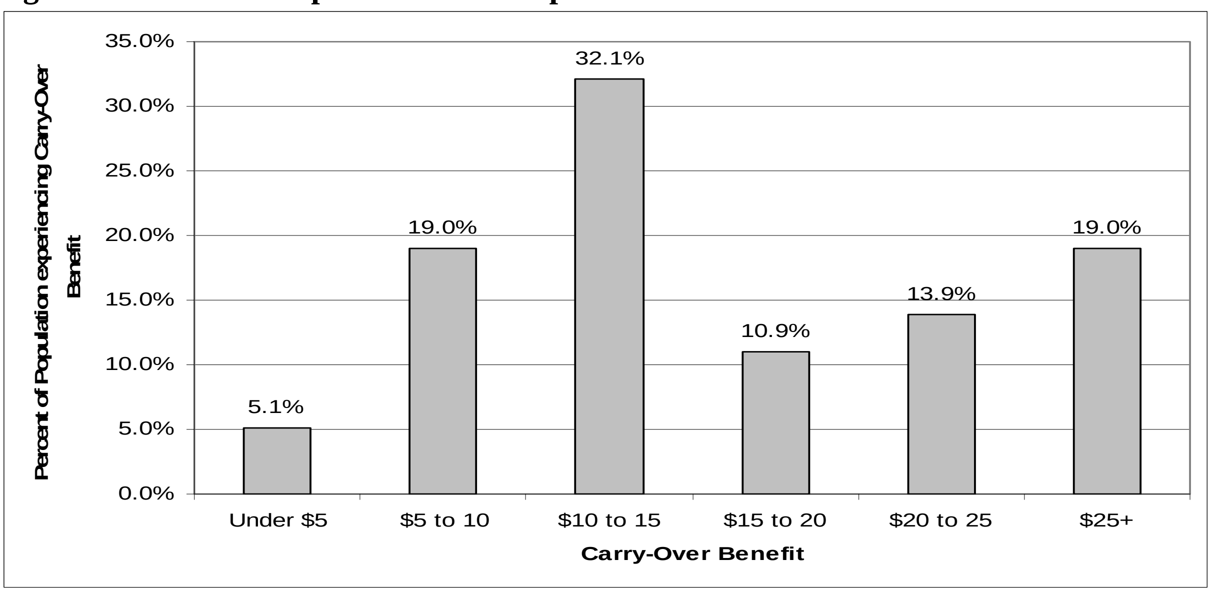
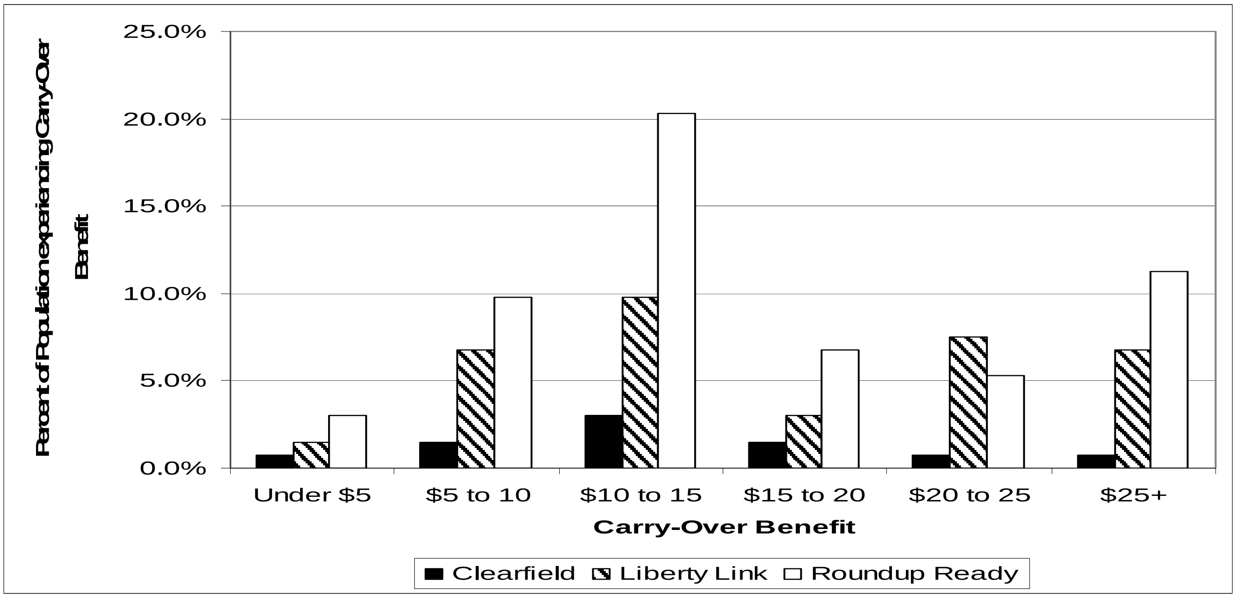


Figure 1.2 presents the same spill-over benefit but in terms of the HT canola system used by producers. Producers using Roundup Ready™ canola reported more and higher spill-over benefits, which is consistent with the greater level of adoption.

Figure 1.2: Incidence of multi-year benefits by GMHT system used in 2006



3.4 Summary of economic benefits for producers

Previous surveys (Phillips 2003 and CCC 2001) put the producer benefit of HT canola at $60-70 million in 2000. Neither study, however, attempted to calculate the impact of any spill-overs or any increased costs from controlling volunteer canola. With the estimates from this survey, we can now modify those earlier estimates based on more detailed information.

The total producer benefit of HT canola can be represented as the direct economic impact of the technology, spill-over benefits and the value of reduced tillage, net of the increased cost for controlling volunteer canola. Phillips (2003) did not include reduced tillage as part of his calculations for direct benefits, hence their inclusion. This survey did not directly estimate the primary economic benefit of the technology to producer, but the data does substantiate that the benefits likely fall in the range of $10.62 and $11.14 per acre, as calculated by Phillips and the CCC (2001). Using the $11.14/acre benefit as a baseline, we can then consider the potential importance of the spillovers and volunteer control costs.

The direct benefit ($11.14/acre) is applied to the total acres cultivated in 2005, 2006, and 2007. Next, the low and high estimates[7] of the spillover benefits were applied to actual acres cultivated. The value of reduced tillage, $153.8M can be added to each of the years.

[7] The range of low/high spillover estimates were calculated from the 54% of producers that realized some benefits with 33% assigning a value of $15.05/acre, creating a range of spill-over benefits when discounting for proportions of $4.97/acre to $8.19/acre.

Finally, the additional cost of volunteer canola control cost[8] ($1.12/acre) was deducted from the total. Using the actual canola acreage for 2005-7, we estimate that the total economic benefit from HT canola ranged from $343 million to $422 million per year (Table 1.10). Over the three year period, the average benefit was in the range of $354 million to $397 million. The cumulative impact of HT canola is estimated to be between $1.063 billion and $1.192 billion, over the 2005-07 period.

In relative terms, the cost of volunteer canola control has a marginal impact on the technology. The reduction in total benefits is reduced by 4% on average per year. Much more important, however, is the spill-over benefits, which account for 19% to 28% of the total net benefits of the new technology.

In relative terms, the volunteer control cost has a marginal impact on the technology. Much more important, however, is the multi-year benefits, which account for between 33% and 45% of the total net benefits of the new technology.

Table 1.10: Direct and spill-over benefits of HT canola (C$M)

Year	Acres	Direct	Spill-over		Reduced tillage	Cost of volunteer control	Total Benefits	
			Low	High			Low	High
2005	12.6M	$141M	$63M	$103M	$153M	$14M	$343M	$383M
2006	12.8M	$143M	$64M	$105M	$153M	$14M	$346M	$387M
2007	14.8M	$165M	$73M	$121M	$153M	$17M	$374M	$422M
Average	13.4M	$150M	$67M	$110M	$153M	$15M	$354M	$397M

4. Conclusion

This section of the study had three economic objectives: first, to examine weed control in HT canola, but more specifically to determine if herbicide resistance was developing; second, to identify if control of volunteer canola had changed following the widespread adoption of HT canola; and third, to attempt to quantify any multi-year producer spill-over benefits.

Producers have experienced a change in weed pressures following the commercialization of HT canola. While not all producers believe that these new weed pressures were due to their adoption of HT canola, many did. Of those that believed the changes they faced in weed pressures were due to the adoption of HT canola, over 94% indicated that the ease, cost and practice of controlling for weeds was either unchanged or had improved. When asked specifically about the management of herbicide resistance in weed populations, a full 76% of respondents indicated that this was either the same or easier following their adoption of HT canola.

[8] The cost of controlling volunteer canola was reported by 26.6% of producers to average $4.23/acre. Allocating this cost across all cultivated acres results in an average per acre cost of $1.12 for the entire prairie region.

Nearly two-thirds (62%) of respondents indicated that the measures taken to control volunteer canola are no different than they were prior to the commercialization of HT canola. When asked about the difficulty of controlling volunteer canola, almost three-quarters (74%) indicated that this was the same or easier than it was pre-HT canola. A mere 8% of respondents indicated that they deemed volunteer canola to be one of the top five weeds that they need to control. Overall, the cost of controlling for volunteers makes only a minor impact on the producer benefits of adoption (i.e. it offsets less than 4% of the benefits of the technology).

The attempt to quantify the reported spill-over benefits produced one of the most surprising results. Our survey found that where they are observed, the spill-over benefits are actually greater than the direct benefits. The average estimate of spill-over benefits was $15 per acre compared to the direct benefit identified by Phillips (2003) of $11 per acre. While some producers did not report any multi-year benefits, the impact of those that did contributed between 19% and 28% of the net benefits to producers in the three years under review.

This under reported and generally undervalued multi-year benefit may help to explain the reality that HT canola was almost fully adopted within six years. Neither the comparative cost of the conventional and HT systems nor the estimated direct economic impact of the technology upon adoption could fully explain the unparalleled adoption of this new technology. Producers had to be realizing some substantial economic benefits that those earlier studies were not fully accounting for. This study confirms that substantial economic benefits are recognized at the producer level. In farming, like any other business, operators use technologies that consistently deliver high returns. The sustained rates of adoption and expansion of the canola acreage in Western Canada are strongly correlated to the economic benefits identified by this survey.

Section 2

Environmental Impacts of Herbicide Tolerant Canola Production

1. Introduction

The first generation of GM plants contained in-put benefits (i.e. benefits that were directed toward the producer, such as, herbicide tolerance and insect resistance). The final food products produced by GM plants were substantially equivalent to the conventional products therefore, did not require labelling, resulting in consumers being unable to establish a direct relationship regarding the benefits of GM plants. While direct consumer benefits from GM plants have been minimal, this is not to suggest that there have not been benefits from this innovative crop technology. The benefits have in fact, been substantial.

Following the limited and controlled introduction in 1995 and 1996, producers in Western Canada rapidly adopted the agricultural innovation of HT canola. Producers are, in reality, private firms and operate as profit maximizers. Based on this, producers will only adopt technologies that provide a sustained benefit to their business operation. Virtually all of the canola seeded for the 2007 crop year in Western Canada was a HT variety. Clearly, producers have identified benefits from the innovation of HT canola.

While producers in Western Canada have identified personal and/or corporate benefits from the production of HT canola, there are also larger societal benefits generated by this innovation. There have been numerous environmental impacts generated and accumulated following the initial commercial production of HT canola in 1997. This section identifies and quantifies the environmental impacts of HT canola in the Western Canadian marketplace.

2. Background

While the total number of acres planted to HT canola has more than doubled since 2002, there is still debate going on as to whether GM crops reduce chemical applications. Brookes and Barfoot (2005) estimated that from 1996 to 2004, the total volume of active ingredient applied to crops had fallen by six percent. They attribute this decline to the commercialization of GM crops. The authors additionally estimate that there has been a 14% reduction in the 'environmental foot print' made by crop agriculture, which is also attributed to GM crops. Young (2006) reported that the introduction of glyphosate-resistant soybean in 1996 and cotton in 1997 has, by 2002, corresponded with an increase in glyphosate use of 27.5 million kg/yr, and 3.2 million kg/yr for the two crops respectively. This same study reported that the average number of herbicide active ingredients applied to soybean decreased from 2.5 in 1994 to 1.6 in 2002 and for cotton the decrease was from 3.1 in 1997 to 2.1 in 2001.

Gianessi, *et al*., (2002) estimate that there is a beneficial pest management impact from GM crops as based on the study of 40 different cultivars. They found that there was a reduction of 46 million pounds of pesticide application. This reduction is made in comparison to non-HT crops. The authors go on to estimate that GM crop varieties that were in development at the time of the report, could reduce pesticide applications by over 100 million pounds.

Proponents on the other side of the debate argue that GM crops increase the amount of pesticide applications. Benbrook (2003) argues that between 1996 and 2003, the level of pesticide use had increase by 50 million pounds. The contrast between the Gianessi, *et al*., report is substantial, with a difference of nearly 100 million pounds over the same period of time. Benbrook (2009), updating the earlier study, reported that genetically engineered crops are responsible for an increase of 383 million pounds of herbicide use in the US. In his analysis, Benbrook fails to differentiate an increase in chemical applications from an increase in crop production. The total acreage for GM corn in the US substantially, yet Benbrook does not take this into account when determining the change in chemical applications. It is quite elementary to realize that if the crop acreage increases, so too, will the number of chemical applications. For example, corn acreage in the US increased by over 16 million acres between 2003 and 2008 (USDA- NASS, 2008). Taken in combination, these assumptions underlying Benbrook's estimates may explain much of the divergence.

An major concern regarding the Benbrook studies is his assumptions about the chemical application he makes between GM crops and conventional crops. The United State Department of Agriculture (USDA) statistical bureau, the National Agricultural Statistics Service (NASS), does not differentiate in its data between GM and conventional crops, so Benbrook is forced to make assumptions about chemical applications on GM crops from those on conventional crops.

There has been one study that does provide a more relevant comparison. The Canola Council of Canada (2001) released a report on transgenic canola that found that the average number of herbicide applications for transgenic canola was just over two, based on a sample of 321. The average number of applications made by conventional canola producers (sample size 315) was 1.78. These results were based on application data from the fall of 1999 and the spring of 2000. While these results do provide an indication of the relative change of herbicide applications associated with the adoption of transgenic crops, little information is provided on the chemical load released into the environment.

While there have been some studies done in the area of herbicide/pesticide application, there have not been any studies done that examine other environmental impacts. The results from the survey of Western Canadian producers identify environmental impacts beyond a reduction in the application of active ingredient.

3. Results and Analysis

One of the significant environmental impacts revealed from the survey was the adoption of HT canola and the increase in producer use of minimum or zero tillage practices. The survey revealed that 65% of the canola grown on the prairies is combined with a zero tillage or minimum tillage method. While in the last two decades changes in such factors as farm size and farm equipment have contributed to a general movement across the prairies away from the conventional practice of summerfallowing, it is evident from this survey that producers that have made this transition to reduced tillage have found a benefit in using HT canola. Young (2006) states that the introduction of glyphosate-resistant soybean and cotton has likely been a factor in recent increases in no-tillage production of these crops in the U.S. The reason for this is that producers are getting very high levels of weed control in fields seeded with HT canola, to the level that there is no longer a need to pre-work fields prior to seeding them in the following crop year. Traditionally, producers have tilled their fields prior to seeding as a form of early weed control. The use of HT canola has drastically reduced this need.

Producers are able to gain superior levels of weed control by utilizing HT canola in their cropping rotations, which allows them to direct seed the second year crop onto the canola stubble. There are two major environmental benefits to be gained from this practice. First, maintaining stubble on the soil increases snow capture and thereby increases spring soil moisture levels while greater levels of soil organic material contributes to moisture conservation in the soil, enabling canola seed to germination in a soil bed that has a higher level of moisture than conventionally tilled fields. This is extremely important in arid areas of the Prairies. Eighty-three percent of respondents indicated that they have greater soil moisture with this tillage method.

Second, the reduction in intensive tillage of land and the move to zero and minimum tillage with HT canola allows producers to seed HT canola with a minimum of soil disturbance, thereby reducing the soil's exposure to wind. When asked about experiences with soil erosion following the adoption of HT canola, 86% of producers identified that they have reduced soil erosion. This is extremely important in arid areas of the Prairies. Soil erosion is problematic for many areas of Western Canada, especially in the lighter soil zones that typically receive less precipitation. When asked about the land that they routinely seed into canola, 41% of producers indicated that they are seeding HT canola into land that they identified as erodable. Producers identified that soil humus is improving on their erodable land.

The challenges of controlling weeds on erodable land previously meant that producers had to utilize some form of tillage and the adoption of HT canola has provided them with a new option. Producers are now able to use zero-till equipment to seed canola and to use the same equipment the following year to seed a cereal or pulse crop. One-third of respondents indicated that they now have improved soil structure following the adoption of minimum or zero tillage with HT canola.

Producers were asked about how their chemical application practices had changed following the adoption of HT canola and they identified that they were making an average of one less application per year. These findings correspond to those of Gianessi, *et al*. (2002) and Brookes and Barfoot (2005). The reduction of active ingredient has been determined based upon the production of the various HT canola systems (Table 2.1)

Table 2.1: Reduction in chemical active ingredient (lbs.)

	1995	**2005**	**2006**	**2007**
Hectares of canola production	5,190,093	5,099,039	5,220,445	6,272,627
Amount of herbicide active ingredient (kg)	3,363,233	2,046,142	2,091,727	2,517,081

The amount of land in canola production has increased by 21% between 1995 and 2007, yet the amount of active ingredient that is applied is 25% lower than what was applied in 1995. Table 2.1 demonstrates that while the production of canola has risen following the introduction of HT canola, the amount of herbicide active ingredient is lower than what was applied previously.

A substantial environmental benefit created by canola producers move to minimum and zero tillage is the value of carbon sequestration. As indicated in the previous section, nearly two-thirds of producers utilize either zero-till or min-till as their preferred form of land management. Harrowing is classified as a method of minimum tillage. Use of tillage has markedly decreased from the year 2000 when 89% of Western Canadian farmers conducted tillage operations as a form of weed control (CCC, 2000). There has been increasingly wide-spread adoption of minimum or zero-tillage practices across Western Canada. One of the barriers to adoption of these reduced tillage management practices had been the lack of effective weed control options. The transition to these methods of land management results in increased stocks of carbon (carbon sinks) maintained in soils being used to produce annual crops. The reduced soil disturbance associated with reduced tillage decreases the rate of decomposition of crop residues and thereby maintains more of that carbon in and on the soil rather than releasing the carbon into the atmosphere contributing to atmospheric greenhouse gas stocks. Furthermore, the practice of continuous cropping, as compared to management systems that include regular fallow periods, may increase in the amount of carbon that is sequestered by annual cropping. McConkey, *et al*., (2007) have determined the value and amount of carbon that is annually sequestered in the various eco-regions in Canada.

The transition of these methods of land management results in an increased level of carbon sequestration by producers. Producers are not tilling their land at the rate they previously did and now practice a land management system that results in the land not being tilled reducing the amount of carbon entering the environment. With the continuous planting of crops, there is an increase in the amount of carbon that is sequestered from the environment by the crop. McConkey, *et al*., (2007) have determined the value and amount of carbon that is annually sequestered in the various eco-regions in Canada.

Canada, as a large nation has numerous eco-regions, but the vast majority of canola is grown in three main regions (Table 2.2). A small amount of canola is produced in the Boreal Shield West eco-region, which is located in the very eastern part of Manitoba. Using the response rate to this survey as a reflection of the percentage of producers in each eco-region it is possible, using the percentage of producers that are using minimum tillage practices, to determine the number of tonnes of carbon that are sequestered annually and the sequestration value. Table 2.2 shows that minimum tillage of canola in Western Canada, sequesters just over 35,000 tonnes of carbon. When this volume is valued using the Chicago Climate Exchange carbon credit value of $5/tonne, the financial benefit is $180,000.

Table 2.2: Value and amount of carbon sequestered using minimum tillage ($C/yr)

Eco-region	**Min-till acres**	**C-S co-efficient (t/ac/yr)**	**Carbon Sequestered (t/ac/yr)**	**Value of Carbon Sequestered**
Boreal Shield West	8,789	.0162	142	$710
Boreal Plains	278,628	.0162	4,514	$22,570
Subhumid Prairies	716,426	.0283	20,275	$101,375
Semiarid Prairies	623,658	.0162	10,103	$50,515
Total	**1,627,501**	**na**	**35,034**	**$180,170**
Source for co-efficients: McConkey, *et al*., (2007).				

The number of producers utilizing zero tillage practices is considerably greater and therefore, the volume and value of the carbon being sequestered is also larger (Table 2.3). Over eight million acres are under zero tillage, which sequesters 436,000 tonnes of carbon. The annual value of this is $2.18 million. When the value of minimum and zero tillage practices are combined, the value of carbon sequestration increases to $2.36 million, while the volume of carbon being sequestered increases to 470,000 tonnes.

Table 2.3: Value and amount of carbon sequestered using zero tillage ($C/yr)

Eco-region	**Zero-till acres**	**C-S co-efficient (t/ac/yr)**	**Carbon Sequestered (t/ac/yr)**	**Value of Carbon Sequestered**
Boreal Shield West	45,031	.0648	2,918	$14,590
Boreal Plains	1,427,637	.0567	80,947	$404735
Subhumid Prairies	3,670,828	.0607	222,819	$1,114,095
Semiarid Prairies	3,195,505	.0405	129,418	$647,090
Total	**8,339,001**	**na**	**436,102**	**$2,180,510**
Source for co-efficients: McConkey, *et al*., (2007).				

A further environmental impact can be calculated for the adoption of HT canola, which is the value of carbon no longer released due to tillage. Now that canola producers have substantially moved to zero and minimum tillage practices, the fields sown to canola are no longer tilled. Since these fields are no longer tilled, the fields do not release volumes of carbon at the time of tillage. Table 2.4 provides a value for carbon that is no longer being released.

Table 2.4: Value and amount of carbon no longer released through tillage ($C/yr)

Eco-region	Zero and minimum tillage acres	C-S co-efficient (t/ac/yr)	Carbon Sequestered (t/ac/yr)	Value of Carbon Sequestered
Boreal Shield West	53,820	.0648	3,488	$17,440
Boreal Plains	1,706,265	.0567	96,745	$483,725
Subhumid Prairies	4,387,254	.0607	266,306	$1,331,530
Semiarid Prairies	3,819,163	.0405	154,676	$773,380
Total	**9,966,502**	**na**	**521,215**	**$2,606075**
Source for co-efficients: McConkey, *et al.*, (2007).				

The combined value of Tables 2.2-2.4 is C$4,966,755, while the total volume of carbon sequestered and not released is 992,351 tonnes.

Without a benchmark, it is difficult to appreciate the value of Tables 2.2 and 2.3. Because the number of acres of land under zero and minimum tillage has increase substantially over the past decade, it is meaningless to compare the above figures to data from a decade ago. To provide a comparable benchmark that is meaningful, we have determined that volume and value of carbon sequestration as if the innovative technology of HT canola had not been commercialized therefore, we assume that the rate of tillage would not have changed. The authors use the Canola Council of Canada data that identifies that only 11% of producers practices zero or minimum tillage in 2000.

The CCC data does not differentiate between zero or minimum tillage so Table 2.5 determines the range of volume and value for carbon sequestration based on the entire 11% being either fully zero tillage or fully minimum tillage. The volume of carbon sequestered ranges from 36,000 to 89,000 and the value of this ranges from $183,000 to $445,000.

When the ranges from Table 2.5 are compared with the combined values of Tables 2.2 and 2.3, it becomes possible to comprehend the environmental impacts of HT canola. Compared to the scenario without HT canola, producers are presently sequestering between 380,000 and 434,000 additional tonnes of carbon. The additional value of this carbon sequestration ranges between $1.915M and $2.177M.

Table 2.5: Value and amount of carbon sequestered using pre-GM land management

Eco-region	MT or ZT acres	Mt co-eff	ZT co-eff	MT t/ac	ZT t/ac	$MT	$ZT
Boreal Shield West	9,207	.0162	.0648	149	597	$745	$2,985
Boreal Plains	291,896	.0162	.0567	4,729	16,550	$23,645	$82,750
Subhumid Prairies	750,541	.0283	.0607	21,240	45,558	$106,200	$227,790
Semiarid Prairies	653,356	.0162	.0405	10,584	26,461	$52,920	$132,305
Total	**1,605,000**	**na**	**na**	**36,702**	**89,166**	**$183,505**	**$445,830**

Clearly, HT canola is so highly valued by prairie producers that any canola variety without this technology stands a minimal likelihood of being adopted by producers. This is evidenced when one examines the results of canola field trials in the prairies over the previous five crop years. Table 2.6 highlights that conventional (non-HT) varieties of canola being developed by the seed industry are rapidly disappearing from prairie agriculture. Conventional canola varieties account for five percent of field trials over the period from 2003 – 2007, but drops to three percent when the trials from 2003 are removed. This percentage corresponds to the percentage of canola production that is non-HT.

Given that seed development firms are eliminating non-HT canola from the varieties that are in the pipeline and when this is included with the HT canola adoption pattern which shows that over the six-year period (2002 – 2007) the adoption rate of HT canola has exceeded 90% for every year, with 2002 and 2007 witnessing virtually full adoption. Adoption rates like this demonstrate that producers are recognizing a substantial economic and environmental benefit from HT canola and that non-HT varieties will not be grown. The marketplace is dictating that HT canola varieties will be the future of the canola industry.

Table 2.6: Canola variety trial data, 2003-07

Year	Conventional	Roundup	Liberty	Clearfield	Total
2007	1	31	8	8	48
2006	2	34	6	8	50
2005	1	35	3	10	49
2004	2	23	4	9	38
2003	6	30	4	4	44
Total	12	153	25	39	229
Source: Canola Council of Canada, 2008.					

4. Conclusions

The following observations can be made about the environmental impacts of HT canola production in Western Canada.

First, environmental impacts have been, and are being, widely observed by prairie canola producers. While the prairie agriculture movement away from summerfallow to zero tillage can not be credited to HT canola, the two technologies have co-evolved together. Control of weeds was one of the barriers in a substantial movement to zero tillage, but the commercialization and adoption of HT canola has introduced a new weed control option that has facilitated this movement. Producers are now able to direct seed HT canola, use the respective herbicide and gain a clear advantage in weed control. Producers that have not or can not adopt HT canola, such as organic producers, are forced to rely on tillage as their leading method of weed control, thus foregoing all of the carbon sequestering benefits, not to mention the dramatic losses in terms of soil erosion and moisture conservation.

Second, the value of carbon sequestration is substantial, especially when contrasted against the situation where HT canola did not exist. Had HT canola not been developed and commercialized in Canada, the difference in terms of carbon sequestering between canola farming practices prior to HT canola and now, is nearly one million tonnes of carbon annually. This is indicative that HT canola can be deemed as one of, if not the, most environmentally friendly crop technology being used in Canadian agriculture.

Third, the marketplace is indicating that HT canola is what is demanded. Innovation is driven by signals and there is a very loud and clear signal coming from prairie producers in that they, by far, prefer HT canola to all other canola varieties. The days of agriculture subsidies are gone and prairie producers require the most innovative and beneficial technologies to be profitable. If HT canola was not delivering agronomic and economic benefits to producers, the prairie canola industry would not be witnessing virtual full adoption of HT canola.

Section 3

Changes in Herbicide-use Following the Adoption of Herbicide Tolerant Canola in Western Canada

1. Introduction

Herbicide tolerant canola was commercialized in Western Canada in 1995 and over the intervening fifteen-year period, numerous changes have taken place regarding herbicide safety, use and application. The adoption of HT canola has reversed the herbicide application situation, whereby herbicides that were the minority of applications in 1995, are now the dominant herbicides.

While canola acreage is price dependant, that is the higher the price, the greater the number of acres sown to canola, there has been a steady increase in the canola acreage in Western Canada over the past seven years. Historically, canola acreage has been affected by short-term price cycles, as acreage previously peaked in 1994 at 14M acres and declined to 8.5M acres in 1996. Acreage then rose back to 14M acres in 1999, but declined to 9M acres in 2002. The most recent canola data from 2008, shows an unprecedented sixth consecutive year of acreage increase, rising to 16M acres. As the number of canola acres has increased over the previous high, the volume of chemicals applied to canola crops has correspondingly increased. This is fairly straight forward logic, if more acres are planted, more acres will need weed control measure, hence more chemical will be applied. However, the focus of this section is to compare the toxicity of the chemicals being presently applied versus the toxicity of the chemicals that were applied to canola prior to the introduction of HT canola. Canola acreage in 1995 and 2006 were virtually identical with 12.98M acres in 1995 and 12.87M acres in 2006.

In the spring of 2007, canola herbicide use data for the 2006 crop year across Western Canada was gathered through a survey conducted by the University of Saskatchewan. This survey gathered detailed information on weed control methods, suite of herbicides used, application rates, acres treated and number of applications. This information has allowed us to identify the top five herbicides presently applied to canola. It was then possible to calculate the exposure of Western Canadian farmers, consumers and the ecology impacts of these herbicides. Comparisons can then be made between the herbicides that were used prior to adoption of HT canola and those reported in 2006. Based on this comparison, it is possible to identify the toxicology changes that have occurred following the first decade of HT canola production and to quantify the impact of these changes.

2. Background

Toxicity comparison of herbicides is not a simple process. Historically, as part of the integrated pest management programs, information was available on application rates and food safety concerns as well as ground water and run-off impacts. This information has been available from the pesticide registration process, which contains data for toxicological and environmental impacts. However, this information would not allow for the direct comparison between herbicide A and herbicide B. The agriculture industry had little knowledge regarding which of two herbicides would be safer to apply if they were roughly equivalent in terms of control and ease of application. In an attempt to establish the opportunity to undertake herbicide comparisons, Kovach, *et al.,* (1992) developed the Environmental Impact Quotient (EIQ) which measures the relative toxicity of chemicals, which is comprised of three separate components: ecological; farm workers; and consumers. The EIQ is regularly updated, providing a consistent tool for comparing different herbicides. Over time, it is possible to determine which form of agricultural crop production has the lowest impact on the environment, farmers and consumers.

The EIQ utilizes a five point ordinal scale to indicate the relative toxicity of chemicals, where one is equated to least toxic or harmful and five is equated to the most toxic or harmful. The farm worker component is comprised of the effects on the applicator and the picker. This later impact is more relevant to fruit and vegetable agriculture than it is to large-scale canola production in Western Canada, where harvesting is extremely mechanized. The consumer component is comprised of the direct consumer effects from consumption and groundwater effects in the environment. The direct consumer consumption of canola does not occur as all consumer consumption of canola is done by the consumption of processed canola oil. The ecological component is comprised of aquatic and terrestrial effects, which includes assessments of chemicals on fish, birds, bees and beneficial arthropod effects.

Herbicides have a range of toxicological impacts and are classified as having either acute or chronic toxicity. Acute toxicity is the direct poisoning of an organism due to exposure, this can be through dermal contact, inhalation or oral ingestion. Acute toxicity measures the short-term poisoning potential of the target organism. A value of exposure is assigned when an amount of material is given all at once to a group of test subjects that results in half of the test population expiring, which is called the lethal dose 50, or LD50. Chronic toxicity is the chemical accumulation within an organism over a long period of time that has the potential to effect growth, reproduction and/or survival. For chronic toxicity no numerical value is assigned, only the notation of no effect, may affect and does cause.

Within the literature there is an emerging consensus regarding the reduction in herbicide use by producers utilizing HT crop technologies (Table 3.1). There is a growing agreement that the amount of active ingredient has decreased, as has exposure. China was the first country to have commercial production of a GM crop, with GM tobacco production in 1992. By 1993, China was producing GM cotton and by 1999, production was in the range of 100,000 to 120,000 hectares. Pray and Ma (2001) undertook one of the early applied benefit studies of GM crops, by surveying cotton farmers in Northern China. The adoption of Bt cotton allowed producers to reduce the number of pesticide applications in a range of 3 to 30 applications, with a more common reduction of 3 to 12 applications. They found that the quantity of pesticides applied to non-Bt cotton was 48kg/ha higher that that applied to Bt cotton.

The first HT/non-HT canola comparison done in Canada was based on data from 1999-2000. The Canola Council of Canada (2001) commissioned a study to assess the agronomic and economic impacts of transgenic canola. At this time, approximately three-quarters of the canola being produced was HT canola. The study examined herbicide input costs, focusing on fields that had been summerfallow in 1999 (where some farmers made chemical applications to the summerfallow field) and were then sown to canola in 2000. The study found that the average per acre cost over the two-year period was C$13.68 for HT canola and C$22.53 for non-HT canola, a decrease of 40%. This reduction is estimated to be the equivalent of 6,000 tonnes in 2000.

Gianessi, *et al*., (2002) estimate a beneficial pest management impact from GM crops, based on the study of 40 different cultivars. They found that there was a reduction of 46 million pounds of pesticide application. This reduction is made in comparison to non-HT crops. The authors go on to estimate that GM crop varieties that were in development at the time of the report, could reduce pesticide applications by over 100 million pounds.

Table 3.1: Contrast of various studies

Research Study	Timeframe of study	Change in herbicide application	EIQ impact
Pray and Ma	1999 in China	48kg/ha decrease	na
Canola Council of Canada	1999/2000	40% decrease	na
Gianessi, et al.	2001	46M lb. decrease	na
Gianessi, et al.	2002	117,000kg decrease	
Benbrook	1996-2003	50M lb. increase	na
Brimner, et al.	1995-2000	20.4% decrease	36.8% decrease
Kleter, et al.	2004 crop year	30% decrease	42% decrease
Brookes and Barfoot	1996-2006	12.6% decrease	24.2% decrease

In a subsequent study by Gianessi, *et al*., (2003) that examined the potential impacts of HT canola on European agriculture, it was estimated that if transgenic canola were produced on one-quarter of the European canola acres, this would correspond to an annual herbicide reduction of 117,000kg.

Some studies suggest that GM crops could actually increase the amount of herbicides. Benbrook (2003) argues that between 1996 and 2003, the level of herbicide use had increased by 50 million pounds. Benbrook (2009), updating the earlier study, reported that genetically engineered crops are responsible for an increase of 383 million pounds of herbicide use in the US. The discrepancy seems to be that Benbrook drew upon USDA National Agricultural Statistics Service (NASS) for his data, which does not differentiate between GM and non-GM crops and hence had to be interpolated based on secondary estimates for GM and non-GM acres. In addition, Benbrook assumed farmers used the recommended rate of application, which is not always an accurate reflection of production decisions. Depending on a variety of factors (e.g. moisture, weed density and insect populations) producers will often apply chemical at a rate that is below the recommended rate, particularly if there is no evidence of the target they want to control. The final factor that discounts Benbrook's assertions are that he does not take into account the increase in the number of acres being planted to the commodities he examines. For example, corn acreage in the US increased by over 16 million acres between 2003 and 2008 (USDA- NASS, 2008). Taken in combination, these assumptions underlying Benbrook's estimates may explain much of the divergence.

Brimner, *et al.*, (2005) used the EIQ method to examine the changes in herbicide use due to HT canola adoption between 1995 and 2000. They found that herbicide use on conventional canola had increased by 55.8%, while herbicide use on HT canola had decreased by 20.4%. In terms of the Environmental Impact (EI) of HT canola, a 36.8% decrease was observed. The authors note that this study was imperfect due to the lack of adequate data for the proper comparison of the two systems due to an arbitrary allocation of herbicides to conventional and HT canola. Herbicide allocation was based upon the assumption that herbicides that were associated with HT canola were the only herbicides used on HT canola, with all remaining herbicides being applied to conventional canola. This created an overestimation of the amount of herbicide used on conventional canola, while at the same time underestimating the amount of herbicide used on HT canola. While the authors of this study struggled to allocate chemical applications between conventional and HT canola, the herbicide applications from 1995 are reliable data and provide the benchmark for herbicide used in this article.

Beckie, *et al*., (2006) examined the first decade of HT crop use in Canada and note that prior to the introduction of HT canola, herbicide options for canola were limited. The most common herbicide application method was to soil incorporate, which had a low efficacy rate and the residual activity of some herbicides resulted in crop rotation restrictions in the subsequent year.

A review study by Kleter, *et al.*, (2007) examined the 2004 US canola crop that compared conventional and transgenic canola. This study is the summary of a four-year study on transgenic crops and their impact on chemical use and the environment, that was conducted by an international team of researchers under the supervision of the International Union for Pure and Applied Chemistry. The application of pesticide active ingredient was lower by 30% in the HT canola. The total EI per hectare was lower by 42%, the ecological impact was lower by 39% and the farmer impact was lower by 54%.

Brookes and Barfoot (2008) use the EIQ methodology to compute and compare EIQ values for conventional and GM crops, aggregating this data to a national level. This research provides an analysis for the changes in herbicide use between 1996 and 2006. In their analysis of HT canola in North America, the authors found that the EIQ decreased by 24.2%. The amount of active ingredient of chemical applied to canola decreased by 12.6% or 7.9 million kg. The application rates used in this study assumed that the highest application rate was used in all instances which resulted in an over-estimation of active ingredient application, thus underestimating the overall benefit.

As the adoption of transgenic crops moves fully into the second decade, there is a small, but growing body of literature that delves into herbicide application and the environmental impact of the application of these herbicides. Not all of the above studies focus specifically on the adoption and production of HT canola, but those that do, illustrate a substantial reduction in herbicide use and a considerably lower EIQ value.

3. Application of EIQ Method

As discussed above the EIQ method developed by Kovach, *et al.*, is compartmentalized in nature, allowing for herbicide impacts to be assessed for each of the three sub-components. While it is important to provide EIQ values to allow for herbicide comparisons, it is also valuable to provide the EIQ subcomponent values and further to this, using the EIQ subcomponent values to determine the environmental impact for the three subcomponents. Given the nature of canola production and the lack of direct consumer consumption, the subcomponents of greater interest are the farm worker and ecological. The environmental impact quotient for farm workers (EIQ_f) measures the effects of herbicide application as a function of acute toxicity (DT), chronic toxicity (C) and plant surface half-life (P).

$EIQ_f = C(DT*5)+C(DT*P)$

The farm worker component of the EIQ is made up of two parts, the applicator and picker effects. The applicator effect is the exposure of the farm worker to herbicides when being applied to the crop. The applicator effect is a function of acute toxicity (in terms of dermal toxicity), multiplied by the chronic toxicity of the herbicide. Because farm workers directly handle herbicides, it is granted a weight of five to reflect the severity of this exposure. The picker effect in relation to canola production, are the herbicide residues that still exist on the crop at harvest. Canola harvesting in Western Canada is very mechanized, which significantly reduces the direct contact between farm workers and the crop. However, it does expose the farm worker to dust and debris dispersed into the air as a result of the harvesting process. Again, chronic and acute toxicity are used along with the persistence of the herbicide on the plant material, reflected by the plant surface half-life. The value of the EIQ_f can range from 6 (the least toxic) to 250 (the most toxic).

The EIQ_f determines a toxicity value for one unit of the herbicide application. Because herbicides are not applied at the same rate, measuring the amount of active ingredient applied can not be used as a direct comparison between herbicides. Measuring the environmental impact to farm workers (EI_f) is calculated by multiplying the EIQ_f by the application rate and by the area that is sprayed.

$EI_f = EIQ_f * Area * Rate$

The EI_f for the benchmark year (1995) has been estimated from previous data and this value is compared to 2006, where we have detailed data on application rate and area sprayed. The 2006 application rate was calculated using a weighted average for the amount of hectares sprayed, producing an average per hectare rate used by farmers. This measurement was done to produce an average which more accurately reflects the amount of herbicide applied to each hectare of land, rather than the average application rate for each field. Herbicides containing the same active ingredient but in different concentration was taken into account, with each herbicide attributing the corresponding amount of active ingredient to the average per hectare rate. This was done to provide a more accurate representation of the amount of active ingredient applied.

Because the EI_f is the exposure to the farm worker on a per area basis the area treated was calculated through the multiplication of the number of passes by the number of hectares treated with a specific herbicide divided by the total area treated by herbicide of the sample population. Area treated with herbicides containing more than one active ingredient, or tank mixes, were attributed to each active ingredient applied.

The EIQ values are also calculated for the other two subcomponents. The environmental impact quotient for consumers (EIQ_c) is the sum of the potential for consumer exposure and the potential for groundwater effects. Consumer exposure is determined by chronic toxicity (C) multiplied by the average of chemical residue potential in soils (S) and on plant surfaces (P), multiplied by the systematic potential (SY) or the pesticide's ability to be absorbed by the plant, plus groundwater effects (L) which measures the potential of the pesticide to leach into consumer drinking water reservoirs.

$$EIQ_c = (C((S+P)/2)*SY)+L$$

The environmental impact quotient for the ecological component (EIQ_e) is a combination of the aquatic and terrestrial effects of chemicals. The effects on fish are measured at the toxicity to fish (F) multiplied by the potential for surface run-off(R). The impact on birds is a measurement of chemical toxicity to birds (D) times the average half-life of chemicals on soil (S) and plants (P), multiplied by three. Impacts on bees are measured as bee toxicity (Z) multiplied by plant surface half-life (P) multiplied by three. Impacts on beneficial arthropods are measured by beneficial arthropod toxicity (B) multiplied by plant surface half-life (P) multiplied by five. The terrestrial impacts are multiplied by factors of three and five, because according to Kovach, *et al.*, the potential for direct exposure effect is higher than it would be for aquatic life. Arthropod exposure is expected to be higher as these organisms can spend their entire lives within a crop, while birds and bees are considered to be more transitory.

$$EIQ_e = (F*R)+(D*((S+P)/2*3)+(Z*P*3)+(B*P*5)$$

The final EIQ values are then a sum of the three subcomponent values, divided by three.

$$EIQ = (EIQ_f + EIQ_c + EIQ_e)/3$$

To make comparisons between herbicides on the consumer and ecology subcomponents, the same format as used for farm workers, that is the specific EIQ subcomponent value multiplied by the area of herbicide application multiplied by the application rate.

$EI_c = EIQ_c * Area * Rate$
$EI_e = EIQ_e * Area * Rate$

The following section provides the EIQ values and the subcomponent values, as well as the EI values for the herbicides used on conventional canola in 1995, prior to the commercialization of HT canola, against the herbicides used on canola in 2006, when the adoption of HT canola was 95%.

4. Results

Land management practices have changed substantially following the adoption of HT canola varieties. When asked about weed management practices, the survey found that many producers have moved to minimum or zero tillage practices, with 64% of respondents indicating that they use one of these two systems (Table 3.2). Producers utilizing Roundup Ready™ systems were more likely to conduct tillage operations than other systems. When asked about weed control measures conducted on their 2006 canola crop, 28% of producers reported the use of herbicide and tillage, with just 7% reporting only tillage. Use of tillage has markedly decreased since 2000, when 89% conducted tillage operations as a form of weed control (CCC, 2000). The adoption rate for HT canola at this time was 76%. The movement to minimum or zero tillage operations across Western Canada began to increase in the early to mid 1990s, just prior to the commercialization of GM canola. As a result, we can not say with confidence that the diffusion of HT canola increased the adoption of zero or minimum tillage systems. It would appear that these two technologies simultaneously evolved.

Table 3.2: Tillage operations and HT canola systems

Tillage method	Clearfield	Liberty Link	Roundup Ready	Average
	(n=40)	(n=135)	(n=154)	(n=340)
Zero-till	60.0%	53.3%	50.6%	53.5%
Cultivation	22.5%	20.0%	24.0%	21.8%
Harrow	12.5%	11.9%	9.7%	10.6%

With weed management practices changing, it is important to examine what has taken place regarding the use of herbicide as a form of weed control. To be able to make a statistically valid comparison between herbicide application prior to the commercialization of HT canola and the situation a decade later, we have undertaken the following. We have taken the application area data from Brimner *et al*. (2005) and the EIQ co-efficient values from Kovach *et al*. (2009) providing us with a representative perspective based on 1995 canola production.[9] Based on this earlier data, we have

[9] We use the 2009 EIQ co-efficients as they are the most accurate and up-to-date data. The co-efficients have been revised periodically since 1992 as more information regarding chemical application becomes

estimated the EIQ, the three EIQ subcomponent values and grams of active ingredient per hectare (g a.i./ha) applied, assuming the lowest application rate was used (Table 3.3). The area of herbicide application exceeds 100% due to tank mixing.

Table 3.3: Top 5 Herbicides used in 1995

Herbicide	EIQ	EIQ_f	EIQ_c	EIQ_e	Grams of a.i./ha	Area Applied (percent)
Ethalfluralin	23.3	15.0	6.0	49.0	1,100	32%
Trifluralin	18.8	9.0	5.5	42.0	800	31%
Clopyralid	18.1	8.0	8.0	38.4	151.2	16%
Sethoxydim	20.9	7.1	4.6	51.0	144	15%
Ethametsulfuron-methyl	19.9	8.0	6.0	45.6	15	15%

Source: Based upon data from Brimner *et al*., 2005 and Kovach *et al*., 2009.

The subcomponent values of the EIQ, the application rate and the application area provide the Environmental Impact to farm workers, consumers and the ecology on a per hectare basis (Table 3.4). The EI/ha, which is the sum of the three subcomponents divided by three, allows for direct toxicological comparison between different active ingredients. These results indicate that ecological impacts accounts for about 72% of the cumulative impact of the top five herbicides applied to canola in 1995. The farm worker impact is considerably lower at 19%, while, as expected, the consumer impact is quite low at 9%.

The top two herbicides that were applied to canola in 1995, have significant ecological impacts, given that these two herbicides were applied to 63% of total canola acres. One of the ecological challenges of farmers using trifluralin (Treflan) was that Treflan had to be soil incorporated as the way of providing the most effective weed control. The result was that the herbicide residues in the soil restricted the options for subsequent crops.

Table 3.4: Environmental Impacts in 1995

Herbicide	EI/ha	EI_f/ha	EI_c/ha	EI_e/ha
Ethalfluralin	25,630	16,500	6,600	53,900
Trifluralin	15,040	7,200	4,400	33,600
Clopyralid	2,737	1,210	1,210	5,806
Sethoxydim	3,010	3,010	662	7,344
Ethametsulfuron-methyl	299	120	90	684
Cumulative impact	**46,715**	**26,052**	**12,962**	**101,334**

The comparison with top five herbicides used in 2006 is provided in Table 3.5. The overall EIQ values for 2006 are marginally lower than that of 1995. The application rate observed in 2006 for glyphosate and glufosinate (1.29 L/ha) is marginally above the

available. By using the 2009 co-efficients we are able to make the most accurate comparison possible between herbicide applications in 1995 and 2006.

recommended rate for glyphosate where the upper margin for the recommended rate is 1.27 L/ha and marginally below the recommended rate for glufosinate where the lower margin is 1.33 L/ha. Odyssey (a tank mixture between imazamox and imazethapyr) was applied at the recommended rate (0.042 kg/ha). Insufficient data was available for 2,4-D application rate and was assumed to be the highest recommended rate. The low application rate for glyphosate and glufosinate can be attributed to a variety of different reasons from the price of herbicides relative to the amount of weeds/m², the type of weeds being treated to the interaction between herbicides in a tank mix on the weed population.

Table 3.5: Top 5 Herbicides used in 2006

Herbicides	EIQ	EIQ_f	EIQ_c	EIQ_e	Grams of a.i./ha	Area Applied (percent)
Glyphosate	15.3	8.0	5.0	33.0	697	48%
Glufosinate	20.2	12.0	8.0	40.6	191	12%
Imazamox	19.5	8.0	8.0	42.6	14.7	4%
Imazethapyr	19.6	15.6	10.6	32.4	14.7	4%
2,4-D	20.7	24.0	7.0	31.0	294	2%

The amount of active ingredient per hectare has dropped substantially between 1995 and 2006. Presently, producers are able to apply herbicides that are considerably more benign than they were in 1995. The lower amount of active ingredient translates into lower EI values (Table 3.6). In 2006, the two leading herbicides account for 75% of the canola acres that were treated. It is interesting to observe that only 70% of respondents report using herbicide. When asked about herbicide applications, 27% of respondents reported no herbicide use. This does not mean that 27% of farmers did not use herbicides to control weeds, as Table 3.2 illustrates that 22% of farmers use cultivation to control weeds. The remaining 8% of farmers represents farmers that will have had excellent weed control and not required herbicides or only needed to spot-spray limited parts of a canola field for weed control purposes.

Table 3.6: Environmental Impacts in 2006

Herbicide	EI/ha	EI_f/ha	EI_c/ha	EI_e/ha
Glyphosate	10,658	5,573	3,483	22,988
Glufosinate	3,858	2,292	1,528	7,755
Imazamox	287	118	118	626
Imazethapyr	288	229	156	476
2,4-D	6,094	7,066	2,061	9,127
Cumulative impact	**21,181**	**15,278**	**7,345**	**40,972**

When comparing the pre- and post-adoption scenarios, it becomes evident that there are substantial environmental benefits following the widespread adoption of HT canola (Table 3.7). The cumulative environmental impact effect drops by 59%. When the subcomponent values of the environmental impact are compared, there is a reduction of 50% or greater in each of the subcomponents. The farm worker and ecology subcomponents decline by 61% and 59%, respectively, while the consumer subcomponent declines by 50%. Recall, that the total canola acreage between 1995 and 2006 differed by 110,000 acres, so to have reductions in the environmental impact of HT canola at these levels is a substantial environmental impact. Additionally, the amount of active ingredient that is applied to canola fields had been enormously reduced, falling from 3.4 million kg in 1995 to 1.9 million kg in 2006. This represents a 44% reduction.

Table 3.7: Differences between top 5 herbicides 1995 and 2006

Comparison	**1995**	**2006**	**Change (%age)**
EI/ha	13,789	8,986	-35%
EI_f/ha	7,877	3,069	-61%
EI_c/ha	3,782	1,230	-67%
EI_e/ha	29,797	22,692	-24%
Grams of a.i./ha	648	361	-44%
Total AI (Millions kg)	3.4	1.9	-1.5

5. Conclusions

The decrease in the environmental impact of herbicides cannot be solely attributed to the adoption of HT canola but is a result of the increased sophistication of Western Canadian agriculture. Farmers utilize HT canola as a tool to increase the flexibility of weed control. There has been a shift in the types of herbicides applied to canola, moving away from soil-incorporated pre-emergent herbicides (trifluralin and ethafluralin) to foliar applied post-emergent herbicides (glyphosate and glufosinate). The shift in herbicides results in a more reactive approach to weed control allowing producers to apply herbicide when needed and at an appropriate rate for the control of weed populations.

The reduction in environmental impact from the adoption of HT canola of 35% in this study is consistent with that of other studies. Kleter, *el al.*, (2007) demonstrated a reduction in EI by 42%, with Brimner, *et al.*, (2005) identifying a reduction in EI by 36.8%, while Brookes and Barfoot (2005) found a reduction of 20.7%. These studies intimate that there is a growing trend within the divergence in herbicide use by canola farmers, showing that as farmers become more accustomed to the new technology they are better able to minimize the input requirements of their crops.

This study contrasts the findings by Kleter, *et al.*, (2007) where they identified that improvements in herbicide use by canola farmers benefited farmers more than the other two portions of the EIQ. This study identifies the consumer subcomponent as the one that gains the most, due to the limited herbicide run-off. The driver behind the decrease in overall toxicity is the decrease in use of active ingredient being applied to canola fields. Based on these findings, it is possible to assert that the adoption of HT canola has resulted in the decrease of active ingredient used by farmers making it one of the most environmentally friendly technological changes in Western Canadian agriculture.

Section 4

Comparison Between Canola Council of Canada and University of Saskatchewan Survey Results

1. Introduction

The Canola Council of Canada has undertaken three studies over the past decade. The first was a report released in 2000 on integrated pest management, the second was a 2001 report that involved an agronomic and economic assessment of transgenic canola and the third, released in 2005, examined herbicide tolerant volunteer canola management in subsequent crops.

The initial study funded by the Canola Council of Canada (CCC) examined aspects of pest management in canola. The objective of this study was to establish a baseline of producer information regarding on-farm pest management practices. Additional information was gathered on producer levels of awareness and knowledge regarding pest management, barriers to adopting pest management and to receive feedback on existing education/training initiatives.

The 2001 study of agronomic and economic impacts of transgenic canola took place in the midst of the rapid adoption of GMHT canola. This provided for a timely assessment from producers that were using both technologies, that is, the new GM technologies and previous non-GM technologies. The objective of this study was to investigate how the new HT canola varieties competed with existing canola varieties.

The third study was a combination of new research and previous survey data. This 2005 report examined weed survey data from 2001 in Alberta, 2002 data in Manitoba and 2003 data in Saskatchewan. This existing data was then incorporated with new data from a Western Canada grower survey. The objective of this study was to identify the cost and controllability of volunteer canola.

Based on the data sets supplied by the Canola Council of Canada, we have been able to make selected comparisons in cases where the same, or comparable, questions were used in the various surveys. Economic and tillage of the data sets has been conducted.

2. Comparison of Economic Data

The Canola Council of Canada's agronomic and economic assessment study provides details regarding farm herbicide expenditures. This 2001 study surveyed 325 farmers producing transgenic canola and 325 farmers producing conventional canola. It is possible to compare the economic cost of herbicide applications between the CCC survey and the U of S survey. The CCC survey found that less herbicide was used in the production of transgenic canola than occurred with conventional canola.

Based on the survey information the amount of herbicide applied to a single hectare can be identified, therefore making it possible to determine the average herbicide expenditure by farmers. This is derived by taking the amount of active ingredient per litre of herbicide and multiplied by herbicide prices that are converted to price per gram of active ingredient ($/gai).

The lack of historic prices for herbicides prevents finding the actual prices for the year in question, so price data for 2008 herbicides was available and used in this comparison. This provides a present comparison of herbicide cost differences however, it does not allow for cost comparisons between time periods.

2.1 Conventional Canola Production, 1995

A study by Brimner, *et al*., (2005) determined the top five herbicides used for canola production in 1995. Table 4.1 presents the top five herbicides, their assumed application rate (which is the lowest recommended rate) and the total cost per hectare. The 1995 cost of canola herbicide applications are estimated to range from $1.84/ha to $16.48/ha. The cumulative amount of active ingredient applied per hectare is 648 grams and the cumulative cost is $41.39.

Table 4.1: Conventional canola top five herbicide costs, 1995

Top 5 Herbicides	g a.i./ha	$/g a.i.	$/ha
Ethalfluralin (Edge)	352.00	0.05	16.48
Trifluralin (Treflan)	248.00	0.03	7.63
Clopyralid (Lontrel)	24.19	0.43	10.49
Sethoxydim (Poast)	21.60	0.09	1.84
Ethametsulfuron-methyl (Muster)	2.25	2.20	4.95

2.2 Conventional Canola Production, 1999

The Canola Council of Canada's integrated pest management study provides a perspective on herbicide use for conventional canola production in 1999. The survey asked producers about their weed management practices, specifically identifying what weeds were problematic for producers and what herbicides they applied to manage weed problems on their farms.

Because many farmers use glyphosate as a burn-off prior to spring seeding it is listed as one of the herbicides used at this time. Using the calculated assumed rates the cost of herbicide application ranged from $1.36/ha to $5.76 (Table 4.2). Of note is the drastic reduction in amount of herbicide used between 1995 and this study. The early economic impact of glyphosate on canola was evident even at this early stage and had benefits for farmers that were not producing Roundup Ready™ canola. For comparison purposes, the cumulative grams of active ingredient per hectare was 320, a drop of 50.6% from 1995. The cumulative price comparison is $16.29, a decrease of 60.6%.

Table 4.2: Conventional canola top five herbicide costs, 1999

Top 5 Herbicides	g a.i./ha	$/g a.i.	$/ha
Glyphosate	88	0.02	1.97
Muster	2	2.20	4.40
Edge	123	0.05	5.76
Poast	16	0.09	1.36
Treflan	91	0.03	2.80

2.3 Herbicide Tolerant Canola Production, 1999 and 2006

The 2000 and 2001 CCC studies provide information on canola herbicide applications in 1999. Using the calculated assumed rates the cost of herbicide ranges from $3.47/ha to $8.48/ha (Table 4.3). The cumulative cost was $33.35/ha.

Table 4.3: Herbicide tolerant canola top five herbicide costs, 1999

Top 5 Herbicides	g a.i/ha	$/g a.i.	$/ha
Glyphosate	328	0.02	7.36
Glufosinate Ammonium	83	0.10	8.48
Odyssey 1	5	1.40	7.02
Odyssey 2	5	1.40	7.02
Lontrel	8	0.43	3.47

The 2006 U of S study provided a picture of the herbicides used by all herbicide tolerant canola producers in 2006. Using the average rates the cost of herbicide ranged from $0.07/ha to $7.43/ha (Table 4.4). The average cost of herbicide for herbicide tolerant canola is significantly lower than that of 1999. A major factor resulting in this the significantly lower herbicide cost is the reduction in herbicide use reported by producers. The cumulative cost drops to $11.57, a decline of 65%.

Table 4.4: Herbicide tolerant canola top five herbicide costs, 2006

Top 5 Herbicides	g a.i./ha	$/g a.i.	$/ha
Glyphosate	331	0.02	7.43
Glufosinate Ammonium	24	0.10	2.43
Imazamox	1	1.40	0.82
Imazethapyr	1	1.40	0.82
2,4-D	5	0.01	0.07

This section shows that the cost of using the innovation of HT canola has substantially declined over time. The per hectare cost of herbicides has dropped. There has been a reduction in cost of 65% between the introduction of HT canola as compared to 2006. The reduction increases to 72% when comparing HT canola in 2006 with the costs of herbicide use in 1995, prior to the commercialization of HT canola. As is the case with most innovations, the cost of using the technology declines as the rate of adoption increases.

3. Comparison of Tillage Practices

Data was organized to differentiate between the types of tillage equipment used. Insufficient information pertaining to the amount of crop residue left on top of the soil prevented types of tillage operations from being classified as reduce tillage or conventional tillage.

Canola systems (HT systems as well as conventional) were examined according to the type of tillage. Tillage was separated into harrow operations and cultivation operations. There was no significant difference between the various canola platforms regarding tillage systems. Comparison between 1999 and 2006 provides an illustration of the shift from conventional tillage to minimum or zero tillage systems.

Tillage used on canola crops in 1999 is illustrated in Table 4.5. Conventional canola is compared to herbicide tolerant systems as a group and individually. Tillage was separated into four different types; no tillage, harrow operations only, harrow and cultivation and cultivation operations only. The final two columns are the total number of observations and the margin of error. Individually no system is significantly different from one another in the 1999 case.

Table 4.5: Canola tillage systems, 1999

Variety	Zero-till	Harrow only	Harrow and Tillage	Tillage	Total	Margin of Error
Clearfield	13.7%	7.7%	47.0%	31.6%	117	9.0%
Liberty Link	8.1%	6.5%	47.6%	37.9%	124	8.8%
Roundup Ready	12.3%	5.1%	50.3%	32.3%	334	5.3%
Total HT	11.7%	5.9%	49.0%	33.4%	575	4.1%
Conventional	6.2%	6.2%	47.6%	40.0%	225	6.5%
Total	10.2%	6.1%	48.6%	35.1%	803	3.4%

It is clear in the data from Table 4.5 that the preferred method of weed control in the production of canola was tillage, as tillage or tillage and harrowing account for over 80% of the land management practices. At this point in time, the practice of zero-tillage was increasing in use, but it was not commonly used in relation to the production of canola, but rather with the use of other crop commodities.

Canola tillage use in 2006 is illustrated in Table 4.6. Individually no system is significantly different from one another in the 2006 case. It was no longer possible to determine values for conventional canola as the number of observations was so low, it created a margin of error that resulted in their being no confidence in the values.

Table 4.6: Canola tillage systems, 2006

Variety	Zero-till	Harrow only	Harrow and Cultivation	Cultivation	Total	Margin of Error
Clearfield	60.0%	12.5%	5.0%	22.5%	40	15.5%
Liberty Link	53.3%	11.9%	14.8%	20.0%	135	8.4%
Roundup Ready	50.3%	9.8%	15.7%	24.2%	153	7.9%
Total HT	52.7%	11.0%	14.0%	22.3%	328	5.4%
Total	53.3%	10.7%	14.2%	21.9%	338	5.3%

Comparing Liberty Link fields between 1999 and 2006 there is a significant increase in the amount of zero till (8.1% to 53.3%), as well as a significant decrease in harrow and cultivation (47.6% to 14.8%) and cultivation (37.9% to 20.0%). Comparing Roundup Ready fields between 1999 and 2006 there is a significant increase in the amount of zero till used (12.3% to 50.3%) and a significant decrease in harrow and cultivation (50.3% to 15.7%). The small sample size of the 2006 Clearfield fields marginally lowers the value of direct comparison between the two.

Between 1999 and 2006 canola fields have experienced a shift in tillage practices away from cultivation and towards the use of zero-till. Herbicide tolerant canola as a whole has seen an increase in use of zero-till by, on average, five-fold. Additionally, there is a shift away from harrowing and cultivation by at least 2.3 fold. Cultivation has decreased in use, by a smaller, but significantly amount.

4. Conclusion

The widespread adoption of HT canola has clearly benefited Western Canadian agriculture and producers. While it was not possible to determine a correlation between HT canola and the movement to zero- and min-till land management practices, the co-evolvement of these technologies has provided substantial benefits. If these two technologies had not advanced within the same time period, it is rather doubtful that the benefits that are being recognized from HT canola would be the level that is witnessed.

While biotechnology continues to have, and likely, always will have its critics, the information that has been presented on the production of HT canola in Western Canada can be used to substantiate the rejection of many of the numerous accusations that are claimed about the production of HT canola in Canada. HT canola is benefiting producers and is the most environmentally friendly farming option presently being practiced.

Section 5

Concluding Comments

Climate change is upon us and we are compelled to act. The Intergovernmental Panel on Climate Change (IPCC) estimates that agriculture contributes 10-12% of anthropogenic green house gas (GHG) emissions. Among all of the choices we may make to reduce agricultural GHG emissions, crop choice is one of the most significant and available options. We have completed a farm-level survey of Western Canadian canola producers with respect to their uptake of herbicide tolerant (HT) varieties. Our analysis of response data indicates significant reduction in chemical applications over the three-year period and fewer tillage passes were required during the period surveyed. We have calculated GHG reductions (tonne/hectare) and the corresponding economic benefits to producers. Environmental benefits, shared by everyone, include fewer chemical inputs, improved soil quality and conservation, and increased carbon sequestration. When compared with non-HT plantings of canola, these environmental benefits weigh in favour of HT canola use.

Western Canadian agriculture has changed dramatically over the past twenty-five years. If crop production options and land management systems are contrasted, the difference is large. New crop commodities are being grown in the Prairies and land management practices have been drastically altered. In addition to the physical changes in farming, there has also been a substantial mental transition. No longer is farming viewed as 'a way of life' it is now viewed as a business venture. To facilitate this transition, new technologies, especially innovations that reduced cost, simplified production and generated long-term benefits were required. In the midst of this agricultural transition appeared HT canola.

Farmers in Western Canada are farming more land per farmer yet are becoming better stewards of the land they farm. Land is the integral aspect of farming and a greater appreciation and understanding of its complexities has taken place. While the economic benefits that have been realized from the adoption of HT canola have been crucial to the actual farmers, what is probably the most important aspect of HT canola is the long-term value created from the improved environmental impacts and the reduction in herbicide applications. Long-term agricultural sustainability is rooted in land management practices.

This report provides a snapshot of canola production in 2006. The changes between canola production in 1995 and 2006 are substantial. This report substantiates the findings of earlier studies commission by the Canola Council of Canada and other studies that have taken place. This report is the first of its kind in that it quantifies additional impacts that have resulted from the commercialization and adoption of HT canola. The findings of this report demonstrate that the benefits of HT canola are two-fold. First, there are immediate financial benefits experienced by farmers and second, there are environmental stewardship benefits that provide long-term benefits to farmers but also to the larger society within which we all live.

As climate change impacts increase, countries and industries will be challenged to adapt. Given the quantifiable benefits of HT canola production, Canada and the agriculture industry, are well positioned to take advantage of these changes.

6. References

Anderson, C. 2008. Personal communication with Program Manager, Canola Council of Canada.

Aulie, P. 1996. Genetically Engineered Herbicide Tolerant Canola: A multiple account evaluation. Master's Thesis, University of Saskatchewan. Saskatoon.

Beckie, H. J., K. N. Harker, L. M. Hall, S. I. Warwick, A. Légère, P. H. Sikkema, G. W. Clayton, A. G. Thomas, J. Y. Leeson, G. Séguin-Swartz and M.-J. Simard. 2006. A decade of herbicide-resistant crops in Canada. *Canadian Journal of Plant Science* 86: 4: 1243-1264.

Benbrook, C. M. 2009. *Impacts of Genetically Engineered Crops on Pesticide use in the United States: The First Thirteen Years*. Available online at: http://www.organiccenter.org/reportfiles/13Years20091126_FullReport.pdf.

Benbrook, C. M. 2003. Impacts of Genetically Engineered Crops on Pesticide Use in the United States: The First Eight Years. *BioTech InfoNet* No. 6. Available online at: www.biotech-info.net/technicalpaper6.html.

Brimner, T., G. Gallivan and G. Stephenson. 2005. Influence of Herbicide-resistant Canola on the Environmental Impact of Weed Management. *Pest Management Science* 61: 47-52.

Brookes, G. and P. Barfoot. 2008. Global Impact of Biotech Crops: Socio-Economic and Environmental Effects, 1996-2006. *AgBioForum* 11: 1: 21-38.

Brookes, G. and P. Barfoot. 2005. GM Crops: The Global Socio-economic and Environmental Impact – The First Nine Years 1996-2004. *AgBioForum* 8: 2/3: 187-196.

Canola Council of Canada. 2008. Prairie canola variety trials. Available online at: http://www.canola-council.org/pcvt.aspx.

Canola Council of Canada. 2005. Herbicide Tolerant Volunteer Canola Management in Subsequent Crops.

Canola Council of Canada. 2001. An Agronomic and Economic Assessment of Transgenic Canola.

Canola Council of Canada. 2000. Final Report on the Pest Management Study Conducted on Behalf of the Canola Council of Canada.

Fulton, M. and L. Keyowski. 1999. The Producer Benefits of Herbicide-Resistant Canola. *AgBioForum* 2: 2: 85-93.

Gianessi, L. P., S. Sankula and N. Reigner. 2003. *Plant Biotechnology: Potential Impact for Improving Pest Management in European Agriculture: Oilseed Rape – Herbicide Tolerant Case Study*. Washington, DC: The National Center for Food and Agricultural Policy. Available on line at: www.ncfap.org.

Gianessi, L. P., C. S. Silvers, S. Sankula and J. E. Carpenter. 2002. *Plant Biotechnology: Current and Potential Impact for Improving pest Management in U.S. Agriculture*. Available on line at: www.ncfap.org.

Kleter, G. A., R. Bhula, K. Bodnaruk, E. Carazo, A. S. Felsot, C. A. Harris, A. Katayama, H. A. Kuiper, K. D. Racke, B. Rubin, Y. Shevah, G. R. Stephenson, K. Tanaka, J. Unsworth, R. D. Wauchope and S.-S. Wong. 2007. Altered pesticide use on transgenic crops and the associated general impact from an environmental perspective. *Pest Management Science* 63: 11: 1107-1115.

Kovach, J., C. Petzoldt, J. Degnil and J. Tette. 2009. A Method to Measure the Environmental Impact of Pesticides, Table 2, List of Pesticides. Available online at: http://www.nysipm.cornell.edu/publications/EIQ/files/EIQ_values_09.pdf.

Kovach, J., C. Petzoldt, J. Degnil and J. Tette. 1992. A Method To Measure The Environmental Impact of Pesticides. New York's Food and Life Sciences Bulletin. No. 139.

Malla, S. and Gray, R. 1999. *The effectiveness of research finding in the canola industry*. A report prepared for Saskatchewan Agricultural Development Fund.

Mauro, I. J. and S. M. McLachlan. 2008. Farmer knowledge and risk analysis: Postrelease evaluation of herbicide-tolerant canola in Western Canada. *Risk Analysis* 28: 2: 463-476.

Mayer, H. and W. H. Furtan. 1999. Economics of transgenic herbicide-tolerant canola The case of western Canada. *Food Policy* 24: 4: 431-442.

McConkey, B., Angers, D., Bentham, M., Boehm, M., Brierley, T., Cerkowniak, D., Liang, C., Collas, P., de Gooijer, H., Desjardins, R., Gameda, S., Grant, B., Huffman, T., Hutchinson, J., Hill, L., Krug, P., Martin, T., Patterson, G., Rochette, P., Smith, W., VandenBygaart, B., Vergé, X., and Worth, D. 2007. Canadian Agricultural Greenhouse Gas Monitoring Accounting and Reporting System: Methodology and greenhouse gas estimates for agricultural land in the LULUCF sector for NIR 2006. Agriculture and Agri-Food Canada, Ottawa, ON.

Nagy, J. G. and Furtan, W. H. 1978. Economic costs and returns from crop development research: The case of rapeseed breeding in Canada. *Canadian Journal of Agricultural Economics* 26: 1-14.

NIST/SEMATECH. e-Handbook of Statistical Methods. 2006. Online Article: http://www.itl.nist.gov/div898/handbook/. Last Accessed: December 17, 2008.

Phillips, P. W. B. 2003. The economic impact of herbicide tolerant canola in Canada. In N. Kalaitzandonakes (ed.) *The Economic and Environmental Impacts of Agbiotech: A Global Perspective*. New York: Klewer Academic Publishers. 119-140.

Pray, C. and F. Ma. 2001. Impact of Bt Cotton in China. *World Development* 29: 5: 813-825.

Saskatchewan Ministry of Agriculture. 2008. *Farm Machinery Custom and Rental Rate Guide: 2008-09*. Available online at: http://www.agriculture.gov.sk.ca/Default.aspx?DN=f4b84942-e058-4b5f-92eb-b4f5435bc9d6.

Smyth, S. and P. W. B. Phillips. 2001. Competitors Co-operating: Establishing a Supply Chain to Manage Genetically Modified Canola. *International Food and Agribusiness Management Review* 4: 51-66.

Statistics Canada. 2008. Field and Specialty Crop Acreage. Available online at: http://www40.statcan.ca/l01/cst01/prim11a.htm.

Statistics Canada. 2006. *2006 Census of Agriculture*. Ottawa: Queen's Printer.

Statistics Canada. No date. Field Crop Reporting Series. Available online at: http://www.statcan.gc.ca/bsolc/olc-cel/olc-cel?catno=22-002-XIB&lang=eng.

Tukey, J. 1977. Exploratory Data Analysis. Addison-Wesley, Reading, MA.

Ulrich, A. W. and Furtan, W. H. 1985. *An investigation in the rates of return from the Canadian Crop Breeding Program*. Saskatoon: University of Saskatchewan.

Ulrich, A. W., Furtan, W. H. and Downey, K. 1984. *Biotechnology and rapeseed breeding: Some economic considerations*. A manuscript report prepared for the Science Council of Canada.

United States Department of Agriculture, National Agricultural Statistics Services. 2008. *USDA expects corn acres to drop in 2008*. Available online at: http://www.nass.usda.gov/Newsroom/2008/03_31_2008.asp

Young, B.G. 2006. Changes in herbicide use patterns and production practices resulting from glyphosate-resistant crops. *Weed Technology*. Volume 20: 301-307.